GENETIC ALGORITHMS IN OPTIMISATION OF DRIED FRUITS AND VEGETABLES QUALITY

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Abstract. The work presents the optimization of the quality characteristics of dried apples and celery obtained during the convective drying process with forced air blow and microwave-convection due to the minimization of qualitative changes, such as colour, taste and smell. For this purpose, the study was performed, during which the samples of apples and celery were dried by methods of convection and microwave-convection. The quality characteristics – taste and smell –- determined using a five-point Tilgner's scale, and colour were evaluated using the computer image analysis. Functional dependencies were then formulated, specifying the changes in the examined quality characteristics on the decision variables, which were: the drying rate in case of convective drying and the microwave power for microwave-convection drying. The issue of the optimization constituted a multi-criteria task. Solutions were sought in the area of feasible solutions defined by the limiting conditions. The optimal solution for the adopted methods of drying and the materials tested were obtained using the method of genetic algorithm.

Key words: quality of dray material, optimization, genetic algorithms.

Introduction

Drying is one of the oldest methods of thermal preservation of plant materials. During drying the water content in the product is reduced, thus reducing the activity value preventing the growth of microorganisms, as well as minimizing the enzymatic and non-enzymatic changes. This operation, which, depending on the conditions employed, has significantly changed the quality of the finished product, among other things, the colour, smell, taste and chemical composition, and shape. The quality of the final product is affected by the choice of the drying method and the parameters associated with the process, such as the temperature, microwave power, air velocity, humidity, the type of raw material and the pretreatment applied, which maintains the sensory characteristics and substances sensitive to high temperatures [1-8]. It has been found that as far as the nutritive value is concerned – in particular the vitamin content in the product, the greater the degree of degradation is, the higher the temperature and the drying time [9; 10].

The choice of the appropriate method and drying parameters, capable of producing a good quality product, can be done by optimizing the process of maximizing the quality of the dried product. One of the tools applicable to the issues of optimization is genetic algorithms [11]. Genetic algorithm is a method based on the natural evolution, described by the search and inheritance procedures that use evolutionary principles of survival of the best adapted individuals. For every generation, a new team of artificial organisms (bit strings) is formed, created from a combination of fragments of the best adapted representatives of the former generation [11; 12]. In Fig. 1 a schematic diagram of the classical genetic algorithm is shown.

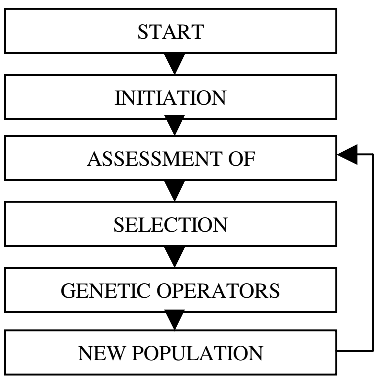

Fig. 1. **Function diagram of the genetic algorithm**

For drying issues the genetic algorithms were used mainly to optimize the neural network architecture by which the processes were modelled [13; 14].

The work attempts to define the drying parameters for apples and celery, through formulation and solution of multi-criteria optimization problems, including minimizing the changes in the quality of the dried material.

Materials and methods

The object of the study was the quality of dehydrates defined by such sensory characteristics as: colour, taste and smell. Samples of apples (variety Champion, representative for consumption fruits) and celery (var. President, commonly used for the production) were dried in the convection oven with forced air blow and in the convection microwave oven, under isothermal conditions. From the material obtained under isothermal conditions in the stage of consumptive maturity there were cubes of 10 mm side prepared, and then they were dried in a thin layer – until the final moisture content of 7 % has been achieved. The convective drying took place with the air flow at rates 0.1-0.3 $m \cdot s^{-1}$ at the temperature of 51 ºC. The microwave-convection drying was carried out for three microwave power values: 170 W, 210 W and 340 W – at the temperature of 50 ºC.

The colour of the fresh material and the dried product was determined by the photograph image of the sample surface. The obtained images of the surface samples were analysed in terms of the colour (brightness) using the program MultiScan v 6.08.

The taste and smell of the samples were evaluated on a five-point Tilgner's scale that includes five classes of quality [15], where the score 5 indicates a very good quality and 1 bad quality. The sensor assessment of each sample, according to the above scale, was performed by five experts.

All measurements were performed in five replicates for each case of convective drying (for the five drying medium flow rates: 0.1, 0.15, 0.2, 0.25, 0.3 $m \cdot s^{-1}$) and microwave-convection (for three microwave power: 170, 210, 340 W).

Optimisation issues

While drying, physicochemical and sensory modifications of the material mainly depend on the drying time and temperature reached by the material. Conditions of the heat and mass transfer affect the drying time and increase of the temperature of the dried material – on the edges of the area there is convective heat and mass transfer whereas diffusion processes occur inside the material. In both drying methods, convective heat exchange and mass transfer depend on the coefficients of heat and mass transfer. These coefficients are a function of the flow rate of the drying agent and its temperature. However, the diffusion processes occurring inside the material have an influence on the thermal properties - as unchangable parameters – and the drying time, which depends on the flow rate of the drying air forced convection conditions [15]. During microwave and convective drying the diffusion processes depend on the dielectric properties of the material (unchangable) and the microwave power [16]. Therefore, when formulating the optimization problem the key variable in the mathematical description of the convective drying process is the flow rate of the drying agent while in the case of the microwave-convection drying it is the microwave power.

The issue of optimization consisted of designating the optimal values of decision variables (the air flow rate and the microwave power, according to the accepted methods of drying), for which the analysed changes in the quality characteristics of the dried material reach a minimum. This issue is a multi-criteria task, due to the adopted criteria for assessing the quality of materials: colour, taste, smell. The functions, defining the changes in the quality characteristics on the speed of the air or microwave power for the adopted drying methods, are described in the empirical models developed by the STATISTICA program using nonlinear estimation methods. The correctness of the model was determined using the coefficient of determination R^2.

The overall multi-criteria optimization model was formulated in the following form – the criterion of optimization as the objective function in the form of a general functional:

$$F(x) = w_1 b(x) + w_2 s(x) + w_3 z(x) \to \min \tag{1}$$

where w_1, w_2, w_3 – weight values (it was assumed that each of the criteria has the same meaning, because the weight is 1).

b – colour;

$$b(x) = \frac{b_f - b_{d.m.}}{b_f} \rightarrow \min \quad (2)$$

s – taste

$$s(x) = \frac{s_f - s_{d.m.}}{s_f} \rightarrow \min \quad (3)$$

z – smell:

$$z(x) = \frac{z_f - z_{d.m.}}{z_f} \rightarrow \min \quad (4)$$

x – decision variable: air flow rate v, $m \cdot s^{-1}$ during convection drying, microwave power during microwave-convection drying N, W;

f – fresh, *d.m.*– dry material.

Each of these functions as described by equations (2), (3) and (4) expresses the relative changes in the analysed values for their values for the fresh material. The solution of the formulated optimization issue proceeded in two stages.

In the first, the optimum solution for the general task described by the objective function expressed by the equation (1), in the domain of feasible solutions, as defined by the following boundary conditions:

$$0 \leq b \leq 0.04;\ 0 \leq s \leq 0.8;\ 0 \leq z \leq 0.8$$

To determine the optimal solution the genetic algorithm method has been applied. To create the genetic algorithm the software Opty.Gen 1.0 was used [17]. It is a program based on the classical genetic algorithm, which consists of the following steps: initiation, the choice of the initial population of chromosomes, evaluation of the suitability of chromosomes in the population, verification of the detention condition, selection of chromosomes, application of genetic operators, establishing a new population, introduction of the “best” chromosome. The program enables to determine the extreme of the function up to nine variables, to follow the progress of the calculations and to save them.

The initial step was to optimize the assumptions and parameters (of chromosomes) in the genetic optimization: the fitness function (objective function), the fields and the accuracy of the calculations. The optimization parameters can be determined by using the following types of selection: roulette, tournament, ranking, genetic operators – crossover, mutation, inversion, and the size of the population [11].

To perform the optimization the Ranking Selection with the Elite Model was used (draft). This model guarantees the “protection” for the best individual throughout the entire course of the calculation, whereas the selection type is highly significant for the speed and accuracy of the found extreme. The Ranking Selection is based on calculating of the function for each individual, then arranging in a series of “the best - the worst” and selecting the best.

The results were recorded to the nearest two decimal places, the selected population was size 15, the crossover probability was 25 %, and the mutation probability was 8 % and the probability of inversion 3 %. The STOP condition was the number of iterations equal to 5.

In the second stage of the search for optimal solutions, the functional F, specifying the objective function in the optimization output task (equation 1), has been described by the decision functions of one variable for each experience combination. The optimal values of particular functions obtained in the first stage, describing the best quality of dehydrates, as well as the optimal value of the functional F, allowed to determine the values of the decision variables for which it was possible to obtain minimum qualitative changes of the dehydrates.

Results and discussion

The obtained results were statistically analysed. The functions, defining the changes in the quality characteristics on the speed of the air or microwave power (in terms of their variability), are described in the empirical models developed by the STATISTICA program using nonlinear estimation methods. The correctness of the models was verified using the deterministic factor R^2. The developed models were used to formulate the objective function as an additive function, determining the overall quality index, which is the sum of the functional dependencies that describe the changes in taste, smell and colour.

And in this manner the dependencies were obtained:

- of convective drying;

  for apples:

$$F(x) = -26.91x^2 + 10.74x - 0.38 \rightarrow \min \tag{5}$$

  at the limiting condition: $0.1 \leq x \leq 0.3$ m·s^{-1};

  for celery:

$$F(x) = -2.02x^2 + 1.21x + 0.5 \rightarrow \min \tag{6}$$

  at the limiting condition: $0.1 \leq x \leq 0.3$ m·s^{-1};

- of microwave-convection drying;

  for apples:

$$F(x) = -0.0001x^2 + 0.029x - 0.49 \rightarrow \min \tag{7}$$

  at the limiting condition: $170 \leq x \leq 340$ W;

  for celery:

$$F(x) = -0.00008x^2 + 0.11x - 3.71 \rightarrow \min \tag{8}$$

  at the limiting condition: $170 \leq x_2 \leq 340$ W.

The deterministic factor R^2 changes between 0.6 and 0.8.

As a result of iterative calculations, using the genetic algorithm, the following minimum values for the analysed relative loss of the quality characteristics were achieved: colour $b(x) = 0.03$, taste $s(x)$=0.02, aroma $z(x) = 0.02$ for which the value of the objective function reached a minimum (F = 0.04).

On the basis of a minimum for the functional F and functional dependencies describing the the relative qualitative loss: b, s, z the optimal values of the decision variables were determined – the air flow rate and microwave power for different methods and analysed materials.

Conclusion

Based on the analysis results, it was found that the drying time of the test samples of the material depends on the flow rate of the drying agent and convective drying of microwave power, in the case of microwave-convection drying – the flow rate of the drying agent and higher microwave power, the shorter the drying time. During drying, the temperature of the material increases. Extension of the time of drying and an excessive temperature rise can cause adverse physical and chemical properties of the material (e.g., apple high temperature may lead to caramelization of sugars, change in the vitamin C content in the material. Therefore, the drying time was determined in such a range so as the change characteristics sensory generally do not exceed the values obtained during the process carried out on an industrial scale.

The application of genetic algorithms has enabled to solve a multi-criteria optimization problem, which consists in minimizing the changes in the quality characteristics of dried apples and celery, obtained during convective drying depending on the speed of the air flow and microwave convection, depending on the microwave power. Based on iterative calculations using genetic algorithms, it was found that the minimum qualitative loss during the convective drying is obtained for apples at the speed of $v = 0.3$ m·s^{-1}, celery $v = 0.1$ m·s^{-1} and during the microwave-convection drying for the apples at the microwave power of $N = 340$ W and celery $N = 170$ W.

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