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Modelling of Barriers to Productivity: A Hybrid TISM Approach

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Abstract

The purpose of this study is to build a structural relationship model based on Total Interpretive Structural Modelling (TISM) and Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) technique for analysis and investigating the barriers responsible for decline in saffron productivity. Nevertheless, saffron harvesting provides livelihood to the farmers but due to the limited geographical scope and climate sensitive cultivation, its productivity has been declining, creating imbalance in saffron supply chain. Many studies have been carried out using hybrid TISM-DEMATEL techniques in many other dimensions, but there is scarcity of knowledge on the contextual relationships among saffron productivity barriers. Nine potential barriers to productivity of saffron were identified. The research study identifies a Lack of scientific awareness, Technical inefficiency, and Climate change as the most significant drivers influencing saffron productivity. Addressing these barriers is crucial for improving the imbalance in the saffron supply chain.

Keywords: *Saffron Productivity, TISM, FDEMATEL, Fuzzy MICMAC, Fuzzy set, Decision Making*

1. Introduction

Saffron (Crocus sativus L.) has been considered the highest price spice globally, famous for its specific aroma, color and flavor characteristics [14]. It is an autumn-flowing crop cultivated on limited geographical area with arid climate. The dried stigma of saffron has been used in pharmacology, biotechnology, food, perfumery, dye industries as organic constituent Giupponi et al., [13]. Saffron, a vital crop with applications across various industries, has garnered attention from scientists and academia for enhancing its productivity. Many research studies have been carried out for enhancing saffron productivity. One such study Sharma et al., [34], emphasises on sustainable application of fungicides for overcoming corm rot, thus increasing saffron yield. Saffron cultivation traditionally takes place in an open environment, where uncontrollable agronomic factors result in undesirably low productivity. An experimental study (Khan et

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al.,[18] proposed saffron farming in a controlled environment to enhance productivity. The authors recommended leveraging Artificial Intelligence (AI) and IoT techniques to enhance saffron growth. These technologies help overcome the barriers to saffron productivity, including rapid climate change, light intensity, pH levels, soil moisture, salinity, and improper cultivation techniques. Given the significance of enhancing saffron productivity by identifying various barriers and implementing solutions, numerous studies have been conducted, including Aymani et al., [4]. Understanding the interactions between the barriers helps identify the causes of under productivity and allows for strategic solutions to improve saffron productivity. To perform a precise and comprehensive analysis of the interactions between factors, Mohamadabadi et.al. [1] employed (total interpretive structural modelling) TISM and (Cross Impact Multiplication Matrix) MICMAC techniques to examine the factors influencing the online customer experience of food delivery services. TISM translates systems in to the hierarchical model explaining its logical interrelationship along with direct and indirect influence of each link (Mathivathanan et al., [21].

Similarly, Hasanuzzaman et al., [16] employed a hybrid approach, integrating TISM and the Decision-Making Trial and Evaluation Laboratory (DEMATEL), to investigate the contextual relationships among critical factors and assess the intensity of their causal relationships in India‘s coal mine industry. Aditi et al., [2] employed the hybrid TISM-DEMATEL approach to examine the barriers to sustainable supplier collaboration in the Indian home appliance manufacturing industry, providing a detailed explanation of each barrier to facilitate effective implementation of sustainable manufacturer-supplier collaboration. However, a significant research gap remains, as no studies have effectively analysed the contextual relationships among the identified barriers to productivity in saffron cultivation. Although previous studies have identified various barriers to saffron productivity, there is a lack of knowledge on interpreting these constructs and understanding their driving forces in enhancing saffron productivity. Therefore, exploring contextual relationships and developing a hierarchical structural model of saffron barriers can help managers, stake holders, and policy makers to identify the essential barriers and determine those of the highest importance for enhancing saffron productivity. Thus, it is imperative to understand the hierarchical relationship along with the cause and effect between the barriers to the saffron productivity to enable the stake holders to overcome these barriers.

An integrated methodology of TISM- FDEMATEL was used to model the barriers for evaluation of hierarchical relationship along with their cause-and-effect intensity under fuzzy state. Literature survey and expert opinion have been utilized to identify 9 potential barriers to the saffron productivity. Further the barriers were categorized under driving and dependence levels with the help of Fuzzy MICMAC, enabling stakeholders to devise strategies for overcoming the barriers to saffron productivity. The paper has four folded objectives:

- To identify the potential barriers to the saffron productivity.
- To model the identified barriers using TISM for establishing hierarchy interrelationships among them.
- To evaluate the intensity of cause–and-effect relationship between barriers under the reduced vagueness and subjective information on account of decision maker’s perceptions using FDEMATEL.
- To group the barriers under various categories while catering fuzziness on account of expert opinion using FMICMAC analysis.

The rest of the research paper is organised as: Section 2 presents literature review on barriers to saffron productivity; Section 3 offers methodology whereas section 4 demonstrates application of the proposed solution methodology. Section 5 presents results and discussions supported by theoretical contribution and stakeholder's implications. Section 7 provides conclusion, limitation and future scope of the research study.

2. Literature survey

The literature survey was carried out to explore the following perspectives: Section 2.1 presents an overview on various factors that hinders productivity of saffron, section 2.2 offers review on various multi criteria decision making methods used in the analysis of barriers to saffron productivity.

2.1. Barriers to saffron productivity

Saffron (Crocus sativus L.) is an autumn flowering crop, suitably grown in arid and semi-arid regions. The dried stigma of saffron exhibits medicinal properties due to the presence of crocin, crocetin, picrocrocin and safranal, which have been found to possess antioxidant and antiproliferative properties Vago et al., [38]. Saffron with such vital qualities have been used in neuroprotective therapy for treating neurodegenerative Etxebeste-Mitxeltorena et al., [9]. Due to the widespread utilization, there has been high demand of saffron. The shortage and the high demand of saffron in medical and allied fields, inspires the quantity and its quality to reach the desired performance Shajari et al., [33].

The saffron crop on account of its high global demand and consumption has a scope in upliftment of socioeconomic status of the growers despite many challenges to its productivity Falahat et al., [10] and Gupta et al., [15]. Saffron being a rain-fed crop, depends on the adequate quantity of water during pre-flowering season. Shortage of water during this period affects the productivity of saffron Razmavaran et al., [28]. However, a research study carried out by Ahmad et al., [3] revealed that small corm size was unsuitable for the sowing which recorded minimum saffron productivity. The research study showed that larger corm size resulted in maximum saffron productivity.

Saffron is majorly cultivated and harvested manually right from corm sowing, harvesting, separating stigma from tepals and stamen till drying of stigma Gresta et al., [14] The non- intervention of mechanization in saffron management mainly attributed to the higher price of saffron. The higher market price of saffron due to high labor cost rendered saffron a loss-making business Molina et al., [23]. As a consequence of non-mechanization and high labor cost scenario, the saffron fields have been diversified to other non-saffron crops. The land conversions for non-saffron crops results in deterioration of microbiome, thus affects soil health Mir et al., [22]. With the help of proper nutrition management, the crop productivity regains which also improves the quality of the soil Sarfraz et al., [31]. Irrespective of integrated nutrition management, Fusarium oxysporumthe has been a devastating cause of corm rot in saffron crop, offers barrier to its productivity. One of the major challenges faced by farmers on account of productivity is the disease management of saffron crop. Corm rot has been highlighted as a major setback for enhancing saffron productivity Gupta et al., [15]. Useful Information to this context has been extended by the authors in this research study. Thus, by adopting proper disease management practices, saffron productivity increases Mansotra et al., [20] and Luo et al., [19]. The government and the stake holders have been playing pivotal role towards increase in saffron productivity, although many factors like climate change and reduced underground water tables impacted the saffron productivity. Although saffron crops can tolerate moderate fluctuations in temperature and water, global climate change has significantly reduced saffron yields by 35% over the past few decades, Sepaskhah and Yarami., [32]. El-Mahrouk et al., [8] studied may ways of enhancing saffron productivity. The authors used potted style of saffron harvesting using peatmoss and foam medium for higher saffron productivity. Despite various research work towards increasing the saffron productivity there remains, however, many challenges to the saffron productivity. One such resistance to the saffron productivity is offered by lack of technical inefficiency Pangave et al., [26]. The authors used smart technology in in tracking and managing saffron crop, enhancing the progress in saffron farming in controlled environment. However, Gandomzadeh et al., [12] stated that lack of scientific awareness of farmers in saffron post harvesting offers barriers to its productivity. The authors proposed different ways of optimizing saffron drying for enhancing its quality. The barriers to saffron productivity along with references have been mentioned in Table 1

Table 1. Barriers to saffron productivity and respective references.

S. No	Barrier	Reference
1	Climate change	Sepaskhah and Yarami., [32]
2	Shortage of rain water during pre-saffron flowering session	Razmavaran et al., [28]
3	Small size of saffron corm	Ahmad et al., [3]
4	Higher cost of production of saffron	Gresta et al., [14], Molina et al., [23]
5	Insufficient nutrition management	Sarfraz et al., [31]
6	Lack of disease management	Gupta et al., [15], Mansotra et al., [20], Luo et al., [19], Sharma et al., [34]
7	Lack of scientific awareness in saffron farming	Gandomzadeh et al., [12]
8	Technical inefficiency in saffron farming	Khan et al.,[18], Pangave et al., [26]
9	Reduced land for saffron cultivation	Mir et al., [22]

2.2. Multicriteria decision making (MCDM) methods used in barrier analysis

Saffron has been in great demand on account of its immense uses in human kind. Hence, it is imperative to understand barriers to saffron production. Multicriteria decision making (MCDM) tools have been used towards the effective solutions of such barriers. MCDM methods have always been a first choice for researchers when evaluating criteria for relative comparison, strength and priority.

Oubahman et al., [25] used a combined MCDM approach of Analytical hierarchy process (AHP) and preference ranking organisation method for enrichment evaluation (PROMETHEE) for a hybrid model for their cost and time effective qualities. Falahat et al., [10] classified climatic variables for the saffron productivity with the help of Arithmetic hierarchy process (AHP) in the regions of Azerbaijan. Khan and Khan., [17] integrated a hybrid approach of Decision-making Trial and Evaluation Laboratory (DEMATEL) and Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) under fuzzy state with ABC analysis in supplier selection problems.

To understand complex systems, the researchers build structural relationship models to represent them graphically. Ben et al., [6] proposed a study for implementation of industry 4.0 technologies, using a combination of Total Interpretive Structural Modeling (TISM) and Fuzzy Cross-impact matrix multiplication applied to classification (FMICMAC) techniques. The authors identified 10 variables offering barriers to the industry 4.0 technologies. Uninterrupted Supply chain is the backbone of all product/ service industries to remain competitive in the market. Interruptions bring disasters to businesses. Supply chain disaster management becomes an important tool to respond to disruptions. In order to understand the relationship between supply chain disaster management barriers, Sumrit and Jongprasittiphol., [37] applied Fuzzy Interpretive Structural Modeling along with MICMAC techniques for identifying the driving and dependence powers of barriers in Thai automotive sector. Similarly, Aditi et al., [2] used a hybrid technique of TISM-DEMATEL for identifying the relationship between the barriers in implementation of sustainable supplier collaboration (SSC) in manufacturing companies.

TISM finds useful implementations in other fields too. Sreenivasan and Suresh., [36] find TISM useful in financial resilience in startups, whereas integrated TISM was used in Agri food supply chains for dissemination of knowledge to other related stakeholders, Zhao et al.,[43]. Similarly, Yadav et al., [41] identified potential Blockchain adopter enablers in Agro supply chains in Indian context. The study explored the interrelationship between driver enablers with their influential powers to put them forward for policy makers and related government organisations.

Digitalization has enhanced the efficiency and quality of life across the world. It has changed manufacturing sector altogether, but there are challenges to adopt digitalization. K et al., [39] studied challenges to adopt digitalization in Industry 4.0 by applying TISM and MICMAC techniques.

Blockchain is immutable technology which is finding use in almost all the area. Of other many fields, hybrid TISM techniques are visible in latest known Blockchain technology. Benefits of blockchain technology has been wide and evident. The use of blockchain technology is visible in many important sectors. Vishwakarma et al., [40] studied challenges to adopt blockchain technology in Healthcare Sustainable Supply Chain using modified total interpretive structural modelling approach.

Prabhu and Srivastava, [27] tried to identify the structural interpretation between Transformational leadership traits of top management viza viz agility of supply chain in small and medium enterprises. According to the authors the commitment of top rank management towards company vision was the potential style of company top management who can drive the agility actions in of manufacturing supply chains.

The civil construction projects used to be delayed due to the reasons some of which are under management control and some outside their control. Since delay in construction attracts fine from the awarding agencies, there has been a need to identify the potential factors which leads to the delay in the construction projects. One such research work has been carried Saha et al., [30] where a combination of TISM and MICMAC techniques were employed for determining the delay factor in constructions projects. Towards adoption of sustainability, the building and construction industry encounters various barriers, which need MCDM tools for the effective implementation. Khan and Khan., [17] proposed Fuzzy Delphi and Fuzzy DEMATEL methods to identify sustainable supply chain enablers for the effective adoption of sustainability in construction industry.

The companies expand beyond the native boundaries by entering in to International joint ventures (IJV). To analyse the performance of IJV, Batra and Dhir [5] studied interrelationships among various inter-partner factors with the help of modified TISM. The authors have identified 12 factors of IJV performance where size asymmetry and commitment among other variables were potential factors towards IJV performance.

Supplier selection is always considered as an important operation in a supply chain. Selecting a non-suitable supplier have adverse effects on the organisation. Therefore, it becomes important to understand the various factors in supplier selection in organisations like startups particularly in pandemic periods. One such study has been carried out using TISM and MICMAC techniques Sreenivasan et al., [35].

Although various studies have been carried out using TISM in many other dimensions, but there is scarcity of knowledge on the contextual relationships among saffron productivity barriers. Furthermore, there is paucity of research literature on modelling of the driver barriers for managerial strategic decision-making process. Thus, there is need to identify and model driver barriers to saffron productivity. This study has been carried out which employs hybrid approach combining TISM and Fuzzy DEMATEL for analysing barriers to saffron productivity. The proposed solution enables the stake holders and the managers to take strategic actions towards overcoming the reduced productivity of saffron and hence help in balancing the supply chain of saffron. To the best of my knowledge, this research work has not been presented before and it is the first attempt towards offering the solution to the potential barriers to the saffron productivity.

3. Methodology

The diverse experiences and insights of experts can enhance research, enabling a more precise analysis of the problem and a deeper understanding of its various aspects. For this research study, a team of experts and stakeholders was established. The experts were agricultural scientists with more than ten years of experience in saffron cultivation. The stakeholders included saffron growers, the primary producers, and policymakers responsible for providing training, subsidies to support saffron farming. Initially, eight experts were invited for in-depth discussions on selecting barriers to saffron productivity. However, with three experts opting out, the final selection and comparison of barriers were conducted with the participation of five experts. Individual discussions were conducted with each expert to identify barriers to saffron productivity. The collected responses were analysed to pinpoint common barriers. These responses were then shared with all participant experts, allowing them to revise their previous inputs. This process was repeated until a consensus was reached on the final set of barriers. Similarly, experts were asked to assess the relationships between pairs of barriers, and the same iterative approach was applied to achieve consensus on these relationships. To protect privacy, the experts' identities and affiliations were kept confidential.

A hybrid methodology is proposed to fulfil the four folded objectives of this research study. Potential barriers to saffron productivity have been identified with the help of literature review and expert consensus. TISM has been used to model the identified barriers by establishing hierarchy interrelationships between the barriers. In order to understand the strength between the interrelationships of the barriers, Fuzzy DEMATEL has been utilized. Lastly, Fuzzy MICMAC analysis has been used to group the barriers in dependent, independent, linkage and autonomous categories.

3.1. Modelling by TISM

Step 1. Identification of variable elements: In this step the barriers are identified with the help of literature survey and mutual expert consensus. Discussions between expert team and the stake holders take place for finalizing key barriers.

Step 2. Determination of contextual relationships between variable elements (barriers): In this step, pair wise contextual relationships have been determined with the help of experts. If relationship exists between barriers under comparison, “Yes” was used otherwise “No” was written in the initial reachability matrix.

Step 3. Interpretation of contextual relationship where “Yes” has been entered in reachability matrix: This stage has been introduced to understand the relationship between the barriers by knowing how barriers are related with each other. An interpretation has been added against the barriers where relation has been established.

Step 4. Reachability matrix and transitivity check: In this stage, indirect relations among barriers have been identified. If for example, there is direct relation between first and second barrier and first barrier has a relation with the third barrier, then a relation has been re-established between second and the third barrier, which has to be reported in the final transitivity matrix. Based on transitivity rule, all the elements having “0” entry in the initial transitivity matrix need to be replaced with “1” to form the final reachability matrix.

Step 5. Level partition: In this step, partition of barriers has been done to understand their positioning in different levels. It is based on three sets; reachability set, antecedent set and intersection set. The three sets have been determined on the basis of driving and dependence powers of barriers. Level 1 has been designated by checking if barriers in reachability set and intersection set were same. The next levels have been designated by removing previously labelled levels from the entire set and performing iterations till all the remaining levels have been designated.

Step 6. Diagraph and TISM model: Based on final reachability matrix, the barriers have been levelled and accordingly arranged graphically. Continuous lines have been used to identify direct linkages where as effective transitive links between barriers have been identified by dashed lines. Thus, I this way final TISM model has been developed.

3.2. Fuzzy MICMAC Analysis

To overcome the biasness of the expert team, fuzzy concept has been clubbed with the MICMAC analysis. Depending on driving and dependence powers, the barriers are grouped mainly under 4 categories. Along x axis, dependence power is plotted while as driving power has been plotted on y axis of the graph. The barriers have been grouped in to Four clusters:

Autonomous Factors: These are the group of barriers that has both weak driving and dependence powers.

Dependence Factors: These are the group of barriers that has weak driving power but strong dependence power.

Linkage Factors: These are the group of barriers that has both strong driving and dependence powers.

Independent Factors: These are the group of barriers that has weak dependence power but strong driving power.

4. Fuzzy DEMATEL Technique

4.1. Fuzzy set theory

In 1965, Zadeh., [42] introduced Fuzzy set theory which pave way to consider the vagueness at the data stage. This is based on the concept of membership function which takes into consideration different linguistic variables. Fuzziness may be developed on account of decision maker‘s perceptions and thoughts towards the data. This concept simplifies the uncertain data by assigning to it the linguistic variables. Bolturk, E. [7] considered Pythagorean fuzzy CODAS for supplier selection process problems.

4.2. Triangular Fuzzy Number

Fuzzy set theory has been introduced by Zadeh in 1965 with a membership function concept. A triangular fuzzy number $\tilde{A}$ is a triplet (l, m, r) and a membership function $\mu_{\tilde{A}}$ is depicted in (Figure 1) as

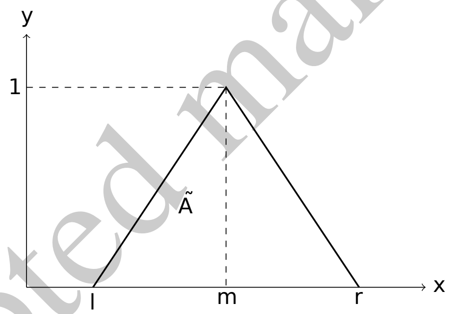

Figure 1. Triangular Fuzzy Number $\tilde{A}$

The relation of triangular fuzzy concept is given as

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < l \\ x - \frac{l}{m} - l, & l \leq x \leq m \\ r - \frac{x}{r} - m, & m \leq x \leq r \\ 0, & x > r \end{cases} \tag{1}$$

Fuzzy numbers are used to deal with ambuiguity in human perceptions. Defuzzification is required for converting fuzzy set into a suitable crisp value. Initially fuzzy set is replaced by crisp set and finally the crisp set is replaced by a single value, Roventa and Spircu., [29]. Converting Fuzzy data into Crisp Scores (CFCS) is proposed by Opricovic and Tzeng, [24] for obtaining better crisp values.

Let $A_ij = (l_{ij}^n, m_{ij}^n, r_{ij}^n)$ is the degree of criterion i that affects criterion j and fuzzy questionnaires n, $(n = 1, 2, \ldots, h)$ The CFCS has 5 main stage algorithm

Stage 1. Normalization

$$xr_{ij}^n = \frac{(r_{ij}^n - \min l_{ij}^n)}{\Delta_{\min}^{\max}} \tag{2}$$

$$xm_{ij}^n = \frac{(m_{ij}^n - \min l_{ij}^n)}{\Delta_{\min}^{\max}} \tag{3}$$

$$xl_{ij}^n = \frac{(l_{ij}^n - \min l_{ij}^n)}{\Delta_{\min}^{\max}} \tag{4}$$

where $\Delta_{\min}^{\max} = \max r_{ij}^n - \min l_{ij}^n$

Stage 2. Compute right (rs) and left (ls) normalized values:

$$xrs_{ij}^n = \frac{xr_{ij}^n}{(1 + xr_{ij}^n - xm_{ij}^n)} \tag{5}$$

$$xls_{ij}^n = \frac{xm_{ij}^n}{(1 + xm_{ij}^n - xl_{ij}^n)} \tag{6}$$

where $\Delta_{\min}^{\max} = \max r_{ij}^n - \min l_{ij}^n$

Stage 3. Compute total normalized crisp values:

$$x_{ij}^n = \frac{xls_{ij}^n(1 - xls_{ij}^n) + xrs_{ij}^n \cdot xrs_{ij}^n}{(1 - xls_{ij}^n + xrs_{ij}^n)} \tag{7}$$

Stage 4. Compute crisp values:

$$Z_{ij}^n = \min l_{ij}^n + x_{ij}^n \cdot \Delta_{\min}^{\max} \tag{8}$$

Stage 5. Integrate crisp values:

$$Z_{ij} = \frac{1}{h(Z_{ij}^1 + Z_{ij}^2 + \cdots + Z_{ij}^h)} \tag{9}$$

4.3. DEMATEL

Decision making trial and evaluation laboratory (DEMATEL) technique was first developed by the Geneva Research Centre of the Battelle Memorial Institute, Gabus and Fontela,[11]. DEMATEL method uses causal relationship to visualize the cause and the effect groups which represent the strength of influence of one group on effect group. DEMATEL method is composed of the following steps: Initailly , a four level pair wise comparison scale is used to represent degree of influence, where scores of 1 represent "very low influence", score of 2 represent "low influence", score of 3 represent "high influence" and the score of 4 represent "very high influence" respectively. Initial direct-relation matrix T is a $n \times n$ matrix obtained by pair-wise comparisons in terms of influences and directions between criteria, in which $T_{ij}$is denoted as the degree to which the barrier i affects the barrier j, i.e., $T = [T_{ij}]_{n\times n}$. Then a normalized direct-relation matrix S, i.e., $S = [S_{ij}]_{n\times n}$ and $0 \leq S_{ij} \leq 1$. Where,

$$K = \frac{1}{\max_{1\leq i\leq n} \sum_{j=1}^{n} a_{ij}} \tag{10}$$

$$S = K \times T \tag{11}$$

$$M = X \times (1 - x)^{-1} \tag{12}$$

Where M is total relation matrix, and I is identity matrix.

$$M = [m_{ij}],\ i, j = 1, 2, \ldots, n.$$

The sum of rows is denoted by D and the sum of columns is denoted by R within the total-relation matrix M as

$$D = \left[\sum_{j=1}^{n} m_{ij}\right]_{n\times 1} \tag{13}$$

$$R = \left[\sum_{j=1}^{n} m_{ij}\right]_{1\times n} \tag{14}$$

Finally, a causal and effect graph can be acquired by mapping the dataset of $(D + R, D - R)$.

5. Implementation of proposed methodology

The solution methodology comprises of hybrid MCDM approach where nine barriers to saffron productivity were identified after mutual consensus of the 5 experts having expertise in saffron cultivation and 3 stake holders. The nine identified barriers were: Shortage of rain water during pre-saffron flowering season (B1), Insufficient Nutrient management (B2), Reduced land for saffron cultivation (B3), Technical inefficiency in saffron farming (B4), Smaller size of saffron corm (B5), Lack of disease management knowledge in saffron farming (B6), Lack of scientific awareness in saffron farming (B7), Climate change on saffron productivity (B8), Higher cost of production of saffron (B9).

With the help of expert team, the identified barriers were compared for contextual relationship among them as shown in Table 2.

Table 2. Contextual relationship between barriers to saffron productivity and their interpretation

S. No.	Relation Between Barriers	Relationship (Yes/No)	Interpretation: How Barriers Are Related
1	B1 – B2	No	Shortfall of rain during pre-flowering stage impacts insufficient nutrition management.
2	B1 – B3	Yes	Rainwater is one of the natural sources of irrigation for the saffron crop. Absence of adequate rainwater results in lower production of saffron, which diminishes profits, forcing farmers to shift to non-saffron crops. Thus, land for saffron cultivation is reduced. (Deficit rainfall drives shifting towards non-saffron crop).
3	B1 – B4	No	Shortfall of rain during pre-flowering stage impacts technical inefficiency in saffron farming.
4	B1 – B5	Yes	One of the requirements for saffron corm growth is sufficient water. Deficiency in rainwater during the pre-flowering stage affects the size of the corm and keeps it under-sized. (Water triggers corm growth).
5	B1 – B6	No	Shortfall of rain during the pre-flowering stage impacts the lack of disease management knowledge in saffron farming.
6	B1 – B7	No	Shortfall of rain during the pre-flowering stage impacts the lack of scientific awareness in saffron farming.
7	B1 – B8	No	Shortfall of rain during the pre-flowering stage impacts climate change.
8	B1 – B9	Yes	Saffron farming is mainly rain-fed cultivation, and a shortage of rainwater will trigger alternative arrangements for water resources such as drip irrigation, making saffron production costlier. (Sourcing other means of rainwater attracts additional costs).

Table 3. Contextual relationship between barriers to saffron productivity and their interpretation

S No	Relation Between Barriers	Comparison of Paired Barriers	Relationship (Yes/No)	Interpretation: How Barriers Are Related
1	B2 – B1	Insufficient Nutrient management impacts Shortage of rain water during pre-saffron flowering season	No	–
2	B2 – B3	Insufficient Nutrient management impacts Reduced land for saffron cultivation	No	–
3	B2 – B4	Insufficient Nutrient management impacts technical inefficiency in saffron farming.	No	–
4	B2 – B5	Insufficient Nutrient management impacts smaller size of saffron corm	Yes	When the parent corm is deprived of adequate nutrition supply, it will produce smaller cormlets. (Lesser nutrients result in smaller cormlets.)
5	B2 – B6	Insufficient Nutrient management impacts Lack of disease management knowledge in saffron farming	No	–
6	B2 – B7	Insufficient Nutrient management impacts Lack of scientific awareness in saffron farming	No	–
7	B2 – B8	Insufficient Nutrient management impacts Climate change.	No	–
8	B2 – B9	Insufficient Nutrient management impacts Higher cost of production of saffron	Yes	Nutrition deficit corms result in smaller cormlets which produce a lower yield of saffron in comparison to input for saffron production. (Imbalance between nutrition and saffron output).

Table 4. Contextual relationship between barriers to saffron productivity and their interpretation

S No	Relation Between Barriers	Comparison of Paired Barriers	Relationship (Yes/No)	Interpretation: How Barriers Are Related
1	B3 – B1	Reduced land for saffron cultivation impacts Shortage of rain water during pre-saffron flowering season	No	–
2	B3 – B2	Reduced land for saffron cultivation impacts Insufficient Nutrient management	No	–
3	B3 – B4	Reduced land for saffron cultivation impacts technical inefficiency in saffron farming	No	–
4	B3 – B5	Reduced land for saffron cultivation impacts smaller size of saffron corm	No	–
5	B3 – B6	Reduced land for saffron cultivation impacts Lack of disease management knowledge in saffron farming	No	–
6	B3 – B7	Reduced land for saffron cultivation impacts Lack of scientific awareness in saffron farming	No	–
7	B3 – B8	Reduced land for saffron cultivation impacts Climate change	No	–
8	B3 – B9	Reduced land for saffron cultivation impacts Higher cost of production of saffron	Yes	Economies of scale produce higher profits and reduce costs. In the case of saffron, reduced land availability will not attract scientific and automated farming for economies of scale, which require larger areas for application. Thus, reduced land triggers higher costs of saffron production. (Economies of scale lead to higher profits).

Table 5. Contextual relationship between barriers to saffron productivity and their interpretation

S No	Relation Between Barriers	Comparison of Paired Barriers	Relationship (Yes/No)	Interpretation: How Barriers Are Related
1	B4 – B1	Technical inefficiency in saffron farming impacts Shortage of rain water during pre-saffron flowering season	No	–
2	B4 – B2	Technical inefficiency in saffron farming impacts Insufficient Nutrient management	Yes	Use of technology has enhanced and improved results on nutrition management in saffron farming. For example, a technically inefficient grower does not know about unmanned aerial spray of fertilizers, which supplies sufficient nutrition to the saffron crop. (Technology leads to better nutrition management).
3	B4 – B3	Technical inefficiency in saffron farming impacts Reduced land for saffron cultivation	Yes	Technical inefficiency leads to underproduction, which compels farmers to shift to other non-saffron crops, thus resulting in reduced saffron lands. (Technical ignorance pushes saffron lands to non-saffron crops).
4	B4 – B5	Technical inefficiency in saffron farming impacts smaller size of saffron corm	Yes	Inefficiency in technology towards saffron farming results in undersized cormlets because farmers continue to follow traditional old practices before the saffron harvesting season, leading to smaller-sized cormlets. (Technical efficiency increases yield).
5	B4 – B6	Technical inefficiency in saffron farming impacts Lack of disease management knowledge in saffron farming	No	–
6	B4 – B7	Technical inefficiency in saffron farming impacts Lack of scientific awareness in saffron farming	No	–
7	B4 – B8	Technical inefficiency in saffron farming impacts Climate change	No	–
8	B4 – B9	Technical inefficiency in saffron farming impacts Higher cost of production of saffron	Yes	Having a technical approach towards saffron farming reduces the cost of production of the saffron crop because using technically efficient tools in saffron harvesting enables maximizing output and reducing costs. (Technical efficiency reduces production costs).

Table 6. Contextual relationship between barriers to saffron productivity and their interpretation

S No	Relation Between Barriers	Comparison of Paired Barriers	Relationship (Yes/No)	Interpretation: How Barriers Are Related
1	B5 – B1	Smaller size of saffron corm impacts Shortage of rain water during pre-saffron flowering season	No	–
2	B5 – B2	Smaller size of saffron corm impacts Insufficient Nutrient management	No	–
3	B5 – B3	Smaller size of saffron corm impacts Reduced land for saffron cultivation	No	–
4	B5 – B4	Smaller size of saffron corm impacts Technical inefficiency in saffron farming	No	–
5	B5 – B6	Smaller size of saffron corm impacts Lack of disease management knowledge in saffron farming	No	–
6	B5 – B7	Smaller size of saffron corm impacts Lack of scientific awareness in saffron farming	No	–
7	B5 – B8	Smaller size of saffron corm impacts Climate change	No	–
8	B5 – B9	Smaller size of saffron corm impacts Higher cost of production of saffron	Yes	Smaller size of cormlets occupies land meant to be used for healthy, big-sized corms for higher saffron production. (Immature corm size produces lesser saffron yield).

Table 7. Contextual relationship between barriers to saffron productivity and their interpretation

S No	Relation Between Barriers	Comparison of Paired Barriers	Relationship (Yes/No)	Interpretation: How Barriers Are Related
1	B6 – B1	Lack of disease management knowledge in saffron farming impacts Shortage of rain water during pre-saffron flowering season	No	–
2	B6 – B2	Lack of disease management knowledge in saffron farming impacts Insufficient Nutrient management	No	–
3	B6 – B3	Lack of disease management knowledge in saffron farming impacts Reduced land for saffron cultivation	No	–
4	B6 – B4	Lack of disease management knowledge in saffron farming impacts Technical inefficiency in saffron farming	No	–
5	B6 – B5	Lack of disease management knowledge in saffron farming impacts Smaller size of saffron corm	Yes	Many diseases negatively affect the growth of corms. For example, corm rot is responsible for the undergrowth of mother-daughter corms. Ignorance of proper disease management in saffron results in smaller corm size. (Proper disease management ensures healthy corm size).
6	B6 – B7	Lack of disease management knowledge in saffron farming impacts Lack of scientific awareness in saffron farming	No	–
7	B6 – B8	Lack of disease management knowledge in saffron farming impacts Climate change	No	–
8	B6 – B9	Lack of disease management knowledge in saffron farming impacts Higher cost of production of saffron	Yes	Lack of disease management knowledge not only results in poor growth of corms and saffron flowers but also damages the corms, requiring replacement with new healthy corms for a sustainable saffron crop. (Insufficient disease knowledge leads to higher production costs of saffron).

Table 8. Contextual relationship between barriers to saffron productivity and their interpretation

S No	Relation Between Barriers	Comparison of Paired Barriers	Relationship (Yes/No)	Interpretation: How Barriers Are Related
1	B7 – B1	Lack of scientific awareness in saffron farming impacts Shortage of rain water during pre-saffron flowering season	No	–
2	B7 – B2	Lack of scientific awareness in saffron farming impacts Insufficient Nutrient management	No	–
3	B7 – B3	Lack of scientific awareness in saffron farming impacts Reduced land for saffron cultivation	No	–
4	B7 – B4	Lack of scientific awareness in saffron farming impacts Technical inefficiency in saffron farming	Yes	A farmer unaware of scientific procedures cannot utilize technical knowledge in saffron fields. (Lack of scientific knowledge leads to poor technical efficiency).
5	B7 – B5	Lack of scientific awareness in saffron farming impacts Smaller size of saffron corm	Yes	The benefits of crop management are achieved by scientifically aware farmers. Lack of scientific awareness leads to bad crop management, which reduces the size of the corm. (Scientific knowledge helps in increasing yield).
6	B7 – B6	Lack of scientific awareness in saffron farming impacts Lack of disease management knowledge in saffron farming	Yes	Disease management protocols for saffron crops depend on the scientific knowledge of farmers. Lack of scientific awareness results in poor disease management knowledge in saffron farming. (Scientific awareness leads to better disease management).
7	B7 – B8	Lack of scientific awareness in saffron farming impacts Climate change	No	–
8	B7 – B9	Lack of scientific awareness in saffron farming impacts Higher cost of production of saffron	Yes	Farmers having scientific knowhow of saffron crops earn good profits by increasing efficiency and reducing costs incurred on saffron harvesting. (Scientific knowledge reduces losses).

S No	Relation Between Barriers	Comparison of Paired Barriers	Relationship (Yes/No)	Interpretation: How Barriers Are Related
1	B8 – B1	Climate change impacts Shortage of rain water during pre-saffron flowering season	Yes	There is a high degree of dependence of climate change having adverse effects on average rainfall. Therefore, climate change highly impacts the shortage of rainfall during the pre-saffron season. (Climate change-induced disaster).
2	B8 – B2	Climate change impacts Insufficient Nutrient management	No	–
3	B8 – B3	Climate change impacts Reduced land for saffron cultivation	Yes	Climate change reduces rainfall, forcing many farmers to shift from saffron crops to non-saffron crops, resulting in reduced land availability for saffron farming. (Climate change-induced crop displacement).
4	B8 – B4	Climate change impacts Technical inefficiency in saffron farming	No	–
5	B8 – B5	Climate change impacts Smaller size of saffron corm	Yes	As saffron is mainly rain-fed, climate change triggers conditions like droughts and uneven weather patterns. These abnormal patterns result in undersized saffron corms. (Climate change-induced hazard).
6	B8 – B6	Climate change impacts Lack of disease management knowledge in saffron farming	No	–
7	B8 – B7	Climate change impacts Lack of scientific awareness in saffron farming	No	–
8	B8 – B9	Climate change impacts Higher cost of production of saffron	Yes	Climate change develops abnormal conditions for saffron production. Rain-deficit saffron fields require a drip irrigation system for survival. This alternative arrangement increases the production costs of saffron. (Alternate source triggers additional costs).

Table 9. Contextual relationship between barriers to saffron productivity and their interpretation

S No	Relation Between Barriers	Comparison of Paired Barriers	Relationship (Yes/No)	Interpretation: How Barriers Are Related
1	B9 – B1	Higher cost of production of saffron impacts Shortage of rain water during pre-saffron flowering season	No	–
2	B9 – B2	Higher cost of production of saffron impacts Insufficient Nutrient management	No	–
3	B9 – B3	Higher cost of production of saffron impacts Reduced land for saffron cultivation	Yes	Higher cost of saffron production dents the profits of the saffron business. Farmers feel reluctant to continue saffron harvesting, resulting in the conversion of saffron lands into residential and commercial projects, thus reducing land availability for saffron cultivation. (Higher production cost drives saffron land usability in commercial forms).
4	B9 – B4	Higher cost of production of saffron impacts Technical inefficiency in saffron farming	No	–
5	B9 – B5	Higher cost of production of saffron impacts Smaller size of saffron corm	No	–
6	B9 – B6	Higher cost of production of saffron impacts Lack of disease management knowledge in saffron farming	No	–
7	B9 – B7	Higher cost of production of saffron impacts Lack of scientific awareness in saffron farming	No	–
8	B9 – B8	Higher cost of production of saffron impacts Climate change	No	–

The contextual relationship matrix was further processed for developing initial reachability matrix, that has been further developed after finding transitivity check in it. The final reachability metric reached this way has been shown in Table 10.

Table 10. : Final reachability matrix for barriers to saffron productivity

	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**
B1	1	0	1	0	1	0	0	0	1
B2	0	1	1	0	1	0	0	0	1
B3	0	0	1	0	0	0	0	0	1
B4	0	1	1	1	1	0	0	0	1
B5	0	0	1	0	1	0	0	0	1
B6	0	0	1	0	1	1	0	0	1
B7	0	1	1	1	1	1	1	0	1
B8	1	0	1	0	1	0	0	1	1
B9	0	0	1	0	0	0	0	0	1

The final reachability matrix has been further used for obtaining reachability sets and antecedent sets along with intersection sets. Five iterations have been performed for level portioning for levels 1to 5. The level portioning has been shown in Table 12.

Table 12. Level portioning matrix

Level Description	**Barrier Symbol**	**Barrier Description**
Level 1	B3	Reduced land for saffron cultivation
	B9	Higher cost of production of saffron
Level 2	B5	Smaller size of saffron corm
Level 3	B1	Shortage of rain water during pre-saffron flowering season
	B2	Insufficient Nutrient management
	B6	Lack of disease management knowledge in saffron farming
Level 4	B4	Technical inefficiency in saffron farming
	B8	Climate change
Level 5	B7	Lack of scientific awareness in saffron farming

The identified barriers were modelled in to TISM by establishing hierarchy interrelationships among barriers by solid arcs as shown in figure 4.1 and transitive links by dashed lines as shown in Figure 2 in the resulting digraph.

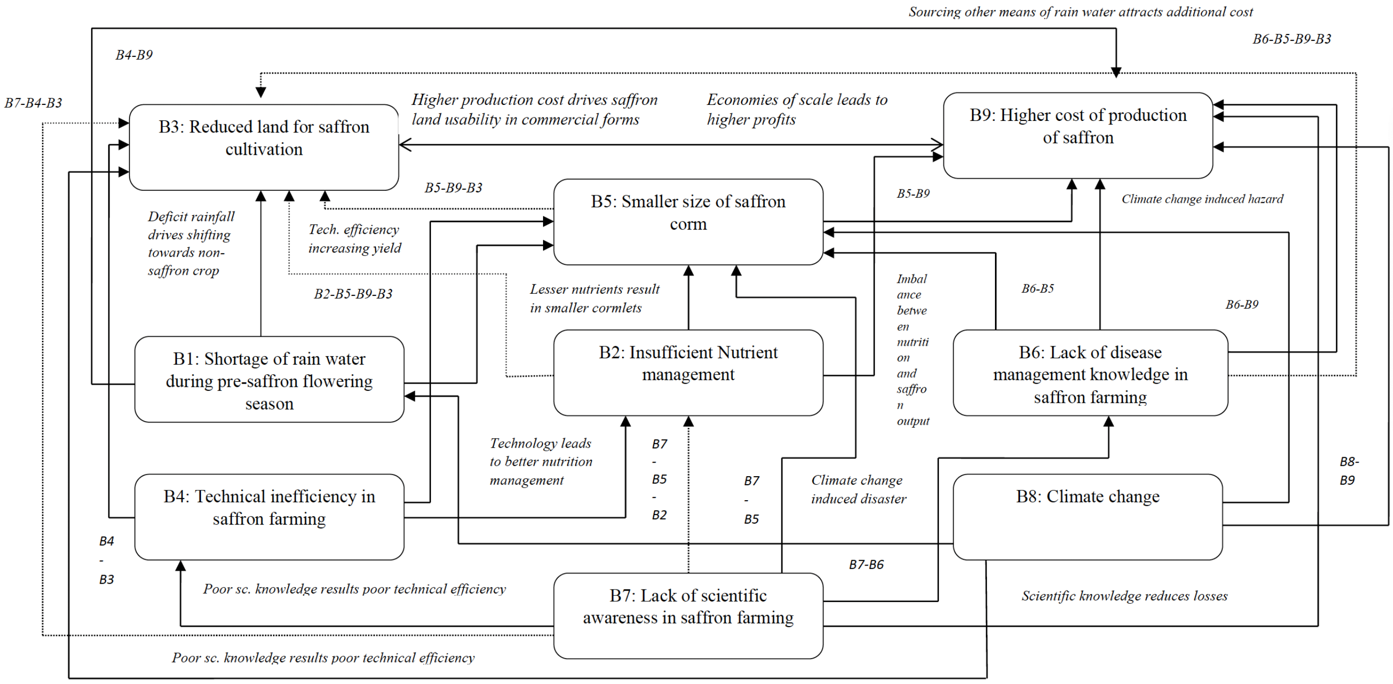

Figure 2. TISM Model showing Levels 1 to 5

After TISM model, the barriers have been categorized in to four groups on account of their driving and dependence powers. In order to cater the uncertainty on account of expert opinion, fuzzy concept has been introduced in decision making process. Fuzzy MICMAC stabilization matrix has been reached with the help of 7-point Likert scale shown in Table 14. and Table 16 respectively. Hence, barriers with strong dependence power and strong driving power have been placed in linkage quadrant, while barriers with weak dependence and weak driving powers finds place in autonomous quadrant. Barriers having weak dependence power but strong driving powers are called independent barriers. Finally, barriers with strong dependence powers and weak driving powers are called dependent barriers.

Table 14. Fuzzy MICMAC stabilization matrix

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	Driving Power
Shortage of rain water during pre-saffron flowering season	0	0	1	0	1	0	0	0	1	3
Insufficient Nutrient management	0	0	0.9	0	0.9	0	0	0	0.9	2.7
Reduced land for saffron cultivation	0	0	0	0	0	0	0	0	0.9	0.9
Technical inefficiency in saffron farming	0	0.9	1	0	0.9	0	0	0	1	3.8
Smaller size of saffron corm	0	0	0.9	0	0	0	0	0	1	1.9
Lack of disease management knowledge in saffron farming	0	0.1	0.9	0	1	0	0	0	0.9	2.9
Lack of scientific awareness in saffron farming	0	0.9	1	0.7	0.9	0.7	0	0	0.9	5.1
Climate change	1	0	0.9	0	0.9	0	0	0	1	3.8
Higher cost of production of saffron	0	0	1	0	0	0	0	0	0	1
Dependence Power	1	1.9	7.6	0.7	5.6	0.7	0	0	7.6	

Table 16. : 7-Point Likert Scale

Linguistic Variable	Triangular Fuzzy Number
No influence (No)	(0,0,0)
Very low influence (VL)	(0, 0.1, 0.3)
Low influence (L)	(0.1, 0.3, 0.5)
Medium influence (M)	(0.3, 0.5, 0.7)
High influence (H)	(0.5, 0.7, 0.9)
Very high influence (VH)	(0.7, 0.9, 1)
Complete influence (C)	(1, 1, 1)

The four groups formed by the categorization of barriers as per their dependence and driving powers is called MICMAC have been shown in the Figure 3.

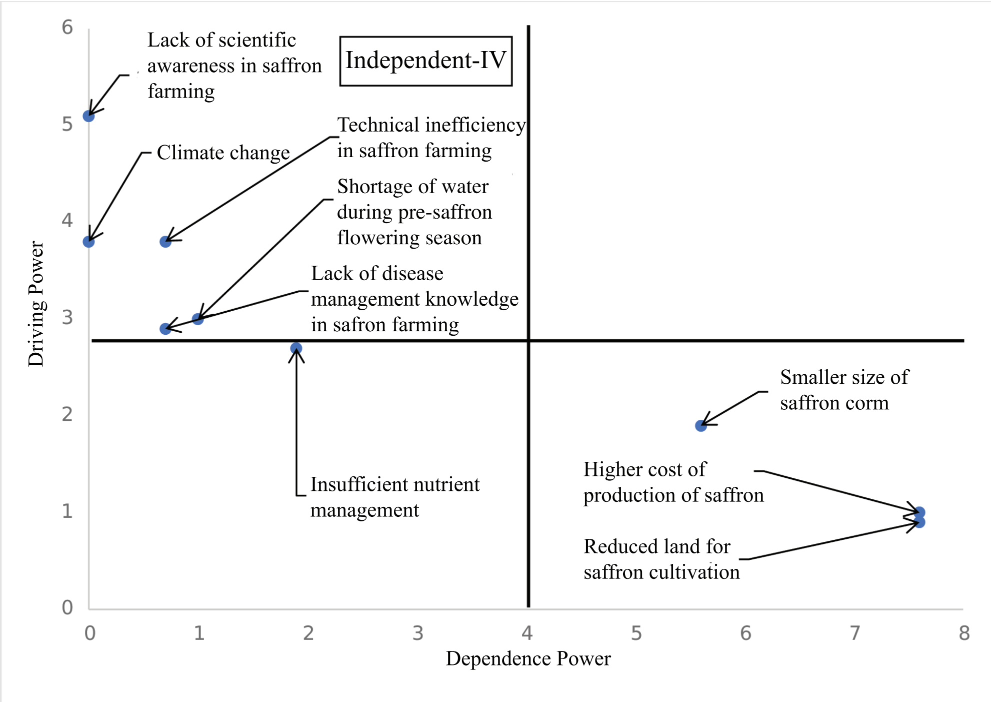

Figure 3. FMICMAC Analysis

Finally Fuzzy DEMATEL has been used to know the cause and effect between the barriers to saffron productivity. The services of the team of experts which was involved in developing contextual relationship matrix has also been utilized in FDEMATEL process. The decision-making team compared barriers using linguistic variables on a 4-point scale, converted to respective triangular fuzzy number (TFN). The barriers had either no influence or had very high influence over other barrier. Using equation 1-9, the response for barriers in comparison has been transformed in to a matrix. The linguistic variables have been transferred in to corresponding TFNs which have been normalized for acquiring crips values for generating total normal crisp values. Using equations 10-14, the matrices have been combined for obtaining the direct relation matrix through aggregating the normalized crisp values from all experts as shown in Table 17.

Table 17. Direct relation matrix through aggregating the normalized crisp values from all experts

Barriers	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**
B1	1.17	0.38	1.17	0.68	1.17	0.30	0.75	0.30	1.17
B2	0.30	1.17	0.82	0.30	0.97	0.30	0.30	0.30	1.04
B3	0.60	0.60	1.17	0.68	0.82	0.60	0.97	0.30	0.97
B4	0.30	1.04	0.97	1.17	0.82	1.04	0.30	0.30	0.97
B5	0.30	0.30	0.68	0.30	1.17	0.30	0.30	0.30	1.17
B6	0.30	0.68	0.68	0.30	1.17	1.17	0.30	0.38	1.11
B7	0.30	0.97	0.68	0.90	0.90	0.97	1.17	0.30	0.97
B8	1.17	0.30	0.90	0.30	0.97	0.30	0.75	1.17	0.90
B9	0.30	0.30	1.17	0.68	0.68	0.30	0.60	0.30	1.17

Direct relation matrix has been developed in to Normalized direct matrix has been further transformed till total relation matrix has been obtained as shown in Table 19.

Table 19. Total relation matrix showing degree of influence among barriers

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	D
B1	0.63	0.65	1.09	0.69	1.09	0.60	0.71	0.40	1.22	7.07
B2	0.38	0.61	0.80	0.47	0.82	0.44	0.48	0.31	0.92	5.23
B3	0.52	0.66	1.03	0.66	0.99	0.62	0.70	0.38	1.13	6.70
B4	0.47	0.73	1.01	0.72	1.00	0.68	0.59	0.38	1.14	6.73
B5	0.34	0.42	0.69	0.42	0.77	0.40	0.43	0.27	0.85	4.60
B6	0.41	0.58	0.84	0.51	0.92	0.62	0.52	0.35	1.01	5.76
B7	0.49	0.75	1.00	0.71	1.05	0.70	0.75	0.40	1.18	7.02
B8	0.64	0.61	1.02	0.61	1.04	0.57	0.69	0.52	1.15	6.86
B9	0.40	0.51	0.88	0.56	0.81	0.48	0.55	0.32	0.98	5.48
R (Dependence Power)	4.29	5.53	8.35	5.34	8.49	5.11	5.42	3.32	9.58	

The value of D, which is the row sum and the value of R which is the column sum has been derived from the total relation matrix. Finally, a causal and effect graph has been acquired by mapping the dataset of $(D + R, D - R)$ as shown in Figure 4.

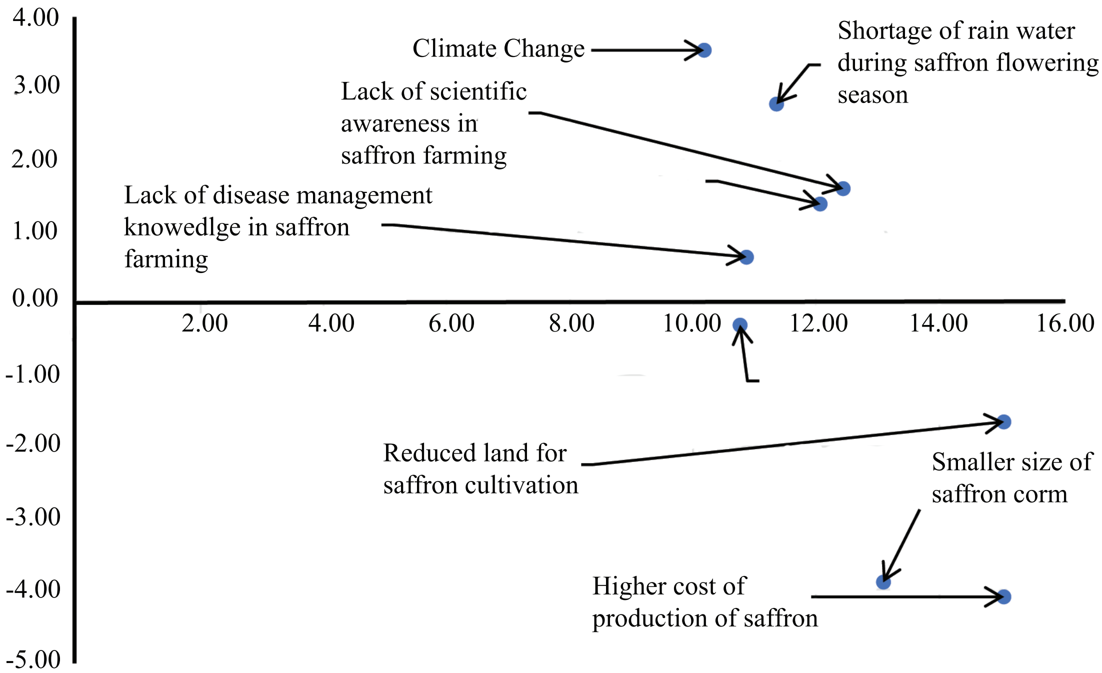

Figure 4. Causal and Effect graph of barriers.

6. Results and Discussions

The TISM model shown in figure 4.1 revealing barrier B3; ie reduced land for saffron cultivation and B9; ie higher cost of production of saffron positioned at level 1 of the diagraph. The level 1 barriers are least affected by the other barriers to the saffron productivity. These barriers occupy the top most position in the diagraph and hence do not get affected by the other barriers in the system, but they both hamper productivity of saffron.

The barrier B5; small size of the saffron corm occupies level 2 in the hierarchical mapping. The small size of saffron corm produces undesirable yield and flowering which negatively impact the saffron productivity.

Level 3 comprises of three barriers, i.e. B1; Shortage of rain water during pre-saffron flowering season, B2; Insufficient Nutrient management and B6; Lack of disease management knowledge in saffron farming. These barriers influence and get influenced by other barriers in the system.

Level 4 is occupied by two barriers, B4; Technical inefficiency in saffron farming and B8; Climate change. This level provides important information about the barriers which hinders the saffron productivity. When farmers lack technical knowledge, they cannot utilize input resources efficiently to produce maximum output in saffron production. Similarly, climate change plays a major role in saffron productivity in rain fed saffron crop. Climate change is responsible for shifting weather conditions which affects negatively saffron productivity.

The final level is occupied by the barrier B7; Lack of scientific awareness in saffron farming. This is the most influential layer which is positioned at the bottom of the model. The lack of scientific awareness in saffron farming leads to the under productivity in saffron. This research article provides in-depth detail of crucial barriers to the saffron productivity and once these barriers are overcome, saffron productivity will increase with increase the economic wellbeing of saffron growers.

Further the barriers to the saffron productivity were also clustered in to four categories with the help of Fuzzy MICMAC analysis. Depending upon the dependence and driving powers, Fuzzy MICMAC categorizes barriers into autonomous, dependence, linkage and driving categories:

1. Autonomous (I): This category includes those factors which have low dependence and low driving powers. These are lease affected factors in the system. In our study no barrier has captured the autonomous quadrant. Barrier B2; insufficient nutrient management lies on the border line between quadrant I and quadrant IV. Largely in our study we do not have any barrier in autonomous quadrant.

2. Dependence (II): This group consists of those elements which have high dependence but lower driving power. The elements of this group occupy the top layers of TISM model. In our study, barriers B3: Reduced land for saffron cultivation, B5: Smaller size of saffron corm, and B9: Higher cost of production of saffron, fall in this category.

3. Linkage (III): The elements of this group have higher dependence as well as higher driving powers. The representatives of this group are highly sensitive and provide stability to the whole system. In our study we do not have any barrier in this category.

4. Independent (IV): The elements under this category have high driving power but low dependence power. These elements by virtue of high driving and low dependence power are called driving fac-

tors. The elements representing this category help in achieving other elements of the system. In our study, the barriers, B7: Lack of scientific awareness in saffron farming occupies the highest position. The other barriers falling in this category are: B8: climate change, B4: Technical inefficiency in saffron farming, B6: Lack of disease management knowledge in saffron farming, and B1: Shortage of rain water during pre-saffron flowering season. The independent category barriers are the most influential barriers which help in overcoming other barriers to the saffron productivity.

6.1. Theoretical contribution

The current research study adds knowledge to the already existing body of knowledge of saffron productivity. This is the first of its kind of research which uses novel methodology utilizing hybrid MCDM techniques in explaining the intrarelationship between major barriers to the saffron productivity. Although existing research has identified the barriers to the saffron productivity but there is paucity of relationships between them to enable the stakeholders to identify the most influential barriers and their effect on other barriers in the system. Towards minimizing fuzziness on account of experts has also been addressed by introducing fuzzy sets in the study. The described fuzzy MICMAC approach allows the readers to visualize the identified barriers in to four categories depending on the barrier dependence and driving powers. Level partitioning has been carried with the help of TISM model where 5 levels have divided 9 identified barriers on their influential capacities. The fusion of TISM-MICMAC in fuzzy environment in the identification and analysis of barriers to the saffron productivity has been offered for the first time in the existing research.

6.2. Stakeholder Implications

Saffron is considered as red gold. The growing demand of saffron worldwide owing to its uses in medical, food and other industries compel stakeholders to find barriers which hinder saffron‘s productivity. By addressing the identified critical barriers in this study, the saffron productivity will be increased.

In this study, the barrier, B7: Lack of scientific awareness in saffron farming is the most critical barrier to the saffron productivity. The stakeholders should focus to overcome the most critical barrier which hinders the saffron productivity. The growers are unlikely to change the ways of pre-and-post cultivation of saffron they used to do traditionally. The growers resist changing to modern practices unless they are made aware of the disadvantages, like decrease in saffron productivity associated with the traditional practices of saffron cultivation. The miscommunication between growers and agriculture experts should be addressed by organization events where the transfer of knowledge is imparted to the farmers. The government organizations associated with the saffron should create awareness among the growers for pre- and post-harvesting modern cultivation methods of saffron cultivation for increased saffron productivity.

The other important barriers to saffron productivity are B4: Technical inefficiency in saffron farming and B8: climate change. To eradicate these barriers, the stakeholders and concerned parties should educate farmers and associated firms with saffron to use technical/scientific tools in saffron farming to boost its efficiency. Moreover, climate changes are largely inevitable to stop but measures can be done to slow its speed. The climate change barrier leads to majorly produce drought-like situations. Hence to save the crop from water scarcity and boost the productivity of saffron, the government and concerned agencies should set up the irrigation facilities installed with water sprinkle systems. By undertaking such initiatives, the adverse effects of climate change can be lowed and saffron productivity can be increased. The other barriers provided in the hierarchy proposed in the framework should be addressed individually by the stakeholders for the higher saffron productivity.

Saffron growers remain hesitant to abandon traditional pre- and post-cultivation practices, such as sun-drying saffron in the open and using unscientific storage methods. These outdated techniques compromise saffron quality, resulting in lower market prices. To address this, policymakers should organize awareness camps to educate farmers on modern post-harvest techniques, including scientific drying and storage methods, to enhance saffron quality, profitability and hence its productivity. These events should encourage the adoption of modern farming tools and techniques to boost saffron yield and, ultimately, increase farmers' income. The introduction of bio fertilizers can help address the lack of organic matter in the soil, while mechanized farming can promote scientific cultivation practices.

Moreover, while climate change is largely inevitable, measures can be taken to mitigate its impact. The study identifies climate change as one of the critical barriers, which lead to drought-like conditions. To combat water scarcity and enhance saffron yield, the agriculture departments should establish adequate irrigation facilities equipped with sprinkler systems. This approach will help minimize the adverse effects of water shortages and improve saffron productivity.

7. Conclusion

The research study investigates various barriers which offer resistance to saffron productivity. Literature survey and expert opinion revealed 9 barriers to saffron productivity. The potential barriers were modelled by TISM for establishing hierarchy interrelationships among them. Out of 72 possible interactions, only 23 direct interrelations were developed among the identified barriers by the help of expert opinion. The final reachability set was formed after performing transitivity check of barriers where total number of interrelations reached to 36. Afterwards, reachability set, antecedent se and intersection sets were developed for level partition of the aforementioned barriers. The level partition thus produced five different levels where the most influential barrier, B7: Lack of scientific awareness in saffron farming was placed at the bottom level and the 5th layer of the hierarchical model. The 4th layer of the model has been occupied by the barrier; B4: Technical inefficiency in saffron farming and the barrier; B8: Climate change. Similarly at the 3rd level, barriers B1: Shortage of rain water during pre-saffron flowering season, B2: Insufficient Nutrient management and B6: Lack of disease management knowledge in saffron farming have been placed in the TISM model. The 2nd level comprises of smaller size of saffron corm and the barriers, B3: Reduced land for saffron cultivation and B9: Higher cost of production of saffron have been positioned at the 1st layer in the TISM model.

The strength of interrelationships and the cause and effect between the identified barriers was measured with the help of DEMATEL fused with fuzzy sets to minimize vagueness of the experts in the study. Same experts who have been engaged in expressing the relationships between the identified barriers were also involved in obtaining the responses for FDEMATEL technique. The results of FDEMATEL suggested that barriers: lack of scientific awareness in saffron farming, technical inefficiency in saffron farming, shortage of rainwater during pre-saffron flowering season, lack of disease management knowledge in saffron farming, climate change and insufficient nutrient management have casual effect over the other barriers: higher coat of production of saffron, reduced land of saffron and smaller size of saffron corm.

Further, with the help of FMICMAC, the identified barriers to saffron productivity have been categorized in to four quadrants depending on their driving and dependence powers in the fuzzy state. The uncertainty and vagueness on account of expert's imprecise knowledge have also been considered in MICMAC so that errors in results were minimized. There were no barriers under autonomous and linkage quadrants in FMICMAC analysis, however barriers: lack of scientific awareness in saffron farming, technical inefficiency in saffron farming, shortage of rainwater during pre-saffron flowering season, lack of disease management knowledge in saffron farming, climate change and insufficient nutrient management have fall under Independent quadrant while as barriers: higher coat of production of saffron, reduced land of saffron and smaller size of saffron corm fall in dependent quadrant. The results of FMICMAC are impressive as it conforms the results obtained from FDEMATEl.

Towards the contribution, this study offers a systematic structural model obtained by using TISM technique and Fuzzy MICMAC analysis. The study further discusses the strength between interrelations of barriers and their casual effect with the help of Fuzzy DEMATEL in consultation with industrial experts while considering their imprecise knowledge. The interrelationships in concurrence with their transitivity relations has not been produced before, despite studies on the identification of barriers to saffron productivity. The study shows that the most crucial barrier to the saffron productivity is the lack of scientific awareness in saffron farming. The stake holders and the concerned government agencies should eradicate the miscommunication between growers and agriculture experts by addressing organization events where the transfer of knowledge is imparted to the farmers. The concerned agriculture department associated with the saffron should create awareness among the growers for pre- and post-harvesting modern cultivation methods of saffron cultivation for increased saffron productivity. Further research studies be carried out using different techniques for comparison and ranking of barriers using TOPSIS in fuzzy environment. The researchers may work on exploring more such barriers affecting the productivity of saffron and work towards developing strategies for their eradication so that this evanesce crop is saved to be used for more scientific ways for human betterment.

Statements and Declarations

I confirm that this work is original, and no prior or duplicate publication of any part of this work has been published elsewhere, nor is it currently being considered for publication in any other journal and there is no conflict of interest.

References

[1] Abdoli Mohamadabadi, T., Nazarian-Jashnabadi, J., Ahmadpour Daryani, M., Al-Rashid, M. A., and Campisi, T. Factors affecting online customer experience of food delivery services during crisis: Tism and delphi techniques. *Sustainable Futures 9* (2025), 95–112.

[2] Aditi., Govindan, K., and Jha, P. Modelling of barriers in implementing sustainable manufacturer-supplier collaboration and coping strategies. *Journal of Cleaner Production 434* (2024).

[3] Ahmad, M. F., H. A., and Ahmad, S. Effect of corm size, row spacing and plant distance on the flower production of saffron (crocus sativus. l) under rainfed conditions of quetta, balochistan. *Sarhad Journal of Agriculture 39* (2023), 396–405.

[4] Aymani, I. E., Qurras, S., Mouden, N., Chliyeh, M., Selmaoui, K., Msairi, S., Benkirane, R., Modafar, C. E., Touhami, A. O., and Douira, A. Effect of endomycorrhizal fungi inoculum on agro morphological behavior and productivity of saffron (crocus sativus l.) under water and salinity stress. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 71* (2023), 183–192.

[5] Batra, I., and Dhir, S. Developing structural modelling of inter-partner factors of international joint ventures performance. *International Journal of Productivity and Performance Management 73* (2024), 186–209.

[6] Ben, R. R., Rajendran, C., Saravana, R., Kouki, F., Alshahrani, H. M., and Assiri, M. Analysis of barriers affecting Industry 4.0 implementation: An interpretive analysis using total interpretive structural modeling (tism) and fuzzy micmac. *Hellyon 9* (2023).

[7] Bolturk, E. Pythagorean fuzzy codas and its application to supplier selection in a manufacturing firm. *Journal of Enterprise Information Management 31* (2018), 550–564.

[8] El-Mahrouk, M. E., Dewir, Y. H., El-Ramady, H., and Seliem, M. K. Vegetative growth and productivity of potted crocus sativus in different growing media. *Horticulturae 9* (2023).

[9] Etxebeste-Mitxeltorena, M., Niza, E., Fajardo, C. M., Gil, C., Gómez-Gómez, L., Martinez, A., and Ahrazem, O. Neuroprotective properties of exosomes and chitosan nanoparticles of tomafran, a bioengineered tomato enriched in crocins. *Natural products and Bioprospecting 14* (2024).

[10] Falahat, S, E., Hadi, H., Sina Siavash Moghaddam, S. S., and Aryanfar, A. Exploring cultivation site of saffron (crocus sativus l.) by utilizing GIS linked to AHP. *Spatial Information Research 27* (2019), 285–293.

[11] Gabus, A., and Fontela, E. World problems, an invitation to further thought within the framework of dematel. *Battelle Geneva Research Centre, Geneva, Switzerland* (1972).

[12] Gandomzadeh, D., Saeidirad, M., and Sabeghi, Y. A comprehensive review of drying techniques and quality for saffron. *Food Measure 18* (2024), 8218—8232.

[13] Giupponi, L., Ceciliani, G., Leoni, V., Panseri, S., Pavlovic, R., Lingua, G., Di Filippo, A., and Giorgi, A. Quality traits of saffron produced in italy: Geographical area effect and good practices. *Journal of Applied Botony and Food Quality 92* (2019), 336—342.

[14] Gresta, F., Lombardo, G. M., Siracusa, L., and Ruberto, G. Saffron, an alternative crop for sustainable agricultural systems. *Agronomy for Sustainable Development 28* (2008), 95–112.

[15] Gupta, V., Sharma, A., Rai, P., Gupta, S., Singh, B., Sharma, S., Singh, S., and Sharma, R. Corm rot of saffron: Epidemiology and management. *Agronomy 11* (2021).

[16] Hasanuzzaman., Chakraborty., K., and Bag., S. Forging a sustainable path: improving India's (Bharat's) coal mining operations for a better tomorrow. *Benchmarking: An International Journal 32* (2025), 513–549.

[17] Khan, F. A., and Khan, M. I. Integration of ABC analysis with fuzzy DEMATEL and fuzzy TOPSIS in supplier selection and ranking problems. *Business Perspectives and Research* (2023).

[18] Khan, R., Farooq, M. S., and Khelifi, A. Internet of things (IoT) based saffron cultivation system in greenhouse. *Sci Rep 14* (2024).

[19] Luo, J., Zhang, A., Tan, K., Yang, S., Ma, X., Bai, X., Hou, Y., and Bai, J. Study on the interaction mechanism between crocus sativus and fusarium oxysporum based on dual rna-seq. *Plant Cell Reports 42* (2023), 91–106.

[20] Mansotra, R., Ali, T., Bhagat, N., and Vakhlu, J. Injury and not the pathogen is the primary cause of corm rot in crocus sativus (saffron). *Frontiers in Plant Science 1424* (2023).

[21] Mathivathanan, D., Mathiyazhagan, K., Rana, N. P., Khorana, S., and Dwivedi, Y. K. Barriers to the adoption of blockchain technology in business supply chains: a total interpretive structural modelling (TISM) approach. *International Journal of Production Research 59* (2021), 3338–3359.

[22] Mir, Y. H., Ganie, M. A., Shaha, T. I., Bangroo, S. A., Mir, S. A., Shah, A. M., Wani, F. J., Qin, A., and Rehman, S. U. Soil microbial and enzyme activities in different land use systems of the northwestern Himalayas. *PeerJ 11* (2023).

[23] Molina, R. V., Valero, M., Navarro, Y., Guardiola, J. L., , and Garcia-Luis, A. Temperature effects on flower formation in saffron (crocus sativus l.). *Scientia Horticulturae 103* (2005), 361–379.

[24] Opricovic, S., and Tzeng, G. Defuzzification within a multicriteria decision model. *International Journal of Uncertainty, Fuzziness and Knowledge based systems 11* (2003), 635–652.

[25] Oubahman, L., D. S., and Esztergár-Kiss, D. Analyzing university students' mode choice preferences by using a hybrid AHP group-PROMETHEE model: evidence from Budapest city. *Eur. Transp. Res. Rev. 16* (2024).

[26] Pangave, V., Khandekar, P., Joshi, M., and Naik, S. IoT based smart saffron cultivation system. *AIP Conf. Proc. 2782* (2023).

[27] Prabhu, H., and Srivastava, A. CEO transformational leadership, supply chain agility and firm performance: A TISM modeling among SMEs. *Global Journal of Flexible Systems Management 24* (2023), 51—65.

[28] Razmavaran, H. M., S. R. A., and Ahmadi, H, S. Water footprint and production of rain-fed saffron under different planting methods with ridge plastic mulch and pre-flowering irrigation in a semi-arid region. *Agricultural Water Management 291* (2024).

[29] Roventa, E., and Spircu, T. Averaging procedures in defuzzification processes. *Fuzzy Sets and Systems 136* (2003), 375–385.

[30] Saha, S., Patil, A., Dwivedi, A., Pamucar, D., and Pillai, A. Analyzing the interactions among delay factors in construction projects: A multi criteria decision analysis. *Reports in Mechanical Engineering 4* (2023), 241—255.

[31] Sarfraz, M., Khaliq, A., Tahir, M. M., Iqbal, M. A., Rehman, Z. U., and Shan, Q. Saffron spice quality in

response to integrated nutrient management under lesser Himalayan conditions of Rawalakot Azad Jammu & Kashmir. *Journal of Plant Nutrition 47* (2024), 18–29.

[32] Sepaskhah, A., and Yarami, N. Interaction effects of irrigation regime and salinity on flower yield and growth of saffron. *J. Hortic. Sci. Biotechnol 84* (2009), 216—222.

[33] Shajari, M. A., Moghaddam, P. R., Ghorbani, R., and Koocheki, A. Does nutrient and irrigation managements alter the quality and yield of saffron (Crocus Sativus L.)? *Agriculture Water Management 267* (2022).

[34] Sharma, A., Gupta, V., Jamwal, G., Gupta, S., Pandit, V., Amin, Z., Mohiddin, F., Hamed, K., and Ashraf, S. Harnessing microbial consortia for sustainable management of corm rot of saffron. *Journal of Basic Microbiology* (2025).

[35] Sreenivasan, A., Shah, B., B., S., and Suresh, M. Modeling of factors affecting supplier selection on start-ups during frequent pandemic episodes like COVID-19. *Benchmarking 30* (2023), 2891–2920.

[36] Sreenivasan, A., and Suresh, M. Readiness of financial resilience in start-ups. *Journal of Safety Science and Resilience 4* (2023), 241—252.

[37] Sumrit, D., and Jongprasittiphol, O. Exploring barriers in supply chain disaster management using fuzzy total interpretative structure modeling approach: Insight from thai automotive industry. *Asia Pacific Management Review 29* (2024), 84–103.

[38] Vago, R., Trevisani, F., Vignolini, P., Vita, C., Fiorio, F., Campo, M., Leri, F., Di Marco, F., Salonia, A., Romani, A., and Bettiga, A. Evaluation of anticancer potential of saffron extracts against kidney and bladder cancer cells. *Food Bioscience 57* (2024).

[39] VImal, K. E. K., Sivakumar, K., Kandasamy, J., V. V., and Mani, R. Barriers to the adoption of digital technologies in a functional circular economy network. *Operations Management Research 16* (2023), 1541–1561.

[40] Vishwakarma, A., G.S., D., Meena, M., Jindal, M. K., Gupta, S., and Jagtap, S. Modelling challenges of blockchain technology enabled healthcare sustainable supply chain management: a modified-total interpretive structural modelling approach. *Operations Management Research 16* (2023), 1781–1790.

[41] Yadav, V., Singh, A., Raut, R., and Cheikhrouhou, N. Blockchain drivers to achieve sustainable food security in the Indian context. *Annals of Operations Research 327* (2023), 211—249.

[42] Zadeh, L. Fuzzy sets. *Information and Control 8* (1965), 338–353.

[43] Zhao, G., Chen, H., Liu, S., Dennehy, D., Jones, P., , and Lopez, C. Analysis of factors affecting cross-boundary knowledge mobilization in agri-food supply chains: An integrated approach. *Journal of Business Research 164* (2023).