Novel hybrid technology for the sustainable development of the circular economy in urban agriculture

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Abstract
Climate change and environmental pollution are just some of the main challenges to be addressed. A number of actions have been taken, in particular the circular economy has proved to be among the most effective in overcoming the traditional approach of the linear economy. Circular economy means not only minimizing the waste produced by giving it a new life, but also preserving the use of resources such as energy and water.
Among the different technologies developed by a circular economy approach, the use of photobioreactors and aquaponics systems are growing. They are closed systems of cultivation and growth of microalgae, which are the most important microorganisms in aquatic ecosystems for the global carbon balance and are fundamental for the capture and bioconversion of carbon dioxide (CO2) into energy, are widely used.
The aim of this study is to highlight the synergistic action that could be provided by the combinated action between a photobioreactor microalgae and an aquaponic system.
Specifically, the algal biomass obtained, after being dehydrated, could be partly used to feed the fish species in aquaculture, while the remaining part is treated in order to produce biofuels and biopolymers that are produced with high added value.
The aquaculture system, in turn, thanks to the metabolism of the fish species involved and specific treatment, i.e. disinfection with UV + ozone, and biological treatment with self forming dynamic membrane, provides a source of nutrients indispensable for algal and vegetables growth.

Keywords: urban agricolture, phototobioreactor, sustainable development, circular economy

1. Introduction

In recent years attention to the environment is growing, but the population increase inevitably leads to the intensification of food production. Traditional practices, however, are not sustainable because they use large soils, high amounts of water, fertilizers and pesticides (Somerville et al., 2014). An excellent opportunity is represented by aquaponics able to guarantee food safety by cultivating km0 products, with reduced spaces and resources (Wei et al., 2019). Aquaponics is the combination of hydroponics, an off-soil cultivation technique that allows faster and higher quality production than conventional techniques, and aquaculture, a technique of breeding aquatic organisms in controlled environments. There are different categories of aquaculture (cages, ponds, tanks) but for this study a RAS (recirculating aquaculture system) was consider. Hydroponic systems, on the other hand, can be realized by foreseeing the cultivation in presence or absence of substrates (such as expanded clay, rock wool, etc.) (Majid et al., 2021). The nutrient solution can be distributed by spraying or partial or total immersion of the roots in tanks. Both aquaculture and hydroponics would need large volumes of water. The metabolic activity of fishes produce waste that, through nitrification processes are transformed into nutrients for plants (Edaroyati et al., 2017). By absorbing them, the plants will operate a phytopurification that will allow to return clean water to the aquacolture. Overall, several national and international actions and measures have been planned and implemented with a view to controlling environmental pressures in order to protect the environment and thereby reduce environmental impacts and especially those related to climate change (Nie et al., 2020). In particular, several technologies have been investigated for the capture and seizure of carbon (CCS, carbon capture and sequestration), which CO2 is one of the main greenhouse gases (Xin et al., 2012). The main phases that characterize CCS technology are: capture, transport, compression and finally storage of CO2. However, one of the main carbon sinks is constituted by plant ecosystems called CCU systems (carbon capture and utilization), in which will be an indirect seizure of CO_2 by photosynthetic organisms (Barbato et al., 2012). Among them, microalgae are an important biological resource with a wide range of biotechnological applications. Microalgae acquire inorganic carbon through the photosynthesis process, making it possible to capture carbon dioxide and sequester it within the algal biomass. The biomass obtained is also a reusable resource, which can be used to produce products, such as renewable biofuels, food, animal feed and other products such as cosmetics, nutraceuticals, pharmaceuticals, bio-fertilisers, bioactive substances (González-Camejo et al., 2020). The systems used in the autotrophic cultivation of microalgae can be divided into two macro-categories: outdoor and indoor systems, which differ respectively according to their contact with the external environment (Mata et al., 2010). Outdoor systems (open Ponds) are characterized by large areas of liquid in which algae is grown. These systems are simple to built, but being in contact with the atmospher,e are potentially systems subject to contamination, as there is free gas trade between environment and system. In addition, in open ponds, growing conditions are not easily manageable, which makes them systems poorly controlled and characterized by a lower growth rate of microalgae than closed systems. Photobioreactors (Pbrs), on the other hand, are systems in which cultivation are in closed containers and this allows to overcome many of the biological limitations and environmental barriers that open systems present.

2. Aquaponics and photobioreactor

Aquaponics

It is an integrated system between an aquaculture tank (90 L) for the breeding of Tilaphia, and hydroponics tank (45 L), for the cultivation of lettuce. To produce safety food and to enhance the quality of water in conventional aquaponic system, the combined treatment of several technologies needs to be implemented: an MBR treatment (membrane bioreactor) for the treatment of fish waste, and an advanced oxidation process (advanced oxidation processes AOPs) with ozone and UV rays for the disinfection of the wastewater. To ensure optimal growth of tilaphia and lettuce, it is necessary to ensure specific ranges of water quality parameters and a continuous amount of nutrients (Somerville et al., 2014). To monitor these quantities, it is necessary to evaluate periodically physico-chemical parameters (pH, temperature, redox potential (ORP), dissolved oxygen (%DO, ppmDO), conductivity and salinity, turbidity, pathogenic bacterial load, carbon, anion and ammoniacal nitrogen content).

Photobioreactor

It is an integrated system for the capture and recovery of carbon dioxide composed of an absorption column and a photobioreactor. The most common species used as a photosynthetic organism is the Chlorella vulgaris. The system consists of a cylindrical photobioreactor, made of plexiglas and having a volume of 40 litres, connected to an absorption column with a volumetric capacity of 8 litres. In 4 diametrically opposite points at about half the height are positioned 4 LED lights that guarantee a light intensity of about 100 μmol/m2 s. For the growing of the algae biomass is necessary to implement a photoperiod, usually of 12:12h.

3. Novel hybrid technology: experimental set-up

The hybrid system will consist of a fish tank, a hydroponic tank, a SFDM reactor tank, an UV lamp, an ozone generator, a compressor for CO_2 injection, a Photobioreactor, and a scrubber column. The aquaponic system will be realized foreseeing a continuous recirculation thanks to the peristaltic pump. The effluent from the aquarium will be partly intended for membrane treatment, disinfection and phytopurification, partly sent to the photobioreactor to grow microalgae. Both the aquaponic and photobioreactor systems will return the purified water to the fish tank. Finally, the microalgal biomass, rich in micro and macronutrients (proteins, lipids and carbohydrates) will be used instead of food for fish "closing the circle" (figure 1). A system prediction has been made has shown in table 1.

Table *1*: Hybrid system pre-sizing reference parameters

Parameters	Value
PBR volume	20% RAS volume
Biomass productivity	1,3 g/l/d
pH	6
Light	100 μmol/m2/s
Temperature	26°C
QCO2 produced from fish tahnk	97,8 mg/m2/h
Algae biomass to add at the fish tank	15% weight
% of nutrient in algae biomass	33,4 lipids 29,7 carbohydrates 29,4 proteins

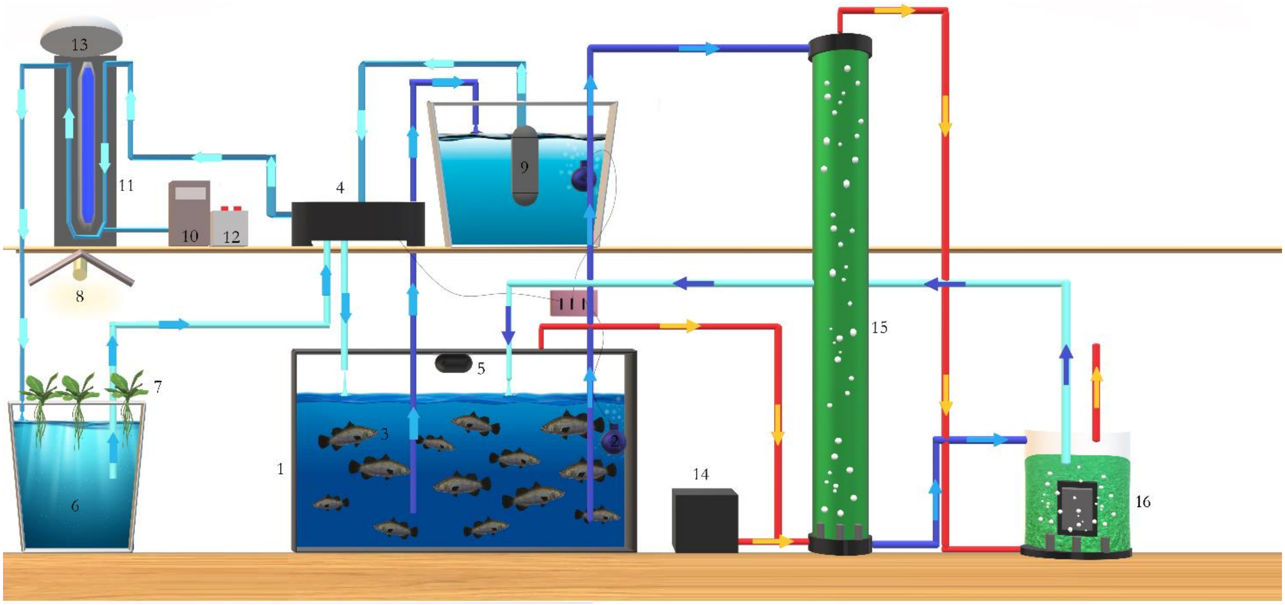
Starting from the volume of the fish tank and the fish biomass, considering the main design parameters of the photobioreactor a preliminary calculation of the volume of the PBR (Vu et al., 2018) and its production of algal biomass has been performed (Kuo et al., 2015) (Kuo et al., 2016). By fixing a EBRT of 5 min, it is calculated the flow rate necessary for the growth of microalgae (Chiu et al., 2015) which, the CO_2 was produced by fish, and partially will be integrated with an air compressor. Finally, the amount of biomass required by the fish was evaluated as a percentage of their weight (Yadav et al., 2020). A summary has shown in table 2.

Table 2: Experimental set-up hybrid system pre-sizing

Parameters	Value
Fish tank	90 l
Photobioreactor	18 l
EBRT	5 min
QCO2 produced	48,5 mg/h
QCO2 request	2955 mg/h
QCO2 addiction	2906,5 mg/h
Biomass request	39,6 g/d
Biomass produced	23,4 g/d

4. Conclusions

In conclusion, the aquaponic is an excellent solution to achieve the goals proposed by the 2030 agenda for sustainable development, ensuring the production of organic food, with added economic value, both in cities and in developing countries that do not have large resources. With the implementation of advanced treatment systems it is possible to improve water parameters and increase the absorption of nutrients. Finally, at the same time is also possible to cultivate algae. The microalgal biomass will not only reduce the carbon footprint, but also will be reused for the production of supplements, feed and biofuel.



Legenda: 1. Fish tank; 2. Aerators; 3. Tilaphia; 4. Peristaltic pump; 5. Automatic feeder; 6. Hydroponic tank; 7. Lettuce; 8. Lamp; 9. Self forming dynamic membrane; 10. Ozone Generator; 11. UV lamp; 12. Electric control; 13. Extractor hood; 14. Air compressor; 15. Scubber; 16. Algae Photobioreactor.

Figure *1*: Experimental set-up hybrid system

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