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Technological Innovation and Digitalisation in Monitoring MSPO Compliance: A Review on Blockchain Technology

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ABSTRACT

The Malaysian Sustainable Palm Oil (MSPO) certification ensures sustainability, environmental responsibility, and ethical practices in the palm oil industry. However, challenges such as supply chain complexity, data manipulation, and a lack of transparency hinder effective compliance monitoring. The agricultural supply chain, particularly in palm oil production, faces issues related to traceability, fraudulent practices, and inefficient record-keeping, making it difficult to uphold sustainability standards. Blockchain technology, with its decentralized and immutable ledger, offers a potential solution to these challenges. Key features such as transparency, security, and smart contracts facilitate real-time data sharing, ensuring greater accountability across the supply chain. This paper explores the role of blockchain in enhancing MSPO compliance by improving traceability, reducing fraud, and fostering trust among stakeholders. Additionally, blockchain-driven digitalisation can automate compliance verification, reducing administrative burdens and increasing operational efficiency. The study further discusses the future prospects of blockchain technology in agriculture, emphasizing its potential integration with IoT and artificial intelligence to create a robust, data-driven ecosystem. The findings suggest that blockchain has the potential to revolutionize MSPO compliance monitoring, paving the way for a more transparent and sustainable palm oil industry.

1. Introduction

The demand for palm oil is escalating in parallel with global population growth, driven by its versatility in a wide array of products, including processed foods, cosmetics, and biofuels. Its competitive pricing compared to other vegetable oils further enhances its appeal. Malaysia and Indonesia are the leading producers, accounting for over 85% of global production, followed by Thailand and Colombia [1]. However, the palm oil industry faces criticism for environmental impacts such as deforestation, peat destruction, biodiversity loss, and exploitation [2]. Palm oil consumption has been linked to health concerns, including cardiovascular diseases due to its saturated content [3], though some studies suggest no conclusive evidence linking it to

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cardiovascular disease [4,5]. Traditionally, palm oil is used in both the food sector (80%) and non-food sector (20%), including biodiesel and oleo chemicals [6]. The growing demand for alternative fuels has positioned palm oil biodiesel as a renewable resource, boosting exports to Europe [7,8]. Expert Market Research forecasts a 5% annual growth in the global palm oil market from 2021 to 2026, with production increasing from 82.8 million tons to 111 million tons [9]. Palm oil accounts for 31% of biodiesel raw materials in Southeast Asia. In 2017, the European Union used 87% of its palm oil imports for biodiesel production, driven by robust legislation supporting sustainable practices. Growing consumer demand for sustainable products has heightened concerns about palm oil sustainability in Europe, emphasizing the need for certified and sustainable imports [10]. This stance was reinforced by the Amsterdam Declaration in 2015, where six EU countries committed to 100% sustainable sourcing by 2020 [11]. As the global population is projected to reach 9 billion by 2050, an additional 35 million tonnes of oils and fats will be required annually, increasing the demand for palm oil and the pressure on producing countries to ensure sustainable production practices [12].

In 2015, the Malaysian government launched the Malaysian Sustainable Palm Oil (MSPO) as a national standard to underscore its commitment to sustainable palm oil production. Properly planned and monitored cultivation and processing of palm oil can help mitigate carbon stock degradation and enhance conservation values [13-15]. The introduction of MSPO by the Malaysia Palm Oil Board (MPOB) reflects a strong commitment to maintaining environmental ecosystems for safe and healthy palm oil production. Consequently, compliance with MSPO became mandatory for all Malaysian palm producers as of December 31, 2019 [16]. In addition, organizations worldwide are applying innovative technologies to reduce the burden they are putting on the environment [17]. Organizations recognize the importance of innovative technologies and comprehend that customer value and their long-term organizational success and, indeed, their survival depends on their ability to integrate new innovations and technology solutions [18].

Furthermore, government institutions are requiring enterprises to improve their compliance with the regulations and directives regulating environmental protection [19]. As a result, corporations are changing their supply chains (SCs) to more ecologically friendly decisions and implementing strategies geared toward improving environmental SC performance [20]. Organizations across the world are implementing novel technology to lessen the environmental impact of their operations [17]. Organizations understand the importance of innovative technologies and customer value, and their long-term organizational performance, and even survival, is dependent on their capacity to incorporate new innovations and technological solutions [18]. Industry 4.0 technologies, including the Internet of Things, artificial intelligence, robots, 3D printers, and BCT, provide significant support for sustainability activities such as reuse, recycling, green procurement, and remanufacturing [21-23]. These technologies must be incorporated into the business process to reap their full advantages [24,25], as they may help coordinate and align business partner goals [26], which, in turn, improves the whole supply chain [27,28], with a particular emphasis on sustainability [29,30]. Practitioners and academics [31] appreciate BCT's ability to build a trustworthy and transparent transaction information ledger. This article investigates the use of blockchain technology in improving MSPO compliance monitoring. Specifically, although blockchain technology has been recognized for its potential in improving transparency and traceability in supply chains, its direct application and integration into MSPO compliance frameworks remain underexplored.

2. Overview of Malaysian Sustainable Palm Oil Compliance

The Malaysian Sustainable Palm Oil (MSPO) accreditation is an important project aiming to guarantee that palm oil production in Malaysia adheres to strict sustainability criteria. The certification procedure monitors compliance by traditional means such as manual inspections, documentation, and audits [32]. While these strategies have played an important role in developing a framework for adhering to sustainability principles, they have inherent limits that reduce their overall efficacy.

Manual inspections are a primary way to determining conformity with MSPO criteria. Inspectors do actual inspections to plantations and mills to assess environmental practices, working conditions, and management systems. This hands-on strategy enables for direct inspection of activities, ensuring that sustainability standards are satisfied. However, manual examinations are time-consuming and resource-intensive, necessitating substantial travel to frequently inaccessible areas [33]. This logistical difficulty might be especially difficult for smallholder farmers who may lack the capacity to conduct frequent inspections. In addition to inspections, paperwork is an important part of the certification process [34]. Palm oil producers are expected to keep detailed records on land usage, chemical treatments, and labor procedures. These papers are used as key references during audits, allowing auditors to verify compliance with MSPO standards. Manual record-keeping, while important, is time-consuming and prone to human mistake. Managing large quantities of documentation can be difficult, resulting in mistakes that jeopardize the validity of compliance evaluations [35]. Audits are another important component of the MSPO monitoring process. Certified auditors conduct these reviews at regular periods, which include analyzing documentation, interviewing stakeholders, and witnessing on-the-ground activities. Audits give a thorough examination of compliance, but they do not provide real-time information. Because audits are conducted on a regular basis, possible noncompliance concerns may go unnoticed for long periods of time, delaying important remedial steps [36].

One of the most significant disadvantages of traditional monitoring systems is their time and resource-intensive nature [37]. Manual inspections need substantial cost in terms of travel, staff, and logistics preparation. Smallholder farmers and smaller plantations may find these standards unreasonably expensive and difficult to maintain efficiently. Furthermore, the dependence on human judgment in audits and inspections involves subjectivity and possible biases, which can impair the consistency and accuracy of compliance assessments. Errors in data collection or documentation increase these issues, resulting in disparities in evaluation findings. Another key restriction is the limited scope of manual checks. Given Malaysia's huge number of palm oil plantations and smallholder farms, it is impractical to undertake regular inspections in all locations [38]. This creates gaps in monitoring and enforcement, increasing the likelihood of undiscovered noncompliance. Furthermore, the problems of data management make it difficult to keep accurate records and undertake significant trend analysis. The reliance on paper-based documentation reduces the capacity to assess compliance over time and identify areas for improvement. The lack of real-time monitoring is another disadvantage of typical MSPO compliance approaches [39]. Because audits and inspections are conducted on a regular basis, problems may go unreported for months, allowing non-compliant behaviors to continue unabated. Delays in finding and rectifying breaches can result in long-term environmental and social problems, weakening the certification process's credibility. Furthermore, a lack of openness in compliance monitoring can lead to trust difficulties among stakeholders [40]. Without accessible and reliable data, consumers and regulatory agencies may dispute the MSPO certification's integrity, thus affecting market demand for certified palm oil goods.

3. Challenges in Agricultural Supply Chain

Agricultural supply chains face significant challenges that undermine their efficiency, transparency, and overall effectiveness. The integration of blockchain technology offers potential solutions to these issues, yet several persistent challenges must be addressed to fully leverage this technology [41,42]. Key challenges in agricultural supply chains include issues of fraud and inefficiency, lack of trust and transparency among stakeholders, difficulties in tracking and tracing agricultural products, and the subsequent impact on food safety, consumer trust, and market dynamics. Fraud and inefficiency are prevalent problems within agricultural supply chains. These issues often arise due to the complexity and length of the supply chain, which involves multiple intermediaries including producers, processors, distributors, and retailers. Each stage presents opportunities for misrepresentation and fraud, such as mislabeling of products, adulteration, and theft. The inefficiency in these systems is exacerbated by the lack of real-time data and the reliance on manual record-keeping, which can lead to delays and errors in tracking products from farm to table [43]. For instance, the prevalence of fraudulent practices such as counterfeit organic products or misreported origins can significantly affect consumer confidence and market stability [44].

Another critical challenge is the lack of trust and transparency among stakeholders in the supply chain. The absence of a unified and transparent system often leads to disputes and a lack of accountability. Stakeholders may be reluctant to share information due to concerns over data security or competitive disadvantage, which can hinder collaboration and the effective resolution of issues within the supply chain [45]. This mistrust can impede the implementation of quality standards and result in discrepancies in product information, further complicating the management of agricultural supply chains [46].

Tracking and tracing agricultural products are inherently challenging due to the perishable nature of agricultural goods and the multiple steps they undergo from production to consumption. Traditional methods of tracking often involve paper-based systems or disparate digital records, which are prone to inaccuracies and inefficiencies [43]. This challenge is particularly acute in large-scale supply chains where multiple products are handled and processed, making it difficult to maintain a coherent and accurate record of product origins and movements. The inability to effectively trace products can result in delays in addressing issues such as contamination outbreaks or product recalls, which can have serious implications for food safety [44].

These challenges have profound impacts on food safety, consumer trust, and market dynamics. Food safety is compromised when supply chains lack robust tracking and transparency mechanisms, as it becomes difficult to swiftly identify and address sources of contamination or other quality issues [45]. The lack of transparency and trust among stakeholders also undermines consumer confidence, which is critical for market success. Consumers are increasingly demanding transparency and assurance regarding the safety and authenticity of their food [46]. When these demands are not met, it can lead to a loss of trust and decreased market share for affected products.

The integration of blockchain technology into agricultural supply chains has the potential to address many of these challenges by providing a decentralized and immutable ledger of transactions. Blockchain can enhance transparency and trust among stakeholders by ensuring that all parties have access to accurate and unalterable records of product movements and transactions. This can reduce opportunities for fraud and inefficiency, improve tracking and tracing of products, and bolster food safety and consumer trust. However, realizing these benefits requires overcoming significant barriers such as the need for widespread adoption, integration with existing systems,

and addressing concerns related to data privacy and security [47,48]. In summary, the challenges faced by agricultural supply chains, including fraud and inefficiency, lack of trust and transparency, and difficulties in tracking and tracing products, have significant implications for food safety, consumer trust, and market dynamics. While blockchain technology presents promising solutions to these issues, its implementation must be carefully managed to address existing barriers and ensure that the technology delivers its full potential in enhancing supply chain transparency and traceability.

4. Blockchain Technology: Key Concepts and Features

Since Nakamoto [49] first presented the concept in the context of Bitcoin, BCT has seen significant evolution. It is now recognized by a variety of industries as a possible game changer. It is well-known for its distributed ledger technology, which acts as a decentralized immutable ledger capable of storing, processing, validating, and authorizing transactions. Every transaction recorded on the blockchain at a given point in time is essentially kept in a single block. Each block has a digital fingerprint of the individual who implants the data, which is known as a hash. Thus, the preceding block's cryptographic identifier creator is appended.

As a result, BCT enables for the development of an immutable and transparent record of all transactions that occur inside the SC [50]. This implies that any component, raw material, or final product can be traced back to its source using the SC. This openness can assist businesses in identifying and addressing inefficiencies, as well as opportunities for improvement in their environmental performance [51]. Driven by sustainable development goals, BCT is one of the technologies demonstrating its worth in a variety of industries and areas of SCM, particularly in terms of sustainability performance [52, 51].

Baralla and Pinna [51] highlighted the use of BCT for SC environmental sustainability, shedding light on BCT's possibilities to help waste management and the circular economy by allowing information transparency, dependability, and automation. Wang and Lucey [53] shown in the financial (cryptocurrency) industry that there is a substantial negative association between BCT and environmental performance. Meanwhile, in the industrial SC sector, references [51,52] demonstrated that BCT adoption has a considerable favorable influence on environmental SCP. Furthermore, ref. [54] confirmed the beneficial effect of BCT adoption on environmental SCP in the automobile industry. Finally, in the agricultural sector, ref. [56] revealed that BCT adoption had a favorable influence on environmental sustainability.

Previous research mostly examined the favorable substantial impact of BCT adoption on overall SC performance and survival, particularly in the post-COVID-19 period [54]. Several studies have also examined the detrimental consequences of BCT adoption, as an energy-consuming technology, on the environmental SCP [55,56]. However, few researches have looked at the impact of BCT adoption, notably on environmental SCP [57].

5. Blockchain’s Role in Enhancing Supply Chain Transparency

Blockchain technology has emerged as a transformational tool for increasing openness and data integrity in a variety of industries, including agriculture. By establishing a decentralized and irreversible database of transactions, blockchain ensures that all stakeholders participating in the agricultural supply chain have access to accurate and unchanging information. This capacity is especially useful in agriculture, where openness and traceability are critical for ensuring food safety, certifying product authenticity, and increasing customer trust.

One of the primary ways blockchain protects data integrity and transparency in the agricultural supply chain is through its decentralized nature. Unlike traditional centralized databases, which are maintained by a single institution, blockchain uses a distributed ledger system. Every member of the supply chain, from farmers to merchants, has access to the same data, which is constantly updated and confirmed by a network of nodes. This distributed method decreases the danger of data tampering or illegal access since every effort to change the data requires consensus from most of the network [43]. This immutability means that once a transaction is recorded on the blockchain, it cannot be changed or deleted, resulting in a permanent and tamper-proof record of the whole supply chain.

Blockchain's capacity to record transactions in real time improves transparency throughout the agricultural supply chain. As items migrate from farm to fork, each transaction is recorded on the blockchain, resulting in a complete and verifiable history of the product's journey. This real-time recording enables stakeholders to track the flow of commodities across the supply chain, from manufacturing and processing to distribution and retail [41,42]. Blockchain's openness enables early discovery of possible issues like as delays, contamination, or fraud, as well as prompt remedial actions [58]. For example, if a batch of product is found to be tainted, blockchain may assist track the contamination back to its source, allowing for a targeted recall while minimizing the impact on the whole supply chain.

Several case studies and examples demonstrate the successful use of blockchain in agriculture to increase transparency. One significant example is IBM's collaboration with Walmart to establish a blockchain-based food tracking system. The IBM Food Trust technology enables Walmart to track the origin of its food goods in seconds rather than days or weeks, as traditional methods previously did [59]. This improved openness not only enhances food safety by allowing for speedier responses to contamination occurrences, but it also fosters customer trust by giving verifiable information about the items they buy.

6. Blockchain and Traceability in Agriculture

Blockchain and traceability in agriculture is an essential component of contemporary agricultural supply chains, assuring food safety, quality control, and customer trust. In today's worldwide economy, when food goods frequently transit many countries before reaching the customer, the capacity to track and trace agricultural products from farm to table has become critical. Traceability systems assist stakeholders in determining the origin and movement of items across the supply chain, allowing them to respond swiftly to concerns such as contamination, fraud, or mislabeling. Blockchain technology, with its decentralized and immutable ledger, provides a strong answer for improving traceability in agriculture by keeping a visible and verifiable record of every transaction and movement of items.

The value of traceability in food safety and quality management cannot be emphasized. In recent years, various cases involving foodborne diseases, contamination, or adulteration have resulted in extensive consumer suffering and huge economic losses for businesses. Effective traceability systems enable the identification and removal of tainted items from the supply chain, reducing the impact on public health and safeguarding food manufacturers' reputations. Furthermore, traceability is critical for adhering to food safety rules and standards, which increasingly require complete records of product origin, processing, and distribution [58].

Blockchain technology improves traceability in agricultural supply chains by creating a secure and transparent platform for documenting all transactions and movements of items. Unlike traditional centralized databases, where data may be changed or manipulated, blockchain works on

a decentralized network where all members have access to the same information. Each transaction is recorded in a block, which is then connected to the preceding block to form an immutable, tamper-proof chain of records [43]. This ensures that data once stored on the blockchain cannot be modified or erased, resulting in a permanent and verifiable record of the whole supply chain.

7. The Future Prospects of Blockchain Technology

Blockchain technology has the potential to alter global agricultural supply chains by increasing transparency, traceability, and trust among stakeholders. As blockchain use grows, current patterns indicate that technology will be further integrated into agriculture, backed up by regulatory advancements and long-term advantages for sustainability and customer trust [60,61]. Blockchain's transformational potential in global agricultural supply chains stems from its capacity to maintain an immutable and transparent record of transactions. Blockchain's decentralized ledger technology assures that every transaction, from farm to fork, is recorded in real time and cannot be changed or interfered with. This transparency is critical in agriculture, where supply chains are frequently complicated and involve several intermediaries, such as farmers, processors, distributors, and retailers [58]. By offering a single, verifiable source of truth, blockchain has the potential to drastically eliminate fraud, inefficiencies, and mistakes in agricultural supply chains, resulting in more dependable and trustworthy systems.

Blockchain technology has the potential to improve traceability in agricultural supply chains, which is an important component of food safety and quality monitoring. Blockchain enables customers and authorities to track the origin of agricultural goods, guaranteeing that they satisfy safety regulations and are free of contamination [62]. This degree of traceability is especially significant in worldwide food markets, where items may cross various countries and fall under different regulatory norms. Blockchain can help bridge these gaps by creating a uniform and transparent record of a product's path through the supply chain, improving food safety and customer confidence [63,64].

Emerging trends in blockchain adoption in agriculture indicate an increasing interest in using this technology for supply chain management. As more agricultural firms become aware of the possibilities of blockchain, they are exploring its usage to improve transparency and traceability [65,66]. For example, some businesses are utilizing blockchain to trace the transportation of perishable items, such as fruits and vegetables, from farms to store shelves [67]. By recording every stage of the supply chain on a blockchain, these organizations can assure that items are handled correctly and arrive in good shape. This trend is projected to continue as more businesses see the importance of blockchain in maintaining the quality and safety of agricultural goods.

In addition to regulatory backing, increased coordination among agricultural supply chain stakeholders is required to fulfill blockchain's full potential. This involves collaborations among farmers, agribusinesses, technology providers, and regulators to create and execute blockchain solutions that meet the unique difficulties of agricultural supply chains [68]. By collaborating, these stakeholders may design blockchain systems that are adapted to the demands of the agriculture industry and deliver maximum advantage in terms of transparency, traceability, and efficiency [68-71].

Blockchain technology has significant long-term benefits for sustainability and customer confidence in agriculture. Blockchain, by providing a transparent and verifiable record of agricultural goods, can assist guarantee that they are produced and managed sustainably [43]. Blockchain, for example, may be used to track pesticide and fertilizer use, ensuring that environmental standards are followed. This kind of openness can assist encourage sustainable

agricultural methods, minimize agriculture's environmental effect, and facilitate the transition to more sustainable food systems.

8. Empirical Research of Blockchain Technology

Technological innovation has emerged as a crucial facilitator in the advancement of sustainability certification programs. According to Lim and Fatin [72], the use of digital traceability systems has considerably improved documentation accuracy and compliance monitoring in Sabah's palm oil factories. Their research, which included surveys of 45 compliance officers, found that digital technologies decreased manual mistakes and expedited reporting for MSPO audits. Similarly, [73] discovered that integrating mobile applications enabled smallholders to track their agricultural practices more efficiently, thereby contributing to certification ready. These studies show that digital solutions are becoming increasingly important in managing operational issues connected with MSPO compliance. Blockchain technology, while still relatively new in agriculture, has garnered popularity because to its transparency and immutability.

A case study by Zhang *et al.,* [74] on cocoa supply chains in Ghana found that blockchain boosted stakeholder confidence and decreased certification fraud by providing real-time, verifiable records of production and trading. Their research used a mixed-methods approach, combining field interviews and blockchain transaction analysis. While the study was not done in the palm oil industry, its implications are also pertinent to MSPO, where difficulties of traceability and data verification are similarly prevalent. This shows that blockchain has the potential to improve monitoring and legitimacy in Malaysia's palm oil certification procedures.

Despite the benefits, various empirical investigations have shown practical problems in using blockchain for certification purposes. For example, [75] conducted detailed interviews with 12 stakeholders from certifying agencies and palm oil enterprises in Peninsular Malaysia. They highlighted hurdles such as expensive establishment costs, a lack of technical competence, and uncertainty about regulatory frameworks. The study also highlighted the lack of understanding among smallholders regarding blockchain technologies, which may impede wider adoption. These findings highlight a gap between technical promise and real-world implementation, emphasizing the importance of conducting a contextual analysis of the MSPO ecosystem, concentrating on digital infrastructure, policy preparedness, and stakeholder ability. While several studies have investigated digital tools and traceability systems, few have given a detailed review of blockchain technology in the context of MSPO compliance. Most present empirical research either targets broad digitisation in agriculture or investigates blockchain in other commodity industries such as coffee or cocoa. The absence of specialized, context-driven evaluations or pilot research on Malaysian palm oil creates a significant knowledge vacuum. As a result, the purpose of this study is to close this gap by examining blockchain's potential for improving MSPO monitoring and identifying major enablers and impediments to deployment.

9. Challenges to Implement Blockchain Technology

The use of blockchain technology brings both benefits and obstacles, since the implementation process is deemed crucial. A single source of truth has been demonstrated to be sufficient for the majority of supply chain management operations [76]. Furthermore, there are few standardized technologies in the supply chain area, and linking blockchain technology would require a significant effort from all enterprises along the supply chain [77]. This method would need vast resources, which would be prohibitive for many businesses. Such extensive regulations, along with a lack of

standards and norms, might result in significant expenses for businesses and organizations [78]. In addition, supply chain managers require additional training to cope with the new regulations and approaches [79]. Other IT professionals must be included in the process to guarantee that everything runs well. There is still a need for speedier and more cost-effective blockchain algorithms to address the system's flaws while building on its virtues. Because of the high-power consumption, high cost of setting up the hardware, and large data storage capacity, the expense of implementing blockchain technology frequently outweighs the benefits it gives to supply chain management. Future research might also focus on making blockchain technology more affordable and usable for smaller-scale activities. Furthermore, blockchain technology faces several weaknesses and open concerns, including security and data protection [80].

10. Conclusion

The Malaysian Sustainable Palm Oil (MSPO) accreditation program has played a critical role in assuring sustainable and ethical palm oil production. However, difficulties like as traceability, transparency, and compliance monitoring continue to exist. Blockchain technology, with its decentralized and irreversible nature, provides a viable approach for improving MSPO compliance. This research looks at the potential use of blockchain in improving MSPO standards and encouraging sustainable palm oil processes. One of the most pressing challenges in the palm oil business is maintaining complete traceability from plantation to customer. Blockchain can transform MSPO compliance by providing an immutable digital ledger that tracks every stage of the supply chain. Smart contracts and unique digital signatures enable parties to verify the validity of palm oil sources, limiting fraudulent activities like mislabelling and unlawful deforestation.

The decentralized structure of blockchain ensures that all stakeholders, including governments, environmental groups, and consumers, have real-time access to data. Increased openness may boost confidence in the palm oil business by giving reliable information on sustainable practices, environmental effect, and social responsibility. Furthermore, data saved on the blockchain cannot be edited or modified, which reduces the danger of corruption and unethical behaviors. MSPO compliance demands stringent monitoring and auditing procedures. Blockchain can automate and streamline these operations by utilizing smart contracts that automatically run compliance checks. For example, IoT sensors on palm farms may provide real-time data to a blockchain system, quickly confirming compliance with MSPO regulations. This reduces the need for manual audits, lowering expenses and increasing efficiency. Smallholder farmers, who may lack the means for compliance verification, pose a substantial hurdle to MSPO implementation. Blockchain can help these farmers by creating a decentralized system for recording their farming techniques and obtaining digital verification of compliance. This not only improves their market access but also guarantees that their long-term efforts are acknowledged and rewarded.

While blockchain has enormous promise, its deployment in MSPO compliance presents obstacles. These include expensive start-up costs, the necessity for digital infrastructure, and opposition to technology adoption. Furthermore, integrating blockchain with current certification systems necessitates coordination between industry stakeholders, politicians, and technical experts. The future of blockchain in MSPO compliance seems bright, with the potential to transform traceability, transparency, and monitoring in the palm oil business. Malaysia can increase its commitment to sustainable palm oil production by utilizing blockchain technology, which ensures environmental protection, ethical standards, and worldwide customer confidence. However, to fully realize the benefits of this disruptive technology, its deployment will need strategic investments, regulatory backing, and industry-wide collaboration. Further study might also focus on

strengthening transaction security and selectively disclosing information only to authorized users, ensuring that no unauthorized individuals acquire access and fraud attempts are thwarted. This might also boost customer security, as many consumers are concerned about their privacy. Another pressing research need is to strengthen supply chains. New ways might be developed to identify each particular product more rapidly, as the infrastructure currently struggles with this process. Furthermore, the transportation infrastructure would need to be improved, as there is currently a lack of openness in this sector.

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