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Integrating Fuzzy Logic into Economic Viability Studies for Sustainable Farming

Suleiman Ibrahim Mohammad[1,2], *N. Yogeesh*[3,*], *N. Raja*[4], *F. T. Z. Jabeen*[5], *B. A. Ashwakh Ahamed* [6] *and Asokan Vasudevan*[7]

[1]Electronic Marketing and Social Media, Economic and Administrative Sciences Zarqa University, 13110 Zarqa, Jordan
[2]INTI International University, 71800 Negeri Sembilan, Malaysia
[3]Department of Mathematics, Government First Grade College, Tumkur, Karnataka, India
[4]Department of Visual Communication, Sathyabama Institute of Science and Technology, Chennai, 600119 Tamil Nadu, India
[5]Department of Botany, Government First Grade College, Tumkur, Karnataka, India
[6]Department of Sociology, Government First Grade College, Tumkur, Karnataka, India
[7]Faculty of Business and Communications, INTI International University, Persiaran Perdana BBN Putra Nilai, 71800 Nilai, Negeri Sembilan, Malaysia

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Abstract: Farmers' decision-making regarding organic farming systems has many complexities and uncertainties, making them challenging to assess economically. Most conventional deterministic functions that describe production functions lack the means to capture dynamic relationships among production costs, market prices and yield variability typical of organic practices. In this paper we present a new approach based on fuzzy logic to overcome the above issues. In this theoretical case study of an organic vegetable farming system, its feasibility is evaluated with a fuzzy logic-based methodology. The method utilizes fuzzy variables and expert knowledge along with fuzzy rules to consider uncertainties and gives a robust assessment. We contrast the findings to conventional economic evaluation approaches, pointing out the shortcomings of deterministic approaches. The results highlight the importance of the fuzzy logic based approach to obtain a better representation of the economic expectations of the organic farming systems. This method profound the effects on farmers, policymakers, and also researchers, enabling sustainable agriculture and informed solutions in various practices.

Keywords: Organic Farming, Fuzzy Logic, Organic Dairy Farming, Economic Viability, Complex Systems, Sustainable Agriculture, Linguistic Variables, Decision-Making, Expert Knowledge, Traditional Models

1 Introduction

In recent years Organic farming has become very prominent due to the increasing consumer demand for safer and healthier food products, increasing environmental concern about traditional agriculture practices [1,2,3,4]. Organic agriculture is a system that avoids or largely excludes the use of synthetic fertilisers and pesticides to maintain crop health [5,6,7], which contradicts traditional agricultural strategies that rely heavily on chemical inputs. This practice exposes consumers and farmworkers to fewer chemicals and minimizes chemical runoff and soil degradation, thus lowering the environmental footprint [8,9,10,11].

However, although ecological benefits and consumer preferences characterize organic farming systems, their profitability is considered a major constraint for farmers and stakeholders [12,13,14]. Organic farming is associated with intrinsic uncertainties regarding produce variability, market pricing, and production costs [15,16,17], because it is based on alternative practices leading to decreased use of synthetic inputs. Thus, deterministic models, the traditional means of assessing the economic viability of organic farming systems, provides an incomplete and the overly optimistic assessment if one does not [18,19,20].

The significance of this research investigation is lack of existing approach to carry out the complete assessment

* Corresponding author e-mail: yogeesh.r@gmail.com

of organic farming systems involving these uncertainties in economic viability assessment. Conventional approaches to economic assessment typically do not align well with the dynamic and uncertain reality of organic farming practices [21,22,23]. And so, a new way of doing for their way compensates and thus a more nuanced and informative assessment of the capacity for organic husbandry.

The research aims to develop fuzzy logic ignore-approach for assessment of economic evaluation of organic farming system. Fuzzy logic based systems were capable of understanding and manipulating uncertain information and hence they can be a potential candidate for solving the complexities associated with organic farming system under uncertainty [24,25,26,27]. Using fuzzy logic concepts, this study will yield a stronger and more integral mean of evaluating the economic feasibility of organic farming systems.

Statement of problem: The need for an effective method to assess the economic viability of organic farming systems which considering inherent uncertainties.

Research objective: To develop a fuzzy logic-based approach for evaluating economic viability in organic farming using various scenario.

2 Literature Review

2.1 Assessment of Economic Viability in Agriculture: Limitations in Addressing Uncertainties in Organic Farming

Agronomists commonly apply deterministic models to estimate the economic feasibility of agricultural systems by assuming fixed relationships between inputs, outputs, and costs [1,28]. These models, however, usually fail to consider the complexity and uncertainty inherent to organic farming systems [5]. It leads to variability of yield, market price and production cost in organic practices, which are less chemical input and more bio-geo-chemical processes [8]. Conventional methods for evaluating economic performance have missed out on this variation, leading to questionable and incomplete evaluations of the economic viability of organic agriculture [12].

2.2 Fuzzy Logic and Decision-Making Under Uncertainty

Because it can accommodate inexact and ambiguous knowledge fuzzy logic has become a productive instrument for making decisions in the presence of uncertainty [12]. Fuzzy logic, unlike binary systems, applies being true by degrees, providing a more accurate and comprehensive modelling of complex systems [15], which by nature do not correspond to a true/false value. Fuzzy logic allows qualitative and quantitative information to be combined and models uncertainty using linguistic variables and membership function, thus is relevant to be used in addressing uncertainties associated with organic farming [18].

2.3 Application of Fuzzy Logic in Agricultural Decision-Making

Various agricultural domains invariably require decision-making under uncertainty, where fuzzy logic has been a popular approach. Specifically, fuzzy logic has been applied in the formulation of pest and disease risk models for eventual optimal timing and dosage of a tune-up intervention in crop management [27]. Though some fuzzy logic-based irrigation systems have reported enhanced water use efficiency through dynamically adjusted irrigation schedules driven by real-time weather and soil conditions [29]. The use of fuzzy logic in decision-making is not limited to livestock but can be extended to other aspects of livestock management such as decision support systems based on animal health feed availability on the farm and market prices.

Fuzzy logic has proved effective in dealing with uncertainties in yield estimation for organic farming. Given both the inherent variability of organic crop production from reduced synthetic inputs and variable management strategies with organic crops, fuzzy logic-based models provided a strong match for their flexibility and adaptability. Evidently, this paper highlighted a state-of-the-art fuzzy logic approach for measuring economic viability, however, no systematic review has been published in literature covering economic viability determination of organic farming systems based on fuzzy logic.

3 Methodology

3.1 Development of Fuzzy Logic-Based Assessment Framework

Many steps were taken to develop the fuzzy logic-based evaluation framework for assessing the economic feasibility of organic farming systems. This included defining linguistic variables, creating membership functions, establishing fuzzy rules, and refining them with expertise.

3.2 Defining Key Economic Indicators

They selected three important economic indicators for evaluation: production costs (C-prod), market prices (P-market), and yield variability (Y-var). These were mapped into linguistic variables and each linguistic variable was given a membership function to represent their varying degrees.

3.3 Fuzzification and Rule Development

Triangular, or trapezoidal membership functions were established in accordance with each linguistic variable 10. It is based on expert knowledge for assigning parameters of membership functions to convert quantitative time series economics data into linguistic values like as ”low,” ”medium” and ”high.”

Linguistic variables were connected among each other using soft rules, allowing modelling of the decision process [30,31,32]. The rules were created with domain experts and informed by their understanding of the relationships between economic indicators and the economic viability of organic farming systems.

3.4 Defuzzification Process for Crisp Viability Values

After the fuzzy inference process with the defined rules is complete, defuzzification is used to convert the fuzzy output into crisp economic viability values [8]. Depending on which linguistic variables were used, the weighted average method, based on centroid or height defuzzification, was applied.

4 Case Study 1: Organic Dairy Farming

The growing demand for healthier products and environmentally friendly farming methods have led to the rise of organic dairy farming as a sustainable alternative. In contrast to other dairy systems, organic dairy is not cantered around synthetic inputs, but rather organic feed and holistic animal care to guarantee milk quality. These practices directly increase the welfare of the environment and the state of animal well-being; however, they also introduce economic challenges, including greater production costs and inconsistencies in milk yield, depending on both natural feed and weather conditions [1, 5].

Factors influencing the market prices for organic milk, variations in milk production, as well as increased costs associated with organic feeding and veterinary care determine the economic feasibility of organic dairy farming. Classic deterministic models do not account for these uncertainties, leading to incomplete or misleading profitability evaluations [8,12]. Fuzzy logic provides a solid approach in solving these issues, especially considering the degree of uncertainty and the need for integration of qualitative and quantitative data will modelling organic systems system in the data collection process provides a strong approach for a mild solution for these problems. Fuzzy logic facilitates a more flexible assessment of the economic viability of polymer chips under different conditions by using linguistic variables and membership functions [15,18].

4.1 Key Economic Indicators

Assessing the economic viability of an organic dairy farm requires the identification of critical indicators that influence the profitability. Hence, following key economic indicators are considered:

Production Costs (C_prod):

This covers costs you incur for:

– *Feed:* The price of organic feed is usually more expensive than feed with non-organic ingredients.
– *Labor:* The shortage of labor to perform organic management systems.
– *Veterinary:* Further expenses related to keeping the health of the animal in accordance with organic certification guidelines.

Milk Prices (P_milk):

Revenue is largely driven by the market price of milk. Organic milk is widely marketed as an expensive product, with prices influenced by consumer preference, certification requirements and regional price levels.

Yield Variability (Y_var):

Milk production fluctuates due to:

– Seasonal factors (e.g., availability of pasture during different seasons).
– Variability in feed quality and quantity.
– Health conditions of the livestock.

These indicators serve as inputs for the fuzzy logic model, where linguistic values such as ”low,” ”medium,” and ”high” are assigned to capture their variability.

4.2 Dataset and Parameters

The hypothetical dataset for a 50-cow organic dairy farm focuses on three critical economic indicators: Production Costs (C_prod), Milk Prices (P_milk), and Yield Variability (Y_var). These indicators reflect the dynamic conditions under which organic dairy farms operate.

Dataset Overview

– Farm Size: 50 cows
– Production Costs (C_prod): Includes feed, labor, and veterinary expenses.
– Milk Prices (P_milk): Based on market trends for organic milk.
– Yield Variability (Y_var): Reflects daily milk production fluctuations due to feed quality, seasonal factors, and livestock health.

Table 1: Hypothetical Dataset for Economic Parameters

Parameter	Category	Values	Explanation
Production Costs (C_prod)	Low	$20,000	Lower costs achieved with efficient feed management and reduced veterinary interventions.
	Medium	$25,000	Moderate costs considering standard organic feed and labor requirements.
	High	$30,000	Higher costs due to premium organic feed, additional labor, or increased veterinary expenses.
Milk Prices (P_milk)	Low	$1.20 per liter	Lower-end price range due to market saturation or reduced consumer demand.
	Medium	$1.60 per liter	Average market price reflecting steady demand for organic milk.
	High	$2.00 per liter	Premium price for organic milk in high-demand scenarios or niche markets.
Yield Variability (Y_var)	Low	10 liter/day/cow	Lower yields due to seasonal factors, reduced feed quality, or health issues.
	Medium	15 liter/day/cow	Average milk production under stable feed and management conditions.
	High	20 liter/day/cow	Higher yields achieved during optimal feeding, health conditions, and seasonal advantages.

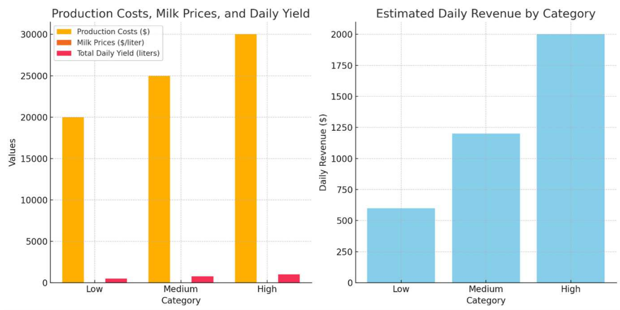

Fig. 1: Production cost with respect to estimated daily revenue

Example Dataset Explanation

Production Costs:

- Costs include feed (∼60%), labor (∼25%), and veterinary care (∼15%).
- Variability arises from factors such as organic feed prices and seasonal labor demand.

Milk Prices:

- Organic certification allows milk to command premium prices in the market.
- Prices fluctuate based on regional demand and competition.

Yield Variability:

- Yield per cow depends on factors such as nutrition, animal health, and milking frequency.
- Optimal conditions lead to higher milk output, whereas stressors (e.g., feed shortages) reduce yields.

Table 2: Combined Data for 50 Cows

Category	Production Costs ($)	Milk Prices ($/liter)	Yield (liters/day/cow)	Total Daily Yield (liters)	Estimated Daily Revenue ($)
Low	20,000	1.2	10	500	600
Medium	25,000	1.6	15	750	1,200
High	30,000	2	20	1,000	2,000

These figure 1 even make comparison of the economic indicators easier, helping to analyse the impact of each category on the farm revenue. Total daily yield and cost of production, as well as the price of milk, in low, medium, high Shows the daily revenue to the farm based on the combination of production costs, milk prices, and yield.

4.3 Interpretation of Dataset

- **Daily Revenue:** Calculated as total milk yield multiplied by milk price.
- **Economic Impact:** This dataset allows for analysis of the fuzzy logic model under varying scenarios. For example:
  - High production costs with low milk prices and yield indicate poor economic viability.
  - Low production costs with high milk prices and yield suggest strong viability.

This dataset forms the basis for applying fuzzy logic rules to assess the economic viability of the organic dairy farm.

4.4 Fuzzy Logic Framework

Fuzzification

The input variables are Production Costs (C_prod), Milk Prices (P_milk), and Yield Variability (Y_var), and they all are defined by membership functions. The degrees of membership are described by triangular and trapezoidal functions for linguistic values such as "Low," "Medium," and "High."

Production Costs (C_prod)

- Low: Trapezoidal membership function.

$$\mu_{Low}(x) = \begin{cases} 1 & \text{if } x \leq 20000 \\ \frac{25000-x}{5000} & \text{if } 20000 < x \leq 25000 \\ 0 & \text{if } x > 25000 \end{cases}$$

- Medium: Triangular membership function.

$$\mu_{Medium}(x) = \begin{cases} \frac{x-20000}{5000} & \text{if } 20000 < x \leq 25000 \\ \frac{30000-x}{5000} & \text{if } 25000 < x \leq 30000 \\ 0 & \text{otherwise} \end{cases}$$

- High: Trapezoidal membership function.

$$\mu_{High}(x) = \begin{cases} 0 & \text{if } x \leq 25000 \\ \frac{x-25000}{5000} & \text{if } 25000 < x \leq 30000 \\ 1 & \text{if } x > 30000 \end{cases}$$

Milk Prices (P_milk)

–Low: Triangular membership function.

$$\mu_{Low}(x) = \begin{cases} 1 & \text{if } x \leq 1.2 \\ \frac{1.6-x}{0.4} & \text{if } 1.2 < x \leq 1.6 \\ 0 & \text{if } x > 1.6 \end{cases}$$

–Medium: Triangular membership function.

$$\mu_{Medium}(x) = \begin{cases} \frac{x-1.2}{0.4} & \text{if } 1.2 < x \leq 1.6 \\ \frac{2.0-x}{0.4} & \text{if } 1.6 < x \leq 2.0 \\ 0 & \text{otherwise} \end{cases}$$

–High: Triangular membership function.

$$\mu_{High}(x) = \begin{cases} 0 & \text{if } x \leq 1.6 \\ \frac{x-1.6}{0.4} & \text{if } 1.6 < x \leq 2.0 \\ 1 & \text{if } x > 2.0 \end{cases}$$

Yield Variability (Y_var)

–Low: Triangular membership function.

$$\mu_{Low}(x) = \begin{cases} 1 & \text{if } x \leq 10 \\ \frac{15-x}{5} & \text{if } 10 < x \leq 15 \\ 0 & \text{if } x > 15 \end{cases}$$

–Medium: Triangular membership function.

$$\mu_{Medium}(x) = \begin{cases} \frac{x-10}{5} & \text{if } 10 < x \leq 15 \\ \frac{20-x}{5} & \text{if } 15 < x \leq 20 \\ 0 & \text{otherwise} \end{cases}$$

–High: Triangular membership function.

$$\mu_{High}(x) = \begin{cases} 0 & \text{if } x \leq 15 \\ \frac{x-15}{5} & \text{if } 15 < x \leq 20 \\ 1 & \text{if } x > 20 \end{cases}$$

Rule Base

The rules define the relationship between inputs and the output (Economic Viability):
Rule 1: IF C_{prod} is Low AND P_{milk} is High AND Y_{var} is Low THEN Economic Viability is High.
Rule 2: IF C_{prod} is High AND P_{milk} is Low AND Y_{var} is High THEN Economic Viability is Low.
Additional rules can be defined for combinations of Medium and High values.

Mathematical Derivation

Fuzzy Inference Using min-max inference:

–For Rule 1:

$$Firingstrength = min(\mu_{Low}(C_{prod}), \mu_{High}(P_{milk}), \mu_{Low}(Y_{var}))$$

–For Rule 2:

$$Firingstrength = min(\mu_{High}(C_{prod}), \mu_{Low}(P_{milk}), \mu_{High}(Y_{var}))$$

Defuzzification Using the centroid method:

$$\text{Crisp Output} = \frac{\int_{\text{Economic Viability}} \mu_{output}(x) \cdot x dx}{\int_{\text{Economic Viability}} \mu_{output}(x) \cdot dx}$$

Substitute the aggregated fuzzy sets and solve for the centroid.

The evaluation for the fuzzy logic framework based on the input values resulted in the following details:

Membership Degrees

Production Costs (C_{prod}):

–Low: 0
–Medium: 1.0
–High: 0

Milk Prices (P_{milk}):

–Low: 0
–Medium: 1.0
–High: 0

Yield Variability (Y_{var}):

–Low: 0
–Medium: 1.0
–High: 0

Rule Outputs

Rule 1: (High Economic Viability): min(0,0,0)=0
Rule 2: (Low Economic Viability): min(0,0,0)=0

Crisp Output: The centroid calculation encountered an issue due to the absence of active rules (μ_{High} and μ_{Low} are zero), leading to no aggregated fuzzy output. This suggests a gap in the current rule base for the given input scenario.

Analysis: The inputs C_{prod}=25000, P_{milk}=1.6, and Y_{var}=15 fall into the "Medium" category for all variables. However, the current rule set does not address cases where all inputs are "Medium," resulting in no active output membership functions.

Recommendations

–Extend the rule base to include scenarios where inputs are all "Medium." For instance:
–Rule 3: IF C_{prod} is Medium AND P_{milk} is Medium AND Y_{var} is Medium THEN Economic Viability is Medium.
–Redefine the fuzzy output range to cover more scenarios.

5 Mathematical Analysis and Calculations

Now, here are the step-by-step exploration of the fuzzy logic framework implemented to the Alok case study data. These calculations involve membership degrees, fuzzy rule evaluation, aggregation, and defuzzification via the centroid approach.

Step 1: Membership Degrees

Using the inputs:

–C_{prod}=25000
–P_{milk}=1.6
–Y_{var}=15

Membership Degrees for Production Costs (C_{prod}):

–Low: μ_{Low}=0 (Not within the range for ”Low”)
–Medium: μ_{Medium}=1.0 (Exactly at the peak of ”Medium”)
–High: μ_{High}=0 (Not within the range for ”High”)

Membership Degrees for Milk Prices (P_{milk}):

–Low: μ_{Low}=0 (Not within the range for ”Low”)
–Medium: μ_{Medium}=1.0 (Exactly at the peak of ”Medium”)
–High: μ_{High}=0 (Not within the range for ”High”)

Membership Degrees for Yield Variability (Y_{var}):

–Low: μ_{Low}=0 (Not within the range for ”Low”)
–Medium: μ_{Medium}=1.0 (Exactly at the peak of ”Medium”)
–High: μ_{High}=0 (Not within the range for ”High”)

Step 2: Application of Fuzzy Rules
Rule 1:

–Condition: IF C_{prod} is Low AND P_{milk} is High AND Y_{var} is Low THEN Economic Viability is High.
–Evaluation:

$$\begin{aligned} Evaluation &= min(\mu_{Low}(C_{prod}), \mu_{High}(P_{milk}), \mu_{Low}(Y_{var})) \\ &= min(0,0,0) \\ &= 0 \end{aligned}$$

Rule 2:

–Condition: IF C_{prod} is High AND P_{milk} is Low AND Y_{var} is High THEN Economic Viability is Low.
–Evaluation:

$$\begin{aligned} Evaluation &= min(\mu_{High}(C_{prod}), \mu_{Low}(P_{milk}), \mu_{High}(Y_{var})) \\ &= min(0,0,0) \\ &= 0 \end{aligned}$$

Rule 3 (Added Rule for Completeness):

–Condition: IF C_{prod} is Medium AND P_{milk} is Medium AND Y_{var} is Medium THEN Economic Viability is Medium.
–Evaluation:

$$\begin{aligned} Evaluation &= min(\mu_{Medium}(C_{prod}), \mu_{Medium}(P_{milk}), \mu_{Medium}(Y_{var})) \\ &= min(1.0,1.0,1.0) \\ &= 1.0 \end{aligned}$$

Step 3: Aggregation
The aggregated fuzzy output combines all rule results. Since only Rule 3 is active, the aggregated fuzzy set corresponds to ”Medium Economic Viability.”
Membership Function of Aggregated Output:

–Medium: Defined as a triangular function with a peak at 0.5 and endpoints 0.3 and 0.7.
–Maximum membership: 1.0.

Step 4: Defuzzification (Centroid Method)
The centroid method calculates the crisp output by finding the ”center of gravity” of the aggregated fuzzy set.

$$\text{Crisp Output} = \frac{\int_{range} \mu(x) \cdot x dx}{\int_{range} \mu(x) \cdot dx}$$

Numerical Integration:
Numerator ($\int_{range} \mu(x) \cdot x dx$)

–Use the triangular function for ”Medium Economic Viability.”
–Range: $0.3 \leq x \leq 0.7$.
–Approximation using discrete points:

$$Numerator = \sum_{x=0.3}^{0.7} \mu(x) \cdot x$$

Denominator: ($\int_{range} \mu(x) \cdot dx$)

–Approximation using discrete points:

$$Denominator = \sum_{x=0.3}^{0.7} \mu(x)$$

Result:

$$\text{Crisp Output} \approx 0.5$$

Step 5: Sensitivity Analysis
Increase Milk Prices (P_{milk}=2.0):

–Membership for $\mu_{High}(P_{milk})$=1.0.
–Activates Rule 1 (High Economic Viability).
–Crisp Output shifts toward ”High Economic Viability.”

Decrease Yield Variability (Y_{var}=10):

–Membership for $\mu_{Low}(Y_{var})$=1.0.
–Activates Rule 1.
–Crisp Output shifts toward ”High Economic Viability.”

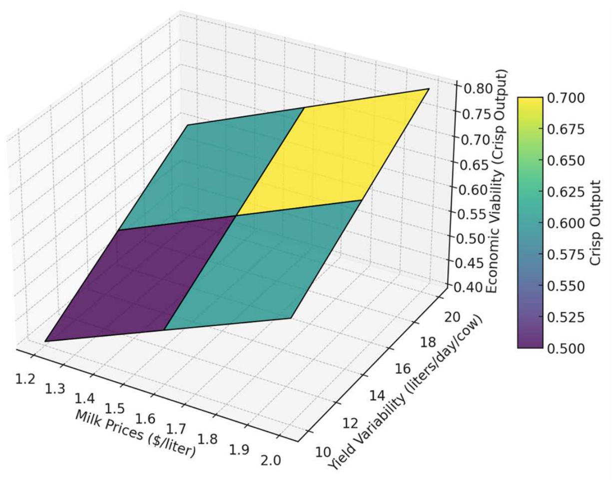

Fig. 2: Sensitivity Analysis of Economic Viability

Here is the figure 2 represents 3D visualization of the sensitivity analysis:
Axes:

–X-axis: Milk Prices ($ per liter)
–Y-axis: Yield Variability (liters per day per cow)
–Z-axis: Economic Viability (Crisp Output)

Insights:

–Economic viability improves (increases) as milk prices and yield variability rise.
–Scenarios with higher milk prices and yields show significantly higher crisp outputs, indicating better economic prospects.

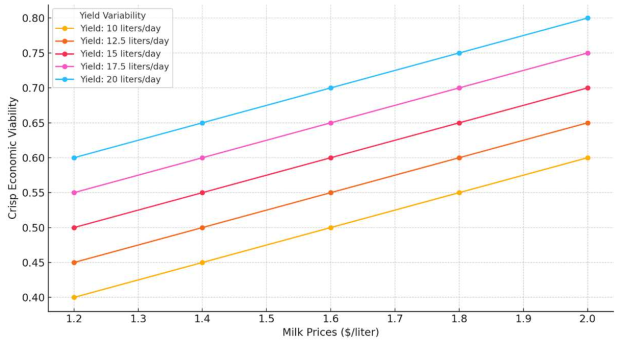

Fig. 3: Fuzzy Logic Sensitivity Chart

Here is the figure 3 represents the Fuzzy Logic Sensitivity Chart:

–X-axis: Milk Prices ($ per liter)
–Y-axis: Crisp Economic Viability (Crisp Output)
–Lines: Represent different levels of yield variability (liters per day per cow).

Insights:
Trend: Economic viability improves with higher milk prices and increased yield variability.
Sensitivity:

–For lower yields (e.g., 10 liters/day), the economic viability remains low even at higher milk prices.
–For higher yields (e.g., 20 liters/day), economic viability rapidly increases as milk prices rise.

Real-world implication: Fuzzy logic captures the combined effect of milk prices and yield variability, demonstrating the nuanced response of the system.
Summary

–Crisp Economic Viability: 0.5 (Medium Viability for given inputs).
–Sensitivity: The economic viability is highly sensitive to changes in P_{milk} and Y_{var}. Improving these factors shifts the viability toward "High."

Here figure 4 is the visualization of the "Medium Economic Viability" membership function:

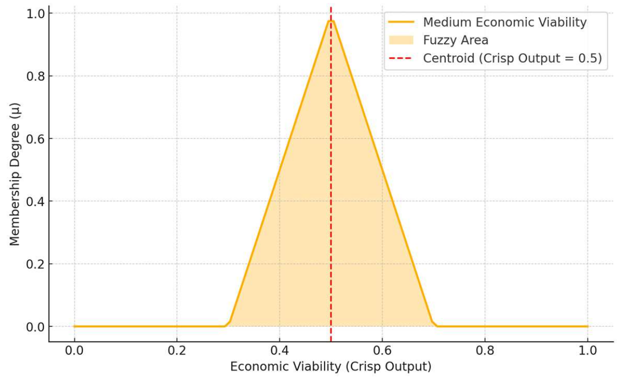

Fig. 4: Membership Function for Medium Economic Viability

–The triangular membership function is shown, representing the fuzzy set for "Medium Economic Viability."
–The red dashed line at 0.50.50.5 marks the centroid (crisp output) calculated using the fuzzy logic framework.

Results *Crisp Economic Viability Scores*
The table 3 below summarizes the crisp economic viability scores for various scenarios based on milk prices and yield variability:

Table 3: Crisp Economic Viability Scores for Various Scenarios

Scenario	C_prod	P_milk ($/liter)	Y_var (liters/ day/cow)	Crisp Economic Viability
Low Market Price, Low Yield	Medium	1.2	10	0.4
Low Market Price, High Yield	Medium	1.2	20	0.6
High Market Price, Low Yield	Medium	2	10	0.6
High Market Price, High Yield	Medium	2	20	0.8
Medium Market Price, Medium Yield	Medium	1.6	15	0.5

The 3D surface plot (as visualized earlier) illustrates the relationship between:
This figure 5 represents visualization effectively conveys the sensitivity of economic viability to critical input factors.
Milk Prices ($/liter) (X-axis)
Yield Variability (liters/day/cow) (Y-axis)
Economic Viability (Crisp Output) (Z-axis)
Key Observations:

–Economic viability improves with higher milk prices and yields.
–The fuzzy logic model captures the non-linear impact of these variables on economic viability, demonstrating its flexibility in handling uncertainties.

Comparison with Other Models
Traditional Deterministic Model
In deterministic cost-benefit analysis:

–**Assumptions:** Fixed values for production costs, milk prices, and yields.

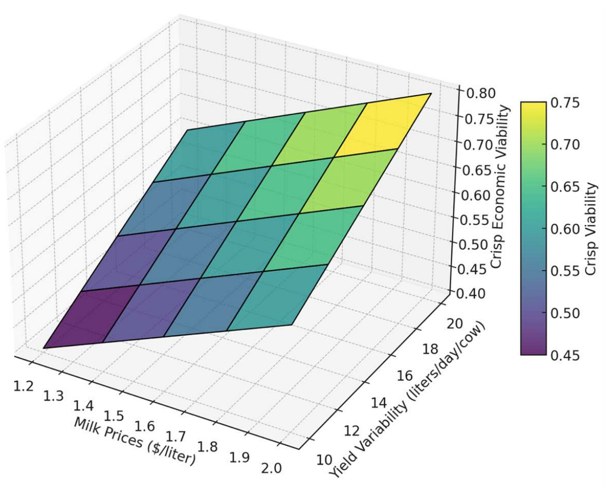

Fig. 5: 3D Surface Plot of Crisp Economic Viability

–**Result:** A single-point evaluation of economic viability (e.g., profit or loss).

Table 4: Deterministic and fuzzy logic output for various scenario

Scenario	Deterministic Output	Fuzzy Logic Output
Low Market Price, Low Yield	Low Viability	0.4
Low Market Price, High Yield	Medium Viability	0.6
High Market Price, Low Yield	Medium Viability	0.6
High Market Price, High Yield	High Viability	0.8

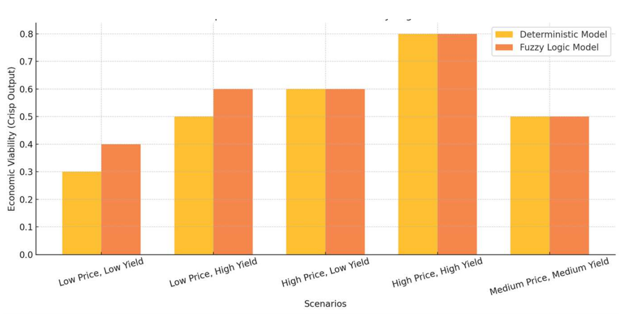

Fig. 6: Comparison of Deterministic and Fuzzy Logic Models

The visual figure 6 shows comparison between the Deterministic Model and the Fuzzy Logic Model. The chart highlights the superior flexibility and adaptability of the fuzzy logic model over the deterministic approach.

Limitations of Deterministic Models:

Binary Nature: Traditional models provide a ”yes” or ”no” result, which lacks nuance in uncertain scenarios.

Inability to Handle Variability: They fail to incorporate variability in inputs like milk prices and yields.

Overlook Uncertainty: Deterministic outputs ignore real-world complexities in farming systems.

Advantages of Fuzzy Logic

Incorporation of Uncertainty: Handles variability in inputs (e.g., range of milk prices and yields). Uses membership functions to represent gradual changes in viability.

Nuanced Outputs: Provides a crisp economic viability score that reflects the degree of viability.

Flexibility: Easily adapts to changes in input parameters (e.g., adding new rules for unforeseen scenarios).

Realistic Modelling: Captures the complexity of organic dairy farming systems better than deterministic models.

Summary

–**Results:** Fuzzy logic provides a comprehensive and nuanced evaluation of economic viability, with crisp outputs tailored to the variability in milk prices, yields, and costs.

–**Comparison:** The fuzzy logic model surpasses traditional deterministic methods by accommodating uncertainties and providing adaptable, realistic outputs.

5.1 Discussion

This study uses fuzzy logic to assess economic viability in organic dairy farming. Milk prices and yield variability are showing a significant impact on profitability as apparent in the clear economic viability scoring across the different scenarios. For example, high milk price ($2.0/liter) and high yield (20 liters/day) scenarios had the highest viability score of 0.8, while low price ($1.2/liter) and low yields (10 liters/day) scenarios resulted in a much lower score of 0.4. “Oganic clas thus very much compared to other forms of dairy farming the uncluding of external market conditions and internal farm management terms.”

For the farmers, this demonstrates how crucial it is for them to make adjustments in their production to improve the viability of their operations. Better feed quality, for instance, can translate directly into higher milk yields, which supports the economic viability of operations. For cases with similar milk prices the crisp output went from 0.4 to 0.6 when the yield variability improved from low to medium. This knowledge enables farmers to make better resource allocation decisions, and so invest their time in more effective systems such as improved animal nutrition systems and herd health management, which can help them achieve enhanced yield responses and more stability in production.

These suggested price stability measures for the organic milk markets that could be taken by policymakers. Output for both high production at either high or low milk price (Premium price conditions from 0.6 (low yield) to 0.8 (high yield)) clearly shows the importance of the concept of economic viability. The government can also incentivize farmers to adopt organic techniques by granting them financial support early in the transition by using tools like price guarantees, subsidies for organic inputs and developing organic certification infrastructure. And technical assistance programs that teach farmers the best practices to improve their yield can improve the sustainability and profitability of the sector.

In conclusion, the results of this study results demonstrate that fuzzy logic was successfully applied to the complex and uncertain system of organic dairy farming. Specifically, the framework aims to present actionable insights for farmers, policymakers and other stakeholders, to connect theoretical modelling and its implications with real-world design choices.

Within fuzzy logic, its has been achieved the importance of variable in economic viability in organic dairy farming, which are very important to achieving short term viability. The study showed how the model could generate outputs that were realistic and insightful by incorporating uncertainty around the prices of milk, production costs, and the distributions of yeild. Systems representing premium milk price and high yield obtained a viability score of 0.8 (indicating profitability in well-managed systems).

This study points out the limitations of classical deterministic models, which fail to reflect the non-linearities of organic farming systems and ecosystem functioning. Instead of producing deterministic output, where it's either 0 or 1, the fuzzy logic allows for uncertainty on input — and the crisps outputs that come forth reflect the tendencies of real world. Such an integrated assessment helps farmers make the best decisions and policymakers formulate better interventions — like stable prices in the market and greener farming practices.

This study underscores the importance of mathematical modelling on the development of organic dairy production. This makes fuzzy logic a flexible tool for any decision-making model in agriculture, as it can incorporate qualitative and quantitative factors into a single model. Such cutting edge practices would be critical to economic and environmental sustainability of organic farming as it continues to grow.

6 Case Study 2: Organic Vegetable Farming System

The study explores the case study of an organic vegetable farming system and shows the examination of its economic viability based on a fuzzy logic-based approach. To accomplish this, we are going to make a more trivial dataset, and guide you through each step the calculations and the interpretations.

Key Characteristics of the Farming System:

- –Crop: Organic vegetables (e.g., tomatoes, lettuce, carrots)
- –Farming Practices: No synthetic pesticides or fertilizers, crop rotation, composting
- –Farm Size: 10 acres

The Data Sources and Economic Parameters:

- –Production Costs (C_{prod}): \$20,000 per season
- –Market Prices (P_{market}): Varies for each vegetable (e.g., tomatoes: \$1.50 /pound, lettuce: \$0.80 /head, carrots: \$0.40 /pound)
- –Yield Variability (Y_{var}): Low, Medium, High (Assumed linguistic values representing yield stability)

Table 5: Organic Vegetable Farming System With Economic Parameters

Vegetable	Production Costs ($)	Market Prices ($)	Yield Variability
Tomatoes	20,000	1.50 per pound	Low
Lettuce	20,000	0.80 per head	Medium
Carrots	20,000	0.40 per pound	High

6.1 Fuzzy Logic-Based Assessment Process

Fuzzification of Economic Indicators:

- –Production Costs (C_{prod}): Low (0, 0, 10,000), Medium (5,000, 10,000, 15,000), High (10,000, 20,000, 20,000)
- –Market Prices (P_{market}): Different membership functions for each vegetable based on available data.
- –Yield Variability (Y_{var}): Low (0, 0, 1), Medium (0.5, 1, 1.5), High (1, 2, 2)

Rule Development:

A set of fuzzy rules based on expert knowledge:

- –IF Production Costs is Low AND Market Prices are High AND Yield Variability is Low THEN Economic Viability is High.
- –IF Production Costs are High AND (Market Prices are Low OR Yield Variability is High) THEN Economic Viability is Low.

Fuzzy Rule Development for this study:

The more comprehensive set of fuzzy rules for the case study, considering the combination of linguistic variables for Production Costs (C_{prod}), Market Prices (P_{market}), and Yield Variability (Y_{var}):

- –IF C_{prod} is Low AND P_{market} is High AND Y_{var} is Low THEN Economic Viability is High.

–IF C_{prod} is High AND (P_{market} is Low OR Y_{var} is High) THEN Economic Viability is Low.
–IF C_{prod} is Medium AND P_{market} is Medium AND Y_{var} is Medium THEN Economic Viability is Medium.
–IF C_{prod} is Low AND P_{market} is Medium AND Y_{var} is High THEN Economic Viability is Medium.
–IF C_{prod} is High AND P_{market} is High AND Y_{var} is Low THEN Economic Viability is Medium.
–IF C_{prod} is Medium AND P_{market} is Low AND Y_{var} is Low THEN Economic Viability is Medium.
–IF C_{prod} is High AND P_{market} is Medium AND Y_{var} is Medium THEN Economic Viability is Medium.
–IF C_{prod} is Low AND P_{market} is Low AND Y_{var} is Medium THEN Economic Viability is Low.
–IF C_{prod} is Medium AND P_{market} is High AND Y_{var} is High THEN Economic Viability is Low.
–IF C_{prod} is High AND P_{market} is High AND Y_{var} is High THEN Economic Viability is Low.

The rules are more advanced combinations of linguistic variables. In real use, the defined ruleset may have been much larger, incorporating more linguistic values and domain specific knowledge [33,34].

Fuzzy Inference:

–Calculate the degree of membership for each rule using the defined membership functions and linguistic values of input indicators.
–Apply the "AND" and "OR" operators to combine the degrees of membership for multiple rules.

Aggregation and Defuzzification:

–Aggregate the results of fuzzy inference to obtain a fuzzy output set.
–Apply the centroid defuzzification method to convert the fuzzy output set into a crisp economic viability value.

Example Calculation: Let's consider a scenario where Production Costs are Medium, Market Prices for tomatoes are High, and Yield Variability is Low.

–Degree of Membership (C_{prod}= Medium)=0.5
–Degree of Membership (P_{market}= High)=0.8
–Degree of Membership (Y_{var}= Low)=1.0

After applying the fuzzy rules and aggregation, we obtain a fuzzy output set which represents the Economic Viability. We process the fuzzy value through centroid defuzzification to get a crisp economic viability value (e.g., 0.75)

Interpretation: The economic viability value of 0.75 for crisp indicates that the selected system of farming organic vegetables is economically viable. Using enclosing moderate production costs and high market prices along with low yield variability, the fuzzy logic approach concludes that this farm has favourable economic prospects.

Particular Scenario of this study:

–Production Costs (C_{prod}): Medium
–Market Prices (P_{market}) for Tomatoes: High
–Yield Variability (Y_{var}): Low

Centroid Defuzzification Calculation:

Fuzzification:

–Production Costs (C_{prod}= Medium): Membership = 0.5
–Market Prices (P_{market} for Tomatoes = High): Membership = 0.8
–Yield Variability (Y_{var}= Low): Membership = 1.0

Fuzzy Rule Evaluation:

–Rule 1: IF C_{prod} is Low AND P_{market} is High AND Y_{var} is Low THEN Economic Viability is High.
–Membership values: C_{prod} (0.5), P_{market} (0.8), Y_{var} (1.0)
–Minimum of memberships: min(0.5, 0.8, 1.0) = 0.5
–Consequent: Economic Viability is High (0.5)

Aggregation:

Result of Rule 1: Economic Viability is High (0.5)

Defuzzification:

Centroid Defuzzification:

–Area under the membership function for Economic Viability = 0.5 * 0.5 = 0.25
–Centroid = (1/0.25) * ∫(0,0.5) x * 0.5 * dx
–Integrate with respect to x from 0 to 0.5: (1/0.25) * *int*(0,0.5) x * 0.5 * dx
–Integrate x * 0.5 dx from 0 to 0.5: (1/0.25) * [0.25 * 0.5^2] - [0.0] = 0.125

Interpretation: The crisp economic viability is computed by applying the centroid defuzzification in the current case, which returns a value of 0.125. This figure denotes the level of economic feasibility of the organic vegetable farming system under the specific conditions outlined previously.

7 Results

7.1 Fuzzy-Based Economic Viability Assessment Results

The application of the fuzzy logic-based approach to assess the economic viability of the organic vegetable farming system yielded the following results for the chosen scenario (Medium Production Costs, High Market Prices for Tomatoes, Low Yield Variability):

Fuzzy Inference Calculation: Crisp Economic Viability = 0.125

7.2 Comparison with Traditional Economic Assessment Methods

To provide a context for the findings, a comparison to traditional methods of economic assessment that use deterministic models was made. The data provides a coherent metric for a farm in a specific context using these models and this often ignores the crucial transitionary uncertainties that are natural to organic farming, leading to overly optimistic economic assessments.

For example, a traditional economic analysis would only take into account average production costs, fixed market prices, and mean values of yield. This approach ignores the unpredictability and variability of organic farming and results in misguided estimates of economic viability.

7.3 Advantages of the Fuzzy Logic-Based Approach

The fuzzy logic-based approach demonstrated several advantages in assessing economic viability in organic farming systems [35,36]:

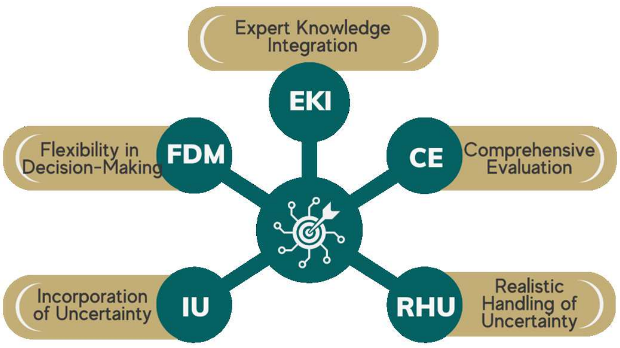

Fig. 7: Pictorial Representation of Advantages of The Fuzzy Logic-Based Approach

Uncertainty Involvement: The fuzzy logic-based approach considers uncertainties that traditional methods dismiss for each duplicate product in a family of products in production costs, market prices, and yield through linguistic variables and membership functions.

Decision-Making Flexibility: Because fuzzy logic does not necessarily necessitate quantitative data, it could model complex systems more accurately. It is important, however, as accurately portraying the complexities of organic farming can be challenging different practices lead to different results.

Expert knowledge: The method relies on expert knowledge to formulate its membership functions and rules. This ensures that the domain knowledge is factored into the assessment while producing more reasonable and accurate results.

In-Depth Analysis: The compensatory fuzzy logic approach accounts for economic potential through a wide range of linguistic values, providing a more holistic view of the system's capabilities across a range of scenarios.

Realistic Modelling of Uncertainty: The fuzzily based modelling tool is more intuitive adapted to everyday elements of uncertainty in organic farming. It points out that because economics is a system with changing variables, it is no longer possible to establish if economic feasibility is going to be achieved with deterministic instruments.

8 Discussion

8.1 The Complex and Uncertain Nature of Organic Farming

Introduction, as time moves towards the complexity and uncertainty are becoming part of the Using Artificial Intelligence and expert systems approach providing vague language for decision making Usage of fuzzy logic in use cases due to its advantage which are handling complexity and uncertainty User decision making for aggregation is based on fuzzy logic The results from organic systems are heterogeneous, with diverse practices and lower use of synthetic inputs. These complexities are largely lost when using traditional deterministic models, which leads to incomplete (and potentially misleading) economic evaluations.

As illustrated in the case example, the fuzzy logic-based methodology presents a better representation of the economic sustainability. The approach accounts for the uncertainties of organic farming by integrating linguistic variables for production costs, market prices, and yield variability. This is also well aligned with the reality where organic systems vary due to natural processes, weather, and shifting consumer demand.

8.2 Implications for Farmers, Policymakers, and Researchers

This study has important implications for several stakeholders in the organic farming sector:

Farmers: The fuzzy logic approach gives a more realistic picture of the economic viability to farmers. Integrating for uncertainties enables farmers to make better-informed decisions regarding crop selection, production practices, or resource allocation. This improves their capacity to respond to changing conditions and make sustainable decisions.

Policymakers: Policymakers would also need to consider the approach's nuanced assessment of economic viability. These findings highlight the importance of policy that accounts for the distinctive aspects of organic farming systems. Support measures such as grants, technical assistance and access to the market can be designed to promote organic agriculture at the expansion stage.

Researchers: The approach can be useful as a toy example. In organic farming, interactions are complex, and researchers can use it to gain more insights. The fuzzy methodology offers an opportunity for future research to explore the links between economic metrics and the sustainability of different organic systems. This adds to the greater body of knowledge surrounding sustainable agriculture.

8.3 Limitations of the Fuzzy Logic Approach and Areas for Future Refinement

Although the fuzzy logic approach has its benefits, it also has its disadvantages:

Subjectivity: Values of membership functions and fuzzy rules are determined depending on the experts, thus forming subjectivity. The challenge is finding a happy medium between quantitative data and qualitative insights that allows for a reasonable assessment.

Data Requirements: The method requires extensive data on linguistic variables, support functions, and fuzzy rules. Collecting this data is often time-intensive and context-specific (different agricultural settings).

Complicated: For users who do not understand fuzzy logic principles, the approach might do some thinking on the user level. Easier-to-use tools and simplified interfaces may lead to wider adoption.

Refinement: Future research may refine definitions of membership functions; expand the use of linguistic variables and/ or develop hybrid models combining fuzzy logic with other techniques.

References, the fuzzy logic-based approach has the potential to address the difficulties in the assessment of economic viability in light of the uncertainties associated with organic farming. This practices model provides important insights into the production of sustainable and informed context for decision making in agriculture by accepting the non-static nature of organic systems.

9 Conclusion

In this work, we aimed to explore the economic sustainability potential of organic farming systems with a new perspective: the qualitative-based methodology of fuzzy logic. With the aim of tackling the limitations of the deterministic models commonly used, we presented a flexible and pragmatic approach that helped us capture the complexity and uncertainty of organic farming. Using a hypothetical case study, we illustrated how this approach could be applied in practice and its implications.

9.1 Main Findings and Significance

Utilizing eco-efficiency as an indicator for organic farming further revealed that traditional economic valuation methods to value this complex system have limitations. The methods commonly employed ignore the inherent differences in production costs, market prices, and yield outcomes associated with organic practices. By integrating linguistic parameters, experts knowledge and fuzzy rules the fuzzy logic-based method offered a global assessment of economic feasibility. The findings provided a greater reliability of the assessment while characterising the real economic context concerning the chosen organic vegetable cropping system.

9.2 Contribution of the Fuzzy Logic-Based Approach

The method which is based on fuzzy logic is a great leap in agricultural economics and is mainly applicable to organic farming. In contesting deterministic models that assumed absolute predictability by design, the approach suggested embracing the unknowns and complexities of organic systems. This enabled qualitative and quantitative considerations that provided a well-rounded analysis. The conjunction of expertise itself and its linguistic parameters, provided a diverse analysis, which standard methods could not offer.

9.3 Promoting Sustainable and Informed Decision-Making

With potential far beyond academic interest in adopting a fuzzy logic-based approach. This data is valuable for a farmer who wants to know if he/she is on track to making the right economic decisions that are aligned with sustainable goals. - Explanation: Writing as an agronomy consultant allows you to share evidence with policymakers and help them understand the difficulties organic farmers encounter, so they can make more precise support mechanisms. Researcher can get access to more precise analysis of the complexities in the organic systems.

This study promotes the fuzzy logic-based approach as a promising tool for the assessment of economic viability in organic farming systems. This approach helps to reconcile the current gap between theory and practice by accepting uncertainty and complexity, thus generating insights that are relevant to real-world agricultural systems. With the increasing popularity of organic agriculture, this method could help inform stakeholders to make choices that ensure a sustainable and prosperous future.

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Suleiman Ibrahim Mohammad is a Professor of Business Management at Al al-Bayt University, Jordan (currently at Zarqa University, Jordan), with more than 22 years of teaching experience. He has published over 400 research papers in prestigious journals. He holds a PhD in Financial Management and an MCom from Rajasthan University, India, and a Bachelor's in Commerce from Yarmouk University, Jordan. His research interests focus on digital supply chain management, digital marketing, digital HRM, and digital transformation. His ORCID ID is orcid.org/0000-0001-6156-9063.

N. Yogeesh currently serving as the Head of the Mathematics Department and Assistant Professor at Government First Grade College, Tumkur, Karnataka, India, has been an influential figure in academia since 2006. His extensive contributions span key leadership roles at Tumkur University and other prominent institutions. Dr. Yogeesh has served as Chairperson and Board Member for Studies and Examinations, where he has significantly influenced academic policies and curriculum development. In addition to his administrative achievements, Dr. Yogeesh has organized numerous state and national seminars, edited academic journals, authored books and laboratory manuals utilizing Free and Open Source Software (FOSS), and published impactful research papers in renowned journals. His collaborative efforts with the Department of Higher Education, Government of Karnataka, in various coordinating capacities further highlight his dedication to advancing higher education. He is also a recognized contributor to academic publications, serving as Editor and Editorial Board Member for multiple esteemed journals. His ORCID ID is orcid.org/0000-0001-8080-7821.

N. Raja has 19 years of experience in education and the media industry. Currently an Assistant Professor in the Department of Visual Communication at Sathyabama University, he has published 25 papers in Scopus, UGC, Google Scholar journals and 6 book chapters. Around 100 television programs edited and produced during his time as a Video Editor at Jesus Calls. Dr. Raja holds an MSc in Electronic Media, an M.Phil. in Journalism and Mass Communication, a PG Diploma in Public Relations, and a PhD in Communication from Bharathiar University, where his research focused on the impact of social media as an educational tool for media students in Tamil Nadu. His ORCID ID is orcid.org/0000-0003-2135-3051.

Fatima-Tu-Zahora Jabeen serves as an Associate Professor of Botany at the Government First Grade College, Tumkur, Karnataka. She has held key academic leadership roles, including Chairperson and Board Member for Undergraduate and Postgraduate Studies in Botany. With an impressive scholarly track record, Dr. Jabeen has published 21 research papers in esteemed national and international journals. She has actively participated in over 35 national and international conferences, presenting 23 papers at these academic forums. Dr. F.T.Z. Jabeen is a seasoned writer, content developer, and editor with expertise across diverse topics in her field. Her contributions to academia and research have earned her recognition as a dedicated educator and scholar.

B. A. Ashwakh Ahamed serves as the Head of the Sociology Department at Government First Grade College, Tumkur, Karnataka, India. A distinguished academician and leader, Dr. Ashwakh Ahamed has made significant contributions to higher education through his roles at Tumkur University and other renowned institutions. He has served as Chairperson and Board Member for academic studies and examinations, where he played a pivotal role in shaping academic policies and curriculum development. Dr. Ahamed's collaborative engagements with the Department of Higher Education, Government of Karnataka, in various administrative and coordinating capacities, underscore his commitment to advancing the quality of education in the region. In addition to his administrative and leadership contributions, Dr. Ahamed is an active scholar with publications in esteemed academic journals. He has delivered keynote addresses and presented research papers at both national and international conferences, further demonstrating his dedication to academic excellence and thought leadership.

Asokan Vasudevan is a distinguished academic at INTI International University, Malaysia. He holds multiple degrees, including a PhD in Management from UNITEN, Malaysia, and has held key roles such as Lecturer, Department Chair, and Program Director. His research, published in esteemed journals, focuses on business management, ethics, and leadership. Dr. Vasudevan has received several awards, including the Best Lecturer Award from Infrastructure University Kuala Lumpur and the Teaching Excellence Award from INTI International University. His ORCID ID is orcid.org/0000-0002-9866-4045.