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Important Factors of Artificial Intelligence in Developing Good Manufacturing Practices Model in Food Industry

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Abstract

Artificial intelligence (AI) has transformed food production processes by enhancing efficiency, precision, and quality, particularly within the framework of Good Manufacturing Practices (GMP). This study examines the role of AI in reducing human error, maintaining consistent product quality, and ensuring compliance with stringent hygiene standards. Key applications include predictive maintenance of production equipment, real-time data analysis for decision-making, and automation of quality control through visual recognition technologies. Despite these advancements, challenges such as high initial investment costs, limited technical knowledge, and data security concerns persist. This research identifies current barriers, explores potential solutions, and outlines a conceptual framework for AI integration with GMP to foster sustainable, efficient, and hygienic food production systems.

Keywords
Artificial Intelligence, Food Production, Hygiene, Efficiency, Good Manufacturing Practices.

1. Introduction
The food industry has experienced improvements in speed, accuracy, and excellence by using artificial intelligence (AI). Nonetheless, there are still a number of significant obstacles, especially related to how AI can magnify these aspects to meet the increasing complexity of contemporary food cultivation. guarantee uniform merchandise quality, limit waste, enforce strict safety guidelines, and save business expenses and resource use (Cao et al., 2025).

Transformative AI provides a way to overcome barriers by enabling predictive maintenance for machines, automating quality checks using visual technology, and helping instant evaluation of data to make choices. However, to achieve the full capacity of AI, a methodology is needed that ensures maximum effectiveness and accuracy, as well as reliability and ethical standardization in its application (Issa et al., 2024).

This research investigates the role of artificial intelligence (AI) in improving efficiency, precision, and quality at various phases of the food production process, specifically within the context of Good Manufacturing Practices (GMP). The food business may use AI to decrease human error, which frequently happens in manual activities, and enhance manufacturing processes in an integrated way. Furthermore, this technology makes it possible to automatically monitor safety and hygienic requirements, guaranteeing more constant adherence to global laws. The objectives of this article are to assess the current obstacles to AI implementation, pinpoint possible uses for AI in the food production industry, and create a plan for a more efficient and long-lasting integration of AI technology (Nath et al., 2024).

This research employed the literature review method to carefully examine the literature and synthesize valid data.

International scientific databases, including Scopus, served as the primary source of data. Using keywords like "Artificial Intelligence", "AI," and "Food," as well as boolean operators (AND, OR) to broaden the search, the research procedure involved finding and choosing relevant literature. The chosen articles satisfied the requirements for inclusion, which included being written in English, published within the previous ten years, and pertinent to the subject of the study.

1.1 Research Objectives

The goal of the research is to identify the key artificial intelligence (AI) components that facilitate the use of a new Good Manufacturing Practices (GMP) model that is more pertinent to the demands of the contemporary food sector. It is anticipated that by incorporating AI, the model will increase operational effectiveness, guarantee adherence to hygienic regulations, and offer creative answers to the problems the food industry experiences.

By analyzing the main advantages of this technology, including real-time analysis capabilities, contamination risk reduction, and manufacturing process optimization, this study focuses on the creation of an AI-powered GMP model. It also looks at how AI might be utilized to develop fresh strategies for enhancing hygienic standards compliance, automating quality control procedures, and guaranteeing sustainable production.

Furthermore, the goal of the research is to pinpoint the essential AI components that affect the effective use of novel GMP models. These elements include AI technology's precision, dependability, openness, security, and effectiveness. This study looks at the difficulties that come with integrating AI, including the need for investment, a lack of technical expertise, and legislative limitations, using R-BiblioShiny and the Literature Review. In order to help the food business fully employ AI in the implementation of more contemporary and sustainable GMPs, this research aims to create conceptual guidelines.

2. Literature Review

2.1 Literature Review

The literature review will therefore underpin the study in attempts to identify relevant literature that showcases deep understanding in regard to the application of artificial intelligence in supporting Good Manufacturing Practices. Presumably, the validity of data retrieved during this process is high; hence, being one of the key bases for research conclusions. In the initial stages of the literature review, specific research questions were identified to clearly set the scope of the study. This was followed by a literature search using keywords such as "AI or Artificial Intelligence" and "Food" on scientific databases like Scopus. The literature found was screened for inclusion criteria: articles relevant to the research topic, in the English language, and published within the last few years up to the most recent. Non-peer-reviewed articles or those not relevant to the research objectives were excluded (Camaréna, 2020).

Following the selection of literature, analysis and synthesis of the material were done to find out the trends in research, methodologies used, and results obtained while applying AI to GMP. The process also provided insight into the gaps in the literature that could be a starting point for further research. In doing so, this literature review provides not only an overview but also new additions to the scientific literature.

2.2 Good Manufacturing Practices (GMP)

Good Manufacturing Practices (GMP) are a set of guidelines that aim to ensure hygiene and safety standards in food production. GMP covers aspects such as environmental hygiene, equipment, raw materials, and labor. The main objectives are to prevent contamination, improve production efficiency, and maintain consistent product quality. Compliance with GMP is a must for the food industry to meet international standards such as Codex Alimentarius (Frank Abimbola et al., 2023).

The integration of artificial intelligence into GMP will go a long way in realizing better efficiency and effectiveness in the implementation of these guidelines. AI technology allows for real-time detection of contamination risks using smart sensors, automates hygiene inspection processes for improved accuracy and consistency, and optimizes production processes through real-time data analysis. By applying AI, the food industry can enhance consumer confidence in the quality of their products and attain higher operational efficiency. Besides, businesses can also be competitive in the midst of regulatory demands and changing market dynamics. In the end, AI in food manufacturing is how AI is transforming food production.

2.3 R-BiblioShiny (BiblioMetrix)

This Research used R and RStudio software with the bibliometrix package to conduct bibliometric analysis. It allows for insights into publication trends, collaboration between authors, and frequently discussed topics in relation to AI and GMP. Biblioshiny, an interactive feature in bibliometrix, was used to visualize the data in a more intuitive and exploratory way (Aria & Cuccurullo, 2017).

The analysis process involves the identification of research trends by annual publication count, the analysis of frequently used keywords to identify the main focus of research, and mapping collaborations of authors and institutions to understand global research networks. It is expected that this approach will contribute significantly to the identification of literature gaps that may inspire further research and open up opportunities for technology development relevant to the food industry.

3. Methods

It involves a quantitative analysis of data. The data have been analyzed with the use of R and RStudio software for this research study (Figure 1). The basic aim of conducting this research paper is exploring research trends, finding out major findings, understanding conceptual relationships in "Use of AI in food production processes under GMP" with the Bibliometrix package, which has been designed by Aria and Cuccurullo (2017) for conducting a bibliometric analysis.

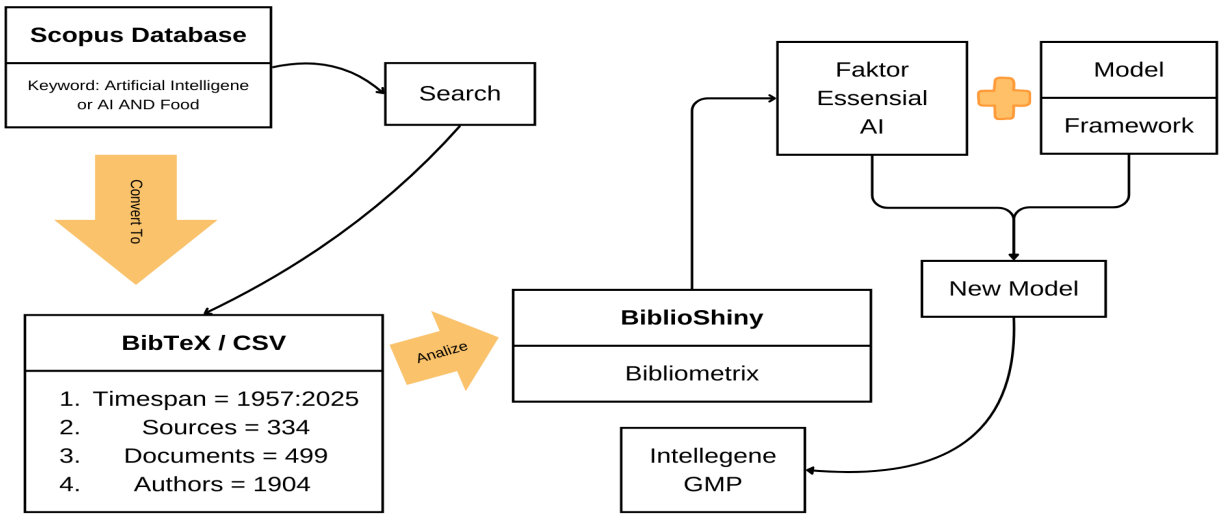

Figure 1. Research method

The literature review is the methodology that will be used in this research. This was chosen because the approach will, through a structured and systematic evaluation of the literature, result in the synthesis of valid and relevant data. Main sources of data will come from international scientific databases such as Scopus. The main stages of the research started with the identification and selection of literature using keywords such as "Artificial Intelligence," "AI," and "Food." The scope of the search was widened by adopting a combination of Boolean operators, AND and OR. The articles to be selected had to fulfill the following inclusion criteria: they had to be within in the English language, and relevant to the research topic.

Data extraction was followed by extraction to extract metadata such as the title, abstract of the papers, name of the author(s), publication year, name of the journal, and keywords. This dataset would then be treated with the Bibliometrix package in RStudio. Publication trends, popular keywords, inter-author collaboration, and visualization of the research network have been studied here. The present work examined publication tendencies within the use of Artificial Intelligence as a support methodology for GMP in the food industry.

The tools used during data analysis were basically R and RStudio software. The bibliometrix package will provide various functions to be used for bibliometric analysis: basic bibliographic analysis covers the number of publications per year, journal distribution, and author productivity. Concept map analysis will establish the relationships of key concepts in research, while collaboration network analysis will evaluate relationships between authors, institutions, or countries. The derived visualizations included word clouds, diagrams for co-word analysis, and network maps that served to enhance data interpretation. The implementation phase started with the download of bibliographic data from scientific databases, cleaning, and formatting in R, according to the needs of the analysis.

Bibliometric analysis was performed in bibliometrix functions, and the results interpreted to answer research questions. The research findings were used for the development of practical recommendations with relevant conceptual guidance which gave deep insight into the use of artificial intelligence in supporting the implementation of good manufacturing practices in the food industries.

4. Data Collection

This section describes the approach to data collection adopted for this research in analyzing the application of AI in GMP support within the food industry. The data collection was conducted systematically so as to make the data relevant and valid. It focuses on data collection by establishing relevant literature or information that would be important and supportive of the research objectives.

Data collection was carried out from two major sources. Secondary data refers to scientific literature searched from databases on Scopus. It includes all journal articles, conference proceedings, and other publications written by the researchers in relation to the research topic. The selection will be made using inclusion criteria: written in English or Indonesian and relevant to the topic of AI and GMP. These were those articles that were either not peer-reviewed or did not specifically address AI in the context of GMP. Besides this, primary data collection was also done wherever necessary through surveys and interviews with food industry and AI technology experts, as well as case studies of companies that have adopted AI to support GMP.

The data collection process identified related literature, as selected by keywords including but not limited to "Artificial Intelligence", "AI", and "Food". Some combinations of boolean operators used include AND, OR. The query was refined to exclude duplication and other irrelevant literatures. The collected information included metadata along with specific data regarding AI implementation, impacts on GMP, and challenges reported. Validation has been performed to check the correctness of the source of data, and relevance for selection based on predefined inclusion criteria was considered.

R and RStudio were the key tools during data analysis. Bibliometrix software allows the said bibliometric analysis that will include identification of publication trends, collaboration networks between authors, and visualization of keyword relationships using this package. Furthermore, in this respect, biblioshiny features of RStudio have been utilized for n-tier interactive visual analysis and deep exploration of data. Microsoft Excel was applied as a supplementary tool to organize the raw data.

Some of the challenging areas while data collection include but are not limited to inaccessibility for some literature without subscription. The data also faced many different issues in its quality, most regarding the specific addressing of integration for AI and GMP. Missed terms led to many the literatures going undetected. For that reason, much cautious approach was engaged and expanded with the searching.

In sum, data collection has been done for this research in a very structured way in order to make data valid and relevant for the purposes of the research objectives. The data obtained is surely going to give very valuable insights into how AI applies to GMP within the food industry and also be a sound basis for analysis and recommendations later in the chapters.

5. Results and Discussion

5.1 Numerical Results

This section presents the results of the numerical analysis obtained through the use of BiblioMetrix (Figure 2). The research period covers 1957 to 2025 with a total number of 334 sources analyzed. From these sources, a total of 499 documents were collected, which represents an annual growth rate of 3.96%.

Figure 2. Analysis Results with BiblioMetrix

The number of authors involved in this study reached 1904, with 57 documents written by single authors. In terms of international collaboration, approximately 29.26% of the documents involved collaboration between authors from different countries, with an average number of authors per document of 4.37. The number of unique keywords identified during the analysis was 1370, which provides a broad view of the topics covered in the literature.

In terms of document age, the average age of the analyzed documents is 3.38 years. In addition, the average number of citations per document is 10.33. This analysis shows that the documents analyzed have significant relevance and make a meaningful contribution to the understanding and development of the research topic. Figure 3 provides a visualization of the results of this analysis with details that support data interpretation.

5.2 Graphical Results

The research period from 1957 to 2025 shows an increasing trend in the number of documents each year, with an average growth of 3.96%. This growth is likely driven by advancements in AI technology (Figure 3), increasing regulatory requirements, and a growing consumer demand for safer and more efficient food production methods

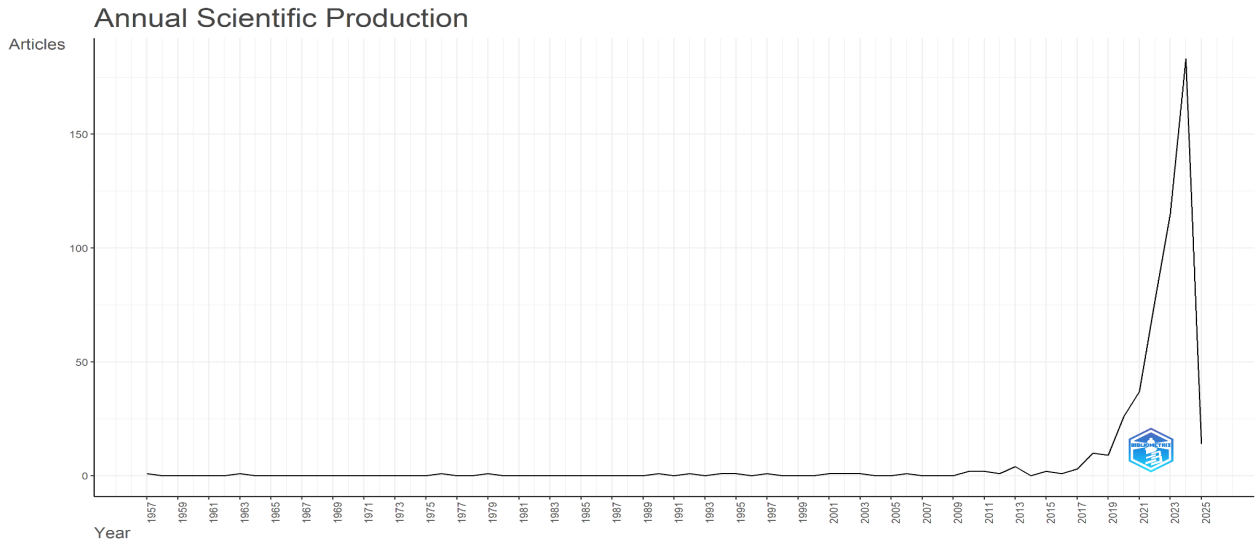

Figure 3. Graph of Research Trends from 1957 – 2025 (significant growth at 2017)

One notable observation is the significant increase in publications in the year 2017, coinciding with the rapid evolution of machine learning techniques and their application in industrial processes. Another key factor contributing to this trend may include global emphasis on sustainability and innovation in food production, which has encouraged interdisciplinary collaboration in research.

The majority of documents in this study involved collaboration, with the international collaboration rate reaching 29.26%. This reflects the global relevance of AI and Good Manufacturing Practices (GMP) research, as well as the necessity for cross-national collaboration to address industry-wide challenges. Countries with advanced technology infrastructure have likely led this growth, providing platforms for data sharing and collaborative advancements.

The average citation of 10.33 per document highlights the impact and importance of the analyzed works in advancing knowledge. This indicates that the subject area is not only active but also carries significant influence in shaping research directions. For instance, many studies have laid the groundwork for integrating AI into GMP compliance strategies, driving further innovations in automation, predictive analytics, and food safety management.

By linking these findings to practical implications, it becomes clear that future research should focus on overcoming identified challenges, such as high initial investments and workforce training requirements. Additionally, exploring emerging technologies like IoT and blockchain in combination with AI could further revolutionize GMP practices, ensuring sustainability and scalability.

5.3 Most Relevant Identification

The following is a detailed description of the results of identifying relevant sources in this research (Figure 4):
In this research, the most relevant sources have been identified based on the number of documents published on the topic of applying Artificial Intelligence (AI) in Good Manufacturing Practices (GMP)-based food processes. Foods and Journal of Food Quality are the most dominant journals with 18 documents each. This shows that these two journals are the main references in the topic of AI for food processes, especially in ensuring food quality according to GHP standards.

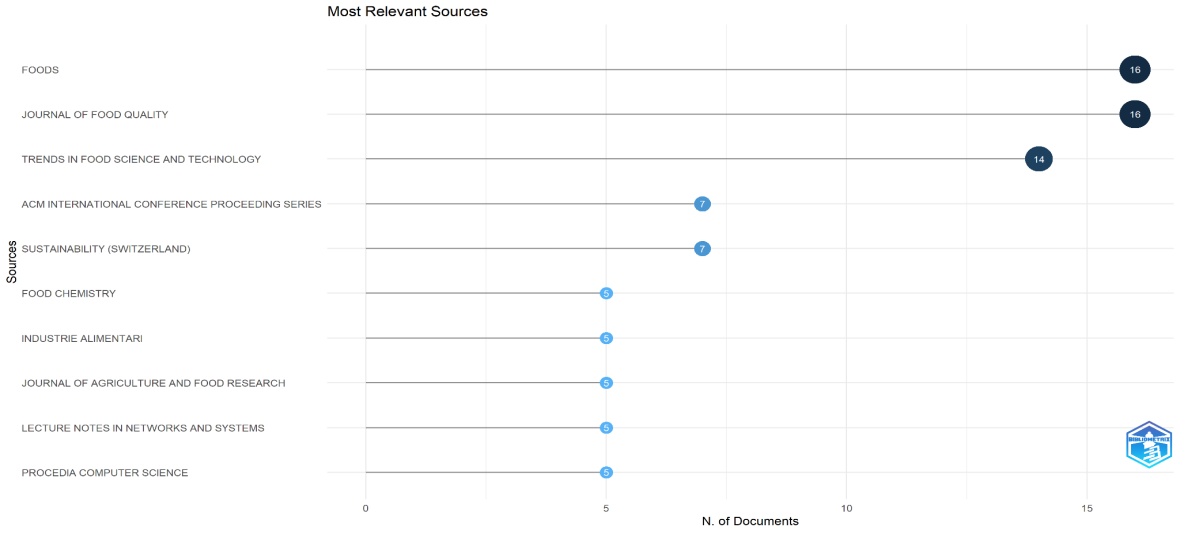

Figure 4. Most Relevant Source

Trends in Food Science and Technology contributed 14 documents. The journal focuses on the latest technological developments in the food industry, thus playing an important role in connecting AI technology with future trends in food processing.

ACM International Conference Proceeding Series and Sustainability (Switzerland) each produced 7 documents. This reflects the relevance of AI research not only from a technical perspective but also in the context of sustainability and multidisciplinary international conferences. This source broadens the perspective of applying AI in maintaining the balance between process efficiency and environmental impact.

Food Chemistry contributed 5 documents. The journal contributes to aspects of food chemistry that can be improved using AI, such as raw material quality testing.

Other sources, such as Industrie Alimentari, Journal of Agriculture and Food Research, and Lecture Notes in Networks and Systems, contributed 3 documents each. These sources focus on the practical, agricultural, and implementation aspects of AI-based systems. In addition, Procedia Computer Science also contributed 3 documents, showing the involvement of AI from a computer science perspective, especially for algorithm development and predictive systems.

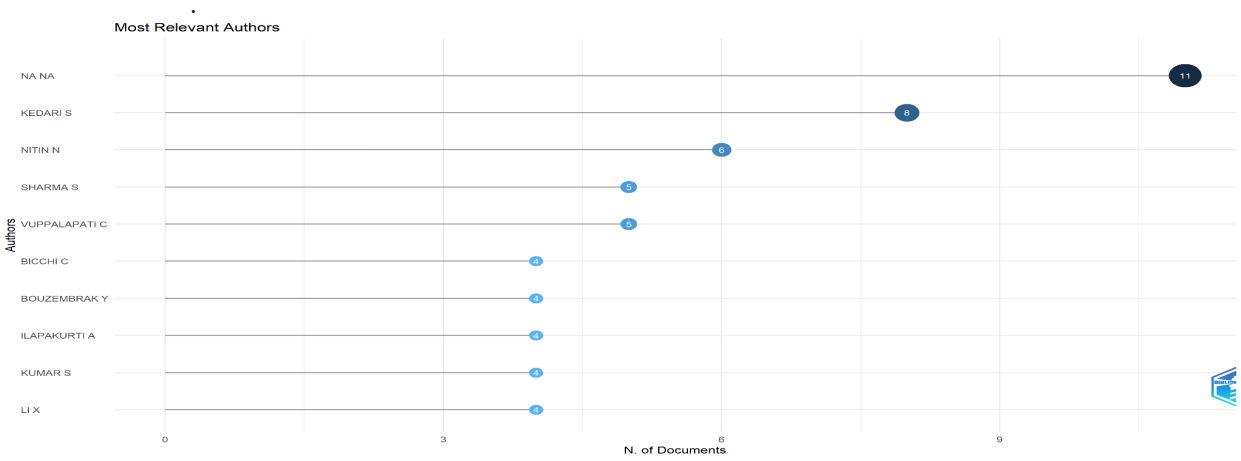

Figure 5. Most Relevant Authors

This research ensures theoretical validity by examining relevant literature and references. The analysis graph shows the list of authors with the highest contribution based on the number of publications or direct relevance to the research topic (Figure 5).

NA NA was the author with the highest contribution, 11, although his identity was not clearly documented. This shows the need for more attention to recording data sources so that the validity of the information can be guaranteed.

KEDAR S came in second place with 8 contributions. His works provide an important foundation that supports this research and show high relevance to the topic at hand.

NITIN N came in third with a contribution of 6. This author also made a significant impact on the development of the theoretical basis of the research.
The literature contributions from these authors play an important role in validating the research results. The next step is to explore more in-depth references from these authors to enrich the findings and strengthen the theoretical foundation of the research.

5.4 Validation

A validation process was conducted to ensure that the proposed new GMP model could be practically applied in a food manufacturing environment. The validation involved five manufacturing experts who have more than 10 years of experience in Good Manufacturing Practices (GMP) implementation in the food industry. The experts were selected based on their experience in adopting modern technologies, including artificial intelligence (AI), in the production process.

The validation phase begins with the presentation of the new GMP model to experts. The model was explained in detail, including its key elements such as speed, accuracy, reliability, sustainability and hygiene. Experts were asked to evaluate the model based on its relevance to the needs of the food industry, its potential benefits in improving production efficiency and quality, and the challenges that might arise during implementation.

The validation results showed that the model was well received by the experts. They gave an average score of 4.5 out of 5 for the model's relevance to industry needs. One of the most appreciated aspects was the model's ability to utilize AI in real-time monitoring and automation of quality control processes, which was considered to significantly reduce the risk of human error. However, some key challenges were also identified, such as the need for high initial investment and the need for specialized training for the workforce to operate AI-based systems.

In addition, the experts recommended several measures to improve the successful implementation of the model. These measures include developing a workforce training program, providing technical support during the initial phase of implementation, and increasing transparency in the system to document each operational step to meet international audit standards. These recommendations suggest that while the new GMP model is considered innovative and relevant, its success will largely depend on operational readiness and ongoing support.

Overall, this validation confirmed that the proposed GMP model has great potential to improve efficiency, quality and compliance with hygiene standards in the food industry. These results provide a strong basis for continuing the implementation of the model on a larger scale, while taking into account the inputs and recommendations from the experts.

5.5 Mapping

The Mapping illustrates the relationship between the key factors in the Good Manufacturing Practice (GMP) model, which include: Standard Operating Procedure, Personnel, Premises, Equipment, Each model focuses on the critical elements that contribute to the successful implementation of modern technology in Intelligene GMP (Table 1).

Table 1. Essential AI Factors in GMP

AI factor	Reference or Citations	Standard Operating Procedure	Personnel	Premises	Equipment
Speed	(Raji et al., 2024)				x
Accuracy	(Kim et al., 2024) (Raji et al., 2024)	x	x	x	x
Realiability	(Singh et al., 2025)	x	x	x	x
Scalability	(Pandey & Mishra, 2024)		x	x	x
Security	(Zhang, 2024)	x	x		x
Transparency	(Kim et al., 2024)	x	x	x	x
Real-Time	(Singh et al., 2025)	x	x		x
Efficiency	(Issa et al., 2024) (Feng et al., 2024)	x		x	x
Integrated	(Raji et al., 2024)	x			x
Sustainable	(Singh et al., 2025)	x		x	x
Hygiene	(Feng et al., 2024)		x	x	x
Effective	(Singh et al., 2025)		x		x

In achieving Intelligene GMP, there are several elements that must be considered. First, the Standard Operating Procedure has accuracy that ensures the procedure is performed precisely, Realibilty maintains consistency, prevents the threat of manipulation, Transparency documents all steps of the procedure, Real-Time automates monitoring and real-time reporting, Efficiency optimizes workflow, Integrated allows the merging of various operational processes to create systemic efficiency, Sustainable supports sustainability with environmentally friendly practices.

Second, Personnel training on the accuracy factor ensures that operational steps are carried out precisely, Realibility follows disciplined procedures, Scalability can increase production, Security prevents violations, Transparency documents every process, Real-Time can work with technology for a quick response, Hygiene ensures hygiene procedures, Effective works efficiently for operations.

Premises in the aspect of accuracy selects the appropriate environment appropriately, Realibility maintains stability in operations, Scalability designs expansion without affecting efficiency, Transparency monitors and improves the openness of the production process for inspection, Efficiency manages operations well, Sustainable supports environmentally friendly sustainability, Hygiene prevents contamination by meeting sanitation standards.

The last one is Equipment affects speed by speeding up the process with optimization, Accuracy ensures production in accordance with standards, Realibility predictive maintenance, Scalability adding production capacity without reducing performance, Security prevents data manipulation, Transparency records equipment data for audit purposes, Real-Time provides information on operational conditions directly, Efficiency efficient machines reduce waste of raw materials, Integrated creates an integrated production flow, Sustainable supports environmentally friendly technology,

Hygiene ensures cleanliness of production equipment, Effective optimizes the entire production process in the Standard Operating Procedure.

5.6 New Model

The model proposed herein is an innovative approach based on the key considerations highlighted above: speed, accuracy, reliability, safety, transparency, real-time monitoring, efficiency, integration, and sustainability. The Figure 6 will enable tackling AI implementation challenges within the food industry while improving the deficiencies in the traditional approaches.

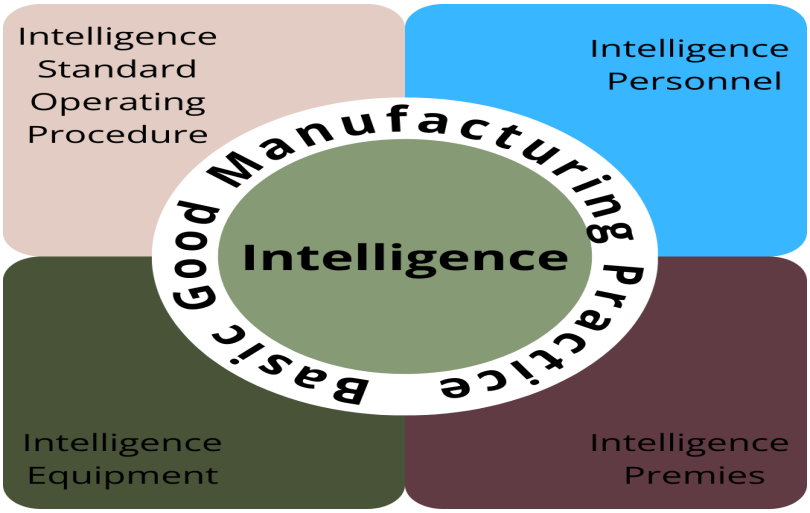

Figure 6. New Model Overview

This model has combined the philosophy of Basic GMP and four key elements: intelligence-based. First, Intelligence SOP, which means applying AI technology to standard operating procedure optimization in order to reach consistency and regulatory compliance. The second is Intelligence Personnel, meaning a smart and skillful workforce supported by data and technology to perform evidence-based decisions.

The third, Intelligence Equipment, employs sophisticated IoT- and AI-based devices to monitor performances in real-time to improvise on the operational efficiencies. Finally, Intelligence Premises focuses on connected manufacturing facilities through smart technologies in developing safe, efficient, and environment-friendly conditions for production.

These four elements are integrated into one with each other and put technological intelligence at the core of the system. In this way, the new model will be able to enhance the efficiency, safety, transparency, and sustainability of food manufacturing. It eventually offers a smart and modern solution ready to face the challenges and opportunities that, in general, the food industry will have in the future.

6. Conclusion

This research has been able to investigate several important aspects related to the application of artificial intelligence in support of Good Manufacturing Practices in the food industry. With systematic collection and analysis of data, major gains were identified for AI: enhancing efficiency, reducing the risk of contamination, and optimization of production processes. The results from the studies reveal that great potential exists when AI is applied together with GMP to improve general quality and safety parameters of foods.

Besides the identified benefits, some of the major challenges that were also noted include limited access to technology, high initial investment requirements, and limited technical knowledge at the operational level. In this regard, the research provides practical recommendations to support AI implementation, such as workforce training, development of more affordable technologies, and drafting of supporting policies.

The novelty of the research is that it develops a conceptual guide that can enable the food industry to integrate AI with GMP effectively and sustainably. It is tailored to ensure that the application of technological innovations within companies does not hamper the compliance with rules and standards that ensure safety and hygiene. With this comprehensiveness, the study lays a good foundation for further research and strategy development in the implementation of AI.

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Davian Massaro Wibawa is an active student at Institut Teknologi Sains Bandung (ITSB) who is currently studying in the Informatics study program. Throughout his education, Davian has shown a deep interest in the field of artificial intelligence (AI), a discipline that is increasingly relevant in today's digital transformation era. As a technology-

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