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An optimal model for the multi-lever and multi-species production in edible fungus circular system *

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Abstract. Edible fungus is the core of the material and energy conversion in the edible fungus circulatory system. In order to make both economic and ecological benefits maximize, according to the process of multi-lever and multi-species circular production of edible fungus, we optimize the edible fungi circular production process through mathematical model and solve the model by genetic algorithm.

Keywords: edible fungus, optimal model, circular production

1 Introduction

It is more and more important for economic and ecology develop in step, so do edible fungus industry. [9] uses a project named " Edible Fungus Wastes Recycling Project " to explore the possibility to implement such Economic and Development Model in Chinese current economy. [7] introduces the recycling methods of edible fungus chaff from soilless cultivation substrate, fungus chaff feed, biological fertilizer, fuel and hormones and pesticide chemicals.

In order to solve the technical problems of recycling edible fungus chaff, [3]analyzes different fungus chaff nutrient content. The result is fungus chaff can replace wood, cotton seed shell and wheat bran as the component elements of the culture medium to produce Pleurotus geesteranus, Tricholoma lobayense, and Pleurotus abalonus. [7] and [16] make comprehensive statement about the utilization of edible fungus chaff.

[4] and [13] optimize culture medium formula of some kinds of edible fungus by regression model; [5], [15], and [8] talk about the optimization of environmental factors during the production process. [11] is mainly to present oyster mushroom (Pleurotus) strains were better than shiitake (L.edodes) strains under single, paired, and mixed cropping patterns.Mixed cropping further eliminated the inherent inhibitory effect of sweet potato, basil, or lettuce on fungal growth. Co-cropping fungal species had a synergistic effect on rate of fungal growth, substrate colonization, and fruiting. Use of efficient cropping methods may enhance fungal growth, fruiting, biodegradation of crop residues, and efficiency of biomass recycling.

[2] is to talk about the spent residues such as those obtained after cultivation of edible mushrooms could be a better source of pretreated substrates for biogas production. In [6] this work, a review of knowledge relative to the reintroduction of spent mushrooms substrates in the elaboration of casing layers and base substrates for new cultivation cycles is presented. These applications allow to integrate this type of materials by means of new formulations and methodologies with the added advantages of lowering the production costs and decreasing the environmental impact.

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That is to say, the significance of research on optimal model of edible fungus production to recycle the edible fungus chaff is not only obvious but significant as a research topic.

Based on the above point of views, in this paper, we intend to optimize the circular production of edible fungus which is multi-lever and multi-species. Multi-lever means recycling the fungus chaff several times, and multi- species means including 3 to 4 edible fungus. The paper is organized as follows: at first, we state the problem at the beginning of section 2, then in the middle of section 2 we will provide the mathematical model of the problem. section 3 is analysis of the results. In section 4 we will give the conclusion.

2 Modeling

Edible fungus circular production model is the integration of agricultural wastes, fungus chaff and fermentation residue cultivating edible fungus[12]. It is often seen in manufacturing enterprises and park, which can realize the maximization of resource recycling. It is based on agricultural wastes, fungus chaff and fermentation residue to product edible fungus and gain the ends of resources cyclic utilization. As possible as it can utilize the fungus chaff from the last production.

2.1 Description of the problem

Different edible fungus need different culture medium. According to different utilization by substrate components of different characteristics, we can arrange to cultivate the second type of edible fungus reasonably[7]. The first cropsforrotation edible fungus hypha will secrete kinds of enzymes, and the decomposition of fibrin from substrate can be utilized by the second cropsforrotation edible fungus. Fig. 1 represent the process of circular production. Producer should choose different, complementary edible fungus. Such as

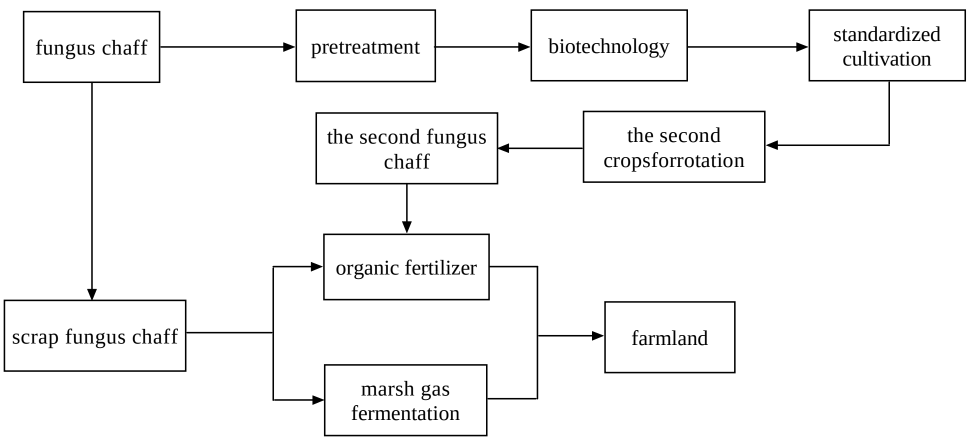

Fig. 1. circular production reduced graph

lignin can't be utilized by straw mushrooms, while the straw mushrooms chaff is suitable for cultivated oyster mushroom, not for Agaricus bisporus.

Although fungus chaff can be used to cultivated edible fungus several times, but not any cropsforrotation, any materials, any crop can be fully used, or use the same proportion of the fungus chaff. Pleurotus nebrodensis fungus chaff is full of nutrition, so it need not add new material to cultivated Coprinus comatua, which is different from other fungus chaff. For another example, champignon fungus chaff can't be superfluous when it is used for the second cultivation.When add below 20%, the output is not affected, still can promote the mushroom grow. When add to 30%, the production decline and mushroom is small of bad quality.

Not all the edible fungus chaff can be utilized for the second time. It is must be good and not polluted. Otherwise, the poisonous and harmful substances in the pollution will affect the growth of secondary cropsforrotation edible fungus. It is also an obstacle in the process of sterilization.

Fungus chaff recycling involves a very important content is the determination of the nutrient content in the fungus chaff. Quantitative and qualitative analysis for the determination of reasonable configuration medium will provide scientific basis for the production.

2.2 Mathematical model

In order to reduce the production cost, utilize edible fungus chaff as more as possible and reduce the discharge of edible fungus chaff, according to the production technology of cultivating edible fungus and the preparation technology of medium, we plan to produce various edible fungus reasonably. So we build the multi-objective optimization mathematical model under the condition of using the goal programming of the problem to obtain a satisfactory solution which can reflect the policymakers' will.

Therefore, it is necessary to optimize the edible circular production by reusing the wastes to reach the enterprise production target. Based on above analysis, we draw the production flow chart as Fig. 2. Combining the flow model we can gain the mathematical model of edible fungus circular production systems as follows.

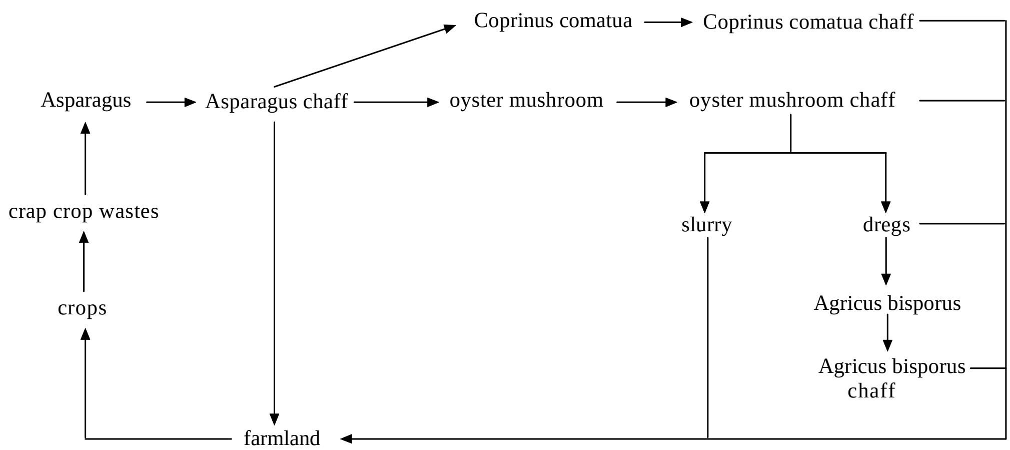

Fig. 2. circular production flow chart

Assumptions

In order to discuss the optimal production problem better, combined with the circular production, we ignore the human resource constraints of edible production mode. We consider the cultivation medium ingredients of edible fungus optimization only.

It can be seen in the optimization process mainly involves three-level cycle and four kinds of fungi from Fig. 2. To simplify the discussion, there are some assumptions:

Firstly, the available agricultural wastes are common which are cotton seed hulls, straw and bran[1];

Secondly, edible mushrooms are also common which are Asparagus, oyster mushroom, Agricus bisporus, Coprinus comatua;

Thirdly, the proportion between medium and edible fungus is 1:1, that is to say, the biological conversion is 100%.

Variables

x_i is denoted as the output of the ith edible fungus; r_i is denoted as the generation rate of fungus chaff when cultivate the ith edible fungus; t_{ij} is denoted as the proportion of the jth raw material in the culture medium to produce the ith edible fungus per unit; b_j is denoted as the supply of the jth raw material; r_{zz} is denoted as the generation rate of the dregs when fungus chaff is converted to marsh gas.

$\mathrm{J}_{\max}$ is denoted as the maximum of cotton seed shell and straw which producer can provide; $\mathrm{J}_{\min}$ is denoted as the minimum of cotton seed shell and straw which producer can provide; $\mathrm{M}_{\min}$ is denoted as the maximum of wheat bran which producer can provide; $\mathrm{M}_{\max}$ is denoted as the minimum of wheat bran which producer can provide.

N is denoted as the types of raw material in the medium which producer can supply.

Among them, $i = 1, 2, 3, 4$ are Asparagus, oyster mushroom, Agaricus bisporus, and Coprinus comatua. $j = 1, 2, \cdots, 10$ are straw(cotton seed hulls), wheat bran, corn flour, gesso, ordinary superphosphate, urea, lime, Asparagus chaff, dregs, and oyster mushroom chaff.

Objective functions

Because the circular production of edible fungi is mainly used in the production enterprises, and the production process of edible fungi has various strains yield maximization, edible fungus profit maximization, the best collocation to use of different agricultural wastes of and other targets.

According to the variable settings, the target function can be expressed as follows.

yield maximization:

$$f(z_1) = \max\{x_1, x_2, x_3, x_4\} \tag{1}$$

wastes used maximization:

$$f(z_2) = \max \sum_{i=1}^{4} \sum_{j=1}^{6} x_i \cdot t_{ij} \tag{2}$$

Constraints

According to the circular system modeling ideas, we can divide the constraints into two groups. They are mainly raw material supply constraints and material balance constraints.

raw material supply constraints:

$$\begin{cases} \mathrm{M}_{\min} \leq \sum\limits_{i=1}^{4} x_i \cdot t_{i1} \leq \mathrm{M}_{\max} \\ \mathrm{J}_{\min} \leq \sum\limits_{i=1}^{4} x_i \cdot t_{i2} \leq \mathrm{J}_{\max} \\ \sum\limits_{i=1}^{4} x_i \cdot t_{ij} \leq b_j \qquad\qquad (j = 1, 2 \ldots, 7) \end{cases} \tag{3}$$

material balance constraints:

$$\begin{cases} \sum\limits_{i=2}^{4} x_i \cdot t_{i8} \leq x_1 \cdot r_1 \\ x_3 \cdot t_{39} \leq x_2 \cdot r_2 \cdot r_{zz} \end{cases} \tag{4}$$

variable constraints:

$$x_i \geq 0 (i = 1, 2, 3, 4) \tag{5}$$

Where Constraints (3) and Constraints (4) satisfies the quantity of consumption do not exceed the upper limit; Constraints (5) enforce the non-negativity restriction on the decision variables.

3 Analysis

This section focuses on the solving and analyzing the optimal model of circular producing which is multi-lever and multi-species. We respectively consider the impact of the changes of the price and the upper supply by RCGA (real-coded GA).

3.1 Genetic algorithm

In general, a GA has basic components, as summarized by Michalewicz[10]:

(1) A genetic representation of potential solutions to the problem.

(2) A way to create a population (an initial set of potential solutions).

(3) An evaluation function rating solution in terms of their fitness.

(4) Genetic operations that after the genetic composition of offspring (crossover, mutation, selection, etc.).

(5) Parameter values that genetic algorithm uses (population size, probabilities of applying genetic operators, etc.).

The general implementation structure of RCGA for our model group is described as follows. It shows a general structure of GA. Let P_t and C_t be parents and offspring in current generation t.

Procedure `The general implementation structure of GA for product diffusion`

Input: problem data, GA parameters
Output: the best solution
begin
  $t \leftarrow 0$;
  initialize P(t) by encoding routine;
  evaluate P(t) by decoding routine;
  while not termination condition **do**
    create C(t) from P(t) by crossover routine;
    create C(t) from P(t) by mutation routine;
    evaluate C(t) by decoding routine;
    select P(t+1) from P(t) and C(t) by selection routine;
    $t \leftarrow t + 1$;
  end
  Output: output the best solution
end

3.2 Solving

Under the guiding principle of optimizing the production, referring to the circular production flow chart and the Tab. 1 material consumption, combined the practical production with the market price of edible fungus, we will analyze the optimization scheme.

Table 1. Material consumption

	Asparagus	Oyster mushroom	Agaricus bisporus	Coprinus comatua
Cotton seed hulls	87.5%	50%	—	—
Wheat bran	8%	—	47%	38%
Corn flour	3%	—	1%	3%
Gesso	1.5%	1%	1%	—
Ordinary superphosphate	—	1%	2%	1%
Urea	—	—	1%	1%
Lime	—	1%	1%	—
Asparagus chaff	—	47%	—	57%
Dregs	—	—	47%	—

Preference to output value

For multi-objective programming problem, we need make a real function for policymakers satisfactory solution according to the decision makers' preference information, which is equivalent to a new single objective function with the same satisfactory solution. The original multi-objective programming problem has already become a single objective problem, we can get the solution by genetic algorithm.

The common methods[14] convert multi-objective programming problem to single objective programming problem are the method of evaluating function, the method of objective programming, the method of stratified sequence, the method of interactive programming, etc. Here we will mainly use the method of linear weighted belonged to method of evaluating function.

Computed result In the process of producing edible fungus, we can optimize the output value. At this time, we can think of any edible fungus market price corresponding to its weights, and transform the multi-objective function into linear weighted multi-objective function. Weight coefficients which are prices reflect the relative importance of target in the producer's mind. It is also the economic benefits the production can bring to producers. If the market price of an edible fungus is higher, the corresponding weight is bigger. Conversely, the lower, the smaller.

According to the model, we can evaluate the parameter. In the assumption, the peak value of straw and the cotton seed shell is 120 tons (minimum 0), the maximum of wheat is 80 tons (minimum 0), And the rest of all the materials are 10 tons. The coefficients in the constraint condition of material balance are:0.4, 0.5, 0.4, 0.8, 0.4, 0.5, 0.5. In addition, the price of Asparagus is 10,000 yuan/ton, the price of oyster mushroom is 4,000 yuan/ton, the price of Agaricus bisporus is 6,000 yuan/ton, the price of Coprinus comatua is 7,000 yuan/ton.

Based above discussions, the implementation structure of RCGA for our model is described as follows:

Procedure `The GA algorithm for model of multi-lever and multi-species circular production of edible fungus`

Step 1. Total income and $x_i, i = 1, 2, 3, 4$ are represented as a N dimensional vector Ch_r;
Step 2. Set the generation counter to zero, $n = 0$;
Step 3. Using uniform distribution, randomly generate initial population gen_0 of trial vectors Ch_r for $r = 1, 2, 3, 4$ from a feasible range in each dimension;
Step 4. Evaluate fitness of each individual of current population by using the fitness subroutine;
Step 5. Increase the generation counter by one, $n = n + 1$;
Step 6. Apply GA to produce gen_{n+1}: preserve the elite chromosomes, select Np parents from population of trial vectors using tournament selection, recombine them using crossover and mutation operators to produce Np child vectors;
Step 7. Evaluate fitness of each chromosome of current population by using the fitness subroutine and store the solution corresponding to the best fit chromosome;
Step 8. Apply the replacement operator and diversity mechanism to the current population;
Step 9. Check for the convergence criterion: if current generation number n is equal to $Gen_{\max}$, stop and print total income corresponding to the best fit vector of the population. Otherwise, go to **Step** 6;

From the program we can be get the objective function value which is total income is 3827879 yuan. Decision variable are $x_1 = 7315.1515$, $x_2 = 87.27273$, $x_3 = 54.54545$, $x_4 = 0$.

3.3 Sensitivity analysis

In the actual production of edible fungi, because of the influence from different market price, the mathematical model will be changed. So it is needed to research on the sensitivity analysis of the price. According to the initial value of price parameter we can be calculate an optimal production plan. If the shadow price of resources in the restrictions increases a unit, the production systems will increase the same profits.

For example, when increase the maximum of bran, production systems will increase profits 4121.212 yuan. At this time, x_4 is a nonbasic variable, and its reducedcost is 3000. Its economic meaning is: relatively, the unit profit of Coprinus comatua is lower and it is not worth producing. If we want to make this product into production system, we should improve the production unit of product. But the prices generally mainly decided by market. So enterprises should decide to reduce the production cost and the minimal cost should reduce is studied here.

When make the sensitivity analysis, we can assume the price changes, the raw material changes or both of the two change and compare the optimization scheme.

First, when the price of the four types change to 8000 yuan/ton, 3400 yuan/ton, 6200 yuan/ton, 8000 yuan/ton,we get a new optimal solution. Now the total income is 3156121 yuan, and the output of four kinds edible fungus change respectively to: 269.2525 ton, 87.27273 ton, 54.54545 ton and 45.89899 ton.

Second, prices are unchanged but the supply of the cotton seed shell reduce to 60 ton. We can see when the supply of cotton seed shell reduce, the output of each edible decrease in proportion. The output are 321.2121 ton, 58.18182 ton, 36.36364 ton and 0.

Third, four prices change respectively to 11000 yuan/ton, 4200 yuan/ton, 6300 yuan/ton, 7800 yuan/ton and the gross of straw and cotton seed hulls become to 70 ton. In this case the optimal production plan changes: 322.7273 ton, 50.90909 ton, 31.81818 ton and 0. Correspondingly, the total income is 3964273 yuan.

3.4 Comprehensive coordination analysis

In the process of comprehensive coordination analyzing, we will use efficiency coefficient method for processing the multi-objective function[14]. After transform the problem to single objective function, the software can solve the problem.

So-called efficacy coefficient method is refers to the multi-objective programming, if a solution to a target function is close to the value of the optimal value, we will think it to the goal of high effect; conversely, it is bad efficacy. The objective function $f(z_t)$ coefficient is defined as:

$$d_t = d_t\{f z_t\}, \tag{6}$$

In addition, $t = 1, 2$, $0 \leq d_t \leq 1$. It is the most satisfactory when $d_t = 1$, while it is the most unsatisfactory when $d_t = 0$.

In this paper, we construct the efficacy coefficient by linear method. Make $\min f(z_t) = f_{t.\min}$, $\max f(z_t) = f_{t.\max}$. It is denoted that

$$d_t = \frac{f(z_t) - f_{t.\min}}{f_{t.\max} - f_{t.\min}} \tag{7}$$

when the efficacy coefficients of two objectives d_t have been solved, we can get the total efficacy coefficient $\sqrt{d_1 \times d_2}$.

When the efficiency coefficient is available, through the calculation by computer we can get a coordinating comprehensive solution.

4 Conclusion

In this paper, we set up the mathematical model of recycling production according to the circular production of edible fungus by genetic algorithm. From the results, we can get two useful conclusions. In the first place, using the edible fungus chaff reproduction can bring great economic benefits. Making full use of edible fungus chaff resources and producing multi-lever and multi-species edible fungus may obtain the economic products to the biggest extent. In the next place, edible fungus chaff comprehensive utilization should adjust measures to local conditions, and the focus is repeated use. So reusing edible fungus chaff is beneficial for ecological environment. Moreover, the simulation of data is not accurate enough since the price is the average of more than 40 areas. In the further research, we will think over change the mathematical model to an uncertain one which the prices of edible fungus are random, rough, or fuzzy.

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