Fuzzy Expert Model for Predicting and Enhancing Button Mushroom Growth Parameters

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Abstract– *Button mushroom farming is a complex agricultural practice requiring precise control and monitoring of various environmental variables to ensure optimal growth conditions and maximize yield. This study introduces a direction and evaluation approach in the context of button mushroom farming, utilizing fuzzy logic through MATLAB for intelligent decision-making. The proposed system focuses on optimizing key input variables, including temperature, humidity, ventilation, and substrate moisture, to steer the direction of the farming process. Simultaneously, it employs fuzzy logic to evaluate the success of the cultivation based on critical output variables such as mushroom yield and quality.*

The input variables are dynamically controlled through fuzzy interface system (Mamdani) in MATLAB, enabling adaptive adjustments to the cultivation environment. Temperature, humidity, ventilation, and substrate moisture are optimized based on real-time sensor inputs, growth stage considerations, and predefined parameters. The system aims to create an intelligent and responsive farming environment that aligns with the specific requirements of button mushrooms at different stages of development.

Output variables, namely mushroom yield, and quality, serve as critical indicators of the system's success. Fuzzy logic algorithms in MATLAB assess the effectiveness of the input controls, ensuring that the cultivated mushrooms meet predefined quality criteria. The evaluation process considers factors such as quantity, size, appearance, and the absence of defects, contributing to the market value and economic viability of the produce.

The direction and evaluation approach presented in this study not only enhances the efficiency and resource utilization in button mushroom farming but also provides a framework for intelligent decision-making. The integration of fuzzy logic through MATLAB offers adaptability, precision, and user-friendly implementation, making it a valuable tool for modernizing and optimizing mushroom cultivation practices. This research contributes to the

[1] **1. INTRODUCTION**

The most widely produced and consumed mushroom variety worldwide is the button mushroom (Agaricus Spp.). Its production in India was previously restricted to the winter months, but as technology advanced, it is now produced virtually year-round in small, medium, and big farms using varying degrees of technology. Mushrooms are a nutritious food that is high in protein. White button mushrooms can be preserved and used to make soups, sauces, and other culinary goods, or they can be sold fresh. It has therapeutic qualities as well. The mushrooms are the only vegetarian source of vitamin D and are cholesterol-free, high in fiber, low in sodium, and high in potassium. They also contain very little sugar. Additionally, some mushrooms contain antiviral and antitumor qualities. Button mushrooms are farmed seasonally in India in climate-controlled cropping buildings. White button mushrooms need 16–18 °C to develop reproductively and 24±2 °C to grow vegetarian (mycelium run). In addition, during cropping, it needs adequate ventilation and a relative humidity of 80–90%. Seasonally, it is grown for six to nine months of the year on the hills and for the winter months on the northwestern plains of India. However, this mushroom can now be grown anywhere in India thanks to advancements in modern farming technologies. Under controlled conditions, growers may produce an average of five to six white button mushroom crops in a year. The type of strain employed, the prevalence of pests and diseases, and the lack of clean spawn are factors that affect crop productivity, both in terms of quantity and quality. In agricultural applications, fuzzy expert systems have become extremely effective tools, especially when it comes to handling the uncertainties and nonlinearities included in biological processes and environmental data. Fuzzy logic, which provides adaptive control based on soil moisture, temperature,

advancement of precision agriculture, promoting sustainable and economically viable solutions for button mushroom farmers.

Keywords– *Button mushroom farming, Fuzzy logic, Mushroom yield, Mushroom quality, Fuzzy inference system*

and plant health indicators, has been applied in precision farming for effective fertilizer management, crop disease diagnosis, and irrigation scheduling. Prakash et al. [1] developed 'Prithvi' to assist farmers in Soybean variety selection, emphasizing local language and updates. Philomine, R. T., Ganesan, N., and Tauro, C. J. M. [2] state that integrating modern expert systems and technology with traditional agricultural practices can revolutionize farming in India by enhancing yield, efficiency, and global prominence. According to Purroy Vsquez et al. [3], effective livestock management, particularly through optimized production systems and supported by Fuzzy Logic-based Expert Systems, enhances productivity, improves rural livelihoods, and maximizes economic gains. Shahzadi et al. [4] proposed an IoT-based Expert System combining smart sensing and automated decision-making to improve cotton crop management and irrigation, achieving 65% user acceptance, and promoting Smart Agriculture. Roseline, Tauro, and Ganesan [5] developed expert systems that integrate farmer experience, agricultural knowledge, and technology to identify crop diseases and enhance yield through modules on pest, soil, and fertilizer management. This research by Djatkov, Effenberger, and Martinov [6] developed a method using fuzzy logic and expert systems to assess and improve the efficiency of agricultural biogas plants, tested on five plants in Bavaria, with plans for continuous updates and expansion to other biogas plant types and socio-economic factors. Navalakhe and Rathod [7] discussed the development of a fuzzy logic- based expert model to enhance soil fertility for soybean crops in Madhya Pradesh using nutrient analysis and fuzzy classification. Rachna Navalakhe, Gayatree Rathodand Pooja Bhatt [8] developed a fuzzy logic- based expert system to model and predict optimal environmental conditions temperature, moisture, oxygen, light, and soil pH for successful soybean seed germination, providing actionable recommendations to enhance crop yields and promote sustainable agriculture. Additionally, a mushroom fuzzy expert system has been developed to enhance the precision in mushroom cultivation, aiding farmers in monitoring and controlling environmental variables like temperature, humidity, and light intensity, ensuring optimal growth conditions and better yield. G.P. and F. Arifin [9] developed a fuzzy logic-based humidity control system using an Arduino ATMega349, effectively maintaining optional condition for oyster mushroom growth. Aysenur Gurgen et.al. [10] utilized fuzzy AHP to explore mushroom consumption preferences, finding growth type, market, packaging, weight, and flavor as key determinants. According to Yusuf Hendrwn et al [11], a fuzzy logic-based automatic control system for temperature and humidity in oyster mushroom cultivation achieved rapid stabilization within 5 minutes, with minimal errors and significantly improved yield and stem length compared to conventional methods. Agustianto, K., et al. [12] developed a fuzzy PID-based temperature and humidity control system for kumbung, achieving 86% accuracy and enhancing mushroom production efficiency by optimizing sensor readings and treatment processes. Dipali et al. [13] created an ESP32 and fuzzy logic controller (FLC) smart Internet of Things (IoT) watering and monitoring system for oyster mushroom cultivation that is more responsive and economical than On-Off control. Dakhole et al. [14] created an Internet of Things-based FIS-ANFIS system for growing oyster mushrooms, demonstrating how ANFIS provides better control over humidity and temperature for increased yield.

2. OVERVIEW OF FUZZY EXPERT SYSTEM

The concept of fuzzy sets was in 1965 by Professor Lotfi A. Zadeh, a pioneer in electrical engineering [15, 16, 17]. This innovative idea offered a fresh approach to understanding systems, logic, and reasoning models. Fuzzy logic, an integral part of introduced fuzzy set theory, relies on relative truth values to facilitate decision making and form statements. By addressing uncertainties present in real world situations and human thought, fuzzy logic provides a robust mathematical frame work. Zadeh also introduced the membership function to effectively handle such uncertainties and enable better decision- making. By incorporating varying degrees of membership for elements, the fuzzy set concept [15] expands the traditional definition of a set within a given universe of discourse.

$$\lambda_Y: U \longrightarrow [0,1]$$

This membership function determines the set of pairs of the element of U and its membership in the fuzzy set defined over the domain U.:

$$Y = \{(u, \lambda_Y(u)): u \in U, \lambda_Y(u) \in [0,1]\}$$

The design of membership functions is based on input parameters that are necessary and deemed appropriate for the quality and quantity of button mushroom. The membership function within the range [0, 1] is defined in the paper using the triangular membership function (trimf). The triangular membership function (trimf) has the following mathematical representation:

$$\text{trimf}(u; m_1, m_2, m_3) = \begin{cases} 0 & \text{if } u \leq m_1 \\ \frac{u-m_1}{m_2-m_1} & \text{if } m_1 \leq u \leq m_2 \\ \frac{m_3-u}{m_3-m_2} & \text{if } m_2 \leq u \leq m_3 \\ 0 & \text{if } m_3 \leq u \end{cases}$$

In fuzzy logic systems, fuzzy sets are frequently represented using a mathematical function called a trapezoidal membership function. When graphed, it has a trapezoidal shape that is determined by four parameters: m_1, m_2, m_3, and m_4. The trapezoid's shape and spread are determined by these characteristics. The trapezoidal membership function (trapmf) has the following mathematical representation:

$$\text{trapmf}(u; m_1, m_2, m_3) = \begin{cases} 0 & \text{if } u \leq m_1 \\ \frac{u-m_1}{m_2-m_1} & \text{if } m_1 \leq u \leq m_2 \\ 1 & \text{if } m_2 \leq u \leq m_3 \\ \frac{m_4-u}{m_4-m_3} & \text{if } m_3 \leq u \leq m_4 \\ 0 & \text{if } m_4 \leq u \end{cases}$$

Button Mushroom cultivation demands meticulous control over various environment factors to achieve optimal growth and maximize yields. The integration of a controlling and monitoring system using fuzzy interface system (Mamdani) through MATLAB introduces an intelligent and adapting approach to steer the direction and evaluation of button mushroom farming. This introduction explores the application of fuzzy logic to optimize key input variables such as temperature, humidity, ventilation, and substrate moisture with the overarching goal of enhancing the farming process and evaluating its success based on parameters like yields and quality.

3. PROPOSED ALGORITHM

This algorithm outlines the procedures that our fuzzy logic-based expert model uses to assess the button mushroom's yield amount, fruiting body diameter, and stalk length as outputs based on several of input factors:

Table 1 Proposed fuzzy expert algorithm for predicting button mushroom YA, FBD, and SL

Step-1	Enter a range of different input elements and output variables into the system. i.e. yield amount (in the percentage) and fruiting body diameter and stalk length (in cm) of button mushroom cultivation in the model.
Step-2	Divide input and output factors in to linguistic term.
Step-3	Using the information available, make suitable membership functions for each linguistic term.

Step-4	Use MATLAB to check rules for yield, diameter, and stalk length in button mushroom cultivation.
Step-5	Determine the rule base evaluation.
Step-6	Compute yield, diameter, and stalk length in mushroom cultivation.
Step-7	Stop.

4. PROPOSED FLOW CHART

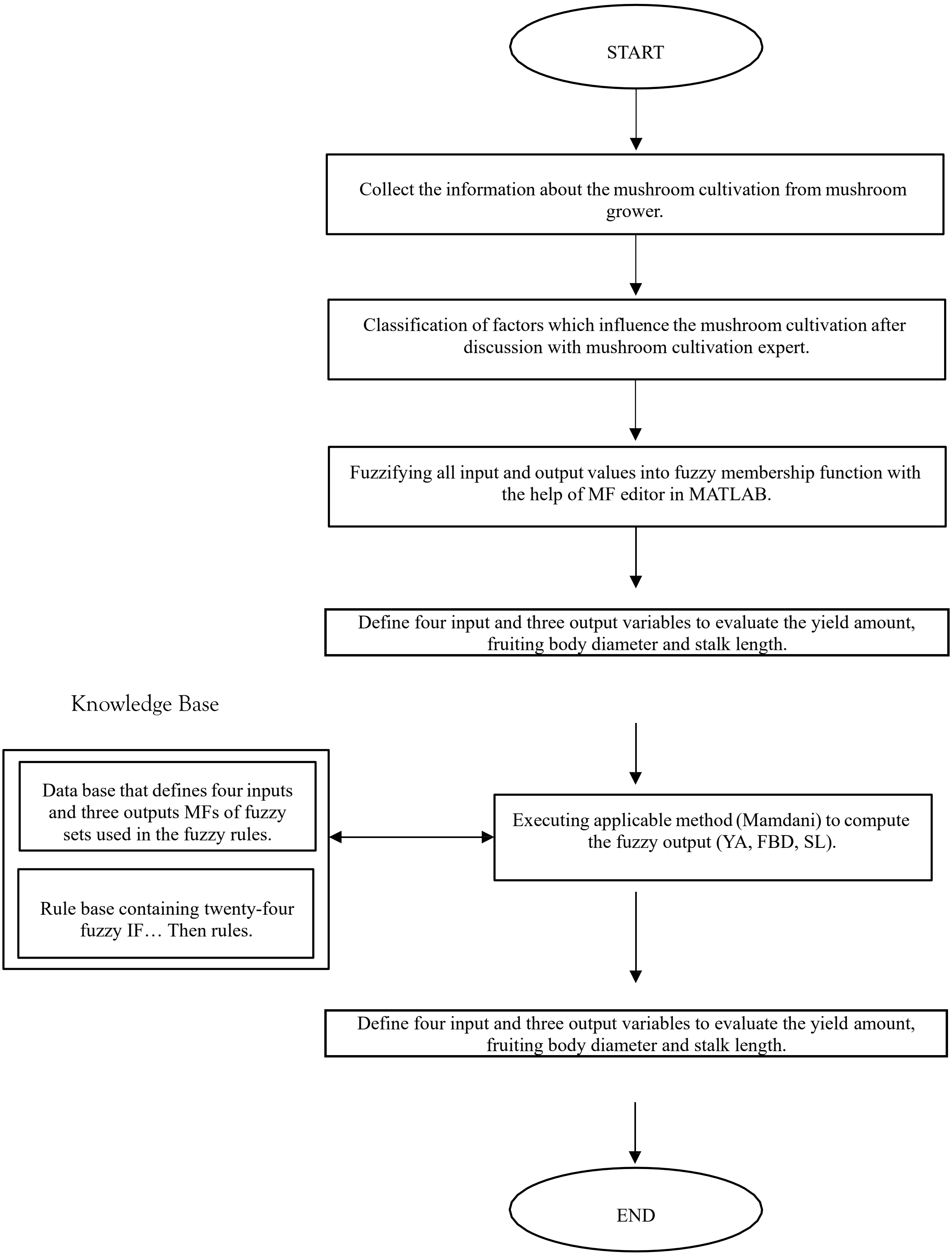


Figure 1 Flow-chart of fuzzy expert model.

5. FUZZY MODELLING METHODOLOGY FOR BUTTON MUSHROOM CULTIVATION

5.1. System Design and Variable Selection.

Four crucial input variables were used to create the fuzzy expert model, which was used to simulate and assess the best farming practices: TMR–Temperature during mycelium run (∘C), TFB- Temperature for Fruit Body development (∘C), CLV-CO_2 Level (ppm), HMD- Humidity (%). These variables were chosen for their direct influence on mushroom physiology and yield, as confirmed by expert cultivators and literature reviews. The following output variables were used to evaluate the results of cultivation: YA-Yield Amount (in %), FBD-Fruiting Body Diameter (in cm) and SL-Stalk Length (in cm).

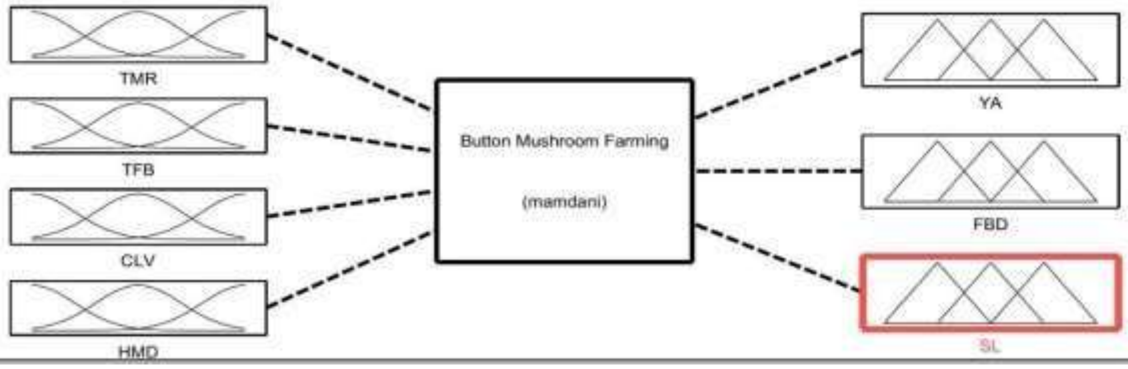
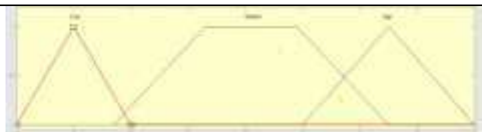
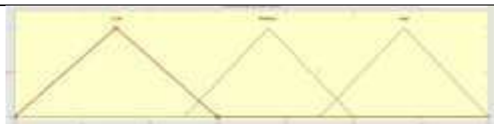
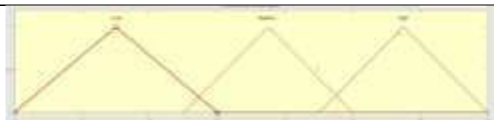


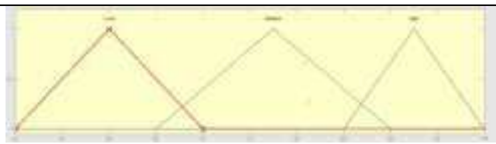
Figure 2 Illustrates the configuration of a fuzzy inference system (Mamdani) featuring four inputs and three outputs.

5.2. Membership Function Development.

Triangular and trapezoidal membership functions were used to define each input and output variable, based on real-world cultivation ranges supplied by mushroom specialists. These variables were given the linguistic classifications Low, Medium, and High, enabling the qualitative interpretation of quantitative data. A graphical representation of these membership functions for each linguistic term is provided in Table 2, which visualizes the fuzzy sets and how different values of the variables are mapped into degrees of membership.

Table 2 The ranges of input/output parameters and their graphical representation of MF

Input/Output parameters				Membership function
Needs	Linguistic Variable (for input variables)			
Input variable	Low	Medium	High	
TMR	18—20∘C	19.7—24.5∘C	23—26∘C	
TFB	13—16∘C	15.5 — 18∘C	17.5—20∘C	
CLV	0—500ppm	400—1000ppm	950—1500ppm	

HMD	50 – 70%	65 – 90%	85 – 100%	

Needs	Linguistic Variable (for output variables)			
Output variable	Low	Medium	High	
YA	0 – 32%	30 – 34%	38 – 100%	

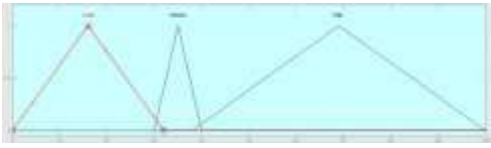
				
	Small	Medium	Large	
FBD	1 – 2.5cm	2 – 5cm	4.5 – 7cm	
SL	0.1 – 1cm	.8 – 3cm	2 – 5cm	

Table 3 Membership function for TMR, TFB, CLV, HMD, YA, FBD, SL

Low	Medium	High
$\lambda_l(u) = \begin{cases} 0 & ; u < 18 \\ \frac{u-18}{1} & ; 18 \le u < 19 \\ \frac{20-u}{1} & ; 19 \le u < 20 \\ 0 & ; u \ge 20 \end{cases}$	$\lambda_m(u) = \begin{cases} 0 & ; u < 19.7 \\ \frac{u-19.7}{1.6} & ; 19.7 \le u < \\ 1 & ; 21.3 \le u < \\ \frac{24.5-u}{1.6} & ; 22.9 \le u \le \\ 0 & ; u \ge 24.5 \end{cases}$	$\lambda_h(u) = \begin{cases} 0 & ; u < 23 \\ u-18 & ; 23 \le u < 24.5 \\ 1 & ; 24.5 \le u < 26 \\ \frac{20-u}{1.5} & ; u \ge 26 \\ 0 & ; \end{cases}$
$\lambda_l(u) = \begin{cases} 0 & ; u < 13 \\ \frac{u-13}{1.5} & ; 13 \le u < 1 \\ 1 & ; 14.5 \le u < \\ \frac{16-u}{1.5} & ; \\ 0 & ; u \ge 16 \end{cases}$	$\lambda_m(u) = \begin{cases} 0 & ; u < 15. \\ \frac{u-15.5}{1.25} & ; 15.5 \le u < \\ 1 & ; 16.75 \le u \\ \frac{18-u}{1.25} & ; \\ 0 & ; u \ge 18 \end{cases}$	$\lambda_h(u) = \begin{cases} 0 & ; u < 17. \\ \frac{u-17.5}{1.25} & ; 17.5 \le u < \\ 1 & ; 18.75 \le u \\ \frac{20-u}{1.25} & ; \\ 0 & ; u \ge 20 \end{cases}$
$\lambda_l(u) = \begin{cases} 0 & ; u < 0 \\ \frac{u-0}{250} & ; 0 \le u < \\ \frac{500-u}{250} & ; 250 \le u < \\ 0 & ; u \ge 50 \end{cases}$	$\lambda_m(u) = \begin{cases} 0 & ; u < 400 \\ \frac{u-400}{300} & ; 400 \le u < \\ \frac{1000-u}{300} & ; 700 \le u < 1 \\ 0 & ; u \ge 100 \end{cases}$	$\lambda_h(u) = \begin{cases} 0 & ; u < 90 \\ \frac{u-900}{300} & ; 900 \le u < \\ \frac{1500-u}{300} & ; 1200 \le u < \\ 0 & ; u \ge 150 \end{cases}$
$\lambda_l(u) = \begin{cases} 0 & ; u < 50 \\ \frac{u-50}{10} & ; 50 \le u < 6 \\ \frac{70-u}{10} & ; 60 \le u < 7 \\ 0 & ; u \ge 70 \end{cases}$	$\lambda_m(u) = \begin{cases} 0 & ; u < 65 \\ \frac{u-65}{12.5} & ; 65 \le u < 77.5 \\ \frac{90-u}{12.5} & ; 77.5 \le u < 90 \\ 0 & ; u \ge 90 \end{cases}$	$\lambda_h(u) = \begin{cases} 0 & ; u < 85 \\ \frac{u-85}{7.5} & ; 85 \le u < 92. \\ \frac{100-u}{7.5} & ; 92.5 \le u < 1 \\ 0 & ; u \ge 100 \end{cases}$
$\lambda_l(u) = \begin{cases} 0 & ; u < 0 \\ \frac{u-0}{16} & ; 0 \le u < 16 \\ \frac{32-u}{16} & ; 16 \le u < 3 \\ 0 & ; u \ge 32 \end{cases}$	$\lambda_m(u) = \begin{cases} 0 & ; u < 30 \\ \frac{u-30}{5} & ; 30 \le u < 35 \\ \frac{40-u}{5} & ; 35 \le u < 40 \\ 0 & ; u \ge 40 \end{cases}$	$\lambda_h(u) = \begin{cases} 0 & ; u < 38 \\ \frac{u-38}{31} & ; 38 \le u < 69 \\ \frac{100-u}{31} & ; 69 \le u < 100 \\ 0 & ; u \ge 100 \end{cases}$

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$\lambda_l(u)$ 0 u − 1 = 2. .5 75 − ; u < 1 u ; 1 ≤ u < 1 . 75 ; 1. 75 ≤ u < {0 ; u ≥ 2.	$\lambda_m(u)$ 0 u − 2 = 51 −. 5 u ; u < 2 ; 2 ≤ u < 3. 5 1. 5 { 0 ; 3. 5 ≤ u < 5 ; u ≥ 5	$\lambda_h(u)$ 0 u − 4. 5 = 71 .− 25 ; u < 4. 5 u ; 4. 5 ≤ u < 5. 7 1. 25 ; 5. 75 ≤ u < 7 {0 ; u ≥ 7
Small	Medium	Large
$\lambda_{small}(u)$ 0 u − 1 = 2. .5 75 − ; u < 1 u ; 1 ≤ u < 1 . 75 ; 1. 75 ≤ u < {0 ; u ≥ 2.	$\lambda_m(u)$ 0 u − 2 = 51 −. 5 u ; u < 2 ; 2 ≤ u < 3. 5 1. 5 { 0 ; 3. 5 ≤ u < 5 ; u ≥ 5	$\lambda_{large}(u)$ 0 u − 4. 5 = 71 .− 25 ; u < 4. 5 u ; 4. 5 ≤ u < 5. 7 1. 25 ; 5. 75 ≤ u < 7 {0 ; u ≥ 7
$\lambda_{small}(u)$ 0 u − 1 ; u <. 1 = 2. .5 75 − ; . 1 ≤ u <. u ; 1. 75 ≤ u < . 75 ; u ≥ 2.	$\lambda_m(u)$ 0 u − 2 ; u < 2 = 51 −. 5 u ; 2 ≤ u < 3. 5 1. 5 ; 3. 5 ≤ u < 5 { 0 ; u ≥ 5	$\lambda_{large}(u)$ 0 u − 4. 5 ; u < 4. 5 = 71 .− 25 ; 4. 5 ≤ u < 5. 7 u ; 5. 75 ≤ u < 7 1. 25 ; u ≥ 7

{ **0**		{ **0**

5.3. Rule Base Construction.

Observed cultivation results were combined with empirical knowledge from domain specialists to create a thorough rule base. The fuzzy IF-THEN rules had the following structure:

A. If (TMR is l) and (TFB is l) and (CLV is l) and (HMD is h) then (YA is l) (FBD is Small) (SL is Small).
B. If (TMR is l) and (TFB is l) and (CLV is m) and (HMD is m) then (YA is l) (FBD is m) (SL is m).
C. If (TMR is l) and (TFB is l) and (CLV is l) and (HMD is l) then (YA is l) (FBD is Small) (SL is m).
D. If (TMR is l) and (TFB is l) and (CLV is m) and (HMD is h) then (YA is l) (FBD is m) (SL is Small).
E. If (TMR is l) and (TFB is l) and (CLV is h) and (HMD is h) then (YA is l) (FBD is Large) (SL is Small).
F. If (TMR is l) and (TFB is l) and (CLV is m) and (HMD is l) then (YA is l) (FBD is m) (SL is Large).
G. If (TMR is l) and (TFB is l) and (CLV is h) and (HMD is m) then (YA is l) (FBD is Large) (SL is m).
H. If (TMR is m) and (TFB is m) and (CLV is l) and (HMD is h) then (YA is m) (FBD is Small) (SL is Small).
I. If (TMR is m) and (TFB is m) and (CLV is m) and (HMD is m) then (YA is m) (FBD is m) (SL is m).
J. If (TMR is m) and (TFB is m) and (CLV is m) and (HMD is m) then (YA is m) (FBD is m) (SL is m).
K. If (TMR is m) and (TFB is m) and (CLV is l) and (HMD is m) then (YA is m) (FBD is Large) (SL is Large).
L. If (TMR is m) and (TFB is m) and (CLV is l) and (HMD is l) then (YA is m) (FBD is Small) (SL is m).
M. If (TMR is m) and (TFB is m) and (CLV is m) and (HMD is h) then (YA is m) (FBD is m) (SL is Small).
N. If (TMR is m) and (TFB is m) and (CLV is h) and (HMD is h) then (YA is m) (FBD is Large) (SL is Large).
O. If (TMR is m) and (TFB is m) and (CLV is h) and (HMD is m) then (YA is m) (FBD is m) (SL is Large).
P. If (TMR is m) and (TFB is m) and (CLV is h) and (HMD is m) then (YA is m) (FBD is Large) (SL is m).
Q. If (TMR is h) and (TFB is h) and (CLV is l) and (HMD is l) then (YA is h) (FBD is Small) (SL is Small).
R. If (TMR is h) and (TFB is h) and (CLV is m) and (HMD is m) then (YA is h) (FBD is m) (SL is m).
S. If (TMR is h) and (TFB is h) and (CLV is h) and (HMD is l) then (YA is h) (FBD is Large) (SL is Large).
T. If (TMR is h) and (TFB is h) and (CLV is l) and (HMD is m) then (YA is High) (FBD is Small) (SL is m). U. If (TMR is h) and (TFB is h) and (CLV is m) and (HMD is h) then (YA is High) (FBD is m) (SL is Small).
V. If (TMR is h) and (TFB is h) and (CLV is h) and (HMD is h) then (YA is High) (FBD is Large) (SL is Small).
W. If (TMR is h) and (TFB is h) and (CLV is m) and (HMD is l) then (YA is High) (FBD is m) (SL is Large).
X. If (TMR is h) and (TFB is h) and (CLV is h) and (HMD is m) then (YA is High) (FBD is Large) (SL is m).

5.4. Inference and Defuzzification.

The fuzzy inference engine assessed system responses by evaluating several input situations. The centroid method was used for defuzzification, transforming fuzzy output data into precise, practical recommendations for farmers.

6. RULE VIEWER

The rule viewer in figure illustrates how the fuzzy rule base process is executed, as well as how the antecedent and consequent of the generated rules are represented, and how the rule viewer comprehends the entire fuzzy rule base process. The following is the ruler viewer:

Figure 3 Evaluation of the rule for button mushrooms with high yields and high quality

The fuzzy rule evaluation for button mushrooms using MATLAB's Fuzzy Logic Toolbox under high yield and quality criteria is shown in Figure 3. Triangular or trapezoidal membership functions are used to represent input or output variables in each column. The output columns' blue sections display the combined fuzzy output, while the yellow shaded regions represent the level of rule activation for the specified input values (e.g., TMR = 24.5, TFB = 18.8, CLV = 1.2, HMD = 60.2). To improve system interpretability and decision-making, this visualization verifies that quantitative data is correctly mapped to linguistic categories such as Low, Medium, and High.

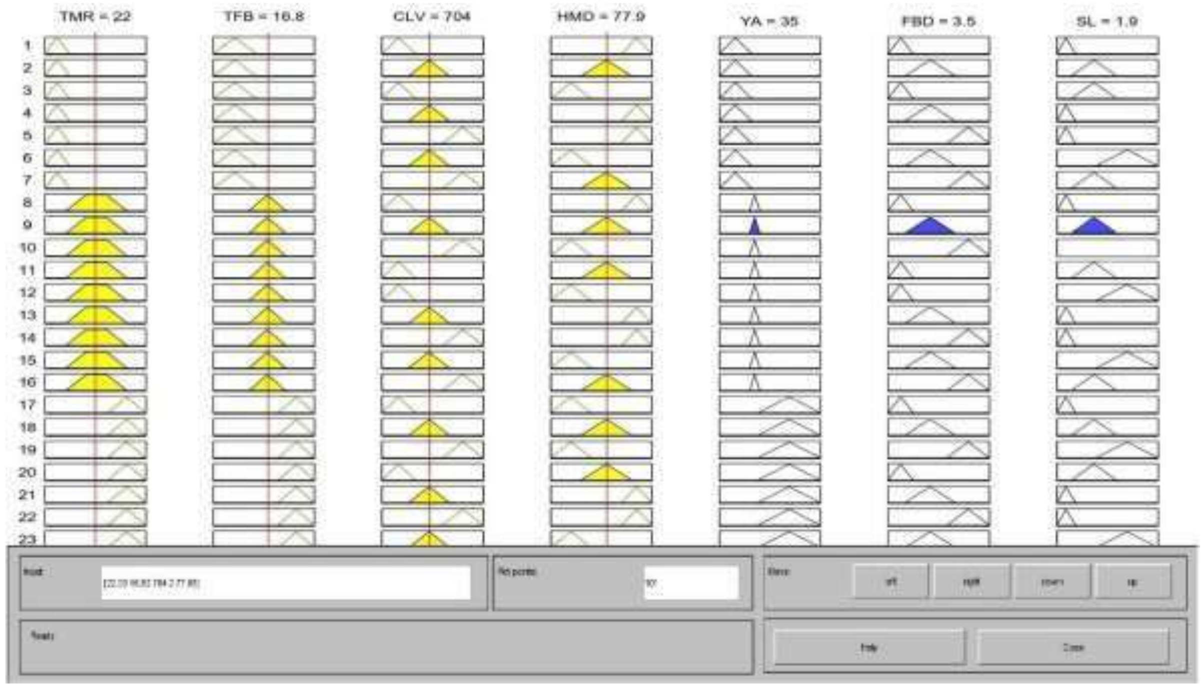

Figure 4 Evaluation of the rule for button mushrooms with medium yields and medium quality

The fuzzy rule evaluation for button mushrooms under environmental conditions, which yields a medium yield and quality, is shown in Figure 4. The diagram illustrates how the system reacts to input values such TMR = 22, TFB = 16.8, CLV = 704, and HMD = 77.9 using MATLAB's Fuzzy Logic Toolbox. The active membership levels for the inputs across linguistic phrases such as Low, Medium, and High are indicated by the yellow shaded zones. The ensuing fuzzy outputs for variables such as stalk length (SL), fruiting body diameter (FBD), and yield amount (YA) are shown by the blue areas. This demonstrates how well the system maps environmental elements to agricultural outputs and how interpretable it is.

Figure 5 Evaluation of the rule for button mushrooms with low yields and low quality

Using MATLAB's Fuzzy Logic Toolbox, Figure 5 illustrates the fuzzy rule evaluation for button mushrooms in situations that lead to low yield and bad quality. The system processes input data like TMR = 19, TFB = 14.5, CLV = 246 and HMD = 92.1. The input fuzzy sets' activation levels are shown by the yellow shaded areas, which primarily correlate to lower linguistic phrases. The system's reasoning towards a low output scenario is confirmed by the blue shaded areas in the output variables, YA (Yield Amount), FBD (Fruiting Body Diameter), and SL (Stalk Length), which represent low membership levels.

7. EXPERIMENTAL RESULT

A fuzzy expert system was developed to evaluate the optimal conditions for button mushroom cultivation using four input variables and three output variables. The input variables included TMR, TFB, CLV, HMD, which are known to significantly influence the growth of Agaricus bisporus. The output variables were defined as YA, FBD and SL. Table 3 list the defined membership functions for the input and output variables. The fuzzy inference system was constructed using expert knowledge and validated with real cultivation data. The membership functions for each input and output were designed based on practical ranges provided by a mushroom cultivation expert. Three scenarios High, Medium, and Low were tested to assess the systems response and evaluate its predictive performance. The fuzzy expert system exhibited robust decision-making across varying inputs, converting knowledge into actionable outputs for mushroom cultivation. Among the three scenarios, the Medium case provided the best balance of resource use and output performance, as predicted by our model.

Table 4 Cases of High, Medium, and Low Button Mushroom Yields and Quality Analysis from the Fuzzy Expert System Rule Viewer

Case	TMR	TFB	CLV	HMD	YA	FBD	SL
High	24.5	18.5	1200	60.2	69	5.75	3.5
Medium	22	16.5	704	77.9	35	3.5	1.9
Low	19	14.5	246	92.1	16	1.75	.551

The yield amount (YA) refers to the weight of fully developed button mushrooms harvested per unit area during a cultivation cycle. YA are influenced by factors such as substrate composition, temperature during mycelium run (TMR), temperature for fruiting body development (TFB), CO2 concentration (CLV), humidity, and ventilation. In the proposed model, the highest yield amount (YA) of 35% was obtained under optimal environmental conditions: TMR = 22℃, TFB = 16.8℃, CLV = 704 ppm, and relative humidity = 77.9%, as illustrated in the referenced Figure 4 and Figure 6.

Figure 6 Harvest yield of button mushrooms, expressed as total fresh weight per cultivation unit.

Figure 7 Optimal fruiting body diameter under ideal conditions for market suitability.

Figure 8 Optimal stalk length achieved under favorable conditions aligned with market demand.

The size of the mushroom's cap, or pileus, which is the most noticeable component of its reproductive structure, is referred to as the fruiting body diameter. In commercial production, fruiting body diameter is a crucial feature for grading mushrooms and influences their marketability. In the developed model, an optimal fruiting body diameter (FBD) of 3.5 cm aligned with market preferences was attained under favorable environmental conditions: TMR at 22 ◦C, TFB at 16.8 ◦C, CLV at 704 ppm, and relative humidity at 77.9%, as shown in Figure 4 and Figure 7.

In mushroom cultivation, the stalk length of the mushrooms is a crucial factor that influences the harvested mushrooms' look and usefulness. The normal stalk length of button mushrooms might change depending on the environmental factors, cultivation techniques, and growth stage. Shorter, thicker stems are generally preferable for regularity and aesthetics in commercial grading and culinary applications, where the stalk length is frequently considered. In the established model, the stalk length (SL) of mushroom 1.9 cm considered optimal for commercial standards was achieved under controlled environmental conditions, specifically: TMR of 22 ◦C, TFB of 16.8 ◦C, CLV of 704 ppm, and relative humidity of 77.9%, as illustrated in Figure 4 and Figure 8.

8. CONCLUSION

The techniques to develop an expert model based on fuzzy logic to determine a button mushroom yield amount, fruiting body diameter and stalk length are discussed. The main objective of this fuzzy expert model is to provide expert opinion about the various inputs and their appropriate rang to suggest the amount of button mushroom production and quality (fruiting body diameter and stalk length) for the farmers or mushroom growers. Information available about various inputs and their suitable ranges are considered as the input and the yield amount, fruiting body diameter, stalk length of button mushroom is taken as the output, then all the input and output variable are classified with linguistic terms and their suitable membership function later, this model has been tested through mushroom cultivation expert. It is found that if the proper rang of all the 4 inputs suggested by the model is taken then, according to the market we can achieve the best quality and quantity of button mushroom to the farmer/grower.

Acknowledgement.

We sincerely appreciate Shri Govindram Seksaria Institute of Technology and Science (SGSITS), Indore, for providing the essential facilities that supported this research. Our gratitude also extends to APN AGROTECH, Singrauli, for supplying the crucial data required for this study. Furthermore, we acknowledge the valuable support from the School of Mathematics, DAVV, Indore, which has significantly contributed to the successful completion of this work.

REFERENCES

[1] Prakash, C., Rathor, A. S., and Thakur, G. S. M., 2013, "Fuzzy Based Agriculture Expert System for Soyabean," Proceedings of the International Conference on Computing Sciences (WILKES100-ICCS2013), Jalandhar, Punjab, India, Vol. 113, pp. 115–123. [2] Philomine Roseline, T., Ganesan, N., and Tauro, C. J. M., 2015, "A Study of Applications of Fuzzy Logic in Various Domains of Agricultural Sciences," Proceedings of the International Conference on Current Trends in Advanced Computing (ICCTAC2015), May 2015, Vol. 1, pp. 15–18.

[3] Vásquez, R. P., Aguilar-Lasserre, A. A., López-Segura, M. V., Rivero, L. C., Rodríguez Duran, A. A., and Rojas-Luna, M. A., 2019, "Expert System Based on a Fuzzy Logic Model for the Analysis of the Sustainable Livestock Production Dynamic System," Comput.

Electron. Agric., **161**, pp. 104–120.

[4] Shahzadi, R., Ferzund, J., Tausif, M., and Suryani, M. A., 2016, "Internet of Things-Based Expert System for Smart Agriculture," Int. J. Adv. Comput. Sci. Appl., **7**(9).

[5] Philomine Roseline, N. G., and Tauro, C. J. M., 2012, "Design and Development of Fuzzy Expert System for Integrated Disease Management in Finger Millets," Int. J. Comput. Appl., **56**(1), pp. 31–36.

[6] Djatkov, D., Effenberger, M., and Martinov, M., 2014, "Method for Assessing and Improving the Efficiency of Agricultural Biogas Plants Based on Fuzzy Logic and Expert Systems," Appl. Energy, **134**, pp. 163–175.

[7] Navalakhe, R., and Rathod, G., 2024, "Fuzzy Expert Model to Assess the Soil Fertility for Soybean Production in Madhya Pradesh," Math. Model. Comput., **11**(3), pp. 730–740.

[8] Navalakhe, R., Rathod, G., and Bhatt, P., 2025, "Anticipating Soybean Seed Sprouting Using Fuzzy Modeling Techniques," J. Xi'an Shiyou Univ., Nat. Sci. Ed., **68**(4), pp. 281–295.

[9] Cikarge, G., and Arifin, F., 2018, "Oyster Mushrooms Humidity Control Based on Fuzzy Logic by Using Arduino ATmega238 Microcontroller," J. Phys.: Conf. Ser., **1140**, p. 012002, IOP Publishing.

[10] Gürgen, A., Yıldız, S., and Yıldız, Ü. C., 2018, "Determination of Mushroom Consumption Preferences by Using Fuzzy Analytic Hierarchy Process," Eur. J. For. Sci., **6**(3), pp. 25–34.

[11] Hendrawan, Y., Anta, D. K., Ahmad, A. M., and Sutan, S. M., 2019, "Development of Fuzzy Control Systems in Portable Cultivation Chambers to Improve the Quality of Oyster Mushrooms," IOP Conf. Ser.: Mater. Sci. Eng., **546**, p. 032013, IOP Publishing.

[12] Agustianto, K., Wardana, R., Destarianto, P., Mulyadi, E., and Wiryawan, I., 2021, "Development of Automatic Temperature and Humidity Control System in Kumbung (Oyster Mushroom) Using Fuzzy Logic Controller," IOP Conf. Ser.: Earth Environ. Sci., **672**, p. 012090, IOP Publishing.

[13] Dipali, D., Subramanian, T., and Kumaran, G. S., 2023, "A Smart Oyster Mushroom Cultivation Using Automatic Fuzzy Logic Controller," J. Discrete Math. Sci. Cryptogr., **26**(3), pp. 601–615.

[14] Dipali, D., Subramanian, T., and Kumaran, G. S., 2023, "A Novel Approach for an Outdoor Oyster Mushroom Cultivation Using a Smart IoT-Based Adaptive Neuro Fuzzy Controller," Int. J. Adv. Comput. Sci. Appl., **14**(5).

[15] Zadeh, L. A., 1994, "Soft Computing and Fuzzy Logic," IEEE Softw., **11**(6), pp. 48–56.

[16] Zadeh, L. A., 1996, "Fuzzy Logic, Neural Networks, and Soft Computing," in Fuzzy Sets, Fuzzy Logic, and Fuzzy Systems: Selected Papers by Lotfi A. Zadeh, World Scientific, Singapore, pp. 775–782. [17] Zadeh, L. A., 1965, "Fuzzy Sets," Inf. Control, **8**(3), pp. 338–353.