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Research article

Modeling and optimization of the oyster mushroom growth using artificial neural network: Economic and environmental impacts

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Abstract: The main aim of the study is to investigate the growth of oyster mushrooms in two substrates, namely straw and wheat straw. In the following, the study moves towards modeling and optimization of the production yield by considering the energy consumption, water consumption, total income and environmental impacts as the dependent variables. Accordingly, life cycle assessment (LCA) platform was developed for achieving the environmental impacts of the studied scenarios. The next step developed an ANN-based model for the prediction of dependent variables. Finally, optimization was performed using response surface methodology (RSM) by fitting quadratic equations for generating the required factors. According to the results, the optimum condition for the production of OM from waste paper can be found in the paper portion range of 20% and the wheat straw range of 80% with a production yield of about 4.5 kg and a higher net income of 16.54 $ in the presence of the lower energy and water consumption by about 361.5 kWh and 29.53 kg, respectively. The optimum condition delivers lower environmental impacts on Human Health, Ecosystem Quality, Climate change, and Resources by about 5.64 DALY, 8.18 PDF*m2*yr, 89.77 g CO_2 eq and 1707.05 kJ, respectively. It can be concluded that, sustainable production of OM can be achieved in line with the policy used to produce alternative food source from waste management techniques.

Keywords: oyster mushroom; life cycle assessment; food production; artificial intelligence; machine learning; big data

1. Introduction

The limited natural resources available, as well as the adverse effects of conventional protein and food production methods on nature and the pressure on protein production sources derived from edible fungi, can establish a good position among conventional methods [1]. Fungi production (FP) and producing a source of protein also play a significant role in reducing environmental impact and recycling agricultural waste [2]. FP leads to a product that contains protein, calcium and essential amino acids are one of the best alternatives to very expensive methods of protein production. 22–27 wt.% of the dry mass of oyster mushroom (OM) (3–4 wt.% of wet mass) is protein, 1 wt.% of its dry mass is fat (including essential and unsaturated fatty acids) and 1 wt.% of its wet mass is salted, which include potassium, phosphorus, magnesium [3–5].

Production of OM as the most economical and effective type of biotechnology, in the field of conversion of lignocellulosic waste into high-quality protein food, which has 50–84% of protein content per dry weight, can also play an effective role to meet the protein needs of diets around the world, also its good taste, medicinal properties, and nutrient content have increased the tendency to produce this product [6–8]. Energy analysis of different production systems and ecosystem resource planning is also an important step towards the efficient use of agricultural resources. In a study [9], they also prepared a substrate for mixing paper, coal, poultry manure, and rice straw for oyster mushroom growth. The results showed that increasing the percentage of rice straw increases the acceleration in the spanning and pinning stage and also increases the quality and weight of the fungal fruiting body. Mandeel et al. [10] grew three different species of fungi called Columbinus, Sajur-Cajou, and Ostritus in different substrates of organic waste, including shredded waste paper, cardboard, sawdust, and plant fibers. The percentage of the dry weight of the substrate was calculated as the weight of the product obtained to determine a factor called biological efficiency. The results showed that Columbine species with biological efficiency of 134.5% in cardboard and 100.8% in the paper compared to other species was at the highest level of biological efficiency. Paper is made of wood and wood, which are composed of cellulose, hemicellulose, and lignin. Cellulose is a high molecular weight quasi-crystalline and polymeric material. Lignin is a polymer with a complex structure. The properties of lignin play a negative role in the paper, and in fact, quality papers are made from lignin-free materials [11,12]. Hemicelluloses are a group of low molecular weight saccharides. These materials are usually monomeric units of hexoses.

The recyclability of biological resources and paper, in addition to its important role in reducing the environmental effects of the decomposition of these materials, greatly reduces the pressure on natural resources to reproduce it. Recycling paper waste and its reuse is one of the most effective and desirable measures in the field of paper waste management [13,14]. The world is changing rapidly, and the interrelationships between production volume, material recycling fumes, and the volume of the waste left in nature have become increasingly vital; the geographical dispersion of resources, crop production, and waste has added to the complexity of this cycle. On the other hand, energy analysis has been a vital necessity for the proper management of scarce resources to improve agricultural production, and in this way, efficient and economic production activities are determined [15]. Efficient use of energy in agriculture is one of the basic requirements for the production of sustainable agricultural products. Improving energy efficiency is increasingly important to reduce energy costs and reduce natural resources and environmental degradation [9]. Another advantage of energy analysis is determining the energy consumption at each stage of the production process and determining the steps that require the least input energy, providing a basis for protecting resources and assisting in the sustainable management and timing of crop operations. Which will be an action in the direction of production sustainability [6]. This study aimed to investigate the growth of OM in substrates consisting of wheat straw and paper waste from economic and environmental points of view. Paper is one of the major wastes of educational centers and offices, and the implementation of similar projects can improve its applications before entering the recycling cycle. The present study investigates the growth rate of OM in a bed of waste paper and wheat straw. This can provide a convenient and inexpensive solution for recycling and reusing paper waste in the production cycle. The measured factor for conducting this research is the quality and quantity of the product from the point of view of economic analysis. Of course, along with the economic analysis of the environmental front, the issue is also important, which will be examined in other studies.

The main factors in evaluating the quality of food are [8]: a) Appearance including color, shape, size and transparency of the product. b) Flavor that is the taste that is evaluated by the tongue and the smell that is inhaled. c) Tissue is primarily the tactile reaction of the physical senses to the components of the product, which is obtained by the contact of a part of the body with different parts of the product. The sense of touch (touch) is the main method for measuring texture. d) Nutritional value includes important nutrients (carbohydrates, fats, proteins) and minor nutrients (minerals, vitamins, fiber). e) Other factors including cost, ease of work, and packaging are also important factors in product quality evaluation and marketing, which are not among the factors of quality assessment. This research consists of three stages: a) The first stage examines the preparation of OM substrate and its production. b) The second stage is to evaluate the OM production process from the environmental point of view using life cycle assessment technique. c) The third phase is to provide a model to predict the OM production parameters integrated by the economic and environmental parameters and the final stage is to optimize the production condition to increase the sustainability of production procedure to achieve the highest production yield during the low-cost process as well as the lowest environmental effects.

2. Materials and methods

2.1. Preparation of the production substrate

According to the purpose of this study, test substrates were prepared from wheat straw and waste paper. The resulting compost straw was shredded by a shredder in sizes of 15–20 cm and the waste paper in a size of 2–5 cm. After crushing the raw materials, the composts were pasteurized and prepared with different mass ratios of straw and waste paper along with seeds. Compost samples of each treatment weighing 12 kg were prepared with two replications. An average of 300 grams of prepared mycelium was added to each 12 kg package. The samples were weighed using an mds11000 digital scale with an accuracy of 10 g. The average weight characteristics of the mushroom production substrate are given in Table 1.

Table 1. The production compost specifications.

Order	Wheat straw weight	Mycelium weight	Paper weight	Total weight
1	12 ± 0.1 kg	0.3 ± 0.01 kg	0 kg	12.3 ± 0.1 kg
2	9.6 ± 0.1 kg	0.3 ± 0.01 kg	2.4 ± 0.1 kg	12.3 ± 0.1 kg
3	7.2 ± 0.1 kg	0.3 ± 0.01 kg	4.8 ± 0.1 kg	12.3 ± 0.1 kg
4	4.8 ± 0.1 kg	0.3 ± 0.01 kg	7.2 ± 0.1 kg	12.3 ± 0.1 kg
5	2.4 ± 0.1 kg	0.3 ± 0.01 kg	9.6 ± 0.1 kg	12.3 ± 0.1 kg
6	0	0.3 ± 0.01 kg	12 ± 0.1 kg	12.3 ± 0.1 kg

The pasteurization stage is one of the most important stages at the beginning of oyster mushroom cultivation. In addition to killing germs and diseases, this step also softens and moistens the compost ingredients, which in turn provides the initial moisture needed for the initial growth of the fungus seeds. For this purpose, before preparing the composts, the ingredients including barley straw and shredded waste paper were heated in boiling water at 100 °C for 1 hour. After removing these materials from the pasteurization chamber, it was sterilized in the environment and at room temperature to remove about 30–35% of the water in the material and also to reduce the temperature of the material. After this step, the pasteurized material was mixed with the seeds and placed in completely sterilized plastic bags, completely closed and tightly, and transferred to the breeding hall. To grow the crop, the composts were transferred to the growth hall. This hall had dimensions of 7.5 meters in length, 3 meters in width, and 2.5 meters in height, which had a cooling and heating system, a humidifier, and proper ventilation. The walls inside the hall had a suitable cover for washing and disinfection, as well as the least contact with the outside environment, and were made in such a way that they retain the least amount of pollution. Exhausts and ventilation in the hall were covered with a suitable filter to prevent the entry of dirt and dust into the hall in addition to creating thermal and moisture insulation. After disinfecting the hall with a formaldehyde solution, the composts are transferred into the hall and placed in a dark environment at a temperature of 23 ± 1 °C and 75% humidity at a distance of about 35 cm from each other, using the appropriate hooks. They hung from the ceiling. After 7–9 days, when about 70–80% of the compost was covered with spans, 2 cm pores on the packages were added to the number of materials inside the composts that could communicate with the hall environment. Create razor blades that are completely sterilized with alcohol. At this stage, the humidity of the hall was increased from 85–95% with the help of the built-in instruments. Depending on the ingredients of the compost, the time it takes for the entire compost surface to be covered by the spans (100% of the surface) varies. This stage lasted from 20 to 25 days. At this stage, the entire coating was removed on the composts and the room temperature was reduced to 20 °C. After about 7–9 days, the mushroom pins appeared. It should be noted that the composts were sprayed twice a day before the pins appeared by special sprinklers. After the fungi appear, it takes about 3–4 days for the product to be ready for picking. The prepared products were arranged in different arrows for consecutive periods and the desired data were recorded. Product yield was studied based on several factors including shape, weight, the largest diameter obtained from the product, color, taste, and percentage function of mushroom yield based on Eq (1) presented by Baysal et al. [16]:

$$\textit{Mushroom biological yield} = (\textit{Fresh mushroom weight})/(\textit{Compost weight}) \quad (1)$$

According to this equation, the weight of each compost was measured before entering the hall as a factor called the weight of wet compost, and after harvesting each arrow, the weight related to the weight of wet compost was divided to the percentage of mushroom yield per arrow obtained in terms of compost ingredients. The obtained products were classified into three quality groups in terms of appearance as well as size, including small, medium, and large size, and the percentage of product allocation to these groups was reported. After all the factors were measured, the products of each flash were given to 5 different people to measure their taste and food quality, so that after cooking and consuming it, they record the result in the forms provided to them. The main discussion in the forms was the condition of the same cooking method, checking the hardness or softness, changing the color and smell, and the degree of elasticity after baking. All these results were presented in a table. After reviewing and studying the results, a general summary was reported at the end of the results and conclusions. Quantitative factors include the length of the mycelium running period, the length of the production period, the length of the crop arrangement period, the distance between the harvest arrows, the performance of each flash, as well as the overall product performance using SPSS software and ANOVA test using Duncan test at probability level. 95% were evaluated.

2.2. Application of life cycle assessment (LCA)

Life cycle assessment is a technique for assessing environmental aspects and potential impacts associated with the production of a product, process, or service [17]. This assessment covers the environmental impact of the entire process or activity, from the extraction and innovation of raw materials, manufacturing, transportation and distribution, use, storage, recycling, and final disposal [18]. ISO 14044 is the latest standard for life cycle assessment provided by this organization. According to this standard, life cycle assessment includes four items: goal and scope determination, life cycle inventory, life cycle impact assessment, and life cycle interpretation. In this study, Simapro software was used to develop a life cycle assessment based on the Impact 2002+ method. Life cycle assessment involves compiling a list of input and output quantities. In this study, an inventory was prepared based on what is presented in Figure 1.

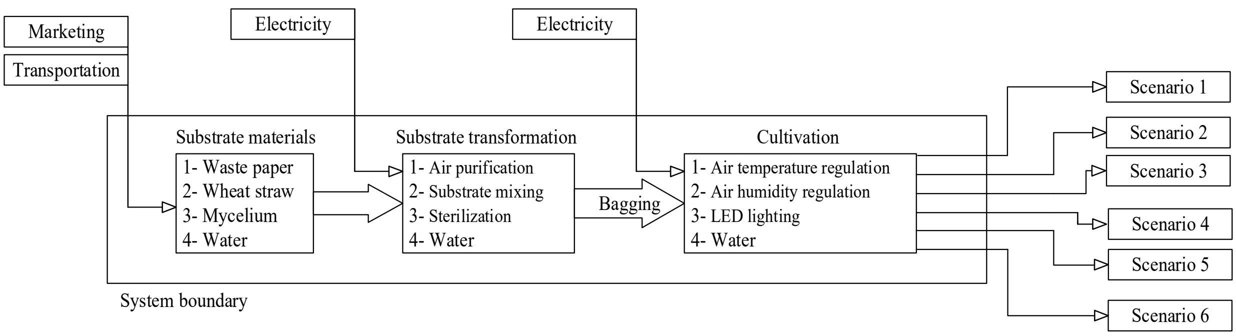


Figure 1. System boundary.

Table 2 presents the inventory used in this study. According to Figure 2 and Table 2, the system contains three main steps, substrate materials preparation, substrate transformation, and cultivation. The main variables of the system are materials, energy, and the main product. LCA has two main outputs including Midpoint indicators (Carcinogens, Non-carcinogens, Respiratory inorganic, ionizing radiation, Ozone layer depletion, Respiratory organics, Aquatic ecotoxicity, Terrestrial ecotoxicity, Terrestrial acid/nutria, Land occupation, Aquatic acidification, Aquatic eutrophication, Global warming, Non-renewable energy, and Mineral extraction) and Endpoint indicators (Human health, Ecosystem Quality, Climate change, and Resources). In this study, both Midpoint and Endpoint indicators have been presented and studied. LCA was developed into main six scenarios including using 0, 20, 40, 60, 80, and 100% of waste paper content in the production bed for comparing their environmental impacts.

Table 2. Life cycle assessment inventory.

Life cycle stage	Input	Material
Substrate materials	Waste paper	Transport
	Wheat straw	Transport
	Mycelium	Mycelium inoculated rye seeds
		Transport
		Electricity
	Water	Tap water
Substrate transformation	Air purification	Electricity
	Substrate mixing	Electricity
	Sterilization	Natural gas
	Plastic bags	Polyethylene
	Water	Tap water
Cultivation	Air temperature regulation	Electricity
	Air humidity regulation	Water
		Electricity
	LED lighting	Electricity
	Ventilation	Electricity

2.3. Modeling procedure

The modeling process was performed using the multi-layered perceptron (MLP) method as an effective and popular artificial modeling tool that can be successfully employed by different modeling and control systems [19]. The main explanation about the MLP technique can be found in our previous research works [20]. MLP was developed using MATLAB software. MLP was only employed for modeling the whole production system for estimation of the output variables. This has been corrected in the main text The architecture of the developed MLP model is presented in Figure 2. Accordingly, the inputs of the study were chosen to be the percentage of paper and the percentage of wheat straw (two inputs), and the outputs of the study were chosen to be biological yield, Energy consumption, water consumption, economic cost, and the Endpoint indicators (eight outputs) as the main environmental criteria. MLP was selected to be a single hidden layer architecture, due to the lower volume of the dataset. The rate of training and testing data was selected to be 70:30 due to the number of dataset. MLP was trained by the use of 70% of the total dataset in the presence of the 8, 10, 12, 14, and 16 neurons in the hidden layer for finding the best architecture. The output transfer function was selected to be tangh(x) according to a former study [21].

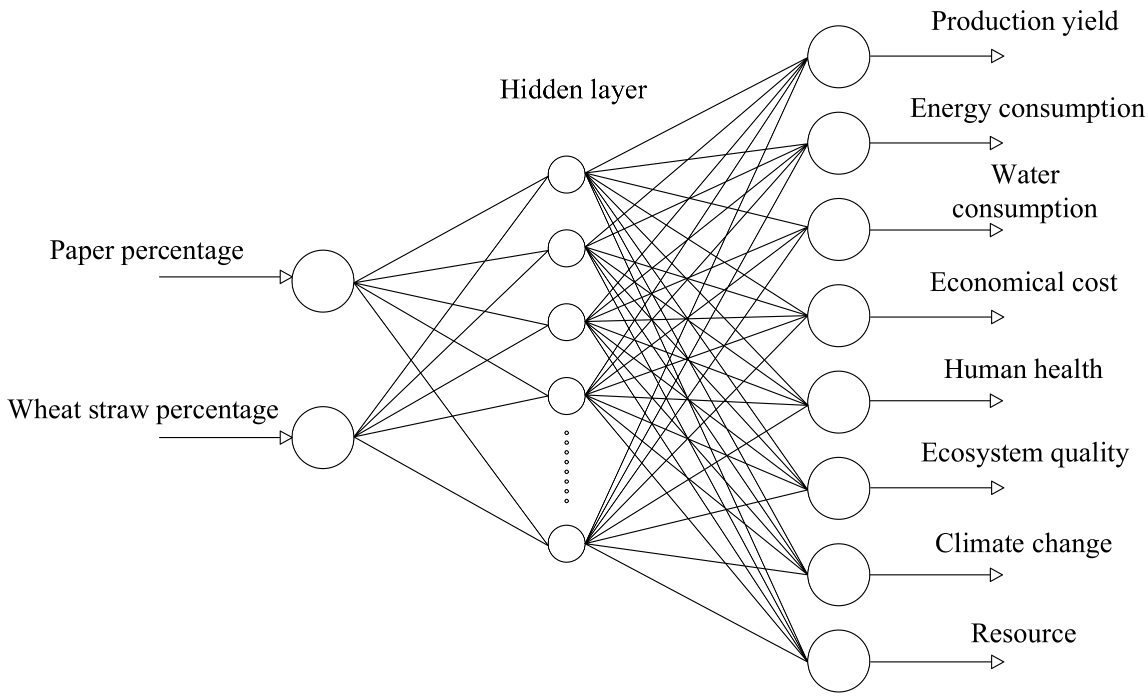


Figure 2. The architecture of the MLP model.

The evaluation of the MLP model for comparing the output values with target values was performed using two frequently used evaluation criteria, including root-mean-square error (RMSE) (Eq (2)) and correlation coefficient (CC) (Eq (3)). These evaluation criteria can measure the accuracy of the model and generate the error values. Where X and Y are output and target values, respectively, and N is the number of data.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - Y_i)^2} \tag{2}$$

$$Correlation\ coefficient = r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \sum(Y_i - \bar{Y})^2}} \tag{3}$$

Methods sections of papers on research using human subject or animals must include ethics statements that specify:

2.4. Optimization process

Optimization was performed by the use of response surface methodology (RSM) for finding the best condition from the viewpoint of economic and environmental aspects. RSM is a mathematical technique that fits a quadratic model for mapping the process. Accordingly, uses comparison logic to find the best production condition [22]. The processing was performed to achieve the maximum biological yield, minimum energy and water consumption, maximum net income, and minimum environmental impacts. Figure 3 presents the schematic diagram of the optimization procedure. RSM was performed by response surface toolbox of the design expert software. Initial variable selection and their limitations have been performed by central composite method. wheat straw and paper concentration have been selected as the independent variables and the outputs of the ANN were selected as the dependent variables. quadratic equations have been selected as their higher determination coefficient. Variables have been defined according to their lower and higher ranges. Finally, thirteen experiments have been imported to the design table. The main parameters for the optimization process have been presented by Eqs (4)–(10). These equations present the main quadratic equations in the codec format for analyzing the RSM and developing the optimization surfaces.

$$Yield = 3.64 - \left(6.05 \times \mathrm{A}\right) + 2.13 \times \mathrm{A} \times \mathrm{B} \tag{4}$$

$$Energyconsumption = 408.55+(50.91 \times \mathrm{A})-23.91 \times \mathrm{A} \times \mathrm{B} \tag{5}$$

$$Waterconsumption = 33.55+(3 \times \mathrm{A})-1.5 \times \mathrm{A} \times \mathrm{B} \tag{6}$$

$$Totalincome = 11.84-(22.12 \times \mathrm{A})-7.94 \times \mathrm{A} \times \mathrm{B} \tag{7}$$

$$Humanhealth = 2.74+(6.3 \times \mathrm{A})-2.3 \times \mathrm{A} \times \mathrm{B} \tag{8}$$

$$Eco.quality = 4.92+(49.41 \times \mathrm{A})-19.2 \times \mathrm{A} \times \mathrm{B} \tag{9}$$

$$Cli.change = 43.64+(1005.96 \times \mathrm{A})-368.86 \times \mathrm{A} \times \mathrm{B} \tag{10}$$

$$R. = 828.62+(19170.57 \times \mathrm{A})-7028.28 \times \mathrm{A} \times \mathrm{B} \tag{11}$$

where, A and B refers to the wheat straw and paper concentrations.

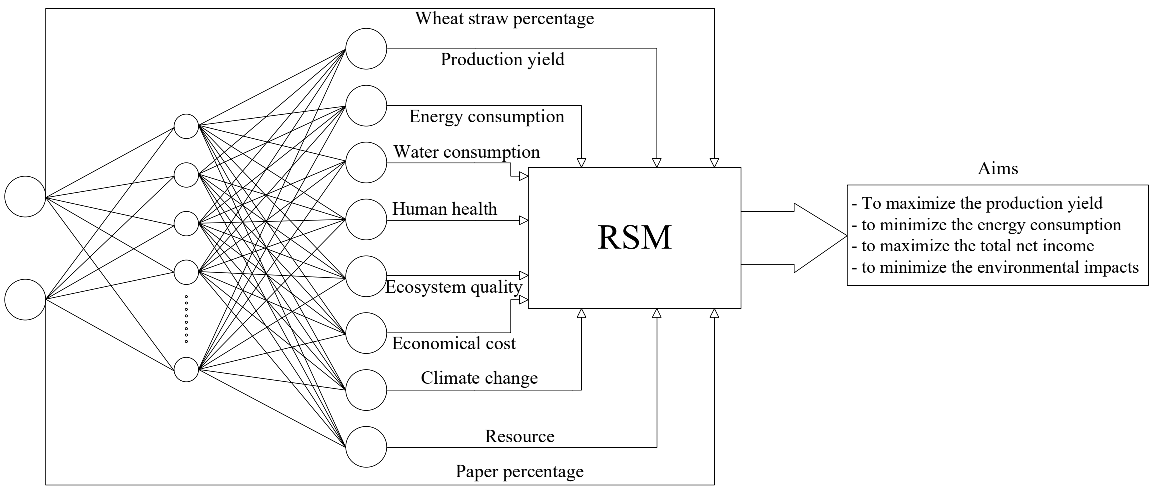


Figure 3. The schematic diagram of the optimization procedure.

3. Results and discussion

3.1. Substrate preparation results

The substrates prepared for growing oyster mushrooms were a mixture of waste paper and barley straw. After the pasteurization stage, different percentages of waste paper, straw, and straw were mixed and oyster mushroom seeds were added to them. Three composts were prepared from each group and all reports were submitted based on the average amount of three composts for one group. The groups contained 0, 20, 40, 60, 80 and 100% paper. According to Table 3, it can be seen that the slowest mycelium running is related to 100% paper bed with an average of 34.9 days, which is the time required to cover 100% of the compost surface with mycelium. Accordingly, the substrate containing 20% paper, with an average of 21.4 days to cover 100% of the compost surface, had the fastest mycelium running and with an average of 5.5 flash arrows had the highest number of harvest arrows. As can be seen from Table 3, the lowest number of flashes was for 100% paper substrate, with an average of 1.15 flashes.

Table 3. Productivity evaluation.

Production bed	Yield	Product growth	Pinning	Mycelium running	Number of flashes
P0	2925 ± 35	49.6 ± 0.56	28.6 ± 0.56	25.55 ± 0.63	4.25 ± 0.35
P20	4550 ± 70	55.5 ± 0.77	25.4 ± 0.63	21.4 ± 0.56	5.5 ± 0.0
P40	4090 ± 56	52.2 ± 0.35	25.2 ± 0.28	22.2 ± 0.28	5.05 ± 0.07
P60	2930 ± 42	50.6 ± 0.91	29.5 ± 0.7	25.75 ± 1.06	4 ± 0.0
P80	1310 ± 14	42.7 ± 1.06	32.7 ± 1.06	28.7 ± 0.98	2 ± 0.0
P100	355 ± 7	57.5 ± 0.71	54.6 ± 0.56	34.9 ± 0.14	1.15 ± 0.2

Note: P0 = 0% paper + 100% wheat straw, P20 = 20% paper + 80% wheat straw, P40 = 40% paper + 60% wheat straw, P60 = 60% paper + 40% wheat straw, P80 = 80% paper + 20% wheat straw, P100 = 100% paper + 0% wheat straw.

The main factor in Table 3 is product performance. According to this factor, the group of 20% paper with an average yield of 4550 grams in 55.5 days had the highest yield and the group of 40% paper with a slight difference from the bed of 20% paper had an average yield of 4090 grams in an average of 52.2 days. Other groups with relatively large differences with 20% and 40% groups, including 40% substrate with an average yield of 2930 g in an average of 50.6 days, zero percent paper substrate with an average yield of 2925 g in an average of 49.6 days on average Yield and 80% substrates with an average of 1310 g in 42.7 and 355 g in 57.5 days had the lowest product yield. Baysal et al. [16] reported the slowest spin thigh for bed 80% paper and 20 manure with an average of 37.6 days and the fastest spin thigh for bed with 80% paper and 20% rice straw with an average of 15.8 days. After the mycelial stage and knowing the number of harvest flashes, it was time to evaluate the product. Accordingly, to evaluate production, the amount of product produced in different arrows in terms of the function of ingredients in Table 4 was reported. In this table, the product performance factor based on Eq (1) was used. All these results are based on the average amount of product found from the three replicates of the substrates.

Table 4. Evaluation of the production bed (compost).

Bed	Relative humidity of bed	PH	Biological yield	Yield per production days
P0	67.5 ± 0.73	9	2.925 ± 0.035	0.058
P20	59 ± 1.45	8.5	4.550 ± 0.07	0.082
P40	57.75 ± 0.35	8.5	4.090 ± 0.056	0.078
P60	51.4 ± 0.7	8	2.930 ± 0.042	0.058
P80	42 ± 0.0	7.5	1.310 ± 0.014	0.03
P100	34.75 ± 0.35	7.5	0.054 ± 0.0005	0.0009

Note: P0 = 0% paper + 100% wheat straw, P20 = 20% paper + 80% wheat straw, P40 = 40% paper + 60% wheat straw, P60 = 60% paper + 40% wheat straw, P80 = 80% paper + 20% wheat straw, P100 = 100% paper + 0% wheat straw.

According to Table 4, a substrate consisting of 20% paper and 80% straw, with a biological yield of 4.55 and a production yield of 0.082 per day, followed by a substrate consisting of 40% paper with a biological yield of 0.094 and production yield equal to 0.087 per day showed the highest yield and 100 paper bed with a yield of 0.054 and production yield of 0.0009 showed the lowest yield. The substrate pH was reported to be 8.5 for substrates containing 20 and 40% paper and 7.5 for 100 paper substrates. According to Table 4, the relative humidity obtained for the bed of 20 and 40 percent of paper were reported to be 59 and 57.7, respectively, which was 34.75 in the P100-bed, which could be one of the important reasons for the poor performance to be considered a bed. Figure 3 presents the production yield against the production days based on wheat straw percentage. As is clear from Figure 4, the maximum production yield and the minimum production days are related to the range of 60 to 100% of wheat in the production bed. This means that a specific percentage of paper and wheat can increase the production yield and reduce the production delay. Increasing the paper percentage in the production bed reduces the production yield and increases the production days, which means increasing the production delay. After studying the product features based on experimental data, it was time to evaluate the product by different people. Accordingly, according to the method mentioned in the Materials and Methods section, the products obtained from each bed were provided separately to five different individuals to produce the results in the same form after consuming the product with the same and specific cooking and storage method. Provide us with special services. Some reports are given in Table 5.

Figure 4. Production yield against production days.

Table 5. Results of product quality review by the consumer.

Bed	Smell change after cooking	Color change after cooking	Crispness and softness after cooking	Shelf life in the refrigerator without discoloration
P0	No change of smell	Gray and dark	Stiff and elastic	8 days
P20	No change of smell	Partial gray	Soft and crisp	7 days
P40	No change of smell	Clear	Soft and crisp	7 days
P60	No change of smell	Clear	Soft and crisp	5 days
P80	No change of smell	White and no color change	Very crisp	5 days

Note: P0 = 0% paper + 100% wheat straw, P20 = 20% paper + 80% wheat straw, P40 = 40% paper + 60% wheat straw, P60 = 60% paper + 40% wheat straw, P80 = 80% paper + 20% wheat straw, P100 = 100% paper + 0% wheat straw.

It should be noted that compost containing 100% paper was not tested in this test due to lack of fungus during data collection time and also low crop production. According to reports, for the product obtained from the substrate containing 100% straw, hard and elastic state after baking and for the substrate containing 80% paper, very brittle products were reported after baking. Also, the change of color of the product to dull and dark color after baking in a bed of 100 straws and straws compared to the product made of 80% paper, which did not change color, is evidence that as the percentage of paper in the production bed increases, the color of the product after baking does not change, but instead becomes crispy. Reports indicated that the odor did not change after cooking in the products obtained from the substrates. Also, as shown in the table, the shelf life of refrigeration at an average temperature of 4 °C, 8 days for 0% paper substrate, and 5 days for 60 and 80% paper substrates were reported. The result is that with increasing the ratio of paper in the production medium in this study, the shelf life of the product in the refrigerator has decreased.

Every production process needs an economic study to investigate the sustainability of the production process. In this study, the economic study of production was done by considering the amount of water and electricity consumed and their cost as variable costs and the price of paper and straw as a fixed cost of each production period. For this purpose, a cost chart was drawn based on the revenue from the production of the product versus the cost from the consumption of energy inputs (including water and electricity). Table 6 shows the revenue and cost of producing the product.

Table 6. Results of the economic analysis.

Bed	Production bed Cost ($)	Electricity cost ($)	Water cost ($)	Sell ($)	Net income ($)
P0	2.83	1.89	1.29	13.54$	7.53
P20	2.56	1.37	0.93	21.47	16.61
P40	2.3	1.62	1.12	19.27	14.23
P60	2.04	1.725	1.17	13.82	8.88
P80	1.77	1.85	1.27	6.16	1.27

Table 6 shows the economic analysis related to production costs (including the cost of seeds, paper, straw, and energy for compost production), the cost of water and electricity consumption for crop production, and the final income from sales and net income. As it turns out, the difference in the cost of producing the substrate is related to the amount of straw, seeds, and paper. According to the results, the highest sales revenue and net income related to the bed containing 20% of paper is equal to 21.47 and 16.61$, respectively, and the lowest sales revenue and net income related to the bed containing 80% paper is equal to 6.16 and 1.27$, respectively.

3.2. LCA results

Figure 5 indicates the results of the midpoint impacts, and Figure 6 presents the results of the Endpoint impacts according to the IMPACT 2002+ method. these indicators are normalized in the range of 0 to 100%. As is clear from results for both midpoint and endpoint impacts, 100% of paper content provides the higher environmental impacts. The lower environmental impacts are related to 20 and 40% of paper content. On the other hand, 0% of paper content (100% of wheat straw content) generates higher environmental impacts compared with 20 and 40% of paper content.

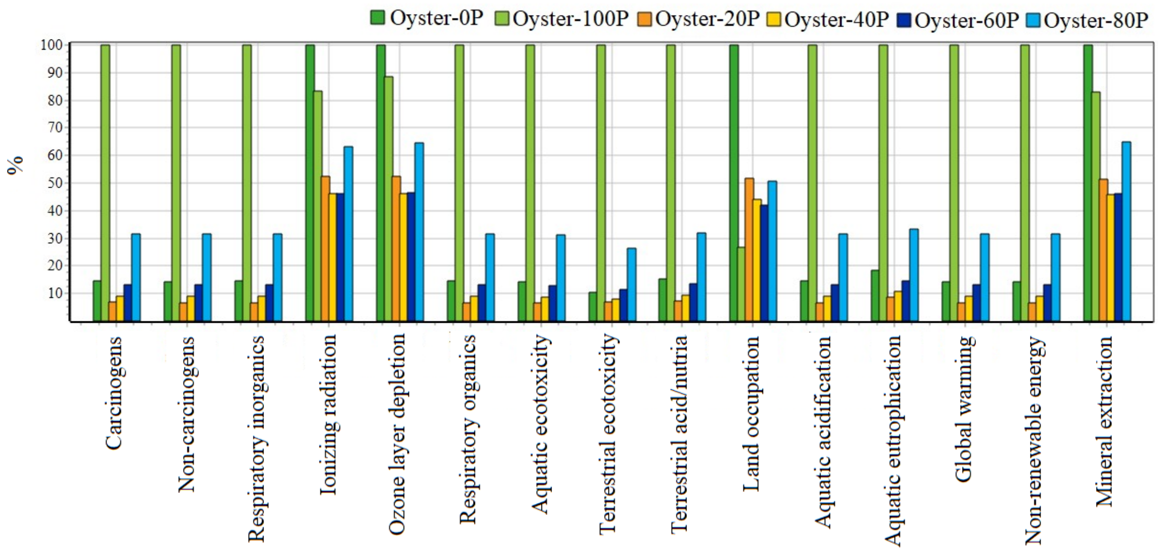


Figure 5. Midpoint environmental impacts for each scenario.

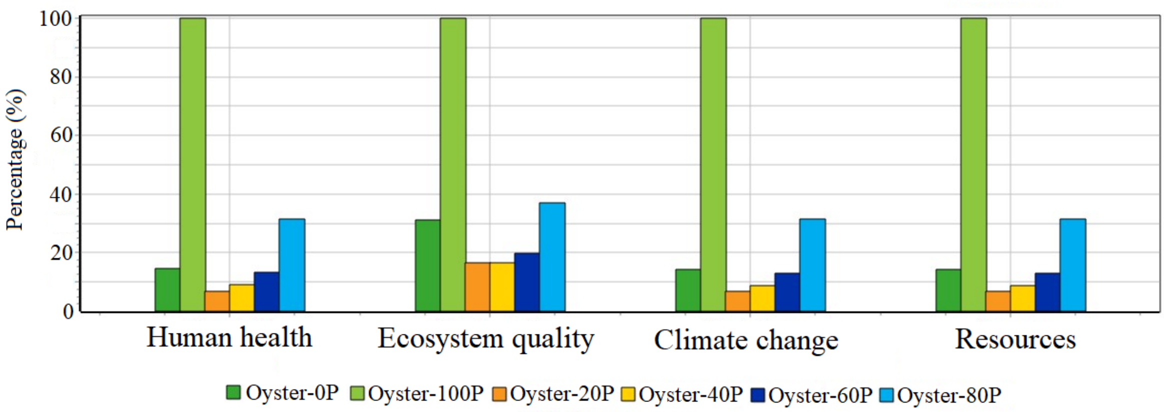


Figure 6. Endpoint environmental impacts for each scenario.

Accordingly, it can be concluded that a specific range of paper content (20–40%) can reduce the environmental impacts. Increasing the paper content from 40 to 100 and also lower than 20%, increases the environmental impacts.

Table 7 presents the validation results for the LCA outputs from the similar studies.

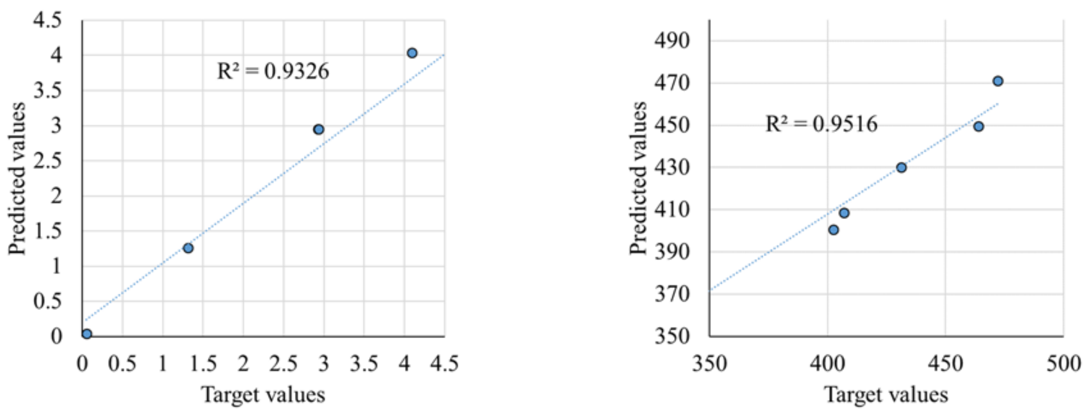
Table 7. Validation results for the LCA outputs.

Product name	unit	Straw mushroom [23]	This study	Agaricus bisporus [24]	Agaricus bisporus [25]	Agaricus bisporus [26]
method	-	CML based line 2001	IMPACT 2002+	CML 2000 Leiden	TRACI 2.1	IPCC
Global warming	$kgCO_2e$	0.84	2.4	4.42	2.13–2.95	2.34
Eutrophication	gSO_2e	8.3	4.6	-	-	-
Acidification	$gPO_4^{3-}e$	1.9	0.067	-	-	-

3.3. Modeling results

The modeling process was started with 8 neurons in the hidden layer. After each training process, two neurons have been added to the number of neurons for the next training step. This was performed for finding the optimum number of neurons in the hidden layer. This was continued to reach the best architecture. Finally, 10 neurons in the hidden layer were selected as the optimum number of neurons in the hidden layer with the lower RMSE and higher CC values compared with other compositions. Accordingly, the best architecture of the MLP model was selected to be 2-10-8. Table 8 presents the values of the evaluation criteria for 2-8-8, 2-10-8, 2-12-8 and 2-14-8 architectures for training and testing processes.

Figure 7 indicates the plot diagram individually for each output values for the selected architecture.



(a) (b)

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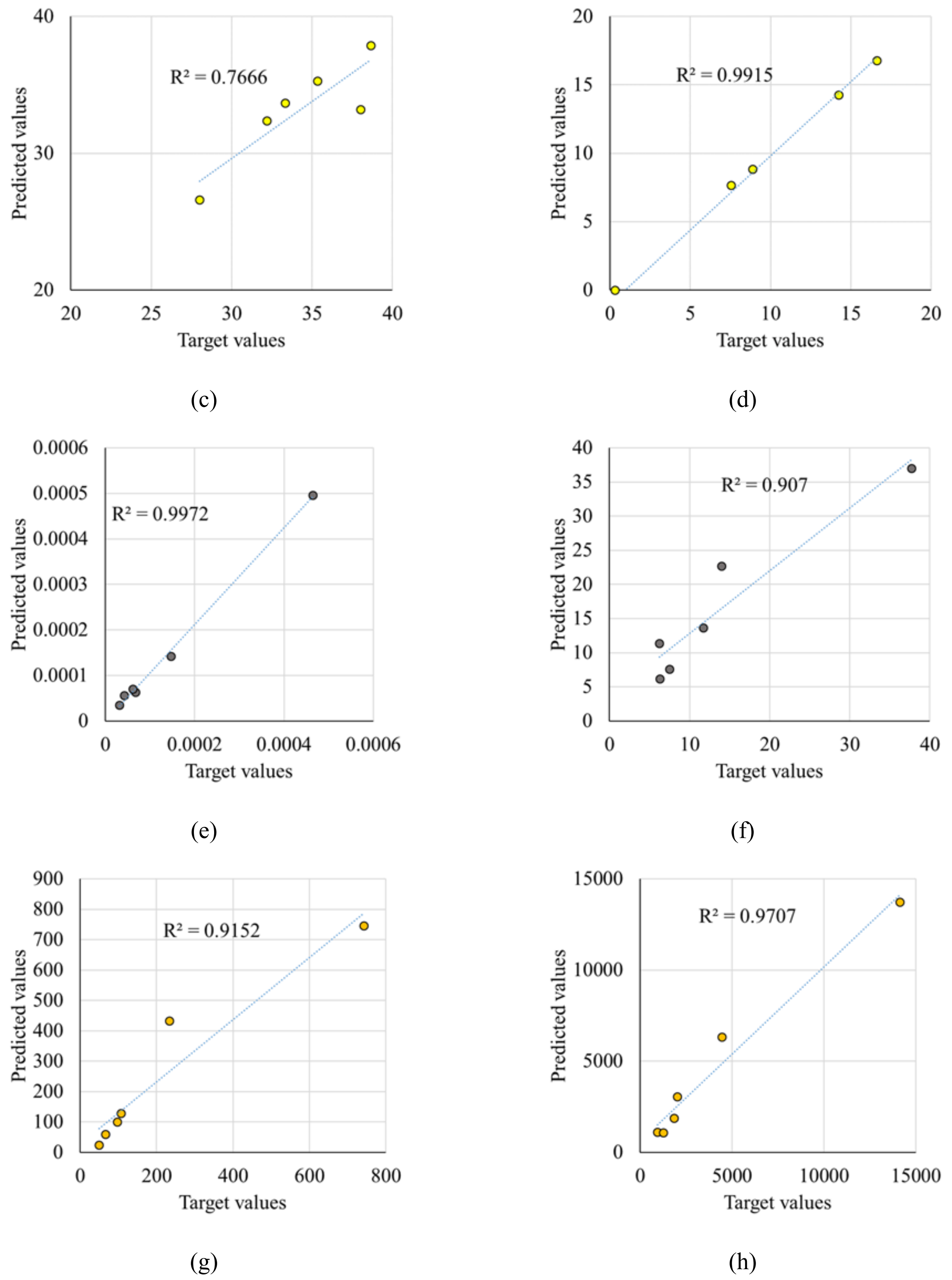


Figure 7. Plot diagrams for modeling process. a) Yield; b) Energy consumption; c) Water consumption; d) Total income; e) Human Health (DALY); f) Eq; g) CC and h) R.

Table 8. Evaluation criteria for the best architecture of MLP in training and testing phases.

No. of neurons	Process	Evaluation metric	Yield	Energy consumption	Water consumption	Total income	Human health	Ecosystem quality	Climate change	Resources
8	Training	RMSE	0.62	14.99	2.9	0.99	2.88E-5	5.01	0.91	1080.1
		CC	0.87	0.95	0.75	0.91	0.94	0.9	0.92	0.91
	Testing	RMSE	0.77	16.88	3.12	1.56	3.01E-5	5.99	1.44	1100.8
		CC	0.83	0.91	0.71	0.88	0.89	0.86	0.89	0.85
10	Training	RMSE	0.47	14.13	2.07	0.86	1.53E-5	4.21	0.82	900.56
		CC	0.96	0.97	0.87	0.99	0.99	0.95	0.95	0.98
	Testing	RMSE	0.52	15.16	2.78	1.01	2.44E-5	5.44	1.31	1008.44
		CC	0.93	0.95	0.82	0.97	0.95	0.91	0.92	0.92
12	Training	RMSE	0.6	15.02	3	0.99	2.52E-5	4.92	0.89	1021.5
		CC	0.88	0.96	0.77	0.91	0.96	0.91	0.92	0.92
	Testing	RMSE	0.79	16.31	3.02	1.56	3.21E-5	5.81	1.21	1059.1
		CC	0.84	0.92	0.75	0.88	0.91	0.88	0.92	0.87
14	Training	RMSE	0.8	17.43	4.31	1.39	3.47E-5	5.65	1.33	1499.1
		CC	0.81	0.85	0.61	0.82	0.83	0.81	0.8	0.79
	Testing	RMSE	0.99	19.01	4.99	2.13	4.01E-5	6.01	2.03	1888.9
		CC	0.71	0.81	0.6	0.71	0.77	0.76	0.73	0.71

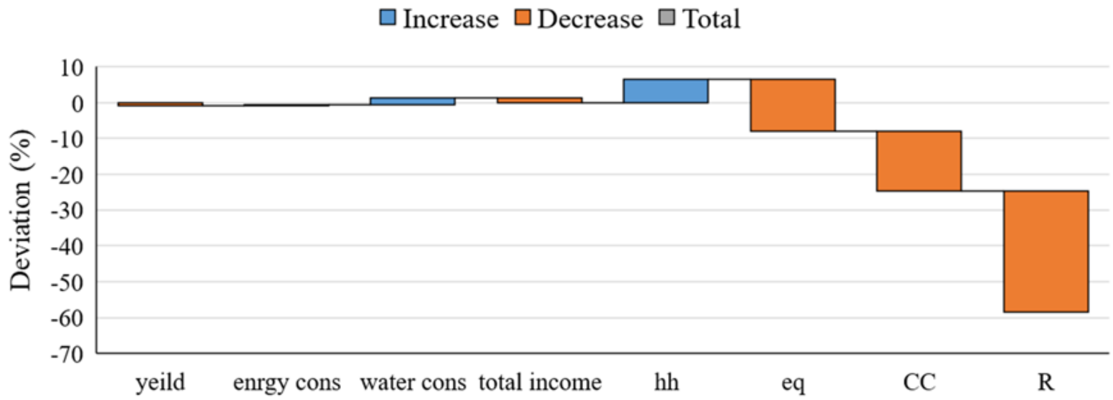
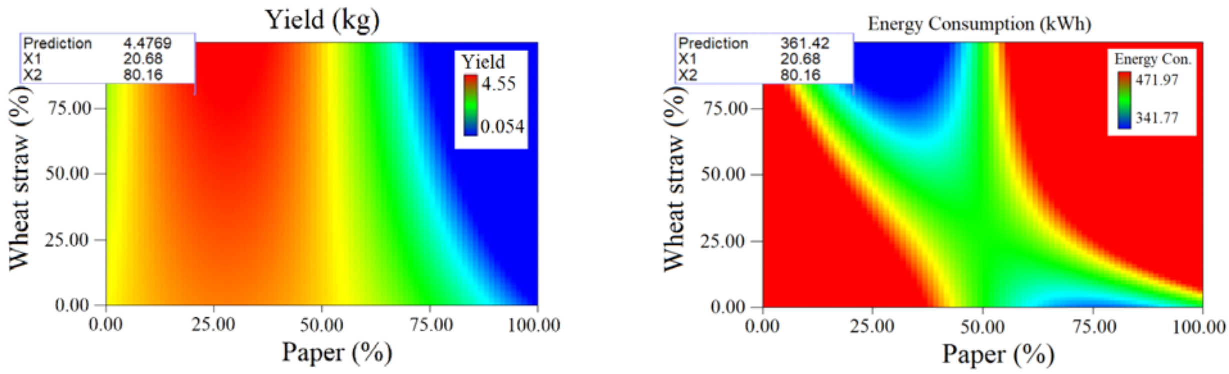


Figure 8. Deviation from target values (%).

Figure 8 presents the deviation percentage of the output values of MLP for 10 neurons in the hidden layer. In fact, Figure 8 presents the positive and negative errors (%) from target values for each output variable. As is clear from Figure 7, the maximum positive deviation is related to Human Health by about +7% and the maximum negative error is related to Resources by about -33%.

3.4. Optimization results

This section presents the optimization results generated by RSM. Accordingly, Figure 9 presents the optimized surfaces for each dependent variable. Optimization was targeted to maximize the yield, total income and to minimize the energy consumption, water consumption, and environmental impacts. In another word, RSM was employed for maximizing the sustainability in OM production from waste paper. This section proposes the best condition for producing OM from waste paper in combination with wheat straw.



(a) (b)

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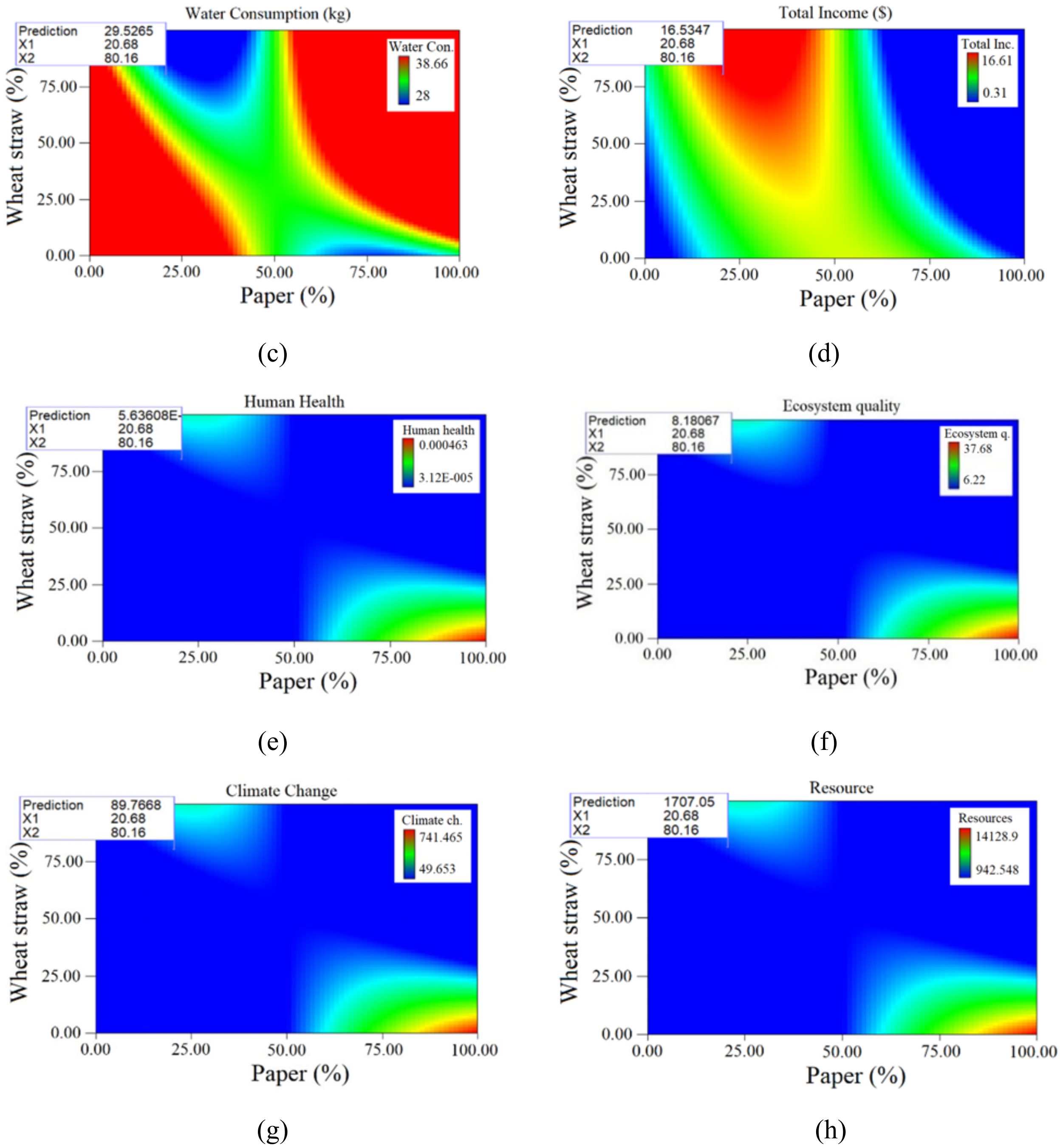

Figure 9. The optimized surfaces for each independent variable. a) Yield (kg), b) Energy Consumption (kWh), c) Water Consumption (kg), d) Total Income ($), e) Human Health (DALY), f) Ecosystem quality (PDF*m2*yr), g) Climate Change (g CO_2 eq), h) Resources (kJ primary).

According to Figure 9, the best condition (optimized condition) for the production of OM from waste paper can be found in the paper portion range of 20% and the wheat straw range of 80%. As is clear, this condition carries higher production yield by about 4.5 kg and higher net income by about 16.54 $ in the presence of the lower energy and water consumption by about 361.5 kWh and 29.53 kg, respectively, as well as the lower environmental impacts on Human Health, Ecosystem Quality, Climate change and Resources by about 5.64 DALY, 8.18 PDF*m2*yr, 89.77 g CO_2 eq and 1707.05 kJ, respectively.

Bamigboye et al. (2019) employed ANN integrated by a completely randomized technique to improve carbon and nitrogen content and growth physical factors for Pleurotus tuber-regium in oyster production. According to the results 0.699 g biomass and 0.291 g EPS per 100 mL medium was obtained [27]. Vieira et al. (2016) employed single RSM to optimize the substrate preparation for oyster mushroom production. according to the results, brizantha grass with 28.5% provided higher mushroom yield in comparison with other substrates [28]. For the future research applying advanced machine learning techniques are proposed. For improving the model performance utilizing either deep learning or hybrid methods is strongly proposed. In this context, evolutionary optimization algorithms are essential to tune the algorithms' parameters and optimally train the models for efficient fitting as described in recent studies, where in fact ensemble-based methods along with hybrids outperform other models.

4. Conclusions

This study was studied to evaluate the substrate obtained from waste paper and wheat straw from the economic and environmental points of view. The study was performed into main four phases. The first phase was to perform the experimental processes. The second phase analyzed the study using a life cycle assessment for achieving the environmental impacts of the studied scenarios. The third step developed an ANN-based model for predicting the process in the presence of the Endpoint indicators from the life cycle assessment technique. The final phase performed an optimization using response surface methodology for finding the maximum production yield and net income along with lower environmental impacts and energy consumption. According to the results of different substrates prepared with different percentages of waste paper and wheat straw, substrates containing 20 and 40% of paper, provided a higher production yield compared with other production beds. The highest sales revenue and net income related to the bed containing 20% of paper is equal to 21.47 and 16.61 $, respectively, and the lowest sales revenue and net income related to the bed containing 80% paper is equal to 6.16 and 1.27 $, respectively. Based on the results of the environmental analysis, the lower environmental impacts were related to 20 and 40% of paper content. On the other hand, 0% of paper content (100% of wheat straw content) generates higher environmental impacts compared with 20 and 40% of paper content. According to the results of the modeling phase, the best architecture of MLP model was selected to be 2-10-8. The last phase provided results of the environmental analysis. The best condition (optimized condition) for the production of OM from waste paper can be found in the paper portion range of 20% and wheat straw range of 80%. As is clear, this condition carries higher production yield by about 4.5 kg and higher net income by about 16.54 $ in the presence of the lower energy and water consumption by about 361.5 kWh and 29.53 kg, respectively, as well as the lower environmental impacts on Human health, Ecosystem quality, Climate change and Resources by about 5.64 DALY, 8.18 PDF*m2*yr, 89.77 kg CO_2 eq and 1707.05 MJ, respectively. It can be concluded that, sustainable production of OM can be achieved in line with the policy used to produce alternative food source from waste management techniques.

Conflict of interest

The authors declare there is no conflict of interest.

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