



Smart Packaging Integration Model Based on QR Code, Digital Watermark, and Environmentally Friendly Materials to Improve the Security and Traceability of MSME Product Packaging

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ABSTRACT

Product counterfeiting, limited traceability, and low adoption of sustainable packaging remain major challenges for MSMEs in increasing consumer trust and market competitiveness. This study aims to develop a smart packaging integration model based on QR Code, digital watermark, and environmentally friendly materials to improve the security, traceability, and sustainability of MSME product packaging. The study uses an exploratory mixed-method approach with a Design Science Research (DSR) framework that includes problem identification, solution objective formulation, artifact design, expert validation, feasibility evaluation, revision, and model finalization. The results of the study produce a three-layer smart packaging model consisting of an information and traceability layer, an authentication and security layer, and a sustainable material layer. Expert validation shows a validity level of 89.6% and a feasibility evaluation reaches 84%, indicating that the model is in the highly valid category and very feasible for limited implementation. QR Code integration enables batch-based information and traceability access, digital watermark strengthens product authentication, while environmentally friendly materials support the principles of a circular economy. Theoretically, this research integrates the Smart Packaging Framework, Supply Chain Traceability Framework, and Circular Economy Theory into a single conceptual model. Practically, the model provides an adaptive, affordable, and relevant smart packaging implementation alternative for MSMEs to improve supply chain transparency, brand protection, and product competitiveness.

ABSTRACT

Product counterfeiting, limited traceability, and low adoption of sustainable packaging remain critical challenges for micro, small, and medium enterprises (MSMEs) in strengthening consumer trust and market competitiveness. This study aims to develop an integrated smart packaging model based on QR codes, digital watermarks, and environmentally friendly materials to enhance packaging security, traceability, and sustainability. An exploratory mixed-method approach was employed using the Design Science Research (DSR) framework, encompassing problem identification, objective definition, artifact design, expert validation, feasibility evaluation, revision, and model finalization. The study produced a three-layer smart packaging model consisting of the information and traceability layer, authentication and security layer, and sustainable material layer. Expert validation achieved a score of 89.6%, while feasibility evaluation reached 84%, indicating that the model is highly valid and highly feasible for limited implementation. QR codes facilitate product information access and batch-based traceability, digital watermarks strengthen product authentication, and sustainable materials support circular economy principles. Theoretical contributions include the integration of the Smart Packaging Framework, Supply Chain Traceability Framework, and Circular Economy Theory into a unified conceptual model. Practically, the proposed model offers an adaptive and cost-effective smart packaging solution for MSMEs to improve supply chain transparency, brand protection, and product competitiveness.

1. INTRODUCTION

The security and transparency of product packaging distribution are increasingly becoming strategic issues in the modern, digitalized trade system (Essien et al., 2024; Jarrett et al., 2020; Prof. Dipti A. Mirkute et al., 2025). Amidst the rise of digital transactions, cross-regional distribution, and the expansion of trade through marketplaces, packaging can no longer be understood simply as a physical protector of a product, but has

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transformed into an authentication instrument, information medium, and a key link in the supply chain system (Picard et al., 2021; Prabhu Shankar et al., 2024). When product identity can be easily falsified, labels manipulated, and distribution information difficult to verify, consumer trust in the product is threatened. This problem is made even more serious by the trade in counterfeit goods that remains on a large global scale. The OECD and EUIPO estimate that international trade in counterfeit and pirated goods reached USD 464 billion, or around 2.5% of world trade in 2019. According to previous estimates, its value reached USD 509 billion or around 3.3% of world trade in 2016. Counterfeit goods not only harm brand owners, but can also pose health, safety, and environmental risks, especially in food products, cosmetics, medicines, toys, and various consumer products that are in direct contact with the public (Silkose & Nygaard, 2025). Thus, the weakness of the identification system on packaging is a strategic issue because it is related to consumer trust, market protection, and the integrity of the product supply chain.

Packaging issues are also increasingly complex due to their interconnectedness with environmental concerns (Thomassen et al., 2024). Conventional plastic-based packaging remains a major contributor to short-lived waste, while global recycling capacity has not kept pace with the increasing consumption of packaging materials (Ncube et al., 2021; Torkelis et al., 2024). The OECD reports that only about 9% of plastic waste is actually recycled, while nearly two-thirds of plastic waste comes from products with a lifespan of less than five years, including about 40% from the packaging sector. The UNEP also confirms that about 36% of plastic produced is used for packaging, and about 85% of this ends up in landfills or as hazardous waste. This fact suggests that packaging innovation should not only focus on product safety and information aspects, but also consider material well-being and ecological impacts throughout the packaging lifecycle.

In the Indonesian context, this issue is increasingly important because MSMEs are the backbone of the national economy, yet not all of them have robust packaging systems in terms of security, legality, standardization, and traceability (Purwantiningrum et al., 2018; Purwaningsih & Hardiyati, 2021; Siregar & Razali, 2022). The Coordinating Ministry for Economic Affairs noted that Indonesia's MSMEs reach more than 64 million business units, contributing more than 60% to national GDP, and absorbing nearly 97% of the workforce. However, this substantial economic contribution is not always accompanied by readiness in packaging technology, particularly among MSMEs in the food, cosmetics, herbal, beverage, and locally processed products marketed through offline and online channels. This condition is reinforced by the findings of the Indonesian Food and Drug Authority (BPOM) in October–November 2024 of 235 illegal cosmetic items and/or containing hazardous materials worth more than IDR 8.91 billion in four main regions of Indonesia. This fact confirms that MSME product packaging is not only visually attractive, but must also be able to serve as an instrument for validating product safety, legality, and traceability.

The main problem with MSME product packaging lies in its weak function as an authentication and traceability tool (Irawan & Affan, 2020; Aziz et al., 2021). Most MSMEs still view packaging as a promotional tool, even though it can serve as a product identity, a legal marker, a repository of production information, a link to distribution data, and proof of product authenticity. When packaging only contains statistical information without system verification, consumers find it difficult to ascertain whether the product originates from an authorized producer, has a valid distribution permit, and has not been subjected to label manipulation. Research by Yudisha et al., (2022) on MSME tempeh shows that packaging issues are not only related to appearance, but also to national standardization, BPOM registration, patents, and product appeal. Therefore, MSMEs need packaging models that are not only informative but also safe, operable, and appropriate for the production capacity of small businesses.

Theoretically, this research is based on three main frameworks: the Smart Packaging Framework, the Supply Chain Traceability Framework, and the Circular Economy Theory. The Smart Packaging Framework views packaging as an active and intelligent system that can provide information, authentication, digital interaction, and product quality monitoring (Rahimah et al., 2020). The Supply Chain Traceability Framework positions packaging as a link between product identity, production history, distribution, and authenticity validation, allowing for more transparent product traceability (Jarrett et al., 2020). Meanwhile, the Circular Economy Theory emphasizes the importance of using materials that are recyclable, biodegradable, compostable, or have a lower ecological impact (Muljaningsih et al., 2023). By combining these three frameworks, packaging is positioned not only as a marketing tool, but also as a system for product protection, information management, and material desires.

Literature evidence shows that research on QR Codes, traceability, anti-counterfeiting, blockchain, and smart packaging has grown rapidly in the past five years, but remains largely fragmentary. Xie and Tan developed a modified two-tier QR Code-based anti-counterfeiting architecture for traceability systems, emphasizing that digital data needs to be supported by authentication mechanisms to be more than just claims. Xie & Tan (2021) proposed a blockchain-based and Internet of Things-based food anti-counterfeiting traceability system to address the issues of data storage, data manipulation, and information fragmentation in the food supply chain. Ellahi et al. (2023) also systematically observed that blockchain can enhance transparency, auditability, verifiability, and provenance, but its integration with QR Codes, IoT, RFID, AI, and big data still poses implementation challenges. This third study demonstrates that product traceability requires a digital system that not only provides information but also guarantees data verification and integrity.

Another study emphasized that QR Codes have great potential as a medium for information and traceability, but are not yet robust enough to be used as the sole security system. Wang et al., (2023) developed a hidden-texture anti-counterfeiting QR Code to address the weaknesses of conventional QR Codes that are easily copied, reprinted, and pasted on counterfeit products. Li et al., (2024) in *Trends in Food Science & Technology* showed that QR Codes on food packaging are effective for traceability, quality evaluation, anti-

counterfeiting, and marketing, but still have risks because the code and its links are generally visible and publicly accessible. Escobedo et al., (2023) also showed that QR Codes can be developed into smart labels with information storage functions, temperature sensors, and real-time freshness sensors. Thus, QR Codes on MSME packaging need to be placed as part of a layered security system equipped with digital watermarks, copy detection patterns, sensors, or data-based verification mechanisms.

On the smart packaging side and material shortages, research continues to demonstrate a shift from passive packaging to smart packaging that combines safety, quality monitoring, and reduced environmental impact (Kim et al., 2024). A study in Nature Food introduced a nanocomposite ink-based water-soluble label that integrates QR codes, hidden microprinting, moisture indicators, and anti-counterfeiting protection on food labels. A study in Nature Reviews Bioengineering confirmed that smart food packaging can support real-time food quality monitoring, improve food safety, and reduce product waste (Khan et al., 2024). Another study on bio-based smart packages demonstrated that bio-based materials have the potential to combine these desires with direct product quality monitoring (Upadhyay et al., 2024). This literature demonstrates that ideal smart packaging should not simply include digital features but also address material compatibility, product safety, and environmental impact.

In the national context, several studies have discussed the application of information technology-based traceability, but not many have specifically addressed smart packaging integration models for MSMEs. Usman et al., (2021) designed a blockchain-based broiler supply chain traceability system through an Android application to address weaknesses in recording and information security in the supply chain. Barlianto et al., (2024) developed a Ricetrack prototype based on blockchain and QR Code to improve transparency, traceability, and accuracy of inventory management in the rice supply chain in Bekasi Regency. Pertiwi & Arifani, (2025) also developed a QR Code-based coffee traceability system on the Android platform, with the QR Code as a unique code to access product information from the server. These studies are important because they demonstrate the relevance of QR Code and blockchain in local product traceability, but their focus is still on commodity supply chains, not on smart packaging models for MSMEs that simultaneously integrate QR Code, digital watermarks, and environmentally friendly materials.

Based on this review, this research gap lies in the absence of a smart packaging model that simultaneously integrates three main dimensions: QR Codes for information access and traceability, digital watermarks as a hidden authentication layer, and environmentally friendly materials to support MSME product packaging needs. Previous studies still tend to position QR Codes as information media, blockchain as a recording system, sensors as a quality monitoring tool, or environmentally friendly materials as stand-alone issues. In fact, MSMEs need a model that not only advances technology but is also affordable, easy to implement, secure from counterfeiting, easy for consumers to understand, and suitable for the limited production capacity of small businesses. Thus, this research gap is both conceptual and applicable, namely how to design an integrated smart packaging model that can address the needs of security, distribution traceability, and material needs in an integrated manner.

The novelty of this research lies in the development of a three-layer smart packaging integration model specifically designed to improve the security and traceability of MSME product packaging. The first layer is a QR Code as the primary access to product information, legality, composition, production date, batch number, certification, and distribution history. The second layer is a digital watermark as hidden authentication to minimize the risk of copying, label counterfeiting, and code reuse on unauthorized products. The layers are environmentally friendly to ensure that the three security and traceability enhancements do not neglect the principle of desirability. This novelty is important because the research not only offers packaging digitalization, but builds an integrative model that connects physical products, digital data, hidden authentication, and material desirability in one applicable framework for MSMEs.

The urgency of this research arises because Indonesian MSMEs face dual pressures: increasing competitiveness and consumer trust, while simultaneously adapting to digital transformation and environmental demands. Without a secure and traceable packaging system, MSME products are vulnerable to counterfeiting, manipulation, difficulties in proving product origin, weak distribution oversight, and low credibility in the modern market. Conversely, implementing smart packaging that is appropriate to MSME capacity can strengthen consumer protection, increase trust in local brands, facilitate product traceability, and support more sustainable business practices. Therefore, this research is important academically because it enriches the study of smart packaging, traceability, and the circular economy; and is important practically because it provides an implementation framework for MSMEs, packaging designers, regulators, and supply chain actors. The objective of this research is to develop an integrated model for smart packaging based on QR codes, digital watermarks, and environmentally friendly materials to improve the security and traceability of MSME product packaging.

2. METHOD

This research uses an *exploratory mixed-method approach* with a *Design Science Research (DSR)* framework because the research not only explains the problem of MSME product packaging, but also designs, validates, evaluates, and refines *artifacts in the form of smart packaging* models based on QR Codes, *digital watermarks*, and environmentally friendly materials. The model is aimed at improving product safety, distribution traceability, information usability, and the sustainability of MSME packaging. Thus, the research is structured as a model development process that starts from practical problems, is strengthened by literature reviews, validated by experts, tested for feasibility, and then refined into a final model. Methodologically, the research adapts the DSR stages from Alan R. Hevner and Ken Peppers which include problem identification, determining

solution objectives, designing and developing *artifacts*, demonstration, evaluation, and communication of results (Pertiwi & Arifani, 2025).

This framework is relevant because the *smart packaging model* developed does not stop at the conceptual level but is directed towards becoming a design that can be validated and evaluated systematically. An *exploratory mixed-methods approach* was used because the research began with conceptual exploration and needs analysis, followed by a quantitative assessment of the model's validity and feasibility.

In the qualitative exploration stage, the research data sources consisted of three groups, namely (1) 35 scientific articles selected through a literature review related to *smart packaging*, QR Code-based traceability, digital watermark, anti-counterfeiting system, and sustainable packaging; (2) five regulatory documents and product packaging standards used to identify packaging safety and sustainability needs; and (3) open input from five expert validators and 30 potential MSME users who provided responses to the initial design of the model. The selection of data sources was carried out purposively based on relevance to the objectives of artifact development.

Qualitative elements were used in the literature review, identification of MSME needs, and interpretation of expert input, while quantitative elements were used in the *validation* and *feasibility evaluation stages* using Likert scales, percentages, and validity and feasibility categories. Thus, the *mixed-method approach* was directly integrated into the *artifact development process*.

The integration of qualitative and quantitative data was carried out through a *connecting and merging approach*. Qualitative exploration results were used to determine design requirements and artifact evaluation indicators. Furthermore, quantitative validation results were used to measure the model's feasibility, while open-ended validator comments served as the basis for interpretation and design revisions. With this mechanism, numerical data does not stand alone but is reinforced by qualitative findings to produce a final model that is more contextualized to the needs of MSMEs.

The DSR procedure in this study was carried out through seven sequential stages. The first stage is problem identification, which examines packaging security issues, the risk of label counterfeiting, traceability limitations, and the suboptimal use of environmentally friendly materials in MSME products. The second stage is determining the solution objectives, which formulate the need for a smart packaging model that is safe, traceable, easy to use, and supports material sustainability. The third stage is the artifact design in the form of an initial model that integrates QR Codes, digital watermarks, and environmentally friendly materials.

In the demonstration and artifact testing phase, the study used three packaging prototypes with the same design and material, but with variations in digital product identity to test the consistency of the system. Each prototype was equipped with a 3×3 cm QR Code placed on the packaging surface with consideration for user access. QR Code scanning tests were carried out 150 times, namely 50 scans on each prototype. Testing was carried out using three types of smartphone devices with the Android operating system and a minimum of 12 MP camera to represent the variety of user devices.

The scanning process was carried out under three lighting conditions: low lighting (± 100 lux), normal room lighting (± 300 lux), and bright lighting (± 700 lux). The testing distances were set at 10 cm, 20 cm, and 30 cm from the camera to the QR Code surface. Scanning success was determined based on the device's ability to read the QR Code and display the digital information connected to the system.

The choice of QR Code is supported by literature showing that QR Code on packaging can be used for traceability, quality evaluation, anti-counterfeiting, and transmission of product information, although its use needs to be strengthened with complementary technology because publicly visible codes are still at risk of being copied.

To strengthen the authentication aspect, the research integrates a digital watermark based on *Discrete Cosine Transform* (DCT). This algorithm was chosen because it is able to insert hidden information in the frequency domain of the image so that visual changes on the packaging remain minimal. The watermarking process is carried out in three stages, namely (1) transformation of the packaging image to the frequency domain using DCT, (2) insertion of digital identity information at certain frequency coefficients, and (3) reconstruction of the packaging image while maintaining visual quality.

the *Inverse Discrete Cosine Transform (IDCT)* algorithm. The scanned packaging image is compared with the original watermark data using the *Normalized Correlation (NC)* value. The watermark is declared successfully detected if the NC value is ≥ 0.90 . Watermark testing is carried out 90 times with varying lighting conditions and shooting angles to ensure the system's resilience to changes in the usage environment.

The fourth stage is expert validation to assess the model's relevance, safety, traceability, usability, and sustainability. The fifth stage is a feasibility evaluation to assess the model's readiness from a technical, economic, safety, usability, and environmental perspective. The sixth stage is model revision based on validator scores and comments. The seventh stage is finalization of the smart packaging model. This flow is crucial because robust DSR research must explicitly demonstrate the process of designing, assessing, and refining the artifact.



Figure 1. Design Science Research Flow

Table 1. Stages of Design Science Research

Stage	Activity	External
Problem identification	Identifying safety, traceability, and sustainability issues of MSME packaging materials	Design problem formulation
Objective definition	Defining the need for a safe, traceable, easy-to-use, and sustainable model	Model design criteria
Artifact design	Designing the integration of QR Code, digital watermark, and eco-friendly materials	Early model
Expert validation	Assessing relevance, security, traceability, usability, and sustainability	Expert scores and feedback
Feasibility evaluation	Assess technical, economic, safety, use and environmental feasibility	Model suitability index
Model revision	Refine the model based on validation and evaluation results	Revised model
Final model	Developing the final model of smart packaging for MSMEs	Final three-layer model

Expert validation was conducted to assess the conceptual and applicability feasibility of the developed model. Validators were selected purposively, involving a minimum of 3–5 experts, including packaging design experts, information technology or *traceability experts*, environmentally friendly materials experts, and MSME practitioners or facilitators. The involvement of validators from different fields was necessary because the developed model is multidimensional, combining aspects of digital information, hidden authentication, packaging design, and material sustainability.

In this study, the validation process was conducted by five expert validators selected based on their professional competency and experience in fields related to the model components. The validators consisted of one expert in packaging design and technology, one expert in information technology and digital security systems, one expert in environmentally friendly materials, one academic in the field of technology/information systems, and one practitioner assisting MSMEs. The selection of validators was carried out purposively, considering a minimum of five years of experience in related fields as well as involvement in research, product development, or technology implementation.

The five validators were selected because the developed smart packaging model has a multidisciplinary character. Packaging design experts are needed to assess ergonomics, appearance, and suitability of the design to the needs of MSME products. Information technology experts are needed to evaluate aspects of QR Codes, digital watermarks, information security, and traceability systems. Material experts are needed to assess the sustainability aspects of packaging materials. Meanwhile, academics and MSME practitioners provide perspectives on the feasibility of implementing the model in a real context. The validation instrument is compiled using a Likert scale of 1–5, with categories 1 = very inappropriate, 2 = inappropriate, 3 = quite appropriate, 4 = appropriate, and 5 = very appropriate. Aspects assessed include relevance, security, traceability, usability, and sustainability.

The expert validation instrument consists of 25 assessment indicators grouped into five main aspects. The relevance aspect is used to assess the model's suitability to the needs of MSMEs. The security aspect is used to assess the system's ability to support product authentication and reduce the risk of counterfeiting. The traceability aspect is used to assess the QR Code's ability to provide digital product information. The usability aspect is used to assess the system's ease of use by users. The sustainability aspect is used to assess the packaging material's suitability to environmentally friendly principles.

In addition to scoring, validators were also asked to provide open-ended comments so that the model revision process was not based solely on numbers but also on substantive considerations. The validators' open-ended comments were analyzed qualitatively to identify aspects that still needed improvement. This input included simplifying digital information, improving authentication security, adjusting QR Code design, selecting packaging materials, and considering implementation costs for MSMEs. The instrument's content validity can be strengthened using Aiken's V or the Content Validity Index (CVI) to ensure that each indicator truly represents the construct being measured (Puspitasari & Febrinita, 2021).

In this study, the content validity of the instrument was analyzed using Aiken's V. This analysis was used to determine the level of agreement between five validators regarding the suitability of each indicator with the measured aspect. The Aiken's V value was obtained from the validators' assessment of all indicators using a five-level Likert scale. Interpretation of the Aiken's V value was carried out based on the level of suitability of the indicators, with values closer to one indicating a higher level of content validity. The instrument was declared to have met content validity if it obtained an Aiken's V value ≥ 0.80 . Indicators that met the criteria were retained, while indicators that obtained lower values or received substantive criticism from the validators were revised before being used in the model evaluation.

In addition to expert validation, the study conducted a user evaluation of 30 respondents consisting of MSMEs and potential consumers of MSME products. Respondents were selected using *purposive sampling* with the criteria of having used or purchased commercially packaged MSME products, having basic skills in using a *smartphone* and QR Code scanner, and being willing to evaluate *the prototype*. Each respondent tried *the smart packaging* by scanning the QR Code and accessing the available digital information, then directly assessed the user experience. The instrument used a Likert scale of 1–5 with 20 indicators covering five aspects, namely ease of use, clarity of product information, *traceability benefits*, trust in product authentication,

and perception of the sustainability of packaging materials. In addition to closed-ended assessments, respondents provided open-ended comments regarding the user experience and potential model improvements.

Technical testing was conducted to ensure that the digital components in *smart packaging* function according to the design objectives. QR Code testing was conducted through 150 scanning trials using three packaging prototypes, with each prototype tested 50 times using three Android-based smartphones with a minimum camera specification of 12 megapixels. Testing was carried out in three lighting conditions, namely dim, normal, and bright, as well as three variations of scanning distances, namely 10 cm, 20 cm, and 30 cm, to represent the variety of usage conditions by consumers. The success of the QR Code was determined based on two indicators, namely the ability of the device to read the code and the success of displaying digital information connected to the system. Each test result was recorded as successful or failed to obtain the success rate of QR Code reading.

Digital watermark testing was conducted to evaluate the system's ability to perform hidden authentication using a *Discrete Cosine Transform* (DCT)-based approach, a method of embedding digital information in the frequency domain of images used to maintain the visual quality of packaging while providing an additional layer of security against the risk of counterfeiting. Detection was carried out by extracting hidden information from the scanned packaging image, then the extracted results were compared with the initial watermark information to determine the level of conformity. Testing was conducted 90 times with varying shooting conditions, including changes in lighting and shooting angles, to evaluate the system's consistency in maintaining the authentication function.

3. RESULTS AND DISCUSSION

Result

This research produces a smart packaging integration model based on QR Code, digital watermark, and environmentally friendly materials to improve the security and traceability of MSME product packaging. The model was developed through Design Science Research stages that include problem identification, formulation of solution objectives, artifact design, expert validation, feasibility evaluation, QR Code technical testing, digital watermark authentication testing, limited user evaluation, comparison with existing packaging approaches, model revision, and artifact finalization. The results section not only shows that the model is considered valid and feasible, but also demonstrates the utility of the artifact through four main indicators, namely reducing the risk of label counterfeiting, increasing access to product information, strengthening batch-based traceability, and supporting the use of more environmentally friendly packaging materials.

Needs Model Identification Results

The findings indicate that MSME product packaging requires a system that not only serves as a protective and promotional medium, but also as an authentication tool, information access, product traceability, and support for material sourcing. Key issues identified include weak protection against label counterfeiting, a suboptimal product traceability system, limited information on packaging, and the need to use more environmentally friendly materials.

Table 2. Identification of MSME Packaging Problems and Model Requirements

Main Problem	Form of Problem	Model Needs	Solution Components
Packaging safety	Product labels, codes and visual identities are easily copied	Layered authentication system	Unique QR Code and digital watermark
Traceability	Product information, legality, batch and distribution are not yet connected.	Access searchable product information	Product data based QR Code
Use of information	Packaging information is limited and difficult to verify.	Concise, clear, and easily accessible information	QR Code based product information page
Material sustainability	Packaging materials are not completely environmentally friendly	More sustainable material selection	Recyclable, biodegradable or compostable material
Affordability for MSMEs	Security technology is often considered expensive and complex.	Gradual model according to MSME capacity	Basic, standard, and advanced schemes

Initial Model Design Results

Based on these needs, the initial model was designed as a three-layer smart packaging system. The first layer is QR code-based tracking, which provides access to product information. The second layer is digital watermark authentication, which provides hidden authentication. The third layer is eco-friendly packaging material, which serves as the foundation for the packaging.



Figure 2. Initial Three-Layer Smart Packaging Model

Functionally, the QR code serves as the primary access point to product information, the digital watermark serves as a hidden layer of authentication, and eco-friendly materials serve as the physical foundation of the packaging. These three components are then linked to a product database and a multi-level access system to more securely differentiate public and internal information.

Table 3. Functional Structure of the Proposed Smart Packaging Model

Model Layers	Main Function	Technical Components	Primary User	Benefit
QR Code	Access to information and traceability	Unique code, batch number, product information page, legality data, and distribution history	Consumers, MSMEs, distributors, regulators	Facilitates information verification and product tracking
Digital watermark	Hidden authentication	Watermark on a logo, design pattern, label, or certain visual elements	MSMEs, distributors, regulators, verifiers	Reducing the risk of counterfeiting and misuse of labels
Environmentally friendly materials	The foundation of packaging sustainability	Recyclable, biodegradable, compostable, or low-impact materials	MSMEs, packaging producers, consumers	Reducing environmental impact and supporting a circular economy
Product database	Data storage and management	Product data, batch, legality, certification and distribution	MSMEs and supervisory authorities	Strengthening data integrity and connectivity
Multilevel access	Information access rights settings	Public access and internal access	Consumers, MSMEs, regulators	Maintaining a balance between transparency and data security

Comparison of Models with Existing Packaging Approaches

Model comparisons were conducted to explain the artifact's novelty position. Common packaging approaches used by MSMEs typically only feature visual labels, single QR codes, simple watermarks, or eco-friendly materials without traceability systems. Each approach has its advantages, but remains partial. The proposed model integrates all four main functions into one framework: authentication, traceability, information access, and material sustainability.

Table 4. Comparison Between Existing Packaging Approaches and the Proposed Smart Packaging Model

Feature	Conventional Labels	QR Code Only	Watermark Only	Eco Packaging	Proposed Smart Packaging Model
Product information	✓	✓	✗	✓	✓
Digital access	✗	✓	✗	✗	✓
Hidden authentication	✗	✗	✓	✗	✓
Batch-based traceability	✗	✓	✗	✗	✓
Protection from label copying	✗	Low	Currently	✗	Tall

Environmentally friendly material support	X	X	X	✓	✓
Product database	X	Limited	X	X	✓
Multilevel information access	X	X	X	X	✓
Suitability for MSMEs	Tall	Tall	Currently	Currently	High with gradual scheme
Integrated system	X	X	X	X	✓

Table 4 shows that the proposed model has integrative advantages. QR codes alone excel in information access but are weak in authentication because the codes can be copied. Watermarks only aid authentication but fail to provide product information and traceability. Eco-packaging supports sustainability but fails to address security and traceability issues. The proposed model addresses these weaknesses by integrating QR codes, digital watermarks, a product database, tiered access, and eco-friendly materials.

Expert Validation Results

Expert validation was conducted to assess the feasibility of the integrated *smart packaging model* based on QR codes, *digital watermarks*, and environmentally friendly materials developed in this study. The validation process involved five validators with competencies in packaging technology, information systems, product design, and MSME development. The assessment focused on five main aspects: model relevance, safety, traceability, usability, and sustainability of the packaging material.

Validator selection was conducted purposively based on competency criteria that matched the characteristics of the model being developed. Validators were selected based on several criteria, namely (1) having an educational background or expertise relevant to the field being assessed; (2) having at least five years of professional or academic experience in a related field; (3) having experience in research, product development, technology implementation, or MSME mentoring; and (4) being willing to provide evaluation and input on the development of the smart packaging model.

The five validators involved consisted of: (1) packaging technology experts with experience in the design and development of product packaging systems; (2) information systems experts with competencies in digital technology, QR Codes, and information security; (3) product design experts with experience in the visual, functional, and ergonomic aspects of packaging; (4) environmentally friendly material experts who understand the characteristics of sustainable packaging materials; and (5) MSME support practitioners with experience in implementing product innovation and small business development. The composition of the validators was chosen to ensure that the model was assessed multidimensionally, not only from a technological aspect, but also from the design, sustainability, and implementation readiness aspects.

The expert validation instrument was developed based on the results of a literature review on smart packaging, traceability systems, anti-counterfeiting technology (*anti-counterfeiting systems*), and sustainable packaging. The development of indicators also refers to design requirements obtained from the needs analysis stage within the Design Science Research (DSR) framework. The instrument consists of five main assessment aspects, namely (1) model relevance, (2) system security, (3) information traceability, (4) model usability, and (5) packaging material sustainability.

The relevance aspect is used to assess the model's suitability to the packaging issues faced by MSMEs. The security aspect is used to evaluate the integration of QR codes and digital watermarks to support product authentication. The traceability aspect is used to assess the system's ability to provide product information digitally. The usability aspect is used to assess the ease of implementation of the model by MSMEs and users. Meanwhile, the sustainability aspect is used to assess the suitability of packaging material use with environmentally friendly principles.

Each indicator was assessed using a five-level Likert scale: 1 indicates very inappropriate, 2 indicates inappropriate, 3 indicates somewhat appropriate, 4 indicates appropriate, and 5 indicates very appropriate. In addition to providing quantitative scores, the validator also provided comments and recommendations for improvement as a basis for model refinement.

Table 5. Expert Validation Results for the Smart Packaging Model

Validation Aspects	V1	V2	V3	V4	V5	Average	Percentage	Category	Interpretation
Relevance	5	5	4	5	5	4.80	96%	Very valid	The model is considered very suitable for the packaging needs of MSME products.
Security	4	4	5	4	5	4.40	88%	Very valid	The model is able to improve product identity authentication and protection.
Traceability	5	4	5	4	5	4.60	92%	Very valid	The model supports digital access to product information and distribution.
Utility	4	5	4	4	5	4.40	88%	Very valid	The model is relatively easy to implement by MSMEs and users.
Sustainability	4	4	5	4	4	4.20	84%	Very valid	The model supports the use of more environmentally friendly packaging materials.
Average Total						4.48	89.6%	Very valid	Model is usable with minor revisions

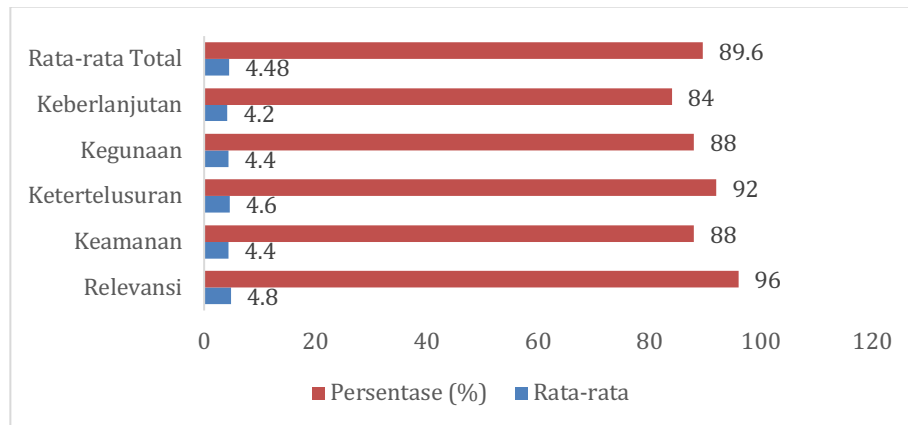


Figure 3. Expert Validation Results Graph

The validation results show that the model obtained an average score of 4.48 or 89.6%, so it is included in the very valid category based on the criteria of 81–100% very valid, 61–80% valid, 41–60% quite valid, 21–40% less valid, and 0–20% invalid. The highest value is in the relevance aspect (96%), which indicates the suitability of the model to the packaging needs of MSMEs, especially informative, safe, attractive, and traceable packaging. The traceability aspect (92%) shows that QR Codes, batch numbers, and product databases are considered capable of strengthening traceability through digital identities that contain information on legality, production date, production location, and batch status. Meanwhile, the security and usability aspects are each 88%, indicating that digital watermarks can increase technical barriers to label counterfeiting and QR Codes can be used without special devices, although the implementation of databases and tiered access still requires MSMEs' digital literacy.

The sustainability aspect received the lowest score, at 84%, but remained in the highly valid category. This score indicates that the selection of environmentally friendly materials is the most sensitive aspect because product protection needs differ for dry, liquid, cosmetic, herbal, and wet food products. Cost, food contact safety, printability, durability, and material availability also influenced the assessment. Based on the overall results, the model was declared to meet the validity criteria and can proceed to the feasibility evaluation stage, with minor improvements based on validator input, especially in the flexibility of material selection, simplification of technology implementation, and ease of access to digital information.

In the user evaluation stage, the model feasibility category is determined based on the percentage of the score against the maximum score of the instrument with the criteria of 81–100% very feasible, 61–80% feasible, 41–60% quite feasible, 21–40% less feasible, and 0–20% not feasible. These criteria are used to determine the level of readiness for implementation of the smart packaging model based on user perceptions.

Feasibility Model Evaluation Results

The feasibility evaluation of the model was conducted to determine the level of readiness for implementing a *smart packaging model* based on QR codes, *digital watermarks*, and environmentally friendly materials in the context of MSMEs. This evaluation aims to assess the extent to which the model can be implemented technically, economically, operationally, safely, and environmentally sustainable. The assessment was carried out by five validators who have competencies in the fields of packaging technology, information systems, product design, and MSME development. Aspects evaluated include technical feasibility, economics, safety, usability, and environmental. The evaluation results are used as a basis for determining the level of implementability of the model before it is applied more widely to MSME products.

Table 6. Results of the Smart Packaging Model Feasibility Evaluation

Eligibility Aspect	V1	V2	V3	V4	V5	Average	Percentage	Category	Implications
Technical	4	5	4	4	5	4.40	88%	Very worthy	The model can be applied to the MSME packaging design system.
Economy	3	4	4	4	3	3.60	72%	Worthy	Implementation needs to be adjusted to the cost capacity of MSMEs
Security	4	4	5	4	5	4.40	88%	Very worthy	The model is able to strengthen authentication and reduce the risk of counterfeiting.
Use	4	5	4	4	4	4.20	84%	Very worthy	The model is relatively easy to use by MSMEs and consumers.
Environment	5	4	4	5	4	4.40	88%	Very worthy	Model supports the use of environmentally friendly packaging materials
Average Total						4.20	84%	Very worthy	The model is suitable for limited implementation.

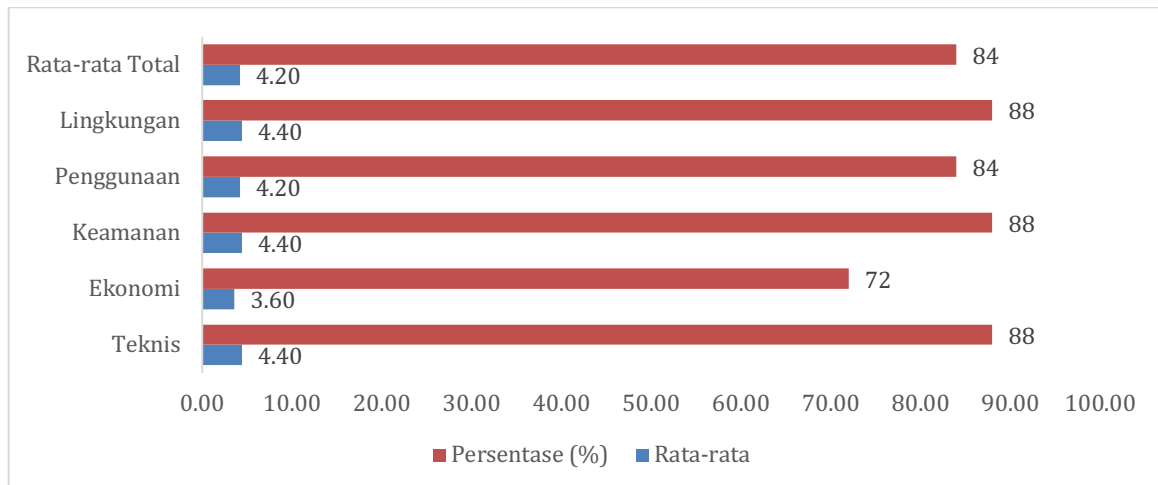


Figure 4. Model Feasibility Evaluation Graph

The evaluation results showed that the model achieved an average score of 4.20, or 84%, categorizing it as highly feasible. The technical, safety, and environmental aspects achieved a score of 88%. This score indicates that the model can be integrated into packaging design without compromising visual functionality, enhances authentication, and supports the use of more sustainable materials.

The usability aspect received a score of 84%. This score indicates that the model is relatively easy to use for consumers and MSMEs. Consumers only need to scan a QR code to access product information. MSMEs can start with a simple information page before developing a more complex database.

The economic aspect received the lowest score, at 72%. This score represents a significant finding. The low economic score occurs because implementing the model requires additional costs for three key components: creating a QR Code information system, inserting a digital watermark into the packaging design, and selecting environmentally friendly materials. For micro-SMEs, the costs of label redesign, high-quality packaging printing, domain or product pages, and batch data management can be an initial burden. This indicates that technology adoption in MSMEs is heavily influenced by perceived cost, ease of use, immediate benefits, and internal resource readiness.

These economic findings formed the basis for developing a tiered implementation scheme. The model is not intended as a single technology package that must be fully implemented from the outset. Instead, the model is designed so that MSMEs can start at a basic level and then progress to standard and advanced levels, depending on their business capacity.

Product Prototype and Packaging Appearance

Packaging prototypes are developed to demonstrate the model's applicability to MSME products. Prototypes can take the form of snack pouches, cosmetic boxes, coffee packaging, herbal drink bottles, or locally processed product packaging. The prototype design includes brand identity, product information, a unique QR code, a digital watermark, information on environmentally friendly materials, a batch number, production date, legality, and manufacturer data.



Figure 5. Prototype of MSME Product Packaging Based on QR Code, Digital Watermark, and Environmentally Friendly Materials

Figure 3 should show the front and back of the packaging. The front contains the product name, brand identity, eco-friendly material claims, and key visual elements. The back contains the QR code, batch number, ingredients, production date, expiration date, distribution permit, manufacturer's address, and the caption "Scan for product authenticity and traceability." Digital watermarks can be embedded in logos, label ornaments, design backgrounds, or micropatterns.

Table 7. Smart Packaging Prototype Components

Prototype Components	Implementation Form	Function	Expected Output
Brand Identity	Logo, product name, brand colors, and other visual elements	Building product identity and differentiation	The packaging is easily recognizable and has strong visual appeal.
Unique QR Code	QR Code is different for each product or production batch	Provide access to product information and support traceability	Consumers can verify product data and authenticity independently
Digital Watermark	Hidden patterns or codes in logos, labels, or packaging design backgrounds	Adding layers of product authentication and security	Labels are harder to counterfeit and increase brand protection.
Legal Information	NIB, PIRT, BPOM, halal certificate number, or other permits according to product category	Demonstrate compliance with applicable regulations	Increase consumer trust and confidence in the product
Batch Information	Batch number, production date, and production location	Supports product traceability and quality control systems	Products can be easily tracked in case of complaints or product recalls.
Environmentally Friendly Materials	Kraft paper, recycled paper, bioplastic, or biodegradable packaging	Reducing the impact of packaging waste on the environment	Packaging supports the principles of circular economy and sustainability
Digital Information Page	A simple web page or database linked to a QR Code	Store and update product information digitally	Information can be updated without the need to reprint the packaging.

The prototype demonstrates that smart packaging can be implemented without altering the packaging's basic function. The packaging retains its protective and promotional functions, but gains additional functions as a verification and traceability system. This finding is crucial because MSMEs need innovations that don't eliminate packaging's commercial function but instead expand its value.

Discussion

QR Code Scanning Simulation and System Testing

A QR code scanning simulation was conducted to assess whether the QR code could open a product information page and display the appropriate data. The simulation scenarios included initial scanning, product verification, public information access, batch data inspection, and detection of potential code misuse.

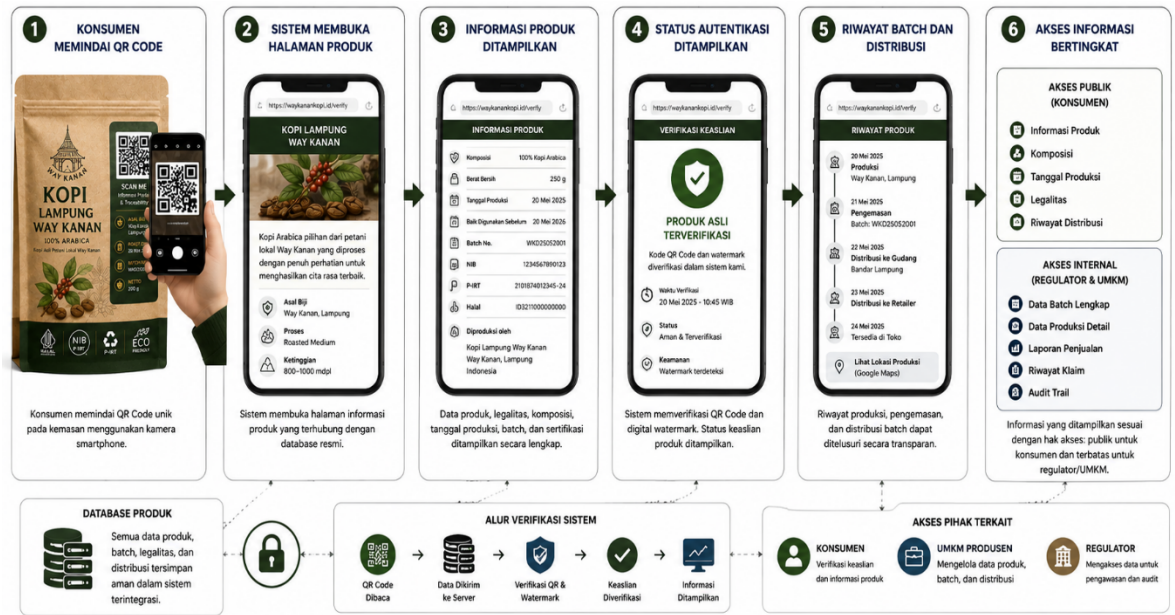


Figure 6. Simulation of QR Code Scanning Flow and Product Information Verification

Figure 6 should show the flow: consumer scans QR Code, system opens product page, product data is displayed, authentication status appears, and batch history can be checked by authorities.

Table 8. QR Code Scanning Simulation Results

Test Aspects	Indicator	Results	Interpretation
QR Code	Scan success rate	96%	QR Code can be read stably on the prototype
QR Code	Average response time	2.14 seconds	Product information pages can be accessed quickly
QR Code	Error rate	4%	Access failure remains at a low level
QR Code	Readability distance	15–30 cm	QR Code can be scanned at normal usage distance
Digital watermark	Detection accuracy	91.8%	Watermarks can be used as additional authentication
Product information	Information completeness	90%	Product data can be displayed in a concise and structured manner
Users	Ease of use	4.45	Users rate the system as easy to use
Users	Trust improvement	4.51	The system increases trust in the product

Simulation results show that QR codes are effective as a gateway to information. However, QR codes still have a weakness because the code can be copied from genuine packaging and affixed to counterfeit products. Therefore, the model requires a digital watermark as an additional layer of authentication. This combination provides consumers with easy access to information, while manufacturers and regulators have an additional tool to verify the authenticity of labels.

Utility Artifact and Final Model

A utility analysis was conducted to demonstrate the artifact's usefulness in solving MSME packaging problems. The final model combines QR codes, digital watermarks, eco-friendly materials, a product database, tiered access, and a phased implementation scheme. The basic, standard, and advanced schemes were combined into the final model to avoid creating separate tables.

Table 9. Utility Artifact and Final Smart Packaging Model

Final Model Dimensions	Component	Utility	Success Indicators
Digital information	Unique QR Code and product information page	Consumers gain quick access to product information	Product information can be verified via mobile phone
Traceability	Batch number, production date, product origin, and distribution history	Products can be traced by batch	Production and distribution history available
Authentication	Digital watermark on logo or visual elements	Reduced risk of label counterfeiting	Original and fake labels can be distinguished
Sustainability	Recyclable, biodegradable, compostable, or low-impact materials	The environmental impact of packaging can be reduced	Materials in accordance with circular economy principles
Data management	Product database	Legality, batch and distribution data are stored in a more structured manner	Data can be updated by MSMEs
Access control	Public access and internal access	More balanced data transparency and security	Consumers and regulators have different levels of access
Implementation	Basic, standard, advanced	MSMEs can choose the level of implementation according to capacity	Adoption can be done in stages

The final model demonstrates that smart packaging for MSMEs must be adaptive. Micro-SMEs can start with QR codes and basic information pages. MSMEs that already have legal documents and packaging designs can still add simple digital watermarks. MSMEs entering the modern market can develop product databases and tiered access. Thus, the model doesn't force MSMEs to implement full technology from the start, but rather provides a realistic implementation path.

Contributions to Design Science Research

Research contributions are analyzed based on the main components of Design Science Research: artifact, utility, evaluation, contribution, and practical relevance. This analysis is crucial because DSR-based research must demonstrate not only the design product but also its usability, evaluation, and scientific contribution.

Table 10. Design Science Research Contribution

DSR Components	Research result	Contribution
Artifact	Three-layer functional smart packaging model	Produces integrative designs based on QR Code, digital watermark, and environmentally friendly materials.
Utility	Security, traceability, information and sustainability	Answering practical packaging problems for MSMEs

Evaluation	Expert validation, Aiken's V, feasibility evaluation, system simulation, and prototype testing	Demonstrates that the model is valid, feasible, and has implementation potential.
Knowledge contribution	Integration of <i>Smart Packaging Framework</i> , <i>Supply Chain Traceability Framework</i> , and <i>Circular Economy Theory</i>	Expanding the study of smart packaging in the context of MSMEs
Practical relevance	<i>Basic</i> , <i>standard</i> , and <i>advanced</i> implementation schemes	Providing a gradual adoption path for MSMEs with different capacities

These results strengthen the research's position because the artifact was not only conceptually constructed but also evaluated through expert validation, content validity analysis, feasibility evaluation, system simulation, and prototype testing. Thus, the model has theoretical relevance, practical utility, and potential for implementation in MSME products.

4. DISCUSSION

The results of the study indicate that the smart packaging integration model based on QR Code, digital watermark, and environmentally friendly materials has high relevance for improving the security, traceability, and sustainability of MSME product packaging. The developed model consists of three functional layers, namely *the information and traceability layer* , *the authentication and security layer* , and *the sustainable material layer* . The integration of these three layers shows that packaging no longer only functions as a product protector and promotional media, but also as an information medium, an authentication instrument, a traceability tool, and a supporter of the circular economy. These findings strengthen *the Smart Packaging Framework* which views packaging as an active system that connects physical products with digital data and sustainability aspects.

The expert validation score of 89.6% indicates that the model is highly valid, with the relevance aspect achieving the highest score (96%). These results indicate that the model is able to address the real needs of MSMEs related to product counterfeiting, limited information, weak traceability, and demands for more sustainable packaging. These findings align with Yudisha et al., who emphasized that MSME packaging challenges are no longer limited to visual aspects but also encompass legality, product identity protection, and increased market competitiveness.

The traceability aspect scored 92%, indicating that the integration of QR codes, batch numbers, product databases, and tiered access effectively improves product traceability. This finding supports *the Supply Chain Traceability Framework* , which places digital identity and product history as the foundation of supply chain transparency. In the context of MSMEs, this capability is crucial because products are often marketed through multiple distribution channels, complicating the tracking process when quality, safety, or legality issues arise.

These results align with research by Usman & Baharuddin (2023), Barlianto et al. (2024), and Pertiwi & Arifani (2025) , which showed that QR codes and digital systems can increase the transparency of product information. However, this study expands on previous studies by integrating material authentication and sustainability into packaging systems. These findings also complement research by Lai et al. (2022) and Ellahi et al. (2023) , which emphasize the importance of transparency and verifiability in digital technology-based supply chains. Unlike the relatively complex blockchain approach, this model offers a more adaptive alternative through QR codes, digital watermarks, product databases, and tiered access that better suits the capacity of MSMEs.

The security aspect obtained a score of 88%, indicating that the *digital watermark component* in the model is perceived as having potential as an additional authentication mechanism to strengthen the digital identity of the product beyond the QR Code function. However, this finding should be understood as the result of conceptual validation of the model design, not as empirical evidence that the implementation of *digital watermarks* has improved the system's ability to prevent or detect counterfeiting. This study has not specifically explained the type of *digital watermark* used, such as *visible watermark* or *invisible watermark* , embedding method , extraction or *detection method*, *robustness* parameters against manipulation, and testing scenarios between original and counterfeit labels.

Given these limitations, the claim that *digital watermarks* can increase technical barriers to counterfeiting and differentiate genuine labels from counterfeit labels should be viewed as a potential design function, rather than as a verified security measure. The technical implementation of *digital watermarks* still requires further testing through experiments involving the digital watermark insertion process, resistance testing against various forms of attacks or manipulation, and evaluation of the level of detection accuracy between authentic and counterfeit products.

These findings support the research of Xie & Tan, (2021) and H. Wang, (2023) which explains that the use of QR Codes alone has limitations because the information contained in them

is relatively easy to copy or replicate, so additional authentication mechanisms are needed. Therefore, the developed model adopts the principle of *layered security*, where the QR Code acts as a medium for open information access, while *the digital watermark* is designed as a hidden authentication layer. This combination conceptually offers a layered security approach to strengthen the digital identity of products, but its actual ability to detect and distinguish genuine labels from counterfeits still requires further technical validation and empirical testing.

The research findings also support the findings of JW Lai & Cheong, (2022) that QR Codes are effective for product traceability and verification. However, this study expands its functionality through the integration of product databases, batch numbers, legality, and hidden authentication. Conversely, unlike Zhang, (2024)'s research, which developed smart packaging based on sensors and real-time monitoring, this study emphasizes the use of technology that is simple, economical, and easy to adopt by MSMEs. These findings indicate that smart packaging does not have to rely on sophisticated technology, but can be developed through an *appropriate technology approach* that has high utility and lower implementation costs.

The usability aspect scored 88%, indicating that the model is relatively easy to use by MSMEs, consumers, distributors, and regulators. However, its implementation still requires digital literacy and consistent data management. This finding supports the theory of technology adoption, which states that innovation acceptance is influenced by perceived benefits, ease of use, and user readiness. Therefore, the model was designed with three implementation levels (*basic*, *standard*, and *advanced*) to allow for gradual adoption according to the capacity of MSMEs.

The sustainability aspect scored 84%, the lowest score compared to other dimensions. This finding indicates that the use of environmentally friendly materials is more complex than the integration of digital technology because it must consider protective functions, print quality, durability, material availability, and production costs. These results reinforce *the Circular Economy Theory*, which positions sustainability as a balance between environmental, technical, and economic aspects. However, the sustainable material aspect in this study is still at the conceptual level and has not been supported by experimental testing of material characteristics. The model does not directly test the *barrier properties*, mechanical properties, food contact safety, biodegradability, *recyclability*, or environmental impact of the proposed materials. Therefore, the mention of materials such as *kraft paper*, *recyclable materials*, *biodegradable materials*, and *compostable materials* in this study should be understood as design alternatives that can be considered according to the characteristics of MSME products, not as evidence that these materials have been empirically proven to provide better environmental performance in the developed model.

These findings align with various studies on *bio-based smart packaging* and smart food packaging, which emphasize the integration of safety, information, and sustainability. However, unlike studies using sensory materials or nanotechnology, this study places greater emphasis on the suitability of materials to the needs of MSMEs in terms of cost, availability, and ease of implementation. Given the limitations of experimental evidence, the results of this study cannot yet be used to conclude the environmental superiority of a particular material. Instead, the findings are better understood as a conceptual basis for selecting alternative materials, which must be further verified through technical, safety, and environmental testing. These results demonstrate that sustainability challenges in the context of this model relate not only to environmental awareness but also to the need to balance ecological, technical, availability, and cost aspects of materials.

The feasibility evaluation results, with a score of 84%, indicate that the model is highly feasible for limited-scale implementation. Technical, safety, and environmental aspects scored high, while economic aspects scored the lowest (72%). These findings suggest that the primary barrier to smart packaging implementation in MSMEs lies not in technology acceptance, but rather in initial investment costs and operational readiness. Thus, the gap between innovation and adoption is more influenced by resource capacity than the quality of the technology itself.

Therefore, the phased implementation strategy through *basic*, *standard*, and *advanced levels* is an important contribution of this research. This approach allows MSMEs to adopt innovations according to their financial and operational capacity. From a practical perspective, this model has the potential to increase consumer trust, reduce the risk of counterfeiting, strengthen supply chain transparency, and enhance MSME brand image. This potential still needs to be verified through empirical testing on actual users and operational conditions. Verifiable information through QR Codes and hidden authentication designs through *digital watermarks* have the potential to reduce information asymmetry between producers and consumers while supporting product readiness for entry into modern markets and exports.

Theoretically, this research integrates *the Smart Packaging Framework*, *Supply Chain Traceability Framework*, and *Circular Economy Theory* into a single conceptual model that positions

security, traceability, and sustainability as a unified system. Practically, this research provides a realistic *smart packaging implementation guide for MSMEs*. Technologically, this research offers a *layered security system that combines QR Code, digital watermark, product database, and eco-friendly materials* in one integrated packaging artifact, thus providing a more comprehensive contribution compared to approaches that only focus on QR Code, *watermark*, or *eco-packaging* separately. The technological contribution lies primarily in the design of the integrated components; the technical effectiveness of the *digital watermark* and the performance of sustainable materials still require separate experimental validation.

However, this study still has several limitations. The model implementation is still at the prototype stage and testing is limited, the number of respondents is relatively small, and the *digital watermark mechanism* has not been experimentally tested using various *embedding*, extraction or detection methods, distortion levels, and different manipulation conditions. Furthermore, the sustainable material components are still conceptual and have not been tested for *barrier properties*, mechanical properties, food contact safety, biodegradability, *recyclability*, or environmental impact. Furthermore, the analysis of implementation costs at each adoption level has not been calculated in detail. Therefore, further research is needed to conduct *pilot projects* in various categories of MSMEs and conduct technical testing of the *digital watermark method*, including the *embedding* and detection processes, resistance to label reproduction or manipulation, and the ability to distinguish authentic from counterfeit labels. Further research also needs to experimentally test various alternative materials based on their *barrier properties*, mechanical properties, food contact safety, biodegradability, *recyclability*, and environmental impact, as well as examine the effect of *smart packaging* on consumer trust, purchasing decisions, brand loyalty, product competitiveness, and readiness to enter modern markets and exports.

Overall, the research results indicate that the *smart packaging integration model* based on QR Code, *digital watermark*, and environmentally friendly materials is suitable for use as a framework for developing MSME packaging. This model is able to integrate security, *traceability*, sustainability, and affordability in one system that is adaptive to the needs of MSMEs, so that packaging can function not only as a product protector, but also as an information medium, authentication instrument, traceability tool, and competitiveness enhancement strategy. In the context of this research evidence, the conclusion mainly refers to the feasibility and validity of the model as an integrated design, while the technical effectiveness of *digital watermark* and the environmental performance of the material still require further empirical testing.

5. CONCLUSION

This study concludes that the integration model of smart packaging based on QR Code, digital watermark, and environmentally friendly materials is suitable for use as a framework for developing safer, traceable, and sustainable MSME product packaging. Through a Design Science Research approach, this study produces three integrated functional layers, namely the *information and traceability layer*, *authentication and security layer*, and the *sustainable material layer*. The QR Code functions as access to product information, legality, batch number, and distribution history, while the digital watermark strengthens hidden authentication to reduce the risk of counterfeiting and copying product identity. Environmentally friendly materials support the implementation of circular economy principles through the use of recyclable, biodegradable, or compostable materials according to product characteristics. The expert validation results of 89.6% indicate the model is in the very valid category, while the feasibility evaluation of 84% indicates the model is very feasible for limited implementation. The research findings indicate that the main challenge of implementation lies in the economic aspect, so that model adoption needs to be carried out in stages through the *basic*, *standard*, and *advanced levels*. Theoretically, this study integrates the *Smart Packaging Framework*, *Supply Chain Traceability Framework*, and *Circular Economy Theory* into a single conceptual model that positions security, traceability, and sustainability as a unified system. Practically, this model has the potential to increase consumer trust, supply chain transparency, brand protection, and MSME competitiveness. The findings also indicate that smart packaging for MSMEs does not have to rely on high-cost technologies, but can be built through the integration of simpler, more adaptive, and affordable technologies. Future research should test the model on various product categories and conduct an empirical analysis of implementation costs to strengthen its readiness for wider adoption.

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