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OPTIMIZING MUSHROOM CULTIVATION PROCESS - CONCEPTS FOR CONTROL AND MONITORING SYSTEM

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ABSTRACT

The first part of the article contains a basic description of the mushroom production process. The analysis of this process allows to propose algorithms for monitoring the growing conditions and controlling the cultivation process – in the latter case with possible human operator intervention. These algorithms, along with their description, are included in the second part of the article - they can be used in the design and implementation of intelligent mushroom farm management systems.

Introduction

Automation and electronics devices and methods are currently extensively used in the widely understood agricultural engineering. Their use for the purpose of controlling and monitoring the cultivation of various agricultural products allows such processes to be made more efficient and less engaging for the human operator (Lakhiar et al., 2018; Navarro et al., 2020). The production of mushrooms is no exception in this regard (Mahmud et al., 2018; Velliangiri et al., 2020).

For proper and effective cultivation of mushrooms, it is necessary to maintain an appropriate microclimate. Depending on the production stage, different climatic conditions are required, such as (Szudyga, 2002):

– adequate humidity of both air and substrate;
– appropriate temperature of the substrate and the environment;
– steady and uniform air circulation;
– ensuring an appropriate concentration of CO_2 inside the production hall.

To increase the competitiveness of mushroom cultivation, production halls must be equipped with intelligent microclimate management systems. For this purpose, it is best to use programmable microprocessor systems. These systems can be freely adapted to the currently installed devices, and the system itself can be supplemented with additional functionalities.

Currently, many microclimate control systems in mushroom farms have various types of limitations, such as (Wachowicz and Raczek, 2010):

- lack of installed soil moisture sensors, what leads to the absence of soil parameters measurements;
- lack of installed air humidity sensors;
- mismanagement of the CO_2 content in the air, while it is the most important parameter in the mushroom growth phase;
- no differentiation of production stages.

The use of an intelligent production management system can be used to optimize the process of mushroom cultivation; an additional aspect is the potential reduction of production costs thanks to reduction of the electricity and water consumption (Szudyga, 2002; Woroncow and Wachowicz, 2011).

The aim of this paper is to describe and analyse the process of mushroom production, and then, based on that analysis, to design the algorithms destined for the control and monitoring system of mushroom production process.

Description of the mushroom cultivation process

The cultivation process in today's mushroom farms begins with the location of the substrate in which the mycelium will properly develop. Currently, such a substrate is purchased from specialized producers; however, the largest farms strive to create a closed cycle of cultivation and production of their own material.

Types of substrate can be divided into three types. So-called phase I substrates, i.e., bales of straw mixed with poultry manure, horse manure, water, and gypsum, are no longer used. Substrate that contains sown and mingled mycelium spores is called phase II substrate; this substrate is already pasteurized. The substrate in which the mycelium has already grown in the tunnels is called phase III substrate. The amount of substrate applied to the shelves ranges from 70 to 100 $kg \cdot m^{-2}$. This number should be determined individually for each crop, depending on the possibility of cooling the substrate. The producers of the substrate offer various mycelia sown in their products - the type of binding capacity and the quality of the obtained mushrooms depends on their type (Sakson, 2007).

When growing mushrooms using the phase II substrate, an additional period of about two weeks should be added after the substrate is placed on the mycelium overgrowth. During this period, a gradual increase of the substrate temperature should be observed, and its overheating cannot be allowed, as the overheating causes the mycelium to die. The conditions in the hall are typically much worse than in specialized phase III tunnels, what results in worse overgrowth of mycelium in the substrate, and in turn results in poorer yield. The two weeks period of keeping the substrate in the hall generates considerable costs that are not incurred when using phase III substrate (Szudyga, 2002).

After the Phase II substrate is outgrown or the Phase III substrate is laid, the next stage of production is the application of the peat blanket to the substrate. This so-called casing layer is enriched with mineral values, in order to increase yield. The amount of casing determines the yield obtained and, as the consequence, the income and profits achieved by the farm. The upper limit of the amount of the casing is determined by the ability of the substrate and the casing to cool down later, and varies between 5 and 7 cm. Before putting the casing on the shelves, it should be properly prepared i.e., its moisture should be equalized throughout the volume and its structure should be uniform. When mixing peat, the so-called CAC-ing (i.e., Compost Added at Casing) technique should be applied, that is, part of the previously laid substrate (about 150-600 $g \cdot m^{-2}$) should be added. The applied casing layer should be properly moistened during the overgrowth process (Sakson, 2008).

After the casing is applied, the mycelium should be properly grown through the peat. At this stage, it is important that the mycelium has grown evenly, but not too much. Too fast growth may result in a decrease in the yield or even its complete loss (Grzeszek, 2012). For that purpose, water is delivered into the substrate, using of the below methods:
- pouring water into the substrate before placing it on the shelves,
- pouring water on the substrate placed on the shelf before applying the casing,
- delivering water partly to the substrate, partly to the casing,
- delivering water through the casing.

If the water is supplied only to the substrate, then the casing itself should also be moistened. Demanded irrigation mostly depends on the properties of the casing layer - if it is dry, lean and light, it requires more water and can be quickly overgrown (Uliński, 2011).

The whole above-described process is called the vegetative phase. In order to obtain mushrooms, the microclimate in the hall should be changed so that it goes into the so-called generative phase, i.e. the formation of fruiting bodies. In mushroom growing, a procedure that allows the microclimate to change and consequently the transition to the next phase of the process is called a shock. Other important procedure is nozzling, i.e. one-time superficial supply of water performed before the shocking process (Sakson, 2008).

The main rule in applying shock is maintaining the proper speed of this process. The slower the microclimate change is, the less it bears fruit and the yield acquisition over time. If the microclimate is being changed faster, a shorter yielding time is obtained, and more abundant. The shock can be started with the air temperature of 24°C, this is the temperature at which fruiting bodies are already forming, and then the temperature is lowered to 17-19 °C in the period of 4-5 days. Proper mixing of the air with temperature changes results in better bud bonding. When the shock starts, the air humidity should be approx. 95%, and it should be reduced by 0.5-1% per day, as it helps to lower the temperature of the substrate (Grzeszek, 2014).

The number of fruiting bodies is also influenced by (Sakson, 2008):
- the amount of CO_2 in the hall - the shock starts with the 3000 - 3500 ppm level and the final level ofCO_2 affects the number of fruiting bodies, as well as their size, according to the dependency shown in Table 1,
- the amount of mycelium in the casing – the more mycelia, the more fruiting bodies,
- the structure of the applied casing should be porous for better bonding,
- the higher the mycelium is located, the more rapidly it reacts to the change of microclimate.

After the shock, it is time for the buds to grow; at this stage, they grow to the expected size and shape. On 4-5 day of the shock, when pinhead-sized buds are visible, the humidity gradually decreases to approx. 90%. While the buds are growing, it is necessary to keep the water from evaporating continuously. After the first-generation seedlings have grown to about one cm diameter, temperature is being gradually decreased – to facilitate growth. The temperature should be lowered even to 16°C, and this temperature should be maintained to the harvest (Szudyga, 2002).

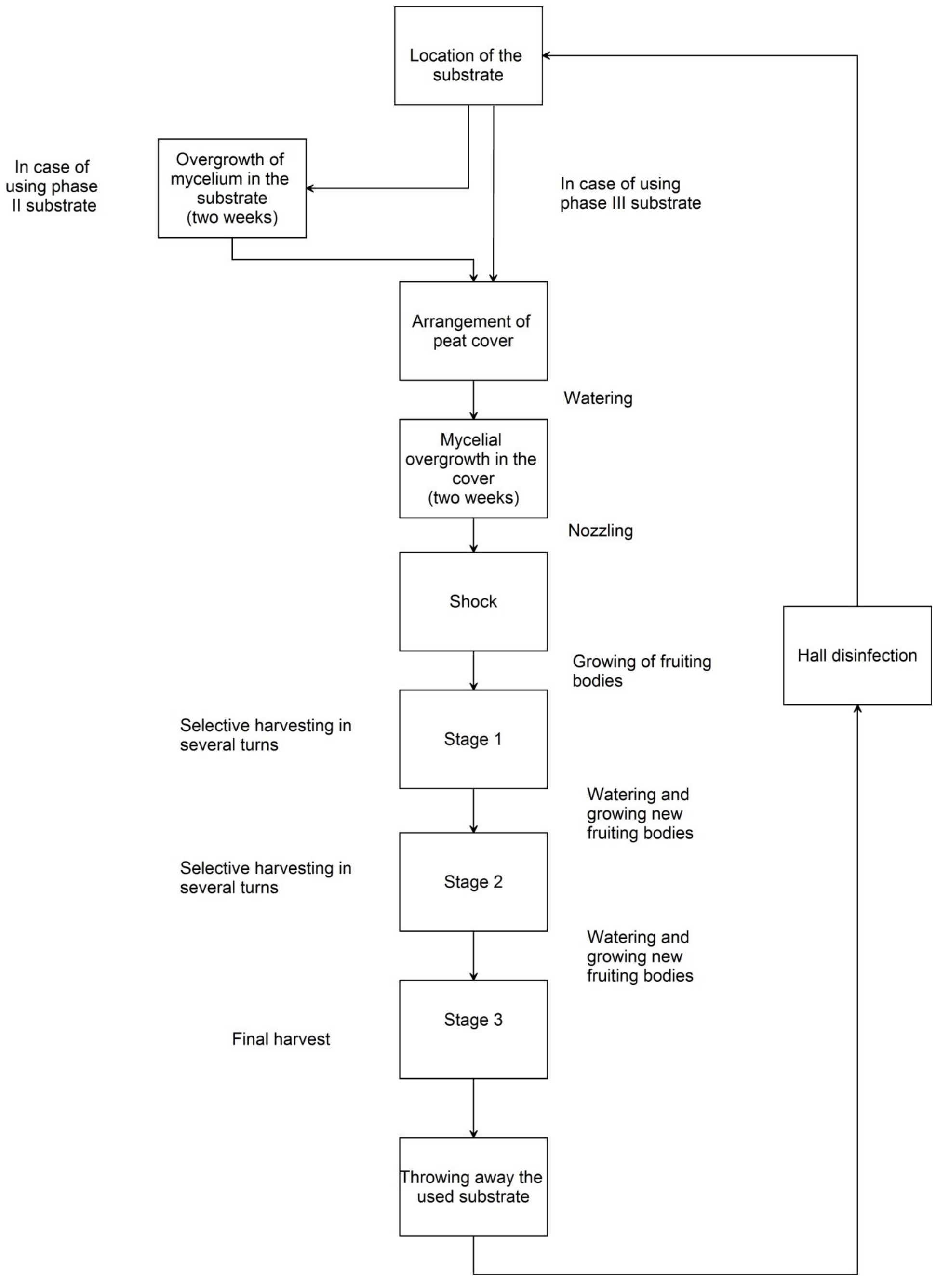

Figure 1. Schematic diagram of mushroom production

Table 1.
Influence of the CO_2 level after the shock on mushroom yield characteristics

CO_2 level (ppm)	Effect on yield
800	Small in large quantity
1200-1600	Medium in average quantity
1600-1800	Large in a small quantity

Growing mushrooms during the growth of fruiting bodies consists mainly in maintaining an appropriate microclimate. It is characterized by an air temperature within the range of 16-18°C, a substrate temperature 2-3°C higher, a CO_2 level within the range of 800-1600ppm with low air movement. During this period, harvesting takes place over several days. Mushrooms are picked manually using a so-called selective system. It consists in picking mushrooms according to a plan, twice a day (Konieczny, 2012).

After harvesting the first stage, an important step is to water the substrate for the second stage; the amount of water ranges from 10 to 16 $l \cdot m^{-2}$, and the watering lasts 12-18 hours. Within a day or two after the end of watering, the temperature in the air and the substrate should be brought to the same temperature as in the first stage. Growth is controlled through microclimate as before. The principle of harvesting is the same as before, after its completion, water is poured in a range from two to 6 $l \cdot m^{-2}$ to obtain the third stage. The fruiting bodies are produced similarly as before, with the difference that the ventilation is reduced to make the climate milder (Szudyga, 2002).

Yield ends after the third harvesting, or sooner in case of developing disease. When the cultivation cycle is completed, it is necessary to sanitize the hall before the new cycle to prevent the spread of diseases (Sakson, 2008).

A schematic diagram of the above-described mushroom production is shown in Figure 1.

Proposed algorithms for monitoring the growing conditions and controlling the cultivation process

Algorithm that controls and monitors the mushroom growing conditions (microclimate control system) is shown in Figure 2.

At the beginning of the system operation, the operator is asked to select the temperature (substrate or air) according to which the regulation will take place. The option of regulating the microclimate regarding the temperature of the substrate is intended for the first stage of mushroom production in phase II, namely the time of mycelium growth in the substrate. During this period, air temperature is of less importance, as it is only an indirect factor in maintaining the appropriate temperature of the substrate.

After switching the system to work in this mode, the operator is asked to enter the expected values, if he does not, the default settings will be selected (values shown in the algorithm in Figure 2). After taking the measurements, the system analyses them and increases the heating, cooling, dehumidification, or humidification in the hall accordingly. An extremely important aspect in the case of mycelium overgrowth in the substrate is preventing its overheating, which occurs above 27°C – when this temperature is exceeded, the system triggers an alarm (Szudyga, 2002).

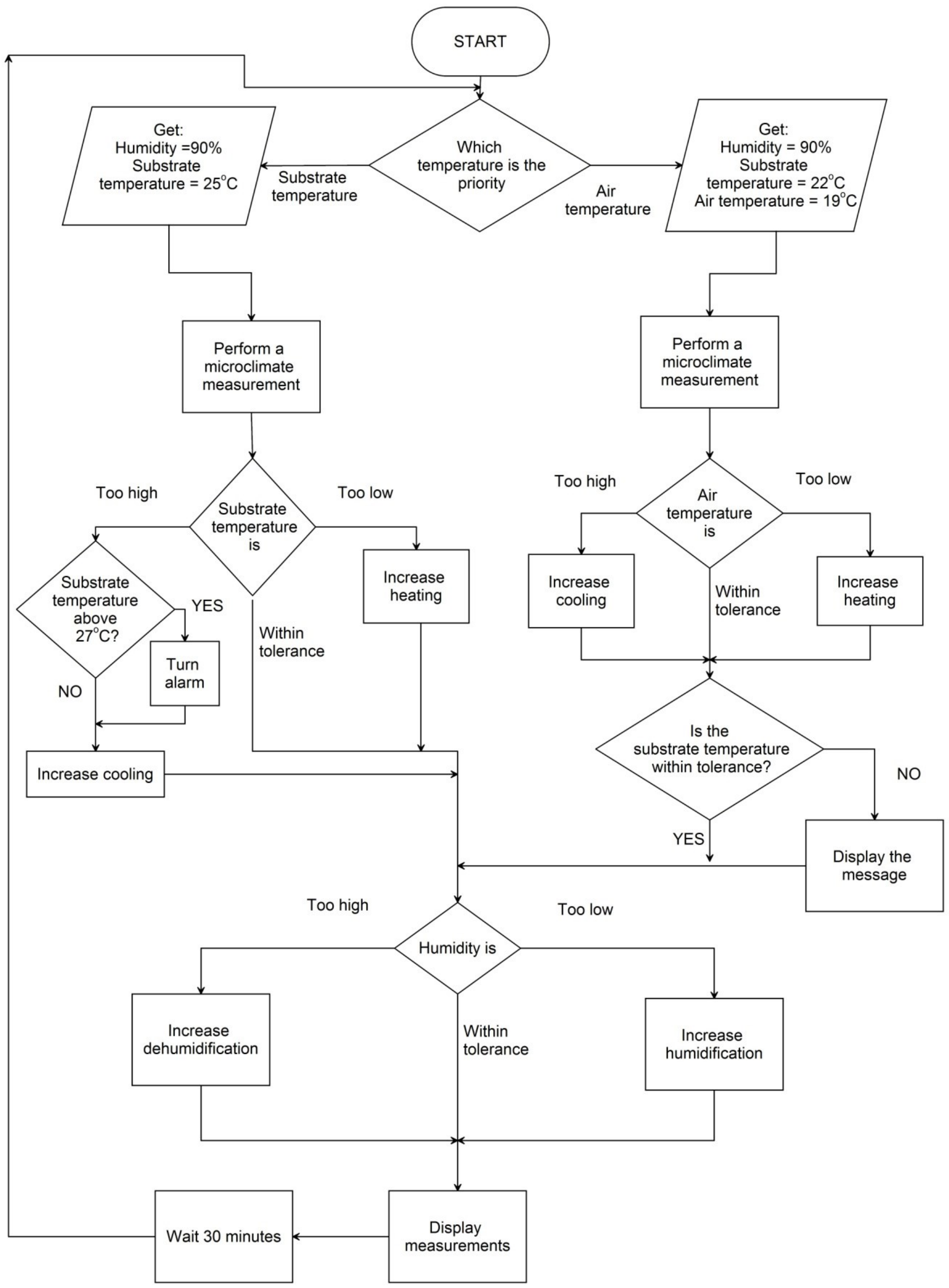

Figure 2. Algorithm controlling and monitoring the growing conditions

The properly designed system controlling mushroom production should also have a function supporting the shock operation. Figure 3 shows the shock algorithm (J and i variables shown in this figure have following use: variable i is used to count 12 30-minute cycles, while variable J is used to count 15 6-hour cycles, which gives a total of 6 days).

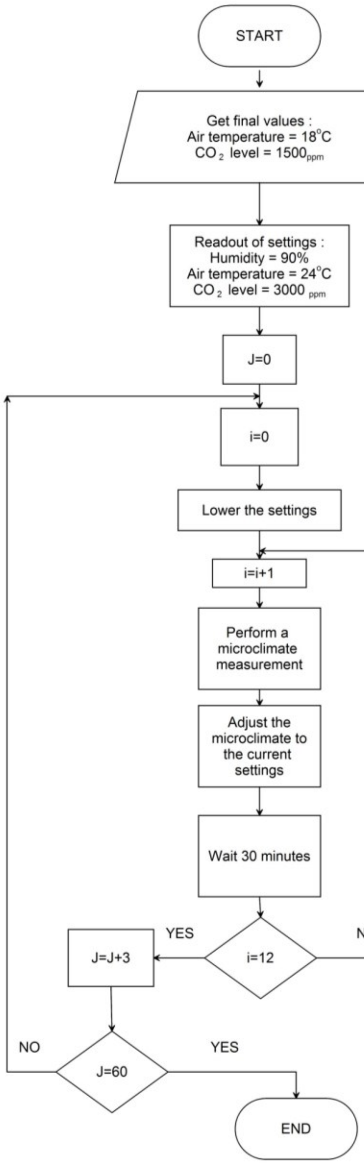

Figure 3. Shock algorithm

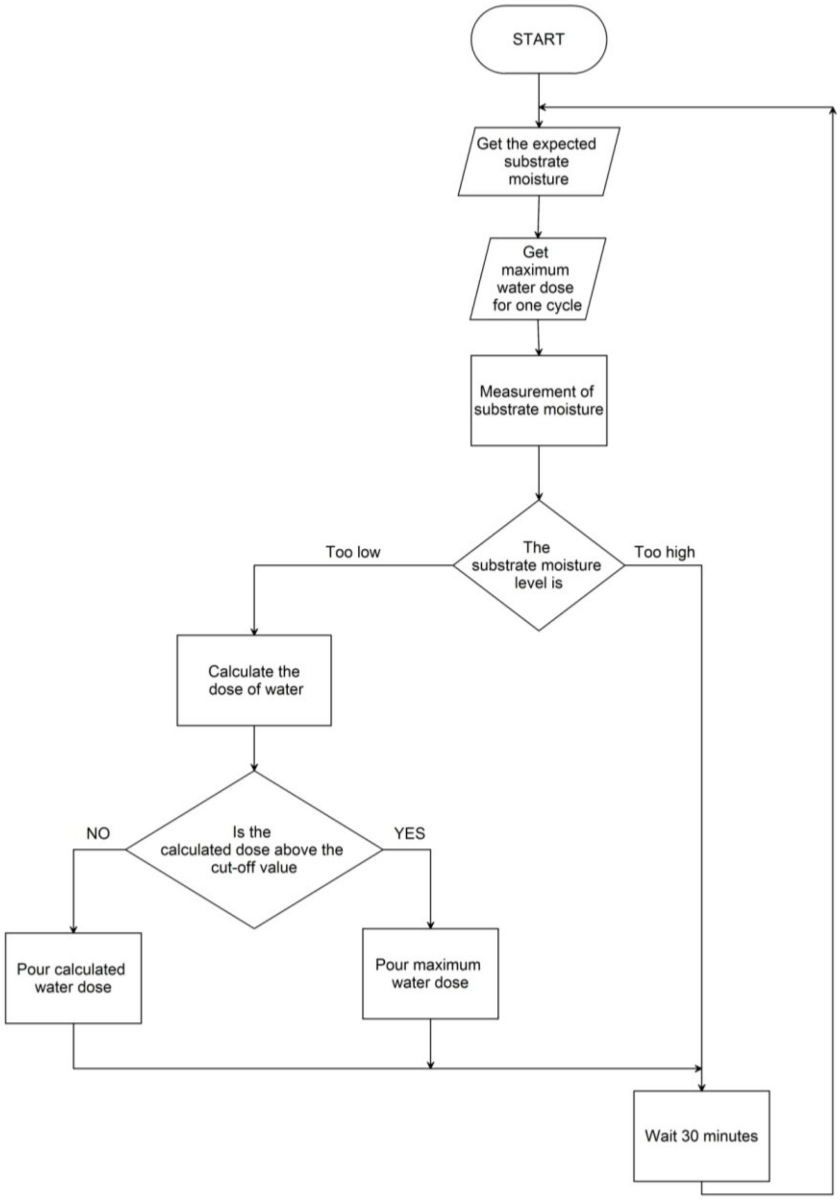

Figure 4.Watering algorithm

The shock process is triggered by the operator, who is asked to enter the final values for air temperature and CO_2 concentration. In the next step, the CPU reads the current values of temperature, humidity, and CO_2 level. Before starting the shock process, these values should be brought to the most optimal (values entered in the algorithm). Based on the expected final values and the actual values at the start of the shock, the drops in temperature or in CO_2 concentration are calculated according to the following principle: (actual value - expected value)/20. For example, when the shock starts at 24°C and we expect 18°C at the end, the drop will be equal to 0.3°C. The decrease in the concentration of CO_2 is calculated in the same way; for example, with the assumed initial concentration of 3000 ppm and the expected final concentration of 1500 ppm, a decrease of 75 ppm will be obtained. The shock operation is carried out slowly and it lasts 5 days with a slow reduction in temperature and CO_2concentration. The initial settings of the microclimate regulation are systematically reduced every 6 hours according to the decrease previously calculated by the CPU. The microclimate parameters are measured and checked every half an hour for the current setting values. Upon completion of the shock operation, a process completion message is displayed to the operator. This function does not affect the course of the climate regulation process, but only supports the operator in systematically reducing the settings to perform a gentle shock (Szudyga, 2002; Konieczny, 2012).

Figure 4 shows the algorithm destined for control of the watering system.

The watering system is activated and deactivated by the operator and it is directly related to the mushroom growing process (as shown in Figure 1). Water is supplied at the beginning of cultivation and between successive crops because watering the fruiting bodies drastically reduces their quality. After starting the system, the operator must enter the expected value of soil moisture, which will be maintained throughout the watering period, as well as the maximum amount of water that can be added in one cycle. By limiting the doses, water accumulation on the surface of the substrate is prevented. After the measurement is completed, the actual and pending values are compared, if the substrate humidity is higher or equal to the set value, then the system does not take any action and ends the cycle. If the measured value is lower than the set value, CPU calculates the water dose considering the upper limit. Then water is supplied to the nozzle, which cuts off its flow after a certain time. The dose itself is calculated based on the humidity value, the size of the shelves, and the pressure of the supplied water. The base configuration of watering system should be performed during the assembly of the system due to the lack of standardized halls, the construction of which affects the calculations (Szudyga, 2002).

Summary

The article proposes the algorithms that can be used in the process of designing and implementation of intelligent mushroom farm management systems. Described algorithms are based on the analysis of the mushroom production process and are destined for monitoring the growing conditions as well as controlling the cultivation process, including the possibility human operator influence on process parameters. The versatility of the proposed methods means that the choice of the implementation method depends on the needs and capabilities of the user - it can be both a microcontroller and, for example, a programmable logic controller.

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OPTYMALIZACJA PROCESU UPRAWY PIECZAREK - KONCEPCJE DLA SYSTEMU STEROWANIA I MONITOROWANIA

Streszczenie. Pierwsza część artykułu zawiera podstawowy opis procesu produkcji pieczarek. Analiza tego procesu pozwoliła na zaproponowanie algorytmów służących do monitorowania warunków uprawy oraz sterowania procesem uprawy – w tym drugim przypadku z możliwą ingerencją operatora. Algorytmy te, wraz z opisem, zawarte są w drugiej części artykułu - mogą one być wykorzystane przy projektowaniu i implementacji inteligentnych systemów zarządzania pieczarkarnią.

Słowa kluczowe: pieczarkarnia, algorytmy sterowania, monitorowanie warunków uprawy