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The Challenges of 3D Food Printing in Malaysian Manufacturing Firms: A Preliminary Study

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Abstract

Additive manufacturing (AM) or 3D printing creates three-dimensional objects by adding materials using digital format files to achieve the desired shape. Researchers worldwide, including those in Malaysia, have shown interest in AM for over a decade. Although 3D printing has gained widespread adoption, 3D food printing is still in its early stages. This study aims to explore the challenges of implementing 3D printing technology in Malaysian food manufacturing firms. The research utilized a semi-structured interview method, conducting in-depth interviews with seven respondents. Snowball sampling was employed to identify potential experts, building upon the recommendations of the initial respondent. The literature review identified nine challenges: time-consuming processes, lack of standardization, scarcity of expertise, extrusion molds and materials, limitations in scalability, cost, food safety, halal compliance, and intellectual property. During the interviews, many respondents revealed that they had not yet integrated 3D food printing into their operations. Furthermore, respondents introduced a new challenge, which was related to spare parts and maintenance. In conclusion, the investigation revealed that the implementation of 3D food printing in Malaysian manufacturing firms is still at an early stage, as evidenced by the challenges reported by the respondents.

Keywords: 3D food printing, additive manufacturing, challenges, food industry

1. Research Background

Industry 4.0 has triggered widespread interest around the world to modernize the existing manufacturing industry. In conjunction with the digitalization of future production, Industry 4.0 places new expectations on competencies. Due

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to consumer demand for high-quality and personalized products growing, manufacturers must supply tailored and targeted products due to advanced technology which leads increasing personnel's pressure to be qualified and recruited with new technical skills [1]. In the post Covid-19 era, additive manufacturing is expected to increase demand for the growth of customized food especially from groups like pregnant women, children, athletes and others [2]. As a result, machine availability can assist factories in reducing idle time and increasing system performance [3].

Additive manufacturing (AM), also known as 3D printing, produces three-dimensional objects by adding materials based on digital files to achieve the desired shape. This paradigm change is being driven by 3D printing, which is considered a major technical driver because it may allow for more efficient and effective prototyping and manufacture of things [4]. Prior research has highlighted the relationship between 3D printing and information and communication technology (ICT), highlighting its potential future impact [5]. 3D printing, on the other hand, has not fully realized its potential [6]; the industry is still in its preliminary phase but rapidly expanding [6]. Manufacturers can shift some of their production activity to customers due to the existing of this technology [7,8].

Interestingly, 3D printing has recently expanded into the food industry. According to Pitayachaval et al. [9], 3D food printers are classified into three types: inkjet printing, extrusion-based printing, and binder jetting. In the process of creating food models using extrusion-nozzle technology, ingredients such as cheese, flesh paste, and dough are extruded. Binder jetting involves layering bonds with powder and binder, and, finally, in the third step, droplets of binder, each measuring less than 100 μm, are precisely deposited onto the powdered surface bed. 3D printing technology uses a print head for on-demand printing with a scanning pattern. Therefore, industry of manufacturing will be facing few challenges due to 3D printing despite its technological advancements. One of the examples is adopting 3D printing technology will reduce the number of workers especially in firms. Thus, having a considerable impact on the economics of countries where low-wage occupations are prevalent is important [10].

Despite the growing popularity of 3D printing in developing countries [11], the majority of research has focused on the attributes of the substrate materials used in food printing and consumer acceptability. However, there is a noticeable gap in studies related to operations management. Furthermore, in Malaysia, academicians are still in the preliminary phases of research concerning 3D printers, not to mention 3D food printers. Additionally, 3D printing is predominantly utilized for prototyping at this time due to the challenges faced by 3D food printers. As a result, there is limited adoption of 3D printers in Malaysia.

To highlight, the main issue is that literature on challenges for the implementation of 3D food printing in Malaysia is still in its infancy regarding this topic. Malaysia's journey to 3D food printing is being restricted by a lack of exposure as well as information on the initiative to transform the sector of manufacturing, especially production and operation, through the use of cutting-edge technology as a whole. This research is being conducted to investigate the challenges of 3D food printing from the perspective of manufacturers and potential manufacturers. This study aims to offer novel insights into the challenges encountered in the realm of 3D food printing, particularly within the context of production and operations in Malaysia. By delving into these challenges, this research endeavors to provide manufacturers and investors with a comprehensive understanding of the complexities inherent in the adoption and utilization of 3D food printing, thus equipping them with valuable knowledge to navigate these hurdles proactively.

2. Literature Review

2.1. Challenges of 3D Food Printing

Prior research has extensively examined the challenges associated with 3D food printers on a global scale [12]. Employing a systematic literature review (SLR), this study extracted 40 papers from a pool of 268 journal articles obtained from two prominent databases, Scopus and ResearchGate, in order to discern the challenges surrounding the adoption of 3D food printers in manufacturing firms. Consequently, a conceptual framework was derived based on the insights garnered from the literature review. Figure 2 illustrates the nine selected challenges of 3D food printers derived from the findings of the SLR.

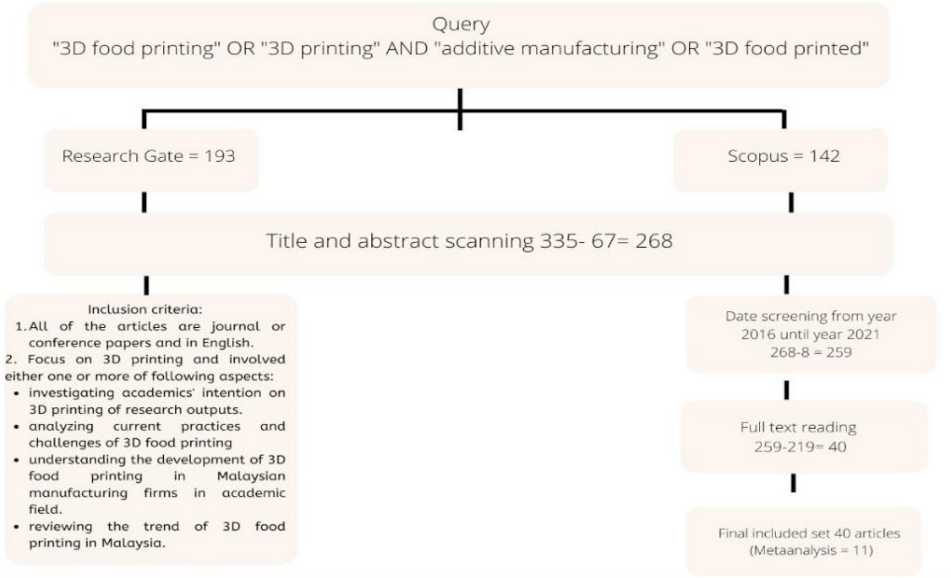

Fig. 1: The process of SLR finding challenges throughout this study.

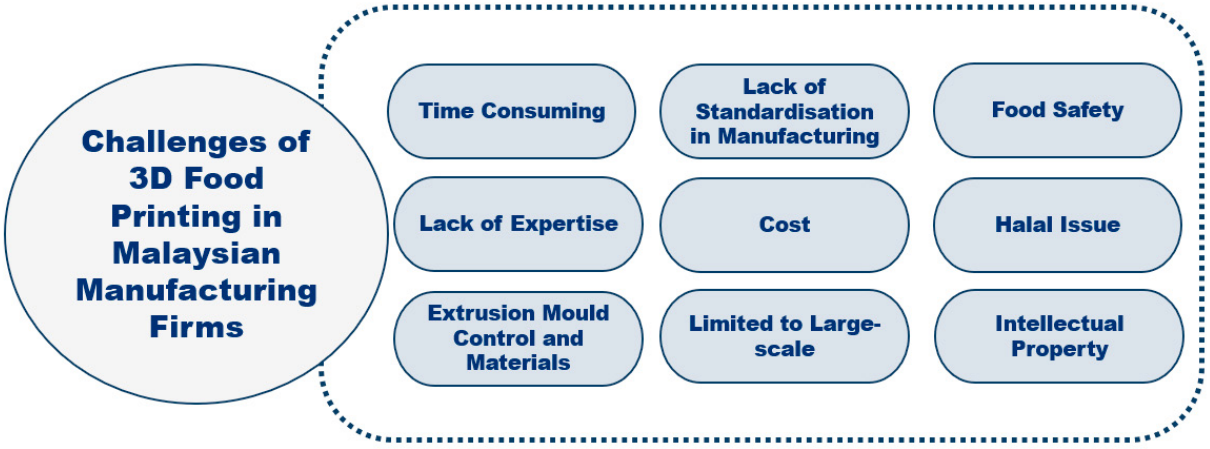

Fig. 2: Conceptual framework of challenges of 3D food printer obtaining from SLR.

2.2. Time Consuming

In general, 3D printing is a time-consuming process when it comes to completing the final product [13]. Currently, its application in healthcare settings within hospitals faces significant challenges. This is primarily because most products require extensive preparation before they can be converted into extrudable inks. As noted by Burke-Shyne et al. [14], the production of 3D-printed items can be quite time-intensive. Consequently, if healthcare or manufacturing with bulk products opts for 3D printing, the entire printing process becomes prolonged without the presence of intensive labor. This prolonged production cycle may diminish public interest in 3D-printed foods, especially in the realm of personalized nutrition. However, as technology advances and improves, these challenges are likely to be addressed. Therefore, businesses employing 3D printing technology should consider the necessity of transforming and enhancing their value creation process through digitization. Embracing a fundamentally different approach rooted in the concept of digitization is a prudent course of action at this time [13].

2.3. Lack of Expertise

3D printing faces a significant challenge in the manufacturing sector due to a lack of expertise and training among the workforce. According to Maresch & Gartner [6], operating 3D printing requires a deep understanding and technical skills, making it particularly challenging for those new to the technology or when dealing with complex prints. As a result, there is a growing demand for 3D printing education among employees, with calls to integrate it into the education system for the future. Small businesses striving to keep pace with the rapidly evolving business landscape may find this challenge especially difficult. To gain support, employees must first persuade their managers to take an interest in 3D printing before becoming eligible for relevant training courses [5]. It is a technology that all manufacturers should seriously consider. Therefore, company representatives should use this opportunity to deepen their knowledge of 3D printing in preparation for its implementation in the workplace.

2.4. Extrusion Mould Control and Materials

The next challenge is to enhance process productivity by employing larger nozzle or laser diameters and increasing printing speed [15]. However, 3D food printers suffer from a lack of precision and resolution, placing them at a disadvantage. Researchers have reported using a larger nozzle diameter and a faster printing speed to ensure acceptable printing accuracy. Another technique to increase printing productivity is to use multi-nozzle printers to produce numerous objects simultaneously. However, because this could potentially delay the monitoring system and present technological challenges, further research is needed to achieve optimal process productivity while maintaining printing accuracy. By layering realistic food textures, a 3D printer provides a new technique for developing food with inserted food texture elements. Post-processing is a concern because the product of 3D printing differs slightly from conventional manufacturing methods [16]. This means it does not meet the requirements for finishing layers, as metal AM products have a different surface finish than traditional manufacturing processes. The conventional method tends to produce a smoother surface compared to 3D printing [17]. In other words, the food texture of 3D food printing produces a rough or grainy appearance, and the need for post-processing to remove moisture or strengthen the printed foods results in uneven surfaces and the likelihood of gaps between the layers. This is one of the most significant flaws of 3D printers. Although this effect can be reduced by using thinner layers, the entire structure would take more time and effort to create. Several testing procedures, the printed product size, and the minimum amount of filament layers should all be included in standards for objectively measuring mechanical and durability attributes [10].

2.5. Lack of Standardisation in Manufacturing

Ford & Despeisse [17] highlight another challenge faced by 3D printing, which is the absence of norms and standardized manufacturing processes. Due to the diversity of available 3D printers, a single CAD file can be utilized to produce a wide range of products. While the lack of standardization can benefit equipment manufacturers by preventing vendor lock-ins, it also hinders the widespread adoption of more universally compatible 3D printing technologies [16,18]. Although there is a wide array of components, tools, and procedures in use today, there remains a pressing need for standardization in materials, processes, calibration, testing, and file formats. This challenge underscores the importance of defining current expectations and presents an opportunity to establish reasonable standards for the future.

2.6. Cost

According to Rayna & Striukova [19], 3D printing faces two cost-related challenges. Firstly, the investment in technological advances is currently expensive, which may pose a barrier for small firms. This could make achieving cost savings over existing techniques more challenging, such as in the case of preparing food molds for texture-modified foods using manual labor. Secondly, 3D printing has the potential to provide a practical solution for supplementing nutrients according to individual dietary needs and eliminating specific dietary elements. However, it's essential to acknowledge that this customization process can be costly [17]. For example, individuals may aim to achieve short-term nutritional goals like managing diabetes or long-term objectives like preventing non-communicable diseases. Both challenges in 3D food printing highlight the same difficulty in realizing financial and

time savings, which are both linked to the challenge of profit allocation [20]. While major organizations adopting direct manufacturing as an alternative to traditional methods may not experience significant changes, the situation can be markedly different for SMEs and individual entrepreneurs [19]. Indeed, capturing this value in small businesses can be problematic, despite the fact that direct manufacturing allows for the creation of additional value. Utilizing online 3D platforms, for instance, can be expensive, as these platforms understandably seek a share of the value they facilitate.

2.7. Limited to large-scale

3D printing encounters a challenge in the realm of automated fabrication technologies for large-scale food production, such as rice, primarily due to the high initial costs associated with automated equipment. This is partly attributed to the time-consuming nature of 3D printing itself when it comes to food production. Additionally, the adoption of this technology is hindered by the persistence of traditional design approaches and insufficient quantities of materials, mainly because they do not align well with the managerial structures of traditional organizations [10].

2.8. Food Safety

In today's context, food safety can pose both immediate and long-term concerns. People may have reservations about a significant shift in food production, particularly when it comes to 3D-printed food. Initially, there might be caution surrounding 3D-printed food, but once it has been proven to be both safe and delicious, it could potentially become the future of our food supply [21]. For example, concerns about food safety arise when manufacturers employ inadequate equipment and fail to implement proper sterilization procedures.

2.9. Halal issue

Halal food is associated with cleanliness, particularly the hygiene of slaughterhouse facilities, as it can affect the quality of meat due to the risk of microbial contamination [22]. In contrast, cultured printed meat is produced in sterile environments with rigorous inspections and quality controls during processing, significantly reducing the risk of microbial infection. Moreover, given the immense potential of the 3D food printing sector, it becomes essential to address specific concerns, especially when it comes to halal considerations. As these machines are involved in the food preparation process, there is a need to be cautious about the potential introduction of foreign substances [22].

2.10. Intellectual Property (IP)

Furthermore, the management of intellectual property presents another significant concern [5]. As we anticipate future developments in a global supply chain that supports Additive Manufacturing (AM), it becomes crucial to assess the implications for intellectual property (IP) rights, particularly in the context of copyright. Changes in IP regulations, licensing strategies [7], or broader IP sharing norms are potential considerations [17]. Competitors, counterfeiters, and other parties may exploit opportunities to capture images and measurements of trademarked products once they are in the market, enabling them to rapidly replicate them. Additionally, hackers could gain increased access to online databases, facilitating the retrieval of proprietary designs and data related to a wide range of components and finished products.

3. Research Methodology

This study employed a qualitative research approach, involving interviews with experts from manufacturing firms located in Peninsular Malaysia. This methodology was chosen to enable the researcher to gain deeper insights and a better understanding of the subject matter. Additionally, qualitative methods are more suited for acquiring precise and accurate data with the aim of comprehensively grasping the topic. Given that the use of 3D food printers is a relatively novel concept in Malaysia, the study faced limitations in terms of the number of participants involved in the investigation.

Semi-structured interviews were conducted to guide the discussion, allowing the researcher to explore topics in-depth. The research followed an exploratory qualitative research approach, incorporating semi-structured and in-depth interviews. The study included seven respondents, encompassing engineers and managers currently employed in various capacities within their respective companies (see Table 1 for the list of respondents). Furthermore, the research employed snowball sampling, which is one of the purposive sampling strategies to identify the potential repondents.

Saturation is a method employed to guarantee the accumulation of a substantial volume of high-quality data that aligns with the study's objectives. Consequently, the data from interviewees are analyzed until data saturation is achieved and sustained. This demonstrates that there is ample information available to replicate this study should the need arise for further data collection. The interview questions were formulated in response to nine thematic issues that have been highlighted in recent literature.

Table 1: List of respondents

Company (Respondents)	Position	Working Period
A (R1)	Product Engineer	>10 years
B (R2)	Food technologists	1 year
C (R3)	R&D Executive	2 years and 4months
D (R4)	First LineManager	1 year and 7 months
E (R5)	ProductionExecutive	2 years and 6 months
F (R6)	Product Engineer	3 years and 2 months
G (R7)	R&D Executive	2 years and 8 months

4. Results and Discussion

4.1. Challenge of Time Consuming

"Based on my knowledge, if the 3D food printer is being used in my company, I think it will be challenging in term of time because 3D food printer is like basic printer, just the difference is,it produces food with the help of raw materials and ink and will be inserted into the mould and injection." –R2

"Depends on machine and processing, as I know 3D food printing will take time to produce certain products. If the processing takes longer time, then the output will be little, and the manufacturing cost will be higher and the cost of the product will be expensive." –R3

To simplify, all respondents agreed that 3D food printing consumes time which is one of the challenges faced by them during implementation in their factories. The current speed of 3D printer is only suitable for home use although it might slow down the process for mass production. Imagine, the simplest designs that 3D printer could do will take for one to two minutes, then complicated designs might have more than that. Some respondents thought that by separating the food inks would work, or perhaps buying the ready-made. Hence, conventional machine is the most suitable for them as per now because it can cope the high demand and manage well in processing based on standard operation procedure. Food may need to rest or 'set' for some time before being able to transfer to another step or location. Furthermore, to maintain the shape of 3D food printer's product, it needs to enter the 'baking' phase. If printed food is unable to endure the high temperature, then the food will probably look unpleasant especially the food texture. Also, some meals required considerable preparation before they could be turned into extrudable ink.

4.2. Challenge of Lack of Expertise

The next challenge for 3D food printers is a lack of expertise. An expert is an individual who possesses extensive knowledge, skills, and competence in a specific field due to research, education, experience, and practical application. Consequently, when the researcher inquired whether the respondents' companies had technology specialists, a majority of them responded affirmatively. However, it's worth noting that most of the respondents expressed a need for training lasting a few months to address this challenge.

"For currently yes, it is a challenge, because they are more on traditional way of a producing food so uhm I think with current expertise what do they know is only know how to on and off. So, there are a lot a room for improvement to build experts on 3D food printing. I believe, it can be one of the challenges that are pleasing if they wanted to implement." –R4

"Lack of expertise is a challenge because Malaysians manufacturing firms still don't practice 3D food printing yet. As well as Company F, none of us have this technology. Even if we have, maybe we need to hire someone to teach us to using it in the future." –R6

This challenge has also been addressed by Maresch & Gartner [6], who emphasize the need to promote continuous learning within the educational system. This poses a particular challenge for small businesses, as their staff must first pique the interest of management regarding AM in order to gain support for enrolling in relevant courses. In summary, all respondents concur that the shortage of expertise in 3D food printing technology in Malaysia serves as a deterrent, leading them to abstain from adopting this technology.

4.3. Challenge of Extrusion Mould Control and Materials

The next challenge revolves around the extrusion mould control and materials. The discussion also encompassed various aspects of the extrusion mechanism in 3D food printers, covering fundamental factors such as material flow and configuration. Additionally, it explored the uniqueness, applicability, and printability of food materials, the types of extrusion-based techniques, and the critical characteristics and dynamics of food. Below, we summarize the respondents' perspectives on the difficulties encountered when handling 3D food printers in terms of extrusion mold control and materials.

"*To compare the mould and extrusion, manpower is the toughest to handle in the world because people management is always tough because they have different mindset, they come from different background, they are not living things compared to machines they are standardised, can be move, shape into whatever we want to, we can't easily control human. Therefore, in my opinion extrusion mould control and materials are same hard as to handle manpower compared to machines.*" –R1

"*I think this extrusion mould controlling would be an issue if the technology is unable to cope with the demand and unable to copy. I believe in future there will be a method or technology to control them. So, I think people will be improvise a better machine, a different kind of 3D food printer.*" –R5

Put simply, all seven respondents concurred that challenges related to extrusion molds and materials constitute a significant aspect of the AM food domain, as they demand technical expertise for effective handling. Moreover, the unique nature of AM food materials makes them less accessible for general purchase. The literature has also highlighted the importance of aligning food ingredients with suitable 3D printing techniques, addressing this as a pertinent concern. Among the various techniques employed in 3D food printing, such as material extrusion, selective laser sintering, hot air sintering, and liquid binding, the experts expressed a belief that extrusion-based methods hold the most promise for achieving industrial scalability.

4.4. Challenge of Lack of Standardisation in Manufacturing

Consistency is probably the biggest benefit of standardisation in manufacturing. These standards guarantee that products or services manufactured within a particular industry maintain a uniform level of quality and comparability to other similar products or services in the same sector.

Respondent R1 said that: *"Company A deployed a very standardised system due to current machine we have such mixing the ingredients like flour. With that, we able to deploy on such a large scale over such a short period of time."* –R1

Added by Respondent R6: *"I think 3D food printing is able to achieve the standardisation in two condition. Firstly, the technology must be in a lot of numbers to produce let's say hundred pieces of crispy in one day or either one technology must take a lot of time such in three months to achieve hundred pieces of crispy. Then we can call 3D food printing can achieve standardisation in manufacturing."* –R6

Respondent 4, representing Company D, also expressed uncertainty regarding the potential impact of reduced 3D food printing quantities on product standardization. Currently, her company relies on machinery for mass production,

resulting in an almost uniform output—ensuring consistent design, weight, and appearance for approximately 99.99% of their products. However, she pointed out that the adoption of 3D food printing might hinder the attainment of absolute uniformity, casting doubt on the ability to maintain a 100% identical outcome. While they can be similar, they may not achieve identical results, making it a significant challenge to maintain standardization with current 3D food printing practices. Similarly, Respondent R5 shared the same perspective as Respondent R7, highlighting that 3D food printing presents challenges in achieving standardized products compared to the machinery currently in use.

4.5. Challenge of Cost

Cost also plays a big challenge for a company using 3D food printing. Hence, it has been validated during the interview session as a challenge. Below is the respondents' view of how 3D food printing costs a lot.

Respondent R5 stated: *"My company spent more cost in research and development (R&D) for this department workers who are qualified including the cost of this machine, to make sure the operation can be more advanced in future, hence they are just using 3D food printing in small-scale"* –R5

Respondent R7 stated that: *"For now, new technology investment that is not necessary will not be invested especially to those cannot benefits the company. As for example, 3D food printing is not suitable for our manufacturing side since we make a complete dish and cuisine for everyone"* –R7

Based on the aforementioned responses, cost appears to be a potential challenge for certain manufacturing firms within the Malaysian food industry. If a company intends to acquire a 3D printer for installation at their facility, the expenditure could range from $860 to $1720 USD. While these devices are larger than typical inkjet printers, they are still compact enough to be accommodated on a desk. However, it's worth noting that larger-scale printers designed for manufacturers and industrial use can be considerably more expensive.

4.6. Challenge of Limited to Large-Scale

According to the data collected in this study, the consensus among the majority of companies is that 3D food printing is primarily suited for large-scale implementation in food manufacturing firms. This emphasis on large-scale production poses a significant challenge for Malaysian businesses, as all seven respondents reported that they engage in mass production of their products.

Respondent R3 stated: *"Yes, I think it is true because once you invest technology machine, it must be pricey including machine cost, raw materials cost and other cost, so if produce the products, the cost will be higher than the order. Imagine, the manufacturing implement in large-scale."* –R3

Respondent R4 also stated that: *"Uhm, because of 3D printer I have seen some from the internet because of their quite slow, in order to produce one cookie in couple of minutes, currently from traditional machine the cookies will be produced in a split of seconds. Due to the bigger machines compared to 3D printer, it will be easily produced."* –R4

On the contrary, respondents 5 and 6 suggest that workforce reductions have resulted from the implementation of Industry 4.0, involving automated machines and the accompanying training provided to their employees. Ultimately, all respondents concurred that one of the primary challenges of 3D food printing lies in its limitation to large-scale production. It was unanimously agreed that large-scale manufacturing presents a substantial hurdle for the adoption of 3D food printing in manufacturing firms."

4.7. Challenge of Food Safety

"Since Malaysia is still not implementing the 3D food printer yet, the current practice that we had in our manufacturing side is completely safe but I think with the advancement of technology, I think it will come out with good hygiene, more safe, more edible and more friendly environment." –R2

"3D printer is fully automated where it fully enforces and personnel to really look at it to do audit, so food safety wise it can be high risk compare the current one." –R4

"I am not sure in terms of food safety. Maybe it is good." – R7

Based on the data collected from respondents, the majority of companies expressed disagreement with the notion that 3D food printing poses food safety concerns, primarily because they lack a clear understanding of how the technology produces food products. In contrast, Company D is the only entity that acknowledges food safety as a challenge in the context of 3D food printing.

4.8. Challenge of Halal Issue

Religion comprises a system of beliefs and practices that guide individuals in interpreting and responding to supernatural and sacred aspects of life. One of the significant domains where religious guidance plays a role is in dietary practices. In Malaysia, where the majority of food consumers are Muslims, there is a growing awareness of and concern for religious dietary principles among the populace.

Respondent 3 answered: *"It is not a challenge for 3D food printer since the consumer will know the product is halal or not by looking at products' packaging if any manufacturer uses 3D food printer. So, consumers aware of that, thus it is completely halal in the way of hygiene, operation and all."* –R3

In addition, R4 has the exactly same answers with R6 and R7 which are: *"It should not be a problem because depends on how you practice your kind of food, to maintain the cleanliness, because it is not only the pork or no pork things, it is all about we handle the food."* –R4, R6 & R7

Among the ten challenges assessed, the halal issue stands out as the first challenge where the majority of respondents disagreed with its classification as a hurdle in 3D food printing. This perspective is primarily rooted in their assessment of how manufacturers handle and source their raw materials.

4.9. Challenge of Intellectual Property

The last challenge pertains to intellectual property (IP), encompassing patents, trademarks, industrial designs, copyright, geographical indications, and integrated circuit layout designs in Malaysia. Counterfeiting in the food industry has witnessed a notable surge in recent years, paralleling rapid economic growth. Consequently, manufacturers engaged in marketing food products in Malaysia must make diligent efforts to safeguard their intellectual property rights. In contrast to the still-nascent stage of 3D food printing, below are the responses gathered from interviewees regarding IP.

Respondent R1 stated that: *"I am not sure how 3D food printer handles their food but for me in term of packaging maybe it is same to what my current company does for our product. We do IP to protect our food, ot just packaging but the secret ingredients too."* –R1 Respondent

R4 expressed that*: "It can be one of the challenges for 3D printer to have the IP because it is creative and unique, because everyone can do every design, there is no any trademark or register things."*–R4

Additionally, Respondents R5, R6, and R7 shared a similar perspective with R1 regarding intellectual property. They emphasized that unless and until intellectual property is adequately protected, any concept related to a particular food production method remains publicly accessible intellectual property. This means that anyone can replicate the idea and commence selling the same product. Moreover, it's important to note that filing a complaint is only possible if the intellectual property has been formally registered with the requisite documentation.

4.10. New Challenge: Spare parts and Maintenance

Respondent R4 introduced a novel challenge by highlighting the issue of 'spare parts.' She emphasized that: *"Since it is very new and unique, if there is any breakdown happens or defects present on your products, it is hard to repair and find alternative compare to traditional machine."* – R4.

Typically, when a component of a product malfunctions, consumers decide whether to repair it or discard it, depending on factors such as the product's value, repair cost, and the ease of fixing it. Typically, a replacement part needs to be acquired from the manufacturer or its authorized distributors to carry out the repair. Maintaining a stockpile of replacement parts proves to be costly for these organizations, and predicting future demand for these parts is challenging. On the other hand, producing custom spare components as required becomes prohibitively expensive when employing traditional production methods. Nevertheless, access to these files is carefully controlled.

4.11. New Conceptual Framework for Challenges for 3D Food Printing

Based on the findings, all seven manufacturing firms have unanimously agreed on all challenges except for the halal issue. According to their perspectives, the halal issue does not significantly impede the customization of 3D food printer products, as manufacturers rigorously scrutinize the ingredients and take responsibility for their usage. Additionally, they believe that the presence of halal certification logos on packaging adequately addresses this concern for consumers. Consequently, the challenge related to the halal issue has been excluded from the proposed framework, as the majority of respondents do not view it as a significant obstacle. Interestingly, one of the seven respondents in this research has introduced a new challenge, namely, "spare parts and maintenance." She has highlighted that 3D food printers are a relatively new and unique technology. In the event of breakdowns or product defects, finding suitable repairs or alternatives can be considerably more challenging compared to traditional machines. Figure 3 depicts a new conceptual framework for Malaysia's manufacturing sector, specifically within the context of 3D food printing among Malaysian manufacturing firms.

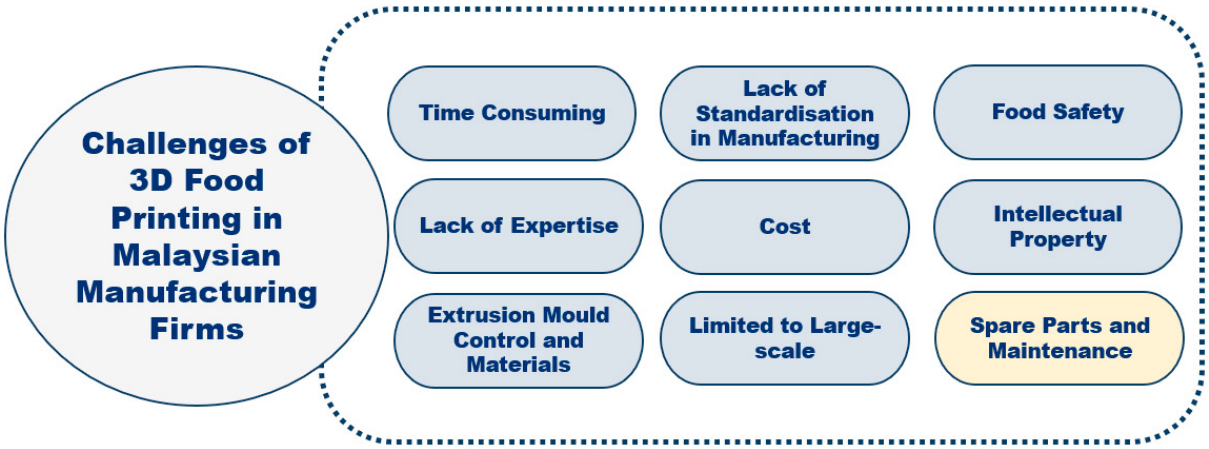

Fig. 3: New Conceptual Framework for Challenges for 3D Food Printing in Malaysian Manufacturing Firms.

5. Conclusion and Recommendation

Malaysia's manufacturing industry plays a pivotal role in the country's economy. To sustain its financial contributions, staying abreast of the latest industrial innovations is imperative. However, our findings reveal that the Malaysian manufacturing sector, particularly in the food industry, is still in its early stages of transitioning from traditional manufacturing methods to the advanced realm of 3D food printing. In this study, we identified numerous challenges hindering the adoption of 3D food printers among Malaysian manufacturers. The majority of respondents have yet to fully integrate 3D food printers into their nationwide operations or incorporate them into their production processes. Their responses indicate that their approaches to addressing key issues related to 3D food printing, such as time consumption, lack of manufacturing standardization, expertise shortages, extrusion mold control and material limitations, costs, halal compliance, limited scalability, food safety, and intellectual property concerns, have remained largely unchanged. One notable challenge that emerged in this study is the aspect of "maintenance and spare parts." This challenge poses a minor obstacle to the successful implementation of 3D food printers in Malaysian manufacturing firms. The resistance to change inherent in conventional manufacturing practices has been identified as a key barrier. Overcoming this resistance represents a crucial step toward embracing 3D food printing technology. The government's role in raising awareness about the importance of 3D food printing in Malaysian manufacturing firms cannot be understated. The majority of companies in Malaysia, and possibly in other developing countries, are still in the nascent stages of exploring 3D food printing. Achieving success in this endeavor demands innovative solutions to these challenges, which can only be realized through collaborative efforts between the government and the private sector.

To encourage large enterprises to embrace 3D food printing, the government should consider offering incentives like development grants and training programs. Additionally, there is a pressing need to update the educational curriculum to equip future manufacturing professionals with the requisite skills and knowledge.

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