Microgreens production process optimization inside a building and assessment of its environmental impacts when compared to conventional processes

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Abstract

The present work integrated the construction of a hydroponic vertical system for the growth of microgreens, followed by the growth of said microgreens (Raphanus sativus), and the life cycle assessment of radish microgreens production, as well as the comparison of the environmental impacts of radish microgreens with the environmental impacts of conventionally grown radish, in a heated greenhouse. The total environmental impacts, measures in kg CO_2eq, was 4.16 kg CO_2eq per kg of microgreens and 18.2 kg CO_2eq per 3 kg of radish. A 1:3 mass proportion was used to compare these two products due to taste intensity difference in terms of everyday use.

As for the different environmental impact categories, the microgreens had a better performance in most of them, except in the categories of ionizing radiation, freshwater ecotoxicity, mineral resource scarcity, and water consumption. On the other hand, a normalized analysis revealed that the most important categories for these two products are human carcinogenic toxicity, freshwater eutrophication, fossil resource scarcity, global warming, and land acidification, in which the microgreens had a better performance than radish. The main contributors to most of the considered environmental impact categories are the mining and processing of materials, especially metals, that integrate the microgreens production module.

Keywords: microgreens, radish, life cycle assessment, environmental impacts, building integrated agriculture, vertical farming

1. INTRODUCTION

Building Integrated Agriculture (BIA) has the potential to offer buildings a new dimension by offering locally grown food, which can increase urban resilience [1]. In addition, this type of production can contribute to the circularity of urban food systems as well as to the reduction of emissions associated with food transportation and waste [2].

1.1 Microgreens

Microgreens are a type of food that has increased in popularity due to its sensory and nutritional properties. Its short cycle of growth and ease of cultivation, combined with the interest it arises in society, make its production in urban agriculture an emerging area of interest. They can be defined as a type of food that includes plant seedlings of herbaceous plants, aromatic herbs and edible wild plants which can vary in size from 5 to 10 cm in height [3]–[5] and that can take up little space in terms of cultivation [6]. There seems to be a consensus that microgreens have higher concentrations of bioactive compounds, such as vitamins, minerals, and antioxidants than mature plants [5], [7]. Furthermore, several studies show that the intensity of light and its type influence not only the photosynthesis rate in plants, but also the accumulation of different organic compounds [8]–[10].

1.2 LCA of microgreens

To date, few studies have evaluated the life cycle of Indoor Vertical Farming (IVF) hydroponic systems for the production of microgreens. In 2022, the case of a prospective technology for the integration of a system of production of broccoli microgreens in a university campus building. The mentioned study shows that the IVF system in question produces 7.5 kg of broccoli microgreens per daily, with a global warming potential of 18.6 kg of CO_{2eq} per kg of microgreens, if they are consumed on campus, and 22.2 kg of CO_{2eq} per kg of microgreens if they are commercialized within a 10 km radius. It was also found that in both scenarios the electricity was the one that contributed with the most emissions [2].

2. EXPERIMENTAL INSTALLATION

2.1 Method

Two hydroponic systems – module 1 and module 2 - were working in parallel, producing batches of radish microgreens. The results are presented in tables 1 through 4 and figure 1. Afterwards, were estimated the amounts of water, electricity and nutrients that are used per kg of radish microgreens. Finally, and LCA of the production of microgreens was performed. A photoperiod 20h was used, the substrate in every batch had a fixed area of 0.18 m^2 and the conditions inside both modules were the same, except for the light – module 1 had four 5 W LED strips and module 2 had a 26 W LED growing light.

2.2 Results

Batches 1, 3, 5 and 7 were produced in module 1 and batches 2, 4, 6 and 8 were produced in module 2. The final weight of the batches from module 2 were used to estimate and average weight of microgreens produced per batch, which is 276g, with a standard deviation of 61.1.

Table 1. Cultivation data for batch 1 and 2

	B1	B2
Total duration (d)	14	14
Germination (d)	8	8
Growth (d)	6	6
h max (cm)	8,5*	12,5
m product (g)	-	214
Fungi presence	No	Yes, slight and localized

Table 2. Cultivation data for batch 3 and 4

	B3	B4
Total duration (d)	10	10
Germination (d)	5	5
Growth (d)	5	5
h max (cm)	12,5	13
m product (g)	194	243
Fungi presence	No	Yes, slight and localized

Table 3. Cultivation data for batch 5 and 6

	B5	B6
Total duration (d)	11	11
Germination (d)	4	4
Growth (d)	7	7
h max (cm)	13	13,3
m product (g)	216	353
Fungi presence	Yes, slight and localized	Yes, slight and localized

Table 4. Cultivation data for batch 7 and 8

	B7	B8
Total duration (d)	11	9
Germination (d)	6	4
Growth (d)	5	5
h max (cm)	13	13
m product (g)	170	294
Fungi presence	Yes, slight and localized	Yes, slight and localized

Figure 1. Comparison of all the batches of microgreens produced in module 1 and 2

It was estimated that the electricity consumption to produce 1 kg of radish microgreens in one module is 9,075 kWh. In terms of water consumption, its 30 L per kg of microgreens. And the nutrient consumption is showed in tables 5 and 6, because the nutrient solution consisted of two separate concentrates that had to be added to water – Aqua Vega A (table 5) and Aqua Vega B (table 6).

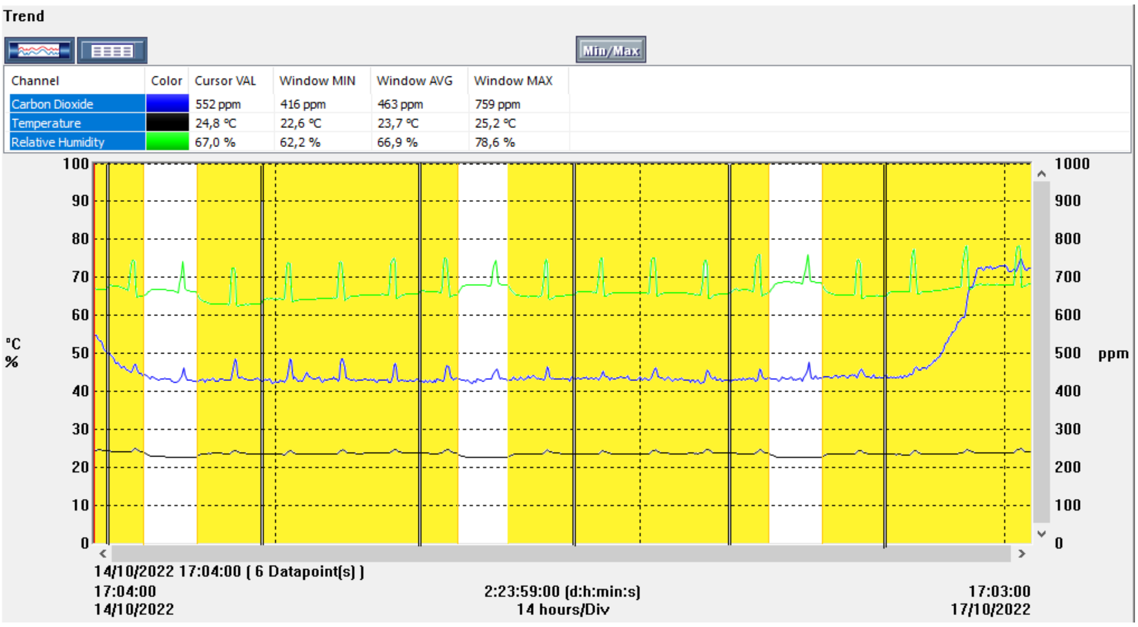
Table 5. Nutrients concentration in the solution Aqua Vega A, and their consumption per kg of radish microgreens.

	Massic % in concentrate solution	**kg / kg of microgreens**
Total N	5	3,00x10^{-3}
K_2O	2,6	1,56x10^{-3}
CaO	2,3	1,38x10^{-3}
MgO	1,3	7,80x10^{-4}
Fe DTPA	0,02	1,20x10^{-5}
Fe EDDHA	0,02	1,20x10^{-5}
Mn DTPA	0,01	6,00x10^{-6}

Table 6. Nutrients concentration in the solution Aqua Vega B, and their consumption per kg of radish microgreens

	Massic % in concentrate solution	**kg / kg of microgreens**
P_2O_5	2,6	$1,56\text{x}10^{-3}$
K_2O	4,2	$2,52\text{x}10^{-3}$
SO_3	2,6	$1,56\text{x}10^{-3}$
Total B	0,01	$6,00\text{x}10^{-6}$
Total Mn	0,02	$1,20\text{x}10^{-5}$
Total Mo	0,003	$1,80\text{x}10^{-6}$
Total Zn	0,01	$6,00\text{x}10^{-6}$

The monitoring results of the relative humidity, temperature and CO_2 concentration inside the production module can be seen on figure 2.



Channel	Color	Cursor VAL	Window MIN	Window AVG	Window MAX
Carbon Dioxide	🟦	552 ppm	416 ppm	463 ppm	759 ppm
Temperature	⬛	24,8 °C	22,6 °C	23,7 °C	25,2 °C
Relative Humidity	🟩	67,0 %	62,2 %	66,9 %	78,6 %

Figure 2. Relative humidity, temperature and CO_2 levels monitoring inside module 2 for a period of 3 days.

3. LCA OF RADISH MICROGREENS PRODUCTION

3.1 Objective and scope

In terms of the objective, the LCA carried out in this study focuses on the life cycle of microgreens production, mapping the environmental impacts associated to the use of materials that constitute the module and the equipment that integrates it, from its production to its end of life, as well as the environmental impacts associated with the use of electricity, water, nutrients, and seeds. As for the scope the impacts from the production of raw materials to the disposal of its components are considered, through the resource usage processes involved in the microgreens production – a cradle to grave approach. However, it should be noted that, considering the relative relevance of the processes in terms of end-of-life scenarios, the analysis was focused on the recycling of the steel plate of which the module is made. The impacts of the dismantling and recovery of equipment such as the water pump and LED lamps were not quantified.

3.2 LCA inventory

The mass of the module, fan, water pump, light bulb, plastic trays and water reservoir that is used up with each kg of microgreens produced over the lifespan of each equipment was calculated by dividing the mass of each equipment by the number of kilos of microgreens produced in the lifespan of a certain equipment, which for the module and the LED lamp was considered to be 10 years, and for the other equipment mentioned 5 years.

Figure 3 illustrates the inventory used in the SimaPro software for the LCA of radish microgreens.

Type	Category	Materials	Units	Quantity	Total quantity (kg)
Infrastructure	Module	Steel sheet	kg/kg of microgreens	$1,25 \times 10^{-1}$	25
		Wood		-	3
	Growth batches	HDPE		$3,33 \times 10^{-2}$	4
	Water reservoir	HDPE		$8,30 \times 10^{-3}$	1
	Fans	Multiple		$3,33 \times 10^{-3}$	4×10^{-1}
	LED lamps	Multiple		$1,50 \times 10^{-3}$	$3,6 \times 10^{-1}$
Inputs	Electricity	-	kWh/ kg of microgreens	9,075	
	Water	Tap water	L/kg of microgreens	30	
	Seeds	-	kg/kg of microgreens	$8,00 \times 10^{-2}$	
	Nutrients	N total		$3,00 \times 10^{-3}$	
		K_2O		$1,56 \times 10^{-3}$	
		MgO		$7,80 \times 10^{-4}$	
		P_2O_5		$1,56 \times 10^{-3}$	
		SO_3		$1,56 \times 10^{-3}$	

Figure 3. Microgreens LCA inventory

3.3 Life Cycle Impact Assessment

The environmental impacts of the life cycle of radish microgreens production, in terms of greenhouse gas emissions, is 4.16 kg CO_{2eq} per kg of microgreens, and the greatest contribution to this value is the consumption of electricity, which is 2.55 kg CO_{2eq} per kg of microgreens. Recycling the steel plate prevents the emission of 0.163 kg CO_{2eq} per kg of microgreens. Figure 4 illustrated the network of the radish microgreens LCA.

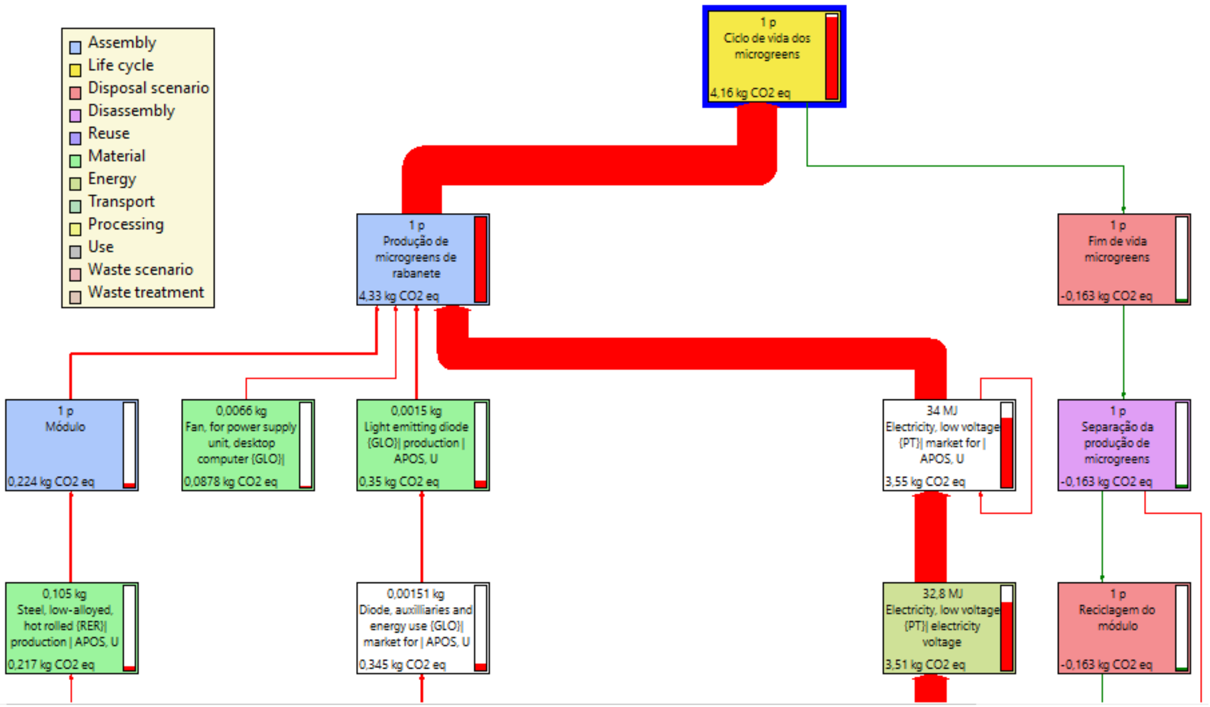
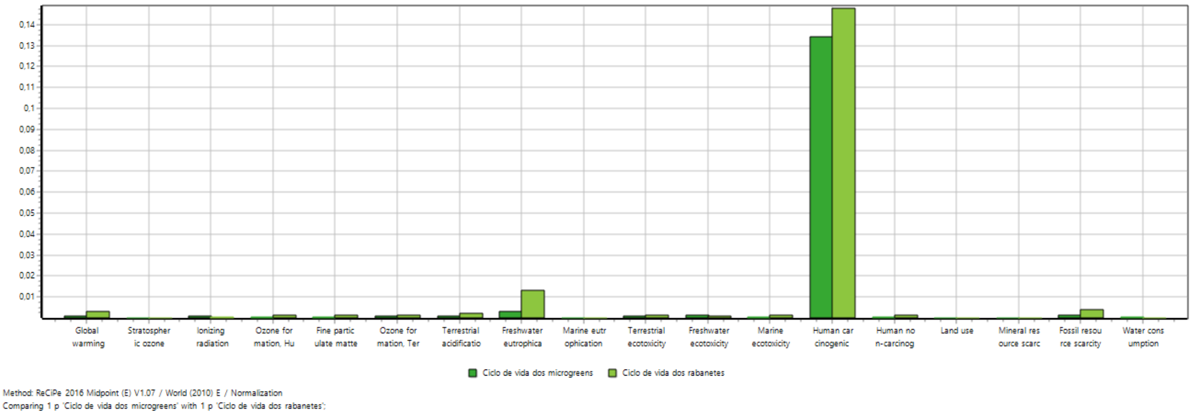


Figure 4. Part of them radish microgreens LCA network

Figure 5 shows the comparison between the environmental impacts of the production of radish microgreens and those of radish produced in a heated greenhouse. The most relevant categories of impact are human carcinogenic toxicity, freshwater eutrofication, global warming, fossil resource scarcity, and land acidification. In all of them the impact of radish microgreens is inferior to the impact of radish.



Method: ReCiPe 2016 Midpoint (E) V1.07 / World (2010) E / Normalization
Comparing 1 p 'Ciclo de vida dos microgreens' with 1 p 'Ciclo de vida dos rabanetes';

Figure 5. Comparative representation of the impacts of radish microgreens and radish in different environmental categories.

4. CONCLUSIONS AND FURTHER WORK

It was observed that, in addition to the duration of cultivation, the presence and intensity of ventilation within the module strongly influence the appearance of fungi. The installation of fans that allowed the excess moisture to be removed from the substrate and air drastically decreased the number of fungi that could be observed, compared to when the ventilation was absent.

The size of the production module proved to be disproportionately large for this crop, as the top level ended up not being used at all, due to the short growth period of radish microgreens. This means that the environmental impacts in terms of equipment and electricity spent on its operation can be diminished by making a smaller module, without compromising the mass of microgreens produced per unit of time. This point is particularly important when considering that the industrial processes of metal production and its end-of-life processing are one of the processes that contribute the most to the categories of human carcinogenic toxicity, freshwater eutrophication, terrestrial ecotoxicity and terrestrial acidification.

So, considering that metal production and coal mining are among the most significant contributor to the most relevant environmental impact categories for radish microgreens and radish, it becomes important to 1) optimize the size of the production module and ensure a responsible end of life treatment and 2) use a shorter photoperiod in order to decrease electricity usage, since the LED lamb was the biggest electricity consumer when compared to the other appliances.

In terms of future work, it is important to do a more detailed comparative analysis of the nutrient consumption since this was not the focus of this work. It would also be interesting to experiment with different substrates in terms of water retention and fungus control. Different photoperiod also could be tried out, and the possible influence that they could have on the total duration of the crop growth, since it is important to minimize the time of residence of the microgreens in the module to guarantee a fresh product. It can also be useful to consider different materials for the production module, for instance plastic instead of a steel sheet, and estimate their environmental impacts.

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