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MORALITY BEFORE KNOWLEDGE

Strategic evaluation of the black soldier fly maggot supply chain for sustainable agribusiness development

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ABSTRACT

Background: Optimal and efficient management is needed in handling food waste so that it does not become an environmental problem that impacts global warming, one of which is in Surakarta. One solution is to use maggots derived from black soldier fly larvae for food waste management. The importance of the role of maggots is not in line with its supply chain in Surakarta City, so the operation system is not optimal. This study aims to evaluate how the maggot supply chain in Surakarta is illustrated and provide strategies for the sustainability of the maggot supply chain in Surakarta amid various existing obstacles. **Methods**: This study uses qualitative descriptive techniques with purposive sampling for the selection of informants and experts and continues with analytical techniques using ISM-MICMAC and AHP. **Findings:** The ISM–MICMAC results identify a four-level hierarchical structure of the BSF maggot supply chain in Surakarta. Labor and technology are the main driver variables with strong driving power and low dependency, playing a crucial role in system performance. Weather factors act as external drivers requiring effective risk mitigation. Operational factors, including feed availability, market demand, and supply chain cooperation, are highly dependent on higher-level drivers, while pest disturbance appears as a purely consequential variable. The absence of linkage variables indicates a relatively stable system structure. Overall, strengthening labor, technology adoption, and climate adaptability is key to achieving a resilient and sustainable maggot supply chain. **Conclusion**: The evaluation of the maggot supply chain in Surakarta City can be divided based on the priority numbers to be paid more attention. There needs to be synergy of cooperation between supply chain actors to ensure the sustainability of production in the future. **Novelty/Originality of this article:** The novelty of this study is that there is no research on the evaluation and strategy of the maggot supply chain in the city of Surakarta as well as the combination of analysis methods using the ISM-MICMAC and AHP approaches.

KEYWORDS: AHP; ISM-MICMAC; maggot; supply chain evaluation; Surakarta.

1. Introduction

The world's population is projected by the United Nations (UN) to reach 8 billion in 2022, followed by 8.5 billion in 2030, 9.7 billion in 2050, and 10.4 billion in 2100. The increase in the world's population is in line with the increase in waste production that will be produced. Research by Ahmad et al. (2023) explains that the world's population in 2023 produces solid waste with a total of 3.9 million tons per day. The daily volume of this waste is projected to increase by 70% in 2050. This is a very important problem to be solved immediately to minimize the negative impact that can be had. Food waste is a condition,

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according to Farahdiba et al. (2023), where food is lost in quantity and quality at the distribution and consumption stages. In fact, countries with high incomes will produce a larger amount of food waste when compared to countries with middle and low incomes. Countries that fall into the category of developing countries will face challenges and problems in food waste management. Indonesia is one of the developing countries that is among the countries that are facing challenges and problems in food waste management.

Organic waste or food waste is one of the sources of problems that has not become a massive concern and has not been managed effectively. According to data processed from the United Nations Environment Programme (2021), Indonesia is the number one ranked country in Southeast Asia for food waste producers, with a total of 20.94 million tons per year, coupled with data from Cahyani et al. (2022), which states that Indonesia is the country with the second largest contribution of food waste, with an estimated waste of 300 kg produced per person per year. The data is not only about statistical figures but also as an illustration that shows that Indonesia's food waste contribution contributes greatly. This large contribution must be an urgency regarding what steps should be taken to overcome the waste problem because if it remains in large quantities, it will have an impact on other problems, not only environmental problems. The problems that can be caused can have an impact on economic problems in the form of excessive resource use and will result in an increase in greenhouse gases so that it can worsen global climate conditions. A wider impact can result in a loss of nutritional content, especially carbohydrates, sugar, protein, vitamin A, and iron in food. Organic waste (food waste) at both the urban and rural levels cannot be said to be optimal in its management. Food waste in urban areas can be said to be geographically the toughest challenge due to limited land for storage and ineffective processing, so technology is needed that can decompose organic waste rapidly and effectively. According to research by Waluyo & Kharisma (2023), food waste is categorized as food waste where food is not consumed due to eating or giving excessive portions and food that is wasted due to mismanagement, whether suitable or unsuitable for consumption, usually due to production errors or exceeding the consumption time limit.

The city of Surakarta is one of the cities that has an area of 44.04 square km with a large daily volume of waste production of 303 tons per day. One of the causes is the increasing number of people and activities, resulting in higher daily waste production. The waste will later end up at the existing landfill, the Putri Cempo Landfill located in Mojosongo, Surakarta City. Data on the volume of waste in Surakarta City, according to the Surakarta City Environment Agency (2020), every year always increases, from 2016 to 2020 sequentially at 303 tons/day, 295 tons/day, 310 tons/day, 303 tons/day, and 294 tons/day. Waste decreased in 2020 due to the Covid-19 pandemic, which required the public to limit social, business activities (hotels, catering, restaurants), and events in the city of Surakarta. The results of research from the Gita Pertiwi research team in 2017-2018 show that the potential of household food waste accounts for 34%, hotels, restaurants, and catering account for 32% of the total food served. This figure is comparable to the food waste produced by households of 70 tons/day and almost 50 tons/day produced by hotels, restaurants, and caterers. Waste, if not managed properly, will result in problems including air pollution caused by the waste decomposition process; water and soil pollution caused by sewage seepage that can trigger skin diseases, diarrhea, typhus, and cholera; and the existence of greenhouse gas emissions, which contribute to global warming due to anaerobic decomposition that produces methane gas (CH_4). Food waste, according to Zulkifli et al. (2025), can harm the environment because the resulting effect is a contributor to greenhouse gases, accounting for 5%, and the contribution of methane gas (CH_4) is 6 to 18%. One of the solutions that can be developed for the food waste problem is the management of food waste through maggot cultivation. Maggots come from the larvae of BSF (Black Soldier Fly) flies that are different from the type of flies in general. In addition, the research of Syahputra et al. (2023) explains that maggots can be used as other products, such as feed for fish, birds, and other livestock.

The reason why maggots need to be considered and used in managing urban food waste includes maggots coming from the Black Soldier Fly (BSF) which has the Latin name

Hermetia ilucens. This type of fly is different from flies found in the general environment, where BSF fly larvae can decompose food waste and livestock feces and do not cause disease. In maggot cultivation, BSF flies and other types of flies will be seen in differences where other types of flies will soon die due to an inappropriate environment. BSF maggot larvae have high adaptability by independently extending their life cycle even in bad conditions. Maggots have different types of digestive enzymes for managing incoming organic matter so that the larvae have a high protein content. The types and sources of feed for maggots mostly come from food waste. The waste includes food waste from markets, kitchens, catering, restaurants, hotels; fresh meat or rotten meat; leftovers from slaughtering livestock; leaves; banana fronds; rice bran; and tofu pulp. The requirements for fulfilling maggot feed are that it is free from water content of around 60-90% so that the maggot does not die, free from non-organic materials (detergents, glass, plastic, rubber, and cans), free from caterpillars, maggots, and houseflies and other insects, and the feed must be in a small size so that it is easy to eat. However, the development of maggots in Surakarta City has not been carried out effectively and optimally, one of the causes of which is the supply chain system that has not been structured and has not been directed. The condition of the supply chain system that is not optimal can be caused by the odor caused by maggot feed, which mostly comes from food waste, causing people to be less interested in developing maggots. People who develop maggots usually look for a development site that is far from the homes of residents so that the odor caused is not a problem. Another disruption is the lack of availability of maggot feed for production fulfillment, so it is necessary to establish cooperation with third parties with a mutually beneficial system.

The supply chain according to Jaya et al. (2021), is a merger of the processes of several forms of business units in groups or independently equipped with raw material equipment, the processing process into finished or semi-finished materials, and the process of delivering materials to the end consumer. The supply chain in the context of maggots involves many actors, such as producers or breeders, distributors, suppliers of organic waste to consumers, poultry farmers and fish farmers. The location used as a research site is the Surakarta City Food Security and Agriculture Office, which cultivates maggots and distributes the maggots. Therefore, there is a need for integration and balance between supply and demand as well as distribution to the end consumer, so that a comprehensive analysis of the maggot supply chain in Surakarta City is needed, which is formulated into a supply chain development strategy. The approach that can be used to formulate the evaluation and strategy of supply chain development is the structuring of elements in the supply chain using a combined analysis between Interpretive Structural Modeling (ISM) and the Matrix of Crossed Impact Multiplications Applied to Classification (MICMAC). Research by Wang et al. (2023) explained that ISM-MICMAC has its own role in the analysis, where ISM aims to build a multi-level hierarchical model of pre-formulated factors while MICMAC is used as a determination of factors that have the greatest driving and dependency forces. After that, further analysis was carried out using the Analytical Hierarchy Process (AHP). AHP, according to the research of Barati et al. (2019), explains that a method developed by Saaty in the 1977 effectively solves complex decision-making by determining the best strategy priorities by minimizing the chance of bias in the decision-making process.

The purpose of this study is to examine and evaluate the maggot development supply chain system in the city of Surakarta, identify the key drivers and dependencies in maggot development, and formulate priority and applicable development strategies using a combination of ISM-MICMAC and AHP analysis tools. The existence of an approach that combines multidisciplinary and participatory research in research is expected to later be an academic and practical reference for local governments, business actors, and communities in realizing productive and sustainable waste management. This research is expected to make a theoretical and practical contribution to the development of urban agribusiness system analysis methodologies, especially in the context of circular economy and bioconversion of organic waste, so this research is important to conduct. The multidisciplinary and participatory approach of science applied in this study is expected to provide an overview of the maggot supply chain system as well as policy directions that can be taken and applied to accelerate the development of sustainable strategies in the city of Surakarta.

2. Methods

This research uses a type of descriptive method with a qualitative approach where, according to the understanding of this research method, the aim is to describe in depth a phenomenon, event, or social condition as it is without any engineering. According to Furidha (2023), qualitative descriptive research is a method for describing data problems based on factual research of common events, phenomena, and social conditions. This research was conducted in the city of Surakarta, Central Java Province (Fig.1). The selection of the location of this study uses a purposive method where the city of Surakarta has a source of organic waste such as traditional markets, restaurants, and hotels so that maggot cultivation can be cultivated to reduce organic waste. Meanwhile, Kim et al. (2021), through a case study in China, showed that bioconversion technology by maggots has proven to be effective for the utilization of household food waste.

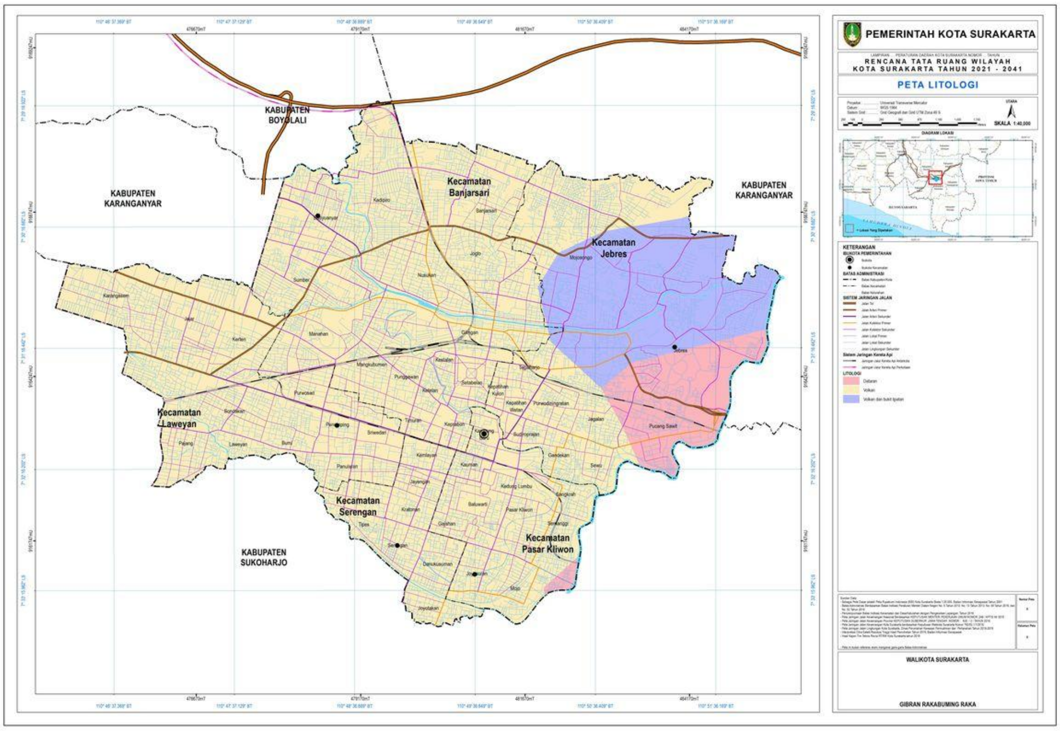

Fig. 1. Map of Surakarta City

The sample used in this study are several experts who have the ability, expertise, and experience in maggot cultivation and play a direct role in the marketing supply chain of maggots. The number of experts used is 10 people consisting of producers, distributors, consumers, service staff, and the Head of the Surakarta City Food Security and Agriculture Office. The data source comes from primary and secondary data. According to Cerar et al. (2021), primary data is raw data about research in the form of direct information collected by researchers and has never been published before. Primary data collection is carried out through various methods, such as problem identification through field surveys, interviews, experiments, and observations. The primary data in this article is sourced from interviews with experts who use questionnaires to conduct advanced analysis of ISM-MICMAC and questionnaires for AHP analysis, while secondary data comes from journals, books, and websites of the Surakarta City Environmental Agency. The tools used to analyze the data use the ISM-MICMAC website and the AHP Super Decision Software version 3.2.

The Interpretive Structural Modeling (ISM) method is one of the analysis techniques introduced by Warfield in 1974. Research conducted by Wu et al. (2023) states that the essence of ISM analysis is to identify what factors affect a system and then analyze these factors to find out the relationship. Research by Agarwal et al. (2023) explains the calculation steps carried out by the ISM, including the following. The first step is to assess the sample by providing whether one element affects the other by tagging using the VAXO or Structural Self Interaction Matrix (SSIM) assessment rules. The VAXO symbol indicates that V is when a row affects a column (i versus j), A is a column affecting a row (j versus i), X is when a row and column affect each other, and O is when there is no relationship between a row and a column. The second step is called Reachability Matrix (RM), which in this step is a follow-up analysis of SSIM by converting symbols into numbers. These changes include if the symbols V, A, X, and O become the numbers 0 or 1, where if the symbol in SSIM is V, then in RM it becomes ij = 1 and ji = 0; if SSIM is on A, then in RM it becomes ij = 0 and ji = 1; if SSIM is on X, then in RM it becomes ij = 1 and ji = 1; and if SSIM is on O, then in RM it becomes ij = 0 and ji = 0. The third step is called Conical Matrix, or the process of ranking between the power driver on the RM and the rest (driver power and dependence) to create coordinates in the MICMAC analysis.

The next analysis used was the Matrix of Cross Impact Multiplications Applied to Classification (MICMAC), developed by Duperrin and Michel Godet in 1973. According to Toulabi et al. (2024), MICMAC is used for the reason of knowing the power drivers and independent variables derived from the ISM. The dependencies and interdependencies between factors at different levels are illustrated by the arrows and nodes in the model that will be depicted in a MICMAC diagram (Fig. 2). The variables will be classified into 4 types of areas, including area I, which is autonomous; area II, which is dependent; area III, which is called independent; and area IV, which is linkage. The explanation of each area includes autonomous areas (weak drivers and weak dependents) where this variable describes a low level of dependency and control. Changes to these variables will not cause significant changes to the system. Dependent areas (weak drivers and high dependents) where the variables show strong dependency accompanied by low control. In this area, it has a small influence on the system but is also greatly influenced by the system. An independent area (strong drivers and weak dependents) where the level of dependency is low and the control is high, so it is referred to as the rest of a system. The last area is linkage (strong driver and strong dependent), where strong dependency is also accompanied by strong control, so it must be studied carefully because it is unstable. If not, then even a small change will change the system significantly.

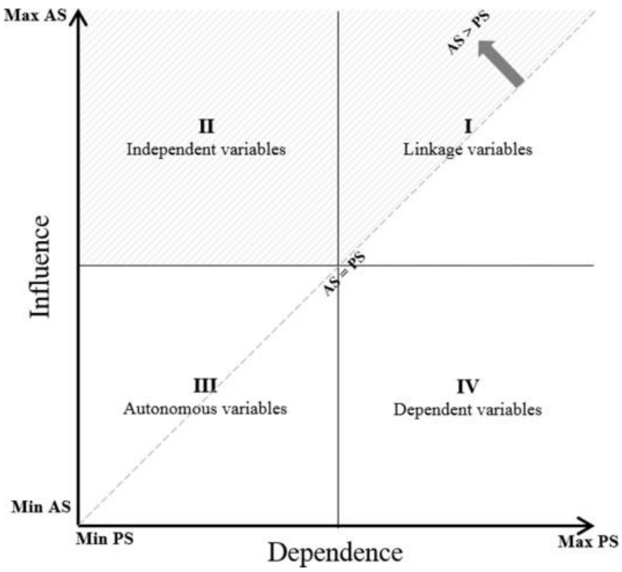

Fig. 2. Examples of quadrant division types in MICMAC analysis

In this study, the first stage was carried out by researchers to identify problems that exist in the maggot supply chain in the city of Surakarta. The problem identification stage was carried out by conducting a direct survey of the maggot production site in the city of Surakarta. After completing the first stage, the next step is to compile a questionnaire based on the results of identifying problems that occur in the maggot supply chain in the city of Surakarta. The questionnaire was prepared according to the questionnaire to determine the structural construction of the relationship between variables derived from the identification of problems as inputs for the ISM-MICMAC analysis, which is in accordance with the research of Chen et al. (2023), who conducted the ISM test first to determine the input to the follow-up analysis before the AHP analysis. The results of the ISM-MICMAC input were analyzed using the ISM website software by entering each judgment from experts. The next step is to calculate the priority weight using the AHP analysis. The AHP method can be analyzed using multicriteria software, one of which is Super Decision software version 3.2. In the AHP analysis, priority weights function as a determinant of which criteria or variables should be prioritized for problem solving so that they can know what kind of decision-making should be made. Research by Goel et al. (2022) explains that the use of combined analysis can definitively analyze information with ISM analysis and rank priority weights using AHP. Judgments between experts from each other, according to Singh & Kumar (2024), can sometimes produce inconsistencies and subjectivity, so to avoid this, Saaty (1977) uses the calculation of consistency index (CI) and consistency ratio (CR), where the result must be less than 0.10, and chooses experts who are experts in the field to avoid too long a distance between values.

3. Results and Discussion

3.1 ISM-MICMAC

Interpretive Structural Modeling (ISM) is an analysis technique used to facilitate decision-making in complex situations. ISM is a modeling technique that describes specific relationships between variables and the overall structure. The output is in the form of a graphical model with levels and quadrants that can be changed (Rusydiana, 2018). Interpretive Structural Modeling (ISM) is one of the approaches that can be used to investigate supply chains. A study conducted by Tham et al. (2020), ISM was used in the analysis of the relationship between criteria and classified the criteria into 4 clusters. This is because the ISM can be used to establish relationships between system metrics, including supply chain parameters (Verma et al., 2018). The MICMAC analysis was constructed using driving power and dependent power values obtained from the final transitivity results of the RM matrix. Furthermore, according to the research of Oktavia et al. (2019), the MICMAC analysis is separated into four quadrants, including linkage, autonomous, independent, and dependent. The function of MICMAC analysis is that, in accordance with MICMAC research, it helps to determine factors that are included as driver factors and dependencies of each element. MICMAC can be a determinant between variables that affect each other and interdependence, which can be classified into 4 group quadrants: autonomous, dependence, independence, and linkage. The ISM-MICMAC analysis used in the study of Khan et al. (2022) is interconnected, which is reinforced by the research of Xie et al. (2023) that the MICMAC method of ISM-MICMAC is an advanced attribute classification that calculates the dependencies and driving forces of influencing factors against the mapping of the status and function of influencing factors.

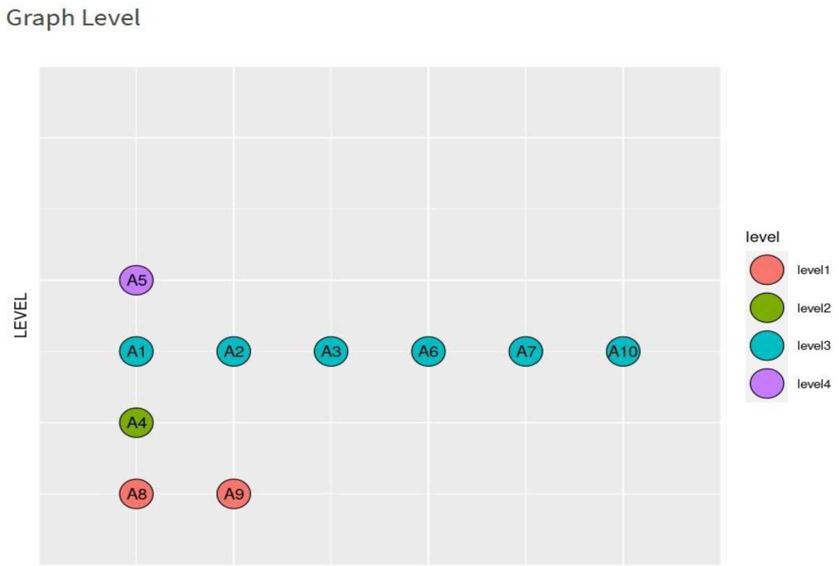

Fig. 3. ISM-MICMAC

The results of the analysis (fig. 3) were obtained from the mapping of the components in the maggot supply chain system in Surakarta, which are divided into four levels. This mapping describes the arrangement of influences between variables from the most basic (main driver) to the most affected (consequential). At Level 1, two main variables were identified, labor (A8) and technology (A9). Research by Yamin et al. (2024) explains that one of the success factors of the dexterity of a supply chain depends on the labor who supposed to do it. Labor can be the main driver because behaviors such as leadership, expertise, social culture, competition, and policy makers are things that only labor must ensure the running of the supply chain. Furthermore, Santa et al. (2022) explained that if you are in a competitive supply chain condition, it requires knowledge and expertise from labor so that they can compete in a healthy manner. However, the condition of labor with each other can be limited because they are influenced by each region, infrastructure, connections, and policies. These two variables of labor and technology have a high driving force but a low level of dependency, so they are categorized as driver variables. Research on the use of technology in maggots by Van et al. (2022) shows that technology has proven to be a major driver in the maggot supply chain, especially the production part. The technology is used in terms of monitoring temperature, light, and pH in maggot eggs and larvae using IoT. Technology is also used in the research of Satria et al. (2023), the process of harvesting, breeding, and controlling feed and pests using photovoltaics with the help of IoT that can control temperature and humidity so that it can be efficient and facilitate the use of resources. According to Dave & Kumar (2021), independent variable zones are made up of critical success factors (CSFs) that show strong impetus but have a weak degree of dependence on other factors. What this means is that the success of the system is largely determined by the optimization of these two factors.

Furthermore, at Level 2, there is a variable weather factor (A4) that, although external and difficult to control, still has a considerable influence on other elements in the system. This indicates the importance of risk mitigation efforts in supply chain management. Maggots cannot live at temperatures that are too low or too high because they can cause maggot larvae and maggot pupae to die. Weather can affect the growth of maggots, especially if maggots are in cold weather during the rainy season. Normally, maggot farmers will protect maggot cultivation places from being submerged in rainwater. According to Salam et al. (2022), weather is influenced by several variables, including temperature, humidity, pH, sun intensity, and moisture content. The optimal number for temperature is 30, the optimal moisture content is 65-90%, humidity is 60-65%, the intensity of the sun is 80% with 110 moles m2°Cμ^{s-1}, and the optimal pH is 6-8. According to Puji (2024), this risk mitigation can reduce negative impacts that can reduce the quality of the product or output produced. Level 3 contains six variables: feed availability (A1), market demand (A2), production constraints (A3), feed contamination (A6), public perception (A7), and synergy of cooperation between supply chains (A10). These variables show a high dependence on factors at the top level. According to Rosalinda et al. (2022), variables that have a dependence on the upper level cannot be overcome technically but need strategic intervention from the policy and institutional levels so that they can be a representation of operational issues that need to be addressed strategically.

Meanwhile, Level 4 has only one variable; pest disturbance (A5), which has the last position in the hierarchy structure. This variable has a role that is greatly influenced by the dynamics of the system but does not have a significant influence on the other components. According to Soesanto (2021), variables that are at the bottom or end can represent operational issues that are greatly influenced by the system but do not encourage system change directly. Thus, the structure of the system that has been formed shows that strengthening in the aspects of labor and technology, as well as readiness to face external challenges such as weather, is the key to the development of a resilient and sustainable maggot supply chain system.

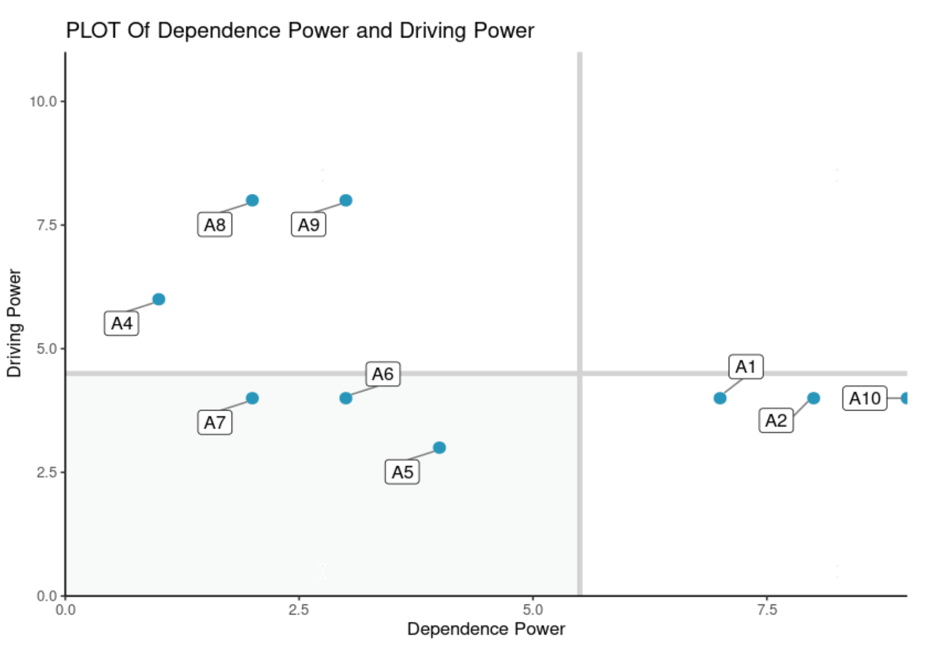

Fig. 4. ISM-MICMAC results in dependent plot and driving power

The results show the driving force and dependence of the maggot supply chain in Surakarta. No linkage variables were found in the system studied, according to the mapping results obtained using the ISM-MICMAC method (Fig. 4). This is shown by the absence of components in quadrant I, areas with equally high driving power and dependency power values, because there are no components that act as dual factors that affect significantly and are greatly influenced by other factors, so the absence of related variables shows that the structure of the system is relatively stable, 'weather factor' (A4), 'HR' (A8), and 'technology' (A9) are defined as independent variables. This means that the success of the maggot supply chain in Surakarta depends heavily on the efficiency of these drivers or that they can influence all other factors. 'Feed availability' (A1), 'market demand' (A2), and 'synergy of cooperation between supply chains' (A10) are defined as dependent variables (these driving factors are highly dependent on other driving factors and require special attention). 'Pest disturbances' (A5), 'feed contamination' (A6), and 'public perception' (A7) are autonomous variables that are not greatly influenced or influenced by other factors.

3.2 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a method introduced by Saaty in 1977 as a basic tool to support the best decision-making based on multicriteria. The opinion of Carpitella et al. (2024) explains that AHP uses a paired comparative analysis technique consisting of objectives, criteria, sub-criteria (if any), and alternatives, where later alternatives are compared with each other for each given criterion so that the best alternative results from several criteria are obtained. AHP has conditions that must be compiled, including alternatives, criteria, and a paired comparison matrix that must be consistent. Therefore, if the consistency ratio is more than the threshold, the analysis cannot be continued, and the researcher must re-evaluate the data and re-analyze. The AHP analysis, according to Shameem et al. (2020), has 3 main cores: a hierarchical structuring model of problems, comparing judgments from experts regarding criteria and alternatives, and synthesizing results. The analysis used in this study does not only use AHP but also uses combined analysis to structure. The analysis used is that AHP is a follow-up analysis of the ISM-MICMAC analysis with the reason to strengthen the existence of the best strategy that can be used in maggot analysis. This is in line with the research of Verma & Rastogi (2024) that to avoid limitations and increase the confidence and reliability of the results, AHP analysis can be combined with other analytical tools. AHP has an advantage to be used in this evaluation analysis because, according to Nassereddine & Eskandari (2017), AHP has a level of adaptation in assessing structured criteria and alternatives, assessing the level of consistency towards responses, and assessing hierarchical structure-based assessments. AHP uses hierarchical analysis in its assessment, according to Zhu et al. (2022), which divides the problem into hierarchical structures starting from objectives, criteria, sub criteria, and alternatives that will later be solved using eigenvectors and pairwise comparison matrices to determine the priority weight of each level and obtain the final goal.

In this study, 3 hierarchies were used: objectives, criteria, and alternatives, because the sub criteria were considered optional, which were analyzed using Super Decisions software version 3.2. The purpose of this study is to evaluate the maggot chain in the city of Surakarta. The criteria used amounted to 4 criteria, including economics and market, environment, human and organization, and technical production. There are 10 alternatives used, feed availability, market demand, production constraints, weather factors, pest disturbances, feed contamination, public perception, labor, technology, and synergy of cooperation between supply chains (fig. 5).

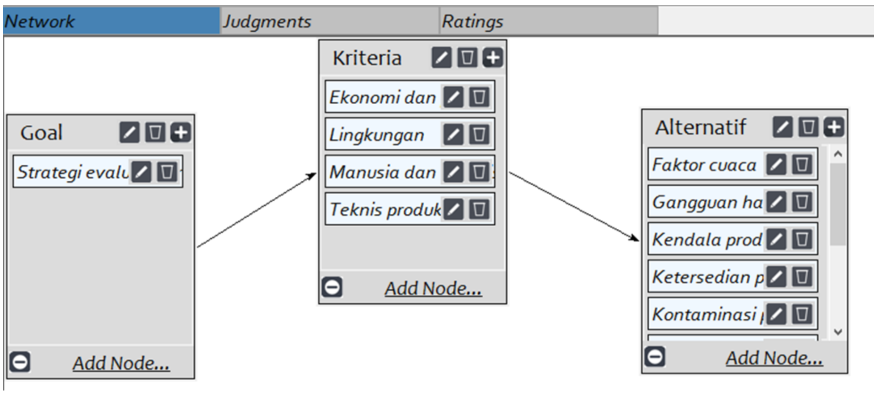

Fig. 5. Objectives, criteria, and alternatives in super decisions software

The calculation of the analysis in AHP using Super Decisions software based on the judgment of several experts in the field of maggot supply chain shows the results that will be divided in the priority scale. The priority scale in the maggot context criteria shows the largest numbers on economic and market criteria compared to other criteria. The priority of the economy and the market was 0.692, followed by technical production at 0.156, people and organizations at 0.092, and the environment at 0.060 (table 1). The results of this priority amount are taken based on paired comparisons sourced from the judgment of experts.

Table 1. Priority among the 4 criteria

Criteria	Priority
Economy and markets	0.692
Environment	0.060
People and organizations	0.092
Production technical	0.156

In the analysis of the maggot supply chain, the role of the economy and the market is the main thing that must be paid more attention to because the economy and the market are the main drivers in the supply chain. There will be no production and distribution if the maggot does not have demand and supply as well as capital if there is no market or consumer buying. The maggot supply chain in Surakarta City consists of producers, distributors, consumers, and food waste suppliers, so these actors are the determinants of the economy and market of maggots in Surakarta City. This is in line with the research of Santoso et al. (2023), which explains that the sustainability of the economic dimension in maggot production is influenced by planning, organizing, directing, and controlling management, so it is important to pay attention to its sustainability considering that maggots are a commodity that is not only useful but also produces added value. Diaz et al. (2024) explained the relationship between global supply chain changes caused by economic and market changes (drastic changes in commodity prices, inflation rates, and drastic changes in demand in several countries). Another thing that makes the technical criteria of production a second priority after the economy and the market is that all aspects used in maggot cultivation generate added value. Almost any stage of the maggot process can be reused, and nothing is thrown away for free. This utilization, for example, can be seen in the maggot pupa, which can be used as feed for poultry, fish, and other livestock; maggots can decompose animal feces to be a soil fertilizer; and maggots can decompose food waste. Research by Handayani et al. (2021) explains that maggot cultivation can turn food waste into something of added value and can be used. One of the reasons why maggots have added value is because of the protein in maggots that comes from food sources that are eaten from food waste.

In economic and market criteria, there are several alternatives given. The priority amount of the 10 largest alternatives is at the alternative market demand of 0.425 (table 2). The other largest alternative priorities are the availability of feed (0.223) and production constraints (0.124). The largest priority scale indicates that alternatives are more considered because they influence the strategy of the largest decisions. The market demand for maggots in Surakarta City is relatively high. The average maggot consumer comes from outside the city, including Sukoharjo, Sragen, and Karanganyar. The role of market demand in the economy and market is that an economy and market will not run if there is no demand for related products. The relationship that occurs can be described as a catalyst for maggot business actors to increase the level of production in maggot cultivation. Research by Benedict & Ghosh (2018) explains the effect of an increase in demand where an increase in demand can lead to an increase in production and employment so that the effect is economic growth. Producers will increase production to meet existing demand in the market so that there are positive effects for the economy (Samosir et al., 2023). This is strengthened by the discussion of this research, where research by Sogari et al. (2019) shows that the increase in demand for insect food can improve the circular economy in several countries. According to China ASEAN Studies & PIM (2022), demand can always be available in the supply chain if actors in the supply chain understand and are responsible for what tasks and obligations must be carried out in relation to the supply chain from upstream to downstream, where in this study it starts from maggot producers or breeders, and maggot feed suppliers to end consumers. Another thing that has a big priority is the availability of food and production constraints that must be considered. The availability of feed, in this case food waste, is related to the production of maggots because with enough feed, maggots will develop with high protein content so that they can increase added value. This added value will have an impact on the economy and the market. Research by Santos et al. (2023) shows that maggots are preferred for animal feed because the larvae are rich in protein and other substances so that livestock can grow healthy. Production constraints must be carefully considered because they will interfere with the production course.

Table 2. Priority in economic and market criteria

Criteria	Priority
Weather factors	0.029
Pest disorders	0.041
Production constraints	0.124
Feed availability	0.223
Feed contamination	0.055
Market demand	0.425
Public perception	0.016
Labor	0.037
Synergy of cooperation	0.029
Technology	0.022

The next criterion is an environment with the same alternatives as the previous criteria. In the environmental criteria, the largest alternative priority was found in the weather factor of 0.283, pest disturbance of 0.280, feed contamination of 0.134, and public perception of 0.109 (table 3). This large priority number indicates that the environment needs to receive more attention so that it does not significantly affect maggot cultivation. The environment is very important in the maggot production process. Maggot eggs will be damaged if they are submerged in water if there is heavy rain accompanied by flooding. Control of temperature and humidity is essential for the successful hatching of eggs until they become larvae. According to Cammack & Tomberlin (2023), the ideal temperature for maggot development is 24-30°C with a humidity of 55-70%, and the temperature prone to failure to hatch in maggots is below 15°C and above 40°C with humidity below 40%. The pest nuisance that usually attacks is rodents, so maggot breeders usually protect maggots from being reached by rodents. Detergents become contaminants in maggot feed so that they can cause death. Feed storage is very important to prevent feed from being contaminated with other chemicals. The last priority is the perception of the public, who think that the maggot emits an unpleasant smell. This unpleasant smell actually does not come from maggot but from food waste used as a source of maggot feed. However, maggots can be used to reduce aroma, such as in research by Beskin et al. (2018), who explain that maggot cultivation can generally be found in places far from densely populated settlements. An experimental study from Burhan et al. (2025) that addresses the problem of unpleasant odor is the addition of effective microorganism 4, or EM4 in maggot feed material. The experimental research proved that EM4 has a positive effect on the odor caused by maggot feed and positively affects the growth of maggots.

Table 3. Priority in environmental criteria

Criteria	Priority
Weather factors	0.283
Pest disorders	0.280
Production constraints	0.025
Feed availability	0.034
Feed contamination	0.134
Market demand	0.019
Public perception	0.109
Labor	0.054
Synergy of cooperation	0.040
Technology	0.023

In other criteria, humans and organizations, they also consist of the same alternatives as other alternatives. Human and organizational alternatives that have the highest priorities are labor at 0.259, synergy of cooperation at 0.244, and public perception at 0.214 (table 4). The magnitude of these numbers indicates the priority of the order of greatest concern.

Table 4. Priority in human and organizational criteria

Criteria	Priority
Weather factors	0.018
Pest disorders	0.020
Production constraints	0.039
Feed availability	0.066
Feed contamination	0.040
Market demand	0.068
Public perception	0.214
Labor	0.259
Synergy of cooperation	0.244
Technology	0.031

In the context of human and organizational discussions, the biggest priority is labor as the main actor in the sustainability of the maggot supply chain. Labor takes control of the supply chain from the production process to purchasing from consumers. However, the fact that occurs in the field is that labor is experiencing a shortage of numbers. This is due to the lack of interest in maggot cultivation, public perception that maggots produce an unpleasant aroma, the assumption that the cultivation process is complicated, and ignorance about supply and demand in the market. The biggest obstacle is that maggot cultivation cannot be placed near densely populated houses because there will be rejection from the surrounding community because of the smell caused. The supply chain can be successful or not depending on the synergy between actors from upstream to downstream, where they understand how and what the tasks of each actor are. The research of Putri et al. (2023) explains that actions can be taken to dampen the scent of maggots other than production sites far from residents' homes, choosing container lids to reduce evaporative aromas, maintaining humidity to prevent intense anaerobic fermentation, choosing the right substrate for rapid degradation so that the aroma can be controlled (for example, with dry carbon [dried husks and leaves]), aeration with activated charcoal to filter out the volatile organic compounds of the maggot, and pre-composting before use. The last criterion in maggot research is production techniques. The alternatives that received the highest priority numbers were labor at 0.283 and feed availability at 0.212 (table 5). These two largest alternatives should be considered in the maggot supply chain because they play an important role.

Table 5. Priority in the technical criteria of production

Criteria	Priority
Weather factors	0.064
Pest disorders	0.090
Production constraints	0.096
Feed availability	0.212
Feed contamination	0.099
Market demand	0.024
Public perception	0.015
Labor	0.283
Synergy of cooperation	0.076
Technology	0.040

Labor in relation to technical production play an important role because without labor, a technical production cannot run. The success rate of maggot cultivation depends entirely on the quality and skills of labor. Production can fail if labor is not trained, even though adequate technology is available. Research conducted by Suryaneta et al. (2022) in

Lampung explains that local maggot farmers are given training from the substrate selection process to harvest. This indicates the importance of trained labor to improve the quality of production and adapt to diverse environments. The use of technology in maggot cultivation in the city of Surakarta can be said to not be used much because producers are used to manual techniques, even though the use of technology can be considered. This is in line with Avila et al. (2022) for the merger between the use of technology and labor so that a smart bin system was developed. Smart bins can perform tasks such as aeration and monitoring of environmental conditions. The division of tasks for labor and technology can facilitate the business sustainability process through automation. In addition, the importance of the availability of maggot feed plays an important role. Maggot business actors strongly avoid leftover vegetable and fruit feed because most of the content is water, and maggots will die or growth will be stunted due to too much water. The problem of the availability of maggot feed in the city of Surakarta can be said to be limited. This is because there is no relationship between the food waste source channel and maggot producers, resulting in producers having to look in distant locations. In addition, other factors such as the absence of regulations from the government on this matter and waste handling are not good. The main source of maggot feed is food waste, but not all food waste can be a source of maggot feed. This is because some food waste contains oil, detergents, high sodium, plastics, vegetables and fruits that contain high water, and other chemicals that can harm maggots. The way producers continue to ensure the availability of optimal maggot feed is to collaborate with hotels, several restaurants, and landfills.

4. Conclusions

The evaluation of the maggot supply chain in the city of Surakarta is a very important discussion as part of the processing and management of urban food waste. Food waste, which is the source of urban problems, can be used as a source of feed for maggots. Maggot is the larva of the black soldier fly (BSF) type of fly which is different from flies in general because this fly does not carry certain types of diseases. Maggots have many benefits as well as positive value and added value because maggots are the source of feed for livestock, soil fertilizer, livestock manure processors, fish bait for fishing, and other organic waste decomposers. Maggot was chosen as an alternative feed for livestock on the grounds that maggot contains high fiber from organic feed sources that contain high protein content, such as bones, rice, tofu dregs, bran, and meat. In fact, although it has many benefits and generates added value, the main maggot production in Surakarta City is not optimal due to the problems caused. The existing problems are, for example, urban residents who reject the existence of maggots because the smell caused by organic feed disturbs the environment, so if they want to produce, they must choose a location far from residents' homes. This is what makes the problems in the maggot supply chain an interesting discussion to research because there is not much to discuss, especially in the city of Surakarta.

The evaluation analysis of the maggot supply chain in this study uses a combined analysis method from ISM-MICMAC and AHP. The goal is to determine the best decision-making strategy to solve the problem and prioritize alternatives from several existing criteria without forgetting the alternatives to each other. The results of the ISM-MICMAC analysis explain that the main driving factors of this study are divided into 2, labor and technology. Labor and technology are determining factors in the sustainability of the maggot supply chain, which, when eliminated, the condition of the supply chain will not run or will not be successful. The follow-up analysis uses AHP analysis to determine the priority of the strategy, with the amount of priority weight divided into several hierarchies. In the analysis of AHP, economic and market criteria hold the first priority among other criteria. On the economic and market criteria, the biggest alternative is market demand; environmental criteria are weather factors; human and organizational criteria are labor; and technical production criteria are labor. The task of all supply chain actors is to always be aware of the responsibility in the maggot supply chain from upstream to downstream (producers to end consumers). Awareness of the responsibility of supply chain actors will have an impact on the synergy of cooperation so that it will ensure the sustainability of the maggot supply chain in the future.

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