Optimization of soaking stage in technological process of wheat germination by hydroponic method when objective function is defined implicitly

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Abstract. The increase in the efficiency of the "numerical" technology for solving computational problems of parametric optimization of the technological process of hydroponic germination of wheat grains is considered. In this situation, the quality criteria are contradictory and a part of them is given by implicit functions of many variables. One of the main stages, soaking, determining the time and quality of germinated wheat grain is studied, when grain receives the required amount of moisture and air oxygen for germination and subsequently accumulates enzymes. A solution algorithm for this problem is suggested implemented by means of software packages Statistica v.10 and MathCAD v.15. The use of the proposed mathematical models describing the processes of hydroponic soaking of spring soft wheat varieties made it possible to determine optimal conditions of germination. The results of investigations show that the type of aquatic environment used for soaking has a great influence on the process of water absorption, especially the chemical composition of the germinated material. The use of the anolyte of electrochemically activated water (ECHA-water) intensifies the process from 5.83 to 4 hours for wheat variety «Altayskaya 105»; and from 13 to 8.8 hours - for «Pobla Runo».

1. Introduction

In order to reduce the labor intensity and the cost of technological preparation of production, it is necessary to develop optimal technological processes. Computer-aided design of technology is based on the development of human-computer systems, such as computer-aided design system (CAD systems) or Computer Automated Process Planning, (CAPP). There are two types of optimization: parametric optimization and structural optimization, which has the greatest influence on the criterium of optimization, since by varying the process structure it is possible to change the cost of the technological process manifold. Though, the latter is of secondary importance but forms the second important stage of optimization.

In parametric optimization, the tools «in demand» are well known methods of mathematical programming and the theory of vector optimization [1]. The choice of a specific method must be related to the peculiarities of the problem being solved, since a method that is successful for solving one of them can be unsuccessful for solving others. The difficulties can be related to the task of an operator describing the topology of the system under study: the operator specifies it not in explicit but
in algorithmic form, in particular, through numerical solutions of systems of equations (differential or algebraic) describing the functioning of the system under investigation [2]. It is possible to have a set of criteria not only inconsistent with each other, but also non-formalizable, based experience and intuition [3]. Concepts of optimization in an implicit form are developed without any records of objective functions and restrictions. [4].

In this paper, an increase in the efficiency of the "numerical" technology for solving computational problems of parametric optimization of the technological process of hydroponic germination of wheat grains is considered. In this situation, the quality criteria are contradictory and some of them are given by implicit functions of many variables. One of the main stages, soaking, determining the time and quality of germinated wheat grains, is studied, when grain receives the required amount of moisture and air oxygen for germination and subsequently accumulates enzymes. Changes in qualitative and quantitative composition of wheat grains depend on the time and conditions of this process.

Dry cereal seeds have moisture content up to 15 %, when normal respiration is possible. When moisture content grows, free water appears, increasing the intensity of respiration and other processes of metabolism improving the permeability of cell walls [5]. The process of moisture distribution goes in accordance with thermodynamic characteristics of moisture transmission in main anatomical parts of grains. The porous structure of grain bran covering absorbs moisture quickly but not able to retain it. Seed covering serves this purpose, namely an aleurone layer of endosperm and seed-bud from which water mainly penetrates [6, 7].

Thus, moisture penetrates into cells of grain tissues not only under the influence of diffusive and osmotic forces but also forms solid solutions with colloidal materials which range from 80 to 85 per cent in wheat grains. When swelling starts, protein substances can absorb up to 250 % of water or more, starch – up to 25%, and mucus – up to 800%. Hydrophobic substances are not swollen and dissolved in it; these are fats and other lipids, coloring agents soluble in fats, carotenoids, chlorophyll, fat-soluble vitamins and others. A part of substances in grains are dissolved in water (sugars, free amino acids, phosphates, most levulezans and others) [6].

The process of germination is divided into the stage of preparation of the material and germination itself. Preliminary preparation of grain consists of removal of extraneous bodies, grain sorting, washing and soaking which lasts from 12 to 72 hours, significantly increasing the time of germination. The research is aimed at the intensification of grains soaking and determination of technological parameters when grain reaches the moisture content required to start germination and to reduce the time of obtaining wheat sprouts to minimal.

2. Materials and methods

Water absorbing ability of grains and the rate of water penetration are caused by their technological properties, among which the most important are: grain hardness, the quality of proteins, initial moisture, the filling of grains and grain size, variety and the growing region.

Wheat spring soft varieties "Altaiskaya 105" and "Polba Runo" harvested in 2015-2016 were used as research objects. In order to maintain normal enzyme processes for wheat germination, the required amount of moisture in varieties «Altayskaya 105» and «Pobla Runo» should range from 30 to 35 %.

The rate of water absorption by wheat grains mostly depends on the temperature of water. Warm soaking is used at water temperature ranging from 20 °C to 23 °C, since at lower temperatures the water absorption process is retarded, while at higher temperatures it is facilitated but unevenly developed, the respiration of grains increases and the growth of microorganisms present on the surface of grain is intensified, but when the temperature of aquatic environment is approximately 40 °C, the germ loses its ability to sprout and dies. Both high moisture content and room temperature enhance the growth of micro flora, which in its turn has a negative effect on the quality and safety of germinated material.

One of the most prospective methods to activate the process of water absorption is to soak it in electrochemically activated water (ECHA-water), i.e. anolyte formed in anode area of diaphragm electrolyzer which has high biocidal activity.
The use of anolyte of electrochemically activated water (ECHA-water) produced in water ionizer Chanson EDEN with indicators which intensify the process of wheat soaking is studied. For these purposes, the grain of both varieties was subjected to soaking in tap water and anolyte with pH 3.5 and oxidative reduction potential of +720 millivolts, when water duty is (from 1:1 to 1:4) and exposed to contact with the aquatic environment from 2 to 18 hours.

Grain soaking is carried out at the temperature of 20-23 °C and mass fraction of moisture in grain is determined at certain intervals. The experiment was repeated three times. Changes of moisture in wheat variety «Altayskaya 105» and «Pobla Runo» are uneven, for the first 4 hours after soaking it is possible to notice the increase in moisture content from 5,6 % to 23-28 % and from 7,6 % to 22-23 % correspondingly, then moisture saturation is retarded. The process of moisture distribution goes in accordance with thermodynamic characteristics of moisture transmission in main anatomical parts of grain.

It is essential to determine minimal soak time $T_{\text{min}}$ and the amount of the aquatic environment when wheat grain reaches moisture content $W_{\text{min}}$ required to start the germination process. The admissible set is specified by restrictions of mass fraction $W$ of grain moisture, while the objective value is the ratio between $V$, the aquatic environment of soaking, and the material for germination.

For soaking process the first step in the optimization of the technological process was the construction of bicubic interpolation splines of defect 1 for function $W=W(T,V)$ given in a tabular form, with interpolation nodes in the experimental data averaged over 3 replicas. Function $W=W(T,V)$ was also approximated by regression models, using software package Statistica v.10. Limitations on the mass fraction of grain moisture gave equation $T$ from $V$ in the form of implicit function $W_{\text{min}}=W(T,V)$. The objective function is $T(V) \rightarrow \text{min}$.

In this situation, the construction of level lines $W=W(T,V)$ allows solving the specified optimization problem graphically using software package Statistica v.10: the vertical straight lines of the desired $T$ must touch level line $W_{\text{min}}=W(T,V)$, while the horizontal line from the point of contact will give the desired pH value. But with a possible increase in the number of arguments (taking into account the hydrogen measure of water alkalinity pH and others), i.e. with the number of arguments more than 2 the above mentioned graphical method loses all its advantages.

In this paper, a formal algorithm for solving this optimization problem is considered, implemented by means of the MathCAD v.15 package, which gives matching (within regression accuracy) results with a graphical method.

### 3. Regression analysis of dependence of grain moisture on the time and water duty

Regression model $W=W(T,V)$ for the available experimental data are chosen as the cup product of a monotonically increasing function at zero with saturation, exponential in variable $T$ (sprouting time) on polynomial quadric variable $V$ (water fraction). The obtained parameters of the regression model for wheat "Altayskaya 105" with germination in ECHA water give the dependence, mm:

$$W = \frac{21,5687 + 10,7846 \cdot V - 2,0286 \cdot V^2}{1 + 1,75392 \cdot e^{-0,37537 \cdot T}},$$

with correlation index $R = 0,86$;

For wheat variety «Altayskaya 105» in electrically activated water (ECHA water):

$$W = \frac{22,7461 + 11,1419 \cdot V - 2,104 \cdot V^2}{1 + 1,78071 \cdot e^{-0,467176 \cdot T}},$$

with correlation index $R=0,88$.

For «Pobla Runo» in water, the dependence is the following:
\[ W = \frac{24.1129 + 8.64154V - 1.6123V^2}{1 + 1.0086e^{-0.12665T}}, \]  
(3)

with correlation index \( R = 0.86 \).

For «Pobla Runo» in electrically activated water (ECHA water), the dependence is the following:

\[ W = \frac{23.6456 + 9.24663V - 1.7196V^2}{1 + 1.10226e^{-0.192168T}}, \]  
(4)

with correlation index \( R = 0.89 \).

The relative error is (1)-(4) 20 %.

4. Minimization of soaking time to reach moisture content from 30-35 %

Relations (1)–(4) give implicitly defined objective function \( W_{min} = W(T,V) \), where \( T(V) \rightarrow \min \), under natural constraints \( 0 \leq T \) and \( 0 \leq pH \). It is necessary to find the global minimum, point \( (T_{min}, V_{min}) \), on the allowed set - domain \( 0 \leq T \) and \( 0 \leq pH \).

A well-known algorithm suggests the following: 1- search for critical points (inside the domain) of target function; 2 – search for critical points (on the boundary of the domain) of each objective Lagrange function; 3– calculating the values of the objective functions in all the found "suspicious" points; 4 – the final choice of the solution by ranging calculated values in ascending order. Stages of this algorithm can be presented in the following way:

1 – the search for critical points (inside the domain) of the objective function is carried out from the system of algebraic equations and inequalities:

\[ dT dV(T,V) = \frac{\frac{\partial W(T,V)}{\partial T}}{\frac{\partial W(T,V)}{\partial V}}, \quad dT dV(T,V) = 0, \quad W(T,V) = 30, \quad T \geq 0, \quad V \geq 0 \]  
(5)

where \( W(T,V) \) are shown in (1)-(4).

2 – the search for critical points (on the boundary of the domain) of Lagrange function is carried out from the system of algebraic equations:

\[ dT dV(T,V) + \lambda = 0, \quad W(T,V) = 30, \quad V = 0 \]  
(6)

where \( \lambda \) is the target Lagrange multiplier.

3 – calculation of the values of the objective function in all the found "suspicious" points \( (T_{min}, V_{min}, \lambda) \) has already been performed in the process of solving (5) and (6).

4 – the final choice of the solution by ranging calculated values in ascending order \( T_{min} \) gives moisture content 30 %:

- for wheat variety «Altayskaya 105», germinated in water, the minimum point for water share is 2.66:1, while the minimal time is 5.83 hours;
- for wheat variety «Altayskaya 105», germinated in electrochemically activated water ( ECHA-water), the minimal time is 4 hours, while the water share is 2.6:1;
- for «Pobla Runo», the minimal time is 13 hours while the water share is 2.6:1;
- for «Pobla Runo», when germinating in ECHA-water, the minimal time is 8.8 hours while the water share is 2.6:1.

5. Conclusion

One of the main stages, soaking, determining the time and quality of germinated wheat grain has been studied, when grain receives the required amount of moisture and air oxygen for germination and subsequently accumulates enzymes.
The increase in the efficiency of the "numerical" technology for solving computational problems of parametric optimization of the technological process of hydroponic germination of wheat grains has been considered. In this situation, the quality criteria are contradictory and a part of them is given by implicit functions of many variables. A solution algorithm for this problem has been suggested implemented by means of software packages Statistica v.10 and MathCAD v.15.

The use of the proposed mathematical models describing the processes of hydroponic soaking of spring soft wheat varieties made it possible to determine optimal conditions of germination (the duration of the process, water duty) and to intensify the germination process which helps grains to reach the level of humidity required for germination. The results of investigations show that the type of the aquatic environment used for soaking has a great influence on the process of water absorption, especially on the chemical composition of the germinated material. The rate of water absorption in wheat variety "Altaiskaya 105"(54 \%) is higher since it has lower grain hardness as compared to wheat variety "Polba Runo" (61 \%). Hence, the endosperm of wheat variety "Altaiskaya 105" is less solid which helps absorb moisture faster, and the use of anolyte (ECHA-water) intensifies the process from 5.83 to 4 hours for wheat variety «Altayskaya 105»; and from 13 to 8.8 hours for «Pobla Runo».

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