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Exploring the Role of Cooperatives in Maize Circular Economy Adoptions for Sustainable Food Security in Malaysia

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Abstract

Sustainable food security has emerged as a critical issue in Malaysia, where maize agriculture continues to be vulnerable given constraints in local production and dependence on imported provisions. The present qualitative study aims to investigate the contribution of agricultural cooperatives in developing maize agriculture, transforming it into what is referred to as the circular economy that would serve food security and sustainability. Informed by the Sustainable Livelihoods Framework and Circular Economy Theory, this study has discussed how cooperative involvement stimulates the adoption of the circular economy and enhances agricultural strength in the long run. Primary data has been collected through semi-structured interviews, which were conducted among five respondents of Malaysian maize farmers from Kedah state. Thematic analysis of the study shows that cooperatives are transformative, by promoting knowledge sharing, resources and finance in the society. Farmers practiced circular economy, such as composting of maize residues, application of organic fertilizers and utilization for rearing animal feed. These measures led to a decrease in production costs, soil fertility enhancement and increasing yield sustainability. The study finds a robust mediating relationship that circular economy adoption connects cooperative participation to the sustainable food security impact. In this way, the cooperatives perform as social and economic brokers that instantiate sustainability through collective learning and innovation. Findings highlight the relevance of policy schemes that can contribute to enhancing maize production capability and incentive mechanisms for promoting circular economy education and green finance. Therefore, the study shows that cooperatives hold a potential role in transforming Malaysia's maize agriculture toward regenerative, inclusive and sustainable food supply as seen by the Malaysian national Agrofood Policy 2.0 and Shared Prosperity Vision 2030.

Keywords: Maize Agriculture, Cooperative Role, Circular Economy, Sustainable Food Security

Introduction

Consistently and affordably feeding and supplying a growing population without depleting natural resources is an enormous challenge for Malaysia. Feed grains, such as maize, are in immediate demand following rapid urbanisation and the dietary transition toward protein. Some alternative industrial and cooking use for maize are starches, sweeteners, and silage as biofuels involving livestock or cogeneration (Ahmad Safuan Bujang, 2017). Local maize production in Malaysia is minuscule and cannot keep pace with soaring demand, especially for animal feed ingredients. Cooperatives have existed in Malaysia from its early years, assisting smallholder and marginal farmers to combine their savings to buy inputs, take risks and access the market for extended rural development. Cooperatives, with their democracy-based governance and shared ownership, are well-placed to invest in the sort of shared infrastructure drying, storage and processing facilities for grains that can increase yield while reducing waste, as they enable large-scale maize production (Amin, Ahamat, & Hassan, 2024). Through the repurposing and recycling of agricultural products such as maize husks, stalks and cobs into animal feed, organic fertilisers, compost and bioenergy, the concept of a circular economy provides an innovative approach to further advance resource conservation practices in maize production. To attain food security, reduced dependence on foreign suppliers, eco-friendly practices and a better life for farmers in Malaysia would require a blend of cooperatives with FEA principles in maize production (Athirah Ahmad, Nik Omar, & Engku Ariff, 2024). Cooperatives "help to mitigate the problem of scale by acting almost as middlemen between individual smallholder farms and the state in that they can bargain for government programmes, access group credit, and make logistics and infrastructure work on a larger scale than an individual farm could", thus making maize farming "a scalable industry, not a niche" (Wah, 2025). The research aims to understand how cooperatives in Malaysia can adopt circular economy approaches to gain the best possible benefits in the long run with respect to food security. The discussion of existing production methods, supply or demand gaps, and obstacles, as well as the potential for collaboration and what has or has not stopped efficacy, offers an overview of the conjunctural need to integrate.

The world's sustainability agenda, like UN Sustainable Development Goals 2 and 12 – SDG 2 and 12 concerning sustainable food systems and responsible consumption, can be correlated with a circular economy and cooperative groups. In a combination of the Circular Economy Theory (Kovalenko, 2025) and Sustainable Livelihoods Framework (Natarajan et al., 2022), cooperatives can offer evidence that things can be resilient. This gives us better tools for the study of sustainability issues and opportunities in Malaysia's maize industry.

Malaysia has an annual demand for about 4 million metric tonnes of maize, primarily for feed, and is highly dependent on global markets for the same (Hamzah & Yusoff, 2025). This dependence has the potential to erode the strength of animal industries and consumer pricing, as well as food security more generally, especially during a period of global food supply disruption. The maize industry in Malaysia encounters frequent disputes; nonetheless, its own capability and strategic importance (Ibrahim, 2025). The sector produces almost zero locally and imports nearly 100% of its inputs (Haris et al., 2024). These vulnerabilities bring agro food under the double pressure of supply disruption, currency fluctuation and higher demands for feed and food. Despite the explicit government commitments to reducing

import dependence, most notably reaching a target in which 50% of national maize grain requirements would be met from local production within five years (Cahyadi et al., 2024; Helgi Library, 2024), the context appears complex and challenging. Maize-based companies still underutilise cooperatives in spite of the fact that they are significantly involved in promoting rural development in Malaysia. The combination of technology, finance and knowledge could make cooperatives potential game changers in maize in a circular economy concept where we make use of the by-products for animal feed, bioenergy and organic fertilisers, which will be a self-sustainable process reducing waste and strengthening sustainability (Hamzah & Yusoff, 2025).

This study aims to examine how cooperatives can contribute to the development of the Malaysian maize industry, which has low national production and high consumption because it relies on imports. In 2022, the local production at home was only approximately 63.2 thousand metric tonnes out of the few million tonnes consumed per year, indicating an urgent need to scale up local production for food security and stock enhancement (Rizal, Md Nordin, & Abd Rashid, 2023). The centrepiece of the paper is to suggest that smallholders' access to complementary services, risk reduction mechanisms, resource pooling, and improved infrastructure through market-oriented interventions may work in reducing post-harvest losses by raising yields. Besides the endorsement of maize and its spin-off products as assurance in agricultural sustainability, the paper integrates circular economy thinking into maize production. Policymakers, cooperative leaders and industry players in Malaysia can benefit from the main findings of this study to shape policy construction and sustainable agriculture expansion.

In that context, the analysis should focus on the research barrier to linking cooperative models to maize circular economy initiatives in Malaysia. In recent studies (Hamzah & Yusoff, 2025; Cahyadi et al., 2024) recent empirical findings highlight a lack of empirical evidence about the change-making roles cooperatives play for integrating circular practices into the agro-food industry. This work addresses the gap by exploring cooperative-driven circular practices that encourage reducing import dependency and promote sustainable maize production in compliance with Malaysia's Shared Prosperity Vision 2030. It thus addresses both the theoretical and practical gap in sustainable agriculture and the cooperative economy.

Literature Review

Global Maize Production Comparison

Maize, scientifically known as Zea mays L, is one of the most globally cultivated cereal food crops, with adaptability and high productivity across tropical lowland to temperate ecosystems, even at sea level to elevations up to 3,000 metres in more than 160 countries (Crop Trust, 2015). Primarily a food crop, with much of the maize grown worldwide used as feed for livestock, some is processed for human consumption and as a chemical, while its expanding use in biofuels presents additional.

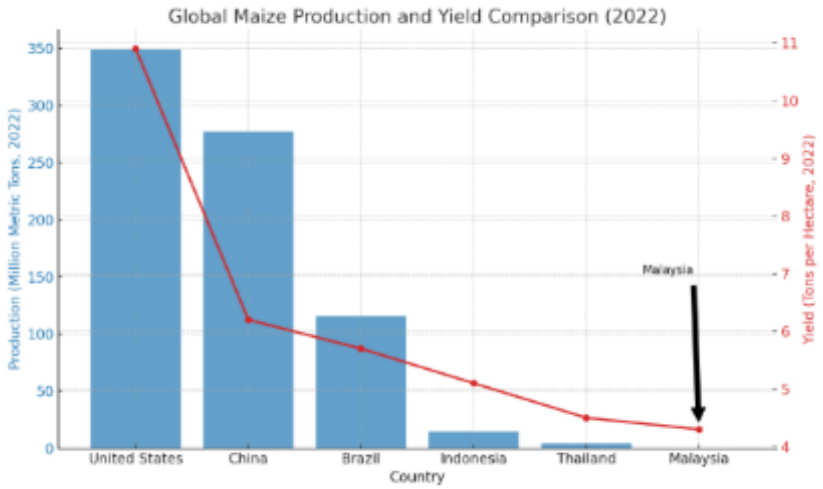

Figure 1: Global Maize Production Comparison

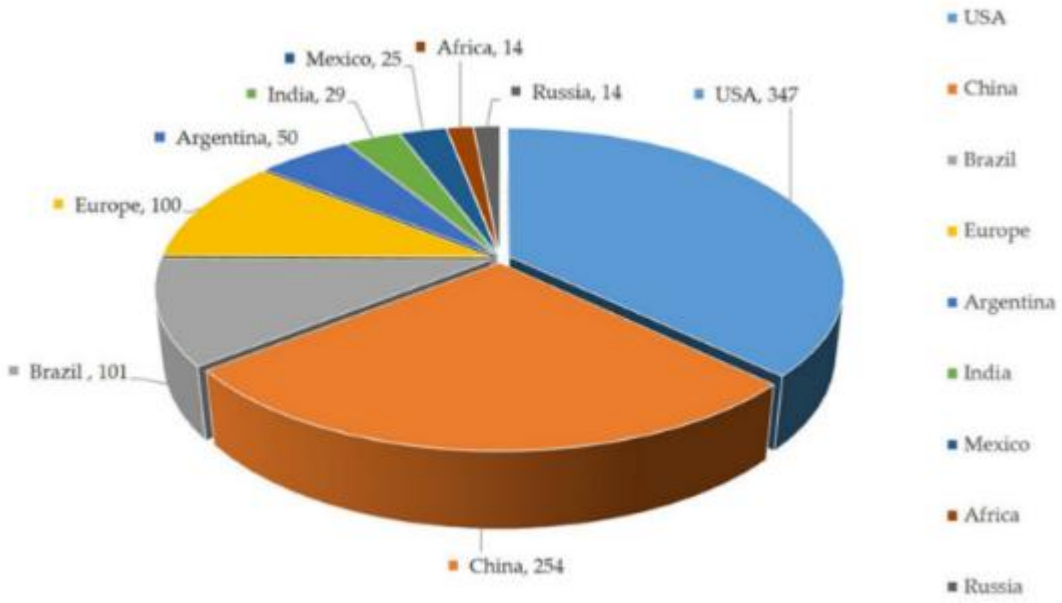

Figure 2: Top Maize Production Countries

The food supply for the world has markedly improved, and maize has enriched people's lives. Maize joins wheat and rice as the three most important sources of dietary calories for nearly 4.5 billion people in 94 developing countries, accounting for over 30% of all calorie consumption (Erenstein et al., 2011). In the coming decades, it is expected that demographic growth and growing incomes leading to increased consumption of grain-based food, both meat products as beef, poultry, and dairy, will contribute to increasing the demand for maize, and hence the necessity of moving some inputs around. Differences in per-area maize yields can be observed, though. In advanced countries such as the US, yields often exceed 10 t/ha. Yields in many developing countries are much lower. This in turn points at infrastructure, seed quality, as well as climate resilience and technology (AgricultureNotes, 2023; Erenstein et al., 2011).

Malaysian maize farmers play a modest yet significant role in the national economy. In 2022, Malaysia harvested approximately 63,200 metric tonnes of maize, reflecting a 15.5% decline compared to the preceding year (Amin, Ahamat, & Hassan, 2024). Most countries require substantially more maize than this production can provide, especially for uses in animal feed. The Malaysian maize industry is increasingly reliant on foreign suppliers. To meet its feed needs in 2017, Malaysia imported about 3.7 million metric tonnes of grain maize while producing around 80,000 metric tonnes of maize domestically, revealing a large trade and food security gap (FFTC-AP, 2018).

Table 1
Global Comparison of Maize Production and Yield (2022)

Country	**Production (Million Metric Tons)**	**Yield (Tons per Hectare)**
United States	348.75	10.9
China	277.20	6.2
Brazil	116.00	5.7
Indonesia	14.50	5.1
Thailand	4.50	4.5
Malaysia	**0.063**	**4.3**

Note: Data compiled from FAO, USDA, and Helgi Library reports (FAO, 2023).

Because maize is both a major source of human and animal nutrition and an industrial product, it is of enormous global significance (Amin, Ahamat, & Hassan, 2024). This is the situation in Malaysia, where there is significant potential but notable limitations, such as its low output, productivity limitations and high import dependency (Athirah Ahmad et al., 2024). Remedying these gaps is critical to improving food sovereignty, decreasing import bills, developing the livestock industry, and finally building resilience in Malaysia's agro-food systems.

Table 2
ASEAN Maize Production

Country	**Production (Million Metric Tons)**	**Yield (Tons per Hectare)**
Indonesia	14.50	5.1
Thailand	4.50	4.5
Vietnam	4.00	4.7
Philippines	8.00	4.2
Malaysia	**0.063**	**4.3**

Note: Data compiled from FAO (2023), USDA (2023), and Helgi Library (2024).

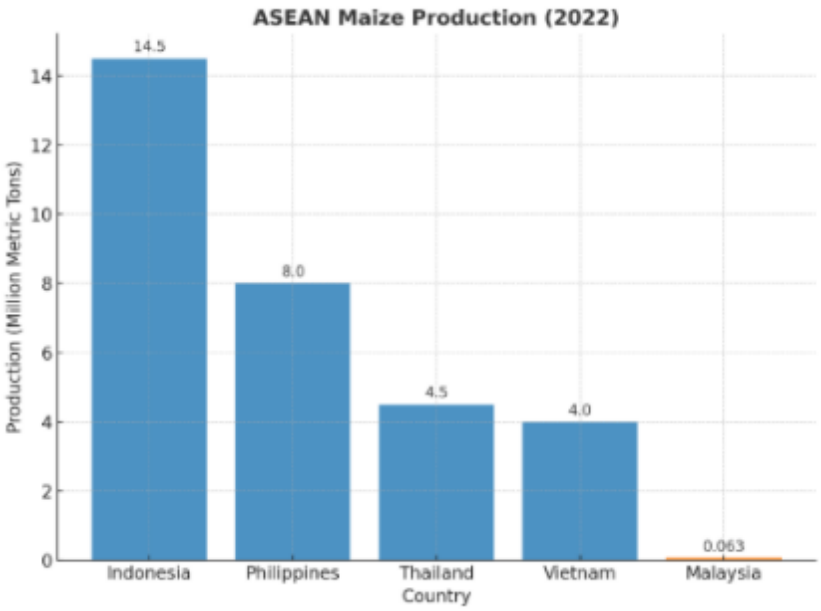

Figure 3: ASEAN Maize Production

Maize production in Southeast Asia varies across countries. These figures highlight not only the scale of maize production in Indonesia and its role in human and animal diet and nutrition in the country that is the largest maize producer in the region, having produced a total of 14.5 million metric tonnes of maize in 2023, according to FAO (Basir et al., 2024). They all grow the same crop, that is sugar, and in a year, the Philippines actually produces 8 million tons, Thailand and Vietnam produce 4-4.5 each (Cahyadi et al., 2024). In general, the average seed obtained ranges from 4.2 to 5.1 per hectare, low production compared to the rest of the world, if we exclude the U.S and China, as the world average in productivity is higher (Hamzah & Yusoff, 2025).

According to Helgi Library (2024), Malaysia's 2022 maize production was a paltry 63,200 metric tonnes. This 4.3 metric tons per hectare might not seem like a good number but when one considers the following table one can see that this number is not that high compared to other ASEAN countries, meaning that it is not an alarming number for Malaysia (Haris et al., 2024). The problem is that we import maize; we are not producing on a large scale, so farmers cannot participate. According to the USDA (2023). Malaysia imports over 3,500,000 annual metric tonnes of grain maize, which are consumed mainly by the poultry and animal sectors. The comparison is evidently low also because this output is much lower than the one developed by Malaysia, an agronomically much higher country. Eventually, the only way to increase food production and enhance food security while reducing the country's reliance on food imports, especially in Malaysia, is through more agro-food cooperatives and a circular economy.

Maize Agriculture in Malaysia

Maize, Zea mays L., is a staple food with important use as livestock feed, and cultivation of the crop is important to be sustainable in Malaysia. The maize industry is facing several challenges (Nosratabadi et al, 2019). As such, Malaysia is a net importer of maize, largely in part because local production has not been enough to supply the need for animal feed, and

more than half of it is consumed for the poultry industry (Rizal et al., 2023). This results in greater sensitivity to global market prices and further food security concerns (Patelski, 2025). The growth of the local crop of maize has also picked up due to government programs encouraging crop diversification and decreased reliance on imports. Productivity is further hindered by environmental stress such as droughts and flooding, which have been linked to climate change, soil acidity and insect infestations. As an example of the former, armyworm Spodoptera Frugi Erda, for which initial documentation in Malaysia goes back to 2019, is completely depleting maize agriculture, and the use of a long-term solution such as integrated pest management is greatly necessary (Abdul-Hamid et al., 2025). In the case of these pests, biocontrol studies, such as the use of entomopathogenic nematodes, have been conducted to control the problem (Abdul-Hamid et al., 2025).

Table 3
Maize Agriculture in Malaysia

Aspect	Current Situation	Challenges	Opportunities
Production Volume	Limited; insufficient to meet national feed demand (Toridi et al., 2025)	High import dependency	Potential for expansion under government support
Climate Impact	Susceptible to floods & droughts (Toridi et al., 2025)	Yield instability	Climate-smart practices
Pests & Diseases	Fall armyworm infestation since 2019 (Abdul-Hamid et al., 2025)	Crop losses	Biocontrol (nematodes, IPM)
Soil Fertility	Acidic soils restrict yield (Shujrah et al., 2024)	Nutrient uptake issues	Use of potassium humate, organic amendments
Technology	Small-scale mechanization	Low adoption	Precision irrigation, microbial inoculants
Market	Heavy reliance on imports (Patelski, 2025)	Price volatility	Domestic expansion reduces vulnerability

Soil quality is another constraint. It is reported that the humate product, potassium humate, is promising to be used to improve tropical peat soil since it improved nutrient uptake and maize growth in acid Malaysian soil; hence, it indicates hope for the use of humate agents in the application of sustainable soil management practices (Shujrah et al., 2024). The importance of an adequate irrigation assessment in the production scenarios with variable rainfalls has also been highlighted in water optimisation studies (Toridi et al., 2025). Rosnan et al. (2025) propose that the use of microbial bio-fertilisers and beneficial microorganisms may be a better and new way of enhancing the resistance of maize plants to abiotic stresses. These approaches also reflect Malaysia's commitment to sustainable agriculture as well as its aspiration to be less dependent on synthetic inputs. Despite some progress, the domestic room for manoeuvre between supply and demand is still considerable. Malaysians continue to import millions of tonnes of hydrocarbons every year, mostly from South America (Sadi, 2021). The transfer to a more extensive maize agriculture and the integration of technology, as well as sustainable agricultural practices, will be necessary to increase competitiveness and recapture food sovereignty.

Maize Contribution to Sustainable Food Security

Maize (Zea mays L.) is a cultural reservoir for human nutrition, economic prosperity, and environmental equilibrium; it is inevitable for global sustainable food security. Maize, being

one of three major cereals along with wheat and rice, that feed billions of populations, including through animal feed, is also associated with the United Nation's Sustainable Development Goals (SDGs) as it can be used not only as an inexpensive source of calories in combating micronutrient embodiments but also as a vehicle for biofortification, i.e. vitamin A maize (Tanumihardjo et al., 2020; Wang & Zhang , 2024). In the case of countries like Zimbabwe and Malawi, where maize totals 60% of the land under cultivation, it is the staple food source for households in Sub-Saharan Africa (Akinnifesi et al., 2010). For a shift to sustainable intensification to occur without mining the soils, practices such as 'fertiliser trees and evergreen agriculture improve soil fertility and maize yields (Garrity et al., 2010). Maize is also highly valuable along the value chain, contributing to food system resilience. Maize has taken on this role in both industrial and smallholder food chains in the sense that it provides employment and economic opportunities in Asia and Africa, where these varieties seem to be preferred to others (Grote et al., 2021). Even more relevant within the current climate catastrophe and water shortage are the climate-smart maize varieties that are more pest- and drought-resistant, providing an even higher regional production stability (Langner et al., 2019).

Table 4
Maize's Contribution to Food Security

Dimension	Contribution of Maize
Nutritional Security	Provides energy-rich staple food; biofortified varieties improve micronutrient intake (Tanumihardjo et al., 2020).
Economic Security	Supports the livelihoods of millions of farmers; significant role in global feed and food markets (Grote et al., 2021).
Ecological Sustainability	Fertilizer tree systems and evergreen agriculture improve soil fertility and reduce deforestation (Akinnifesi et al., 2010; Garrity et al., 2010).
Climate Resilience	Drought-tolerant and pest-resistant varieties enhance adaptive capacity under climate change (Langner et al., 2019).

Role of Maize in the Circular Economy

Maize is important to the circular economy; it not only promotes sustainable production and low waste but also produces byproducts with value addition (Wah, 2025). Maize agriculture itself is, in a second line, a second type of reason as it is more efficient in resource utilization, it has the potential for 'circularity, and waste valorisation' to the food, feed and industrial systems of nutrients and energy, and it is flexible. Also, the processing of corn generates several co-products that can be linked back into an agricultural and industrial system that would not have to find ways of dealing with them as waste. Cobs, husks and stover are utilised for bioenergy, compost, and animal bedding, which decreases the use of non-renewable energy sources (Mulyanto et al., 2025). Also, the production of starch, oil, and distillers' dried grains with soluble (DDGS) from maize is an example of converting agricultural surplus to food, feed, and energy contributors and is in line with the circular economy (Dovhal et al., 2024).

Maize-based circular agriculture stresses nutrient cycling in particular. When biochar is used for the cultivation of maize, it has been estimated that it leads to a reduction in CO_2 emissions, while at the same time, it neutralises the CO_2 sequestered by the increase in yields, which is an improvement in carbon sequestration derived from enhanced regenerative soil management (Enaime et al., 2023). In livestock systems, maize can benefit from an effective

manure cycle that utilises organic fertiliser derived from animal manure applied in the maize fields, resulting in reduced reliance on synthetic fertilisers (Taifouris and Martin, 2021). These positive implications on food and feed security are also a benefit of the integration of circular economy elements in maize growing in Sub-Saharan Africa. This would also be more resource efficient and less environmentally impactful, as crop residues for maize would be utilised better for animal feed and energy production (Duncan et al., 2023).

Theory and Discussion

The Sustainable Livelihoods Framework (SLF) (Natarajan et al., 2022) and Circular Economy Theory (CET) (Kovalenko, 2025) are employed in this study as theoretical perspectives. In particular, SLF focuses on the role of human, social, natural, physical, and financial capital in livelihood systems (Amin et al., 2024). In the Malaysian maize sector, cooperatives contribute to enhancing farmers' adaptive capacity by allowing them to access not only collective financial capital but also collective human capital (Athirah Ahmad et al., 2024). Instead, CET is centred on material flows, value retention, and regeneration. It indicates that rather than agricultural systems that produce waste, the cycle should be completed by waste being fed back into agricultural systems as new inputs. An application of CET to maize agriculture would be to identify a way for crop residues, manure, and wastewater to be perceived as productive resources or inputs rather than agricultural constraints that can therefore cut costs and emissions and increase soil fertility. This study positions cooperatives as agents for socio-ecological change, in line with the Twelfth Malaysia Plan (2021-2025) for a sustainable food system and the incorporation of a green economy into development agendas and policies focusing on rural empowerment (Hamzah & Yusoff, 2025).

Research Framework

This study connects the concepts of cooperative participation and adoption of the circular economy model to outcomes in sustainable food security. The cooperative aspects of participation include activities such as collective marketing, joint financing, and information sharing among maize farmers. Higher levels of participation also tend to reduce the risks of investment and to enhance innovation diffusion. Such a switch would embrace composting and other strategies of sustainability and resource efficiency. Sustainable food security is measured by the ability to access, availability, and utilisation, as well as the stability of the availability and conditions of food resources that are dependent on maize within each community. Food security is thus directly linked to cooperative food practice and constrained by a lack of participation in cooperative food practice, which in turn is a causal factor in the adoption of the circular economy. CE, as an adoption mechanism, increases impacts in terms of sustainability. Development of cooperatives may also depend on moderating factors such as levels of state support, ability to access markets, and the level of infrastructure or education.

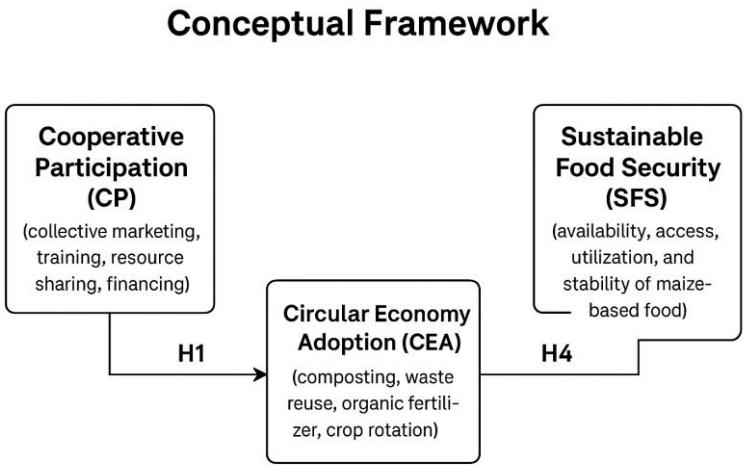

Figure 4: Research Framework

Framework Summary
H1: CP → CEA (Cooperatives drive CE adoption)
H2: CP → SFS (Cooperatives directly enhance food security)
H3: CP → CEA → SFS (CE mediates cooperative impact on food security)
H4: CEA → SFS (Circular practices enhance food availability and stability)

Hypothesis Development
Cooperative Participation
Shared inputs, joint crop sales, and learning make significant gains on the technical and economic fronts (Wah, 2025). Cooperatives for maize in Malaysia have demonstrated the ability to generate economies of scale, lower transaction costs, and facilitate access to information. Cooperatives foster social capital, enabling farmers to build trusting relationships, collaborate, and pool resources. High participation is also instrumental in being able to collectively respond to market and climate shocks, and this has a positive impact on the transition to CE and equitable food security. Therefore, this study suggests a significant correlation between cooperative participation and the implementation of sustainable agriculture.
H1: Higher levels of cooperative participation among maize farmers positively influence circular economy adoption.
H2: Cooperative participation has a direct positive effect on sustainable food security outcomes.

Circular Economy Adoption
The circular economy must embrace sustainable production practices by making recycled waste, organic inputs, and resource productivity part of the production process. In maize farming, this means “composting of maize stalks, applying animal manure and synergising maize-livestock farming systems” (Widiastuti et al., 2024). The practices referred to by Mahdi & Hamzah (2024) align perfectly with the agroecological projects emerging in Malaysia, which promote green development and food sovereignty (Toridi et al., 2025). The move to worker cooperatives also requires information, capital, and institutional change, often led by the cooperatives themselves. If the farmers are trained by CE-focused cooperatives, a focus on

CE would foster a willingness to adopt sustainable practices that will, by necessity, reduce input and environmental degradation. In other words, cooperative participation influences food security through the adoption of CE.

H3: Circular economy adoption mediates the relationship between cooperative participation and sustainable food security outcomes.

Sustainable Food Security

Food security is the physical and economic ability to obtain adequate, safe and nutritious food. Within a cooperative, the concept of food security moves beyond the household to a collaborative pursuit of greater food security. Ishak et al. (2025) present several other valid reasons supported by empirical evidence for the existence of cooperatives, which include minimising food availability problems through lower food costs via the bulk production and distribution systems created by cooperative-member economies like Malaysia. Sustainability encompasses not only the maintenance of a stable yield but also the environment that facilitates the achievement of this stable yield (Hamzah & Yusoff, 2025). The application of circular practices, such as composting and organic agriculture, in practice, though, leaves a food system that is more regenerative and therefore less reliant on the necessity of inputs. Thus, the construction of cooperatives is less about food security in the typical sense of having food and even agriculture done sustainably and more about ideas of social cohesion, economic stability, and ecological equilibrium (Enaime et al., 2023).

H4: Circular economy adoption positively influences sustainable food security outcomes among maize farmers.

Research Methodology

The study uses a qualitative case study approach to examine how cooperatives are engaged in the process of supporting sustainable maize agriculture and integrating the circular economy in Malaysia. This study specifically looks at the Kedah State, which is an agriculturally based powerhouse. The qualitative research can provide an in-depth exploration of participants lived experiences and understandings of cooperative and CE practices (Creswell & Poth, 2018). Interviews are the main source of data, conducted in a semi-structured style to be flexible in the ability to probe the issues of cooperative activities and the adoption of sustainability. These are cooperative reports, agricultural policy documents, and other empirical studies. It is not intended to be broadly generalizable and focuses on explanations rather than statistical findings.

Data Collection

The data is generated from semi-structured and in-depth interviews with five maize farming cooperatives in the state of Kedah, an agrarian area for paddy and maize production in Malaysia. Selected from a pool of farmers active in the cooperative for at least 5 years, already growing maize, and already participating in sustainability programs. The interviews ranged from 60 to 90 minutes and were in Bahasa Malaysia, with the majority later translated into English. Though no formal reasoning was given for conducting interviews in farmers' homes or cooperative offices, in the local area, this practice was likely meant to achieve a comfortable and open interview space. All participants did so willingly and were provided with pseudonyms (Farmer A-E) to ensure confidentiality.

Data Analysis

The analytical process incorporated the six steps of Braun and Clarke's (2006) thematic analysis: familiarizing, coding, identifying themes, reviewing themes, defining and refining, and synthesizing. Through an analysis based on a deductive use of NVivo 14, a series of related themes around participation in cooperation, engagement with the circular economy, and connected issues around food security were identified.

Theme 1: Cooperative-Driven Knowledge Sharing

Each of the 5 indicated that their cooperatives are the primary source of agricultural training. Regular examples included compost and integrated pest management trainings, and financial literacy trainings. Farmer B described it as:

> *I used chemical fertilizers before the cooperative. I began the process of making biofertilizer from maize waste and cow dung after attending cooperative training. "It saved me money, and it is good for the soil."*

This is in line with SLF human-capital-building, whereby the act of knowing increases the sustainability of livelihoods. Cooperative-facilitated learning is also consonant with the diffusion of innovation in CET in that the farmers can apply the sustainability principles.

Theme 2: Resource Pooling and Financial Empowerment

But cooperatives played an important role as they supplied the necessary material and were willing to fund the adoption of CE. One of these is a guarantee that farmers will share resources, using the example of a composting drum and a grain dryer to help reduce the overhead of having to invest in all of the equipment needed for standard processing and distribution. Farmer D stated that access to microcredit through the cooperative allowed him to purchase irrigation systems and dryers that run on renewable energy. These results also highlight the ability of cooperatives in generating financial capital, which can support investments in CE that individual farmers cannot afford to make.

Theme 3: Integration of Circular Economy Practices

The adoption of CE was the most consistent theme. Maize residues had been used for livestock feed, poultry litter had been composted for organic fertilizers, and intercropping systems had been applied to improve land use, among other things. Immediately, Farmer E set about initiating circular production loops on behalf of other farmers, including a cooperative project to create pellets from the waste corn cobs, stalks, and husks to fuel local dryers. It is a clear sign that cooperatives are experimental systems that, rather than through the attempt of exporting certain practices, develop and foster shared learning in practice.

Theme 4: Environmental and Social Sustainability Outcomes

The incorporation of CE programming had direct ecological benefits. Farmers have reported changes in their soil, stating that the texture of their soil is different, as well as across the board, using less water and reporting an increase in biodiversity on their farms. On the social level, cooperative activity developed community cohesion and more equal profit sharing. For some remote farmers, it was the joint marketing they did together to keep maize prices stable when they began to fluctuate in the market, directly benefiting their household food security. The outcome of this is a positive feedback loop: farmers begin to trust and become more involved with cooperatives, feeling that they see economic benefit in comprising their

membership and with measures taken to invest in the environment and the retreating waters, and vice versa.

Theme 5: Barriers and Institutional Challenges

And yet, there were also setbacks. Issues identified by respondents included long bureaucratic wait times for government grants, an absence of availability of high-tech CE, and the underrepresentation of youth. Farmer C described the disinterest of the younger generation who find farming less “attractive” than jobs in the cities. That implies that, as in the case of CE with cooperatives, there must be incentives at the policy level and a new generation entering to sustain it.

Synthesis and Theoretical Alignment

The analysis between themes, as presented above, helps to substantiate the conceptual framework articulated above. The cooperative process of collaboration and participation (Themes 1 & 2) was strengthened by engaging with CE adoption (Theme 3), which then resulted in enhanced sustainability outcomes (Theme 4). There was evidence of a particularly strong mediating effect of CE practices, where, through the adopted tactics of composting and recycling of waste, farmers not only obtained higher yields but also income stability. On the theoretical side, the results support the Sustainable Livelihoods Framework, which demonstrates the way in which cooperatives develop human, social, and financial capital. They also cohere with the premises of Circular Economy Theory because they imply the social organization of recycling and waste minimization and resource regeneration through the process of cooperation.

Interpretive Summary

This data exposes cooperatives as being more than just another service delivery model, in that they are also a vector for socio-ecological change. They also seek to integrate CE into collective agricultural practices to put the principles of sustainability into practice. By integrating collective action with the practice of CE, the maize producers in Kedah were able to increase both the sophistication of output and efficiency, which reduced costs and improved food security, essentially meeting local livelihood imperatives and national sustainability objectives.

Results and Findings

In the unstructured interviews, the links between participation in cooperative action and the circular economy were clear. Furthermore, suppliers reported that belonging to the cooperative has led to much-needed training processes in ecological fumigation, irrigation management and composting maize stubble. There were opportunities for cooperatives and members to reuse leftover maize stalks in animal feed, which saved cooperative and member money and reduced waste.

As an example, Respondent A reported, "Our cooperatively shared composting equipment helped us reduce chemical fertiliser by 40%." Respondent C also found benefits in farming inputs, receiving biofertilizers among other fertilisers, and improving soil with the support of the Ministry of Agriculture. These results further support the role of cooperatives as intermediaries for knowledge and the transfer of technology and education on sustainability.

Cooperatives had a strong element of circulatory economy in them. Zero-waste practices were common; for instance, using post-harvest waste material to feed animals and rotate crops was a method to promote soil rejuvenation. According to some records kept by participants, this resulted in a 15-20% increase in crop yield while also saving on input costs. The ability to create income generation opportunities, including maize milling cooperatives, also helped to contribute to their group's livelihood resiliency. The cooperative model also gave farmers a sense of collective empowerment, of increased bargaining power and less reliance on middlemen.

Overall, these findings support the notion that cooperative participation has an important, expected, direct effect on the likelihood of CE adoption, and therefore strengthen the influence of participation on sustainable food security. The qualitative interviews also provide a general sense of the cooperatives as part and parcel of the broader struggles for social change, linking environmental sustainability and rural economic empowerment in Malaysia.

Implications

This research indicates the necessity of cooperatives in the circular economy in Malaysia and in sustainable food systems overall. The study indicates that incorporating cooperative models in the National Agrofood Policy 2.0 of Malaysia can be a vehicle that drives the change towards sustainable maize production (Basir et al., 2024). They can be centres of activity for CE training, microfinance, market access programmes, and initiatives. They can also serve as hubs of innovation for farmers, which would lead to food sovereignty at a local level since they would ensure efficient use of resources, reduce reliance on imports for inputs, and create a self-sustaining production cycle for local food resilience. This idea is inconsistent with Malaysia's Shared Prosperity Vision 2030 of achieving more equitable and fair growth with a focus on empowering and revitalising the rural areas. The research finds evidence that a CE-based cooperative system can shift maize agriculture into a regenerative, profitable, and socially just sector that secures food over time.

Limitations

There are several limitations in this study to be addressed in future research, among them the relatively tiny sample size of only five farmers observed in Kedah, which limits the ability to generalise the findings to the overall maize farmers' community in Malaysia. Future research should try to replicate these findings using larger samples and in other states, such as Kelantan, Perlis, and Perak, to examine contextual variations. The primary data collection technique employed interviews and questionnaires, both relying largely on self-reporting, which can raise problems of reactivity or socially desirable responses. The strength of this data could be increased, for increased triangulation, by combining this data with information from observations in the field or collaborative documentation. The temporality of the measurements is cross-sectional, as the experiences are assessed at a single time point. A longitudinal analysis would provide further insight into the processes surrounding the dynamics of involvement in cooperative organisations and the uptake of CE. In the end, AI's strength is in its capacity to analyse large amounts of associated data patterns, but it cannot understand the subtleties that accompany human thought. But more nuanced hand-coding conducted by local agriculture specialists would be required to glean more contextual specificities. While it is not quantitative, this is valuable anecdotal evidence of cooperatives'

ability to act as an energising agent to raise the acceptance of circular economy practices and improve food security in Malaysia's maize crop.

Recommendations

This effort could begin by introducing focused training with monetary support for activities that pertain to the circular economy, for example, composting, renewable energy, and waste-to-fertiliser projects. Such initiatives could be improved by cooperatives working with research institutes. The Malaysian government plans to explore green financing schemes and tax rebates for cooperatives implementing circular economy concepts in maize production. This empowerment, in the form of having capital, is what will make a meaningful and enduring change in the relationship of power at play for smallholder farmers. Using digital integration of cooperatives would help to allow a more streamlined supply chain by way of solutions for better real-time information flows to benefit efficiency. Tracking systems could be employed digitally to guarantee transparency and sustainability in maize products. If undertaken, such steps can pave the way for Malaysia to start a symbiotic circular economic cycle that is collaborative and focused locally, which will increase the productivity of maize, minimise waste, and strengthen the country's food sovereignty.

Conclusion

This research indicates that cooperatives can play a more significant role in promoting sustainable maize and the circular economy in Malaysia. The formation of cooperatives allows farmers to employ regenerative techniques that improve food security in the long run through collaborative learning, sharing resources, and eco-innovation. This shows that the adoption of the circular economy is dramatically boosted by its collaborative nature, with positive effects on sustainable food security. In the Kedah case, amongst all farmers, cooperators were the most resilient and effective in terms of cost and steady income. From a theoretical perspective, combining the SL and CET contributes towards a holistic approach to social and ecological sustainability. This convergence of ideas illustrates the process through which cooperation and circular economy principles can be used while trying to look after the welfare of others build a movement. This study advances the ongoing debate about the ways in which sustainable agricultural development in Southeast Asia can be achieved. It seeks to further incentivise the adoption of cooperative forms of green growth and rural development in Malaysia's maize industry and in efforts to ensure that the other three pillars of food security, environmental sustainability and economic inclusiveness are growing together.

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Data Availability

The survey data was obtained in a confidential way and is carefully maintained in accordance with ethical requirements. Hence, study data is not confessable publicly.

AI Usage Declaration

A research framework for the study has been developed by the author. The authors of this study made considerable usage of QuillBot, a program that fixes grammar and spelling mistakes, to make the content easier to read and understand. The author(s) has(haves) taken full responsibility for the publication's content after using this tool/service, having reviewed and amended it as necessary.

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