FRONTIER IN MICROENCAPSULATING TECHNOLOGY RESEARCH IN COCOA: A SCOPING REVIEW

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ABSTRACT –*This paper presents a scoping review of the literature on the microencapsulation of cocoa. This manuscript aims on conduct a review study to seek literature related to the encapsulation of cocoa products. A scoping technique is used on the Web of Science database to search for all journals related to cocoa product encapsulation. The search strategy used the PRISMA standard methodology. The search was conducted in the Web of Science database using keywords related to micro-encapsulation, cacao, and cocoa beans. The search was limited to articles published in English between 2004 and 2022. The resulting studies underwent relevance screening, and pertinent data were subsequently extracted and synthesized to provide an overview of the existing literature on the micro-encapsulation of cocoa. The literature on the microencapsulation of cocoa has been applied in various fields, including Food Science and Technology, Chemical Engineering, and Plant Science. The diverse range of applications for microencapsulation of cocoa includes the development of functional foods and the controlled release of drugs, which are significant breakthroughs in the food industry. However, there is still a lack of research on the microencapsulation of cocoa products. The study concludes that future research in the micro-encapsulation of cocoa could explore the use of other natural polymers as coating materials and investigate the controlled release of cocoa compounds. Such research could help to identify key themes and trends in the literature, contributing to the development of new applications of micro-encapsulation in the food industry.*

Key words: *Theobroma cacao*; PRISMA; Scoping Study; Web of Science; Microencapsulation

INTRODUCTION

Cocoa, scientifically known as *Theobroma cacao* L., is a widely popular food commodity enjoyed all over the world (Grassia *et al*., 2021; Indiarto *et al*., 2022). With a name like *Theobroma*, which translates to "food of the gods," it's no surprise that cocoa is held in such high regard. The consumption of cocoa is constantly increasing, and for good reason. Recent scientific research has revealed that cocoa contains high levels of polyphenols, which are known for their numerous health benefits. Cacao is a rapidly growing tropical forest plant that offers various benefits. It can be cultivated in association with other trees and provides a variety of goods, including timber, firewood, fruits, construction materials, honey, resin, and materials for ritual ceremonies. Cacao also has numerous health benefits. It is rich in antioxidants (Alves *et al*., 2017; Alves *et al*., 2018; Çenesiz *et al*., 2017; Grassia *et al*., 2021), which can help prevent cancer (Maskarinec, 2009; Vettori *et al.*, 2022) and other diseases. Additionally, cocoa products are high in magnesium (Cinquanta *et al*., 2016), which is essential for maintaining healthy bones and muscles (Indiarto *et al*., 2022; Maskarinec, 2009). Furthermore, cacao possesses mood-enhancing properties that can assist in stress and anxiety reduction.

Microencapsulation is an effective technique for incorporating natural compounds into food products (Alves *et al*., 2017; Alves *et al*., 2018; Grassia *et al*., 2021). This method involves trapping unstable compounds in a supporting material to protect them from evaporation, degradation, and the production of off-flavors during storage. Coating materials can be added to microencapsulation using various techniques. However, previous studies have provided limited information on the encapsulation on cocoa products (Grassia *et al*., 2021). There are few sources of literature on this matter. Therefore, this paper objective is focusing onto conducting a scoping review and thematic analysis in relation to micro-encapsulation of cocoa. A scoping technique will be used on Web of Science to search for all journals related to cocoa products encapsulation.

METHODOLOGY

The article presents a comprehensive analysis of various keywords essential for understanding the topic. These keywords include "capsulation," "encapsulates," "encapsulating," "encapsulation," and "micro-encapsulation," which describe the process of enclosing or trapping one substance inside another. Additionally, the analysis includes keywords related to the subject matter of chocolate, such as "cacao," "*Theobroma cacao*," and "cocoa bean." These keywords were gathered from reputable sources, including the Web of Science (WoS) database. Both of this keywords selected are to enable full comprehension of microencapsulation of cocoa research according to publisher meta-data. Incorporating these keywords facilitates a deeper comprehension of the topic and establishes a basis for future research and analysis.

Thematic and scoping reviews are crucial in this context as they offer a structured approach for analyzing and synthesizing extensive literature on a specific topic. By focusing on specific keywords, as well as inclusion and exclusion criteria, researchers can identify relevant studies and extract valuable information from them. This helps to identify key themes and trends in the literature, providing a more comprehensive understanding of the topic. In the case of this article, the scoping review provides an overview of the existing literature on the micro-encapsulation of cocoa, while the thematic review focuses on specific areas of interest, such as the use of natural polymers and the controlled release of cocoa compounds.

Search Strategy

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standard search strategy was used to identify relevant studies on the micro-encapsulation of cocoa. The search was conducted in the Web of Science database using the following keywords: ("capsulation" OR "encapsulates" OR "encapsulating" OR "encapsulation" OR "micro-encapsulation") AND ("cacao" OR "*Theobroma cacao*" OR "cocoa bean"). To ensure that only high-quality articles are included in this study, rigorous publication standards will be applied. Specifically, we will only search for peer-reviewed articles in the Web of Science database, which is known for its strict publication requirements.

Table 1: Keywords search strategy under P/I/O search.

Item	Keywords	Search Terms with Boolean
Population = Cocoa	Cocoa Bean (Santos *et al*., 2023)	TS=("cacao" OR "Theobroma cacao" OR "cocoa bean")
Intervention = Encapsulation	Micro-encapsulation (de Queiroz *et al*., 2020)	TS=("capsulation " OR "encapsulates" OR "encapsulating" OR "encapsulation" OR "micro-encapsulation")
Outcome = non-Applicable	Non-Applicable	Non-Applicable

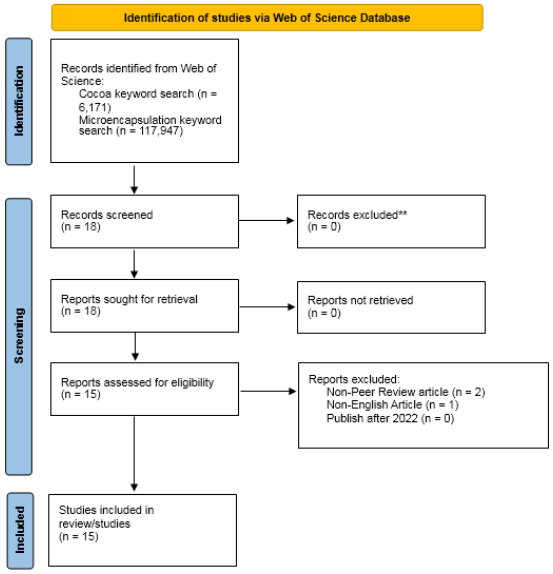

Figure 1: PRISMA 2020 flow diagram for updated systematic reviews which included searches of databases and registers

The search was limited to articles published in English between 2010 and 2022, as the year 2023 is still ongoing and may not have sufficient data available for analysis (refer Figure 1). The inclusion criteria for this study were investigations into the use of micro-encapsulation in cocoa research. Exclusion criteria included studies not focusing on micro-encapsulation or cocoa research, as well as review articles, book chapters, and conference proceedings. These exclusions were necessary to maintain the rigor of the review (Abdirad & Krishnan, 2020; Azzeri *et al*.,

2022). The resulting studies were screened for relevance, and relevant data were extracted and synthesized to provide an overview of the existing literature on the micro-encapsulation of cocoa. The exact exclusion criteria is the study exclude all literature review articles due to its context are not considered as a primary data reported, next, we exclude all non-English articles due to its language barrier and potential information bias due to the barrier. Furthermore, the research exclude any replicated research articles as a countermeasure from redundancy of manuscript included in the research. By adhering to these inclusion criteria, we aim to increase the reliability and validity of our study's findings and provide a comprehensive understanding of the topic at hand. Please note that we will only screen articles written in English to provide a standard in reviewing the content of the articles.

RESULTS AND DISCUSSIONS

This section aims to provide a comprehensive overview of the topic of microencapsulation of cocoa, delving into its main themes and sources. Microencapsulation of cocoa has been applied in various fields, including Food Science and Technology, Chemical Engineering, and Plant Science (Refer Figure 2).

Figure 2: Comprehensive report of cocoa and micro-encapsulation search in WoS database

The diverse range of applications for microencapsulation of cocoa includes the development of functional foods and the controlled release of drugs, which are significant breakthroughs in the food industry. The sources used for this analysis were gathered from the Web of Science, a reputable source for scientific publications, and spanned over a considerable period. Through this analysis, we can observe that microencapsulation of cocoa is a growing area of interest among researchers and is poised to contribute to the development of new applications that can enhance the food industry. It is hoped that further studies and research will be conducted to explore the full potential of microencapsulation of cocoa in various fields.

The publication trend in micro-encapsulation research of cocoa (Figure 3) in the Web of Science database is showing a gradual increase, which reflects a growing interest in this niche field. While the increase may not be exponential, it is still encouraging to see that more research and publications are being added to the WoS database over time.

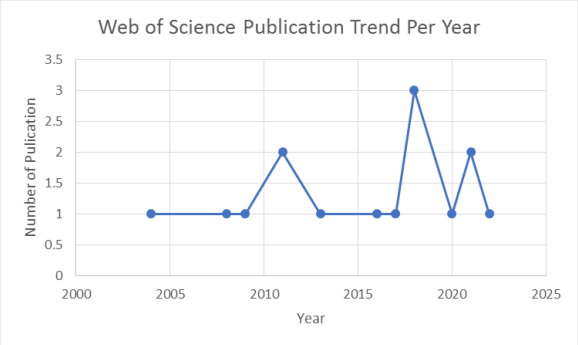

Figure 3: Research manuscript publication trend from early 2000 to 2022.

This suggests that micro-encapsulation is becoming a more widely recognized and studied area of research and that new discoveries and innovations may emerge in the future. It is important to note, however, that the restricted quantity of research and publications in the WoS database could impact the overall trend, and that there may be other sources of information and data that could shed more light on the true extent of this trend. Nonetheless, the fact that micro-encapsulation research is gaining interest in subsequent years is a positive sign for the future of this field.

Table 2: Distribution of Publications on Micro-Encapsulation of Cocoa by Country

Countries/Regions	Record Count	% of 15
ENGLAND	5	33.333
TAIWAN	4	26.667
ITALY	3	20
BRAZIL	2	13.333
CROATIA	2	13.333
TURKEY	2	13.333
AUSTRALIA	1	6.667
GERMANY	1	6.667
GHANA	1	6.667
INDIA	1	6.667
INDONESIA	1	6.667
SCOTLAND	1	6.667
SERBIA	1	6.667
VIETNAM	1	6.667
WALES	1	6.667

The table 2 provides a comprehensive overview of search results for articles on micro-encapsulation of cocoa in the Web of Science database. It presents the number of records and percentage of total records for different countries or regions. The majority of the articles on micro-encapsulation of cocoa come from England, with 5 records representing 33.333% of the total 15 records. Taiwan follows closely with 4 records, equivalent to 26.667% of the total records. The remaining countries or regions listed in the table have fewer records, with percentages ranging from 6.667% to 20%.

It is worth noting that the distribution of articles on micro-encapsulation of cocoa across different countries or regions may reflect the level of research activity or interest in the topic by researchers from those areas. For instance, the high number of records from England and Taiwan may suggest that researchers in those countries or regions have a particular interest in conducting research on micro-encapsulation of cocoa. However, compared to its neighbouring country, Indonesia, Malaysia has not yet established itself as a subject matter expert in this research area. This presents an opportunity for Malaysian researchers to explore this field further.

Table 3: Prominent Author (s) and Articles ranking in WoS.

Authors	Article Title	Source Title	Cited	Year
Altin, G; Gultekin-Ozguven, M; Ozcelik, B	Chitosan coated liposome dispersions loaded with cacao hull waste extract: Effect of spray drying on physico-chemical stability and *in vitro* bioaccessibility (Altin *et al.*, 2018)	Journal of Food Engineering	44	2018
Kuo, YC; Chung, CY	Solid lipid nanoparticles comprising internal Compritol 888 ATO, tripalmitin and cacao butter for encapsulating and releasing stavudine, delavirdine and saquinavir (Kuo & Chung, 2011)	Colloids and Surfaces B-Biointerfaces	37	2011
Sagiri, SS; Sethy, J; Pal, K; Banerjee, I; Pramanik, K; Maiti, TK	Encapsulation of vegetable organogels for controlled delivery applications (Sagiri *et al*., 2013)	Designed Monomers and Polymers	22	2013
Belscak-Cvitanovic, A; Vojvodic, A; Busic, A; Keppler, J; Steffen-Heins, A; Komes, D	Encapsulation templated approach to valorization of cocoa husk, poppy and hemp macrostructural and bioactive constituents (Belscak-Cvitanovic *et al*., 2018)	Industrial Crops and Products	10	2018
Alves, TVG; da Costa, RS; Aliakbarian, B; Casazza, AA; Perego, P; Silva, JOC; Costa, RMR; Converti, A	Microencapsulation of *Theobroma cacao L*. waste extract: optimization using response surface methodology (Alves *et al*., 2017)	Journal of Microencapsulation	10	2017
Jokic, S; Nastic, N; Vidovic, S; Flanjak, I; Aladic, K; Vladic, J	An Approach to Value Cocoa Bean By-Product Based on Subcritical Water Extraction and Spray Drying Using Different Carriers (Jokic *et al*., 2020)	Sustainability	9	2020
Alves, TVG; da Costa, RS; Gomes, ATA; da Costa, CEF; Perego, P; Silva, JOC; Converti, A; Costa, RMR	Quality control of Amazonian cocoa (*Theobroma cacao L*.) by-products and microencapsulated extract by thermal analysis (Alves *et al*., 2018)	Journal of Thermal Analysis and Calorimetry	7	2018
Grassia, M; Messia, MC; Marconi, E; Demirkol, OS; Erdogdu, F; Sarghini, F; Cinquanta, L; Corona, O; Planeta, D	Microencapsulation of Phenolic Extracts from Cocoa Shells to Enrich Chocolate Bars (Grassia *et al*., 2021)	Plant Foods for Human Nutrition	4	2021
Nguyen, VT; Tran, AX; Le, VAT	Microencapsulation of phenolic-enriched extract from cocoa pod husk (*Theobroma cacao L*.) (Nguyen *et al*., 2021)	Powder Technology	1	2021

Indiarto, R; Rahimah, S; Subroto, E; Putri, NAG; Pangawikan, AD	Antioxidant activity and characteristics of a cocoa drink formulated with encapsulated green coffee extract (Indiarto *et al*., 2022)	International Journal of Food Properties	0	2022

The Table 3 provides a summary of the search results for articles on micro-encapsulation of cocoa in the Web of Science (WoS) database. The table lists the authors, article titles, source titles, times cited in WoS Core, and publication years. The authors, article titles, and source titles provide information on the content of the articles, while the times cited in WoS Core provides an indication of the impact and importance of the articles. The publication year indicates the recency of the articles. The top cited article is "Chitosan coated liposome dispersions loaded with cacao hull waste extract: Effect of spray drying on physico-chemical stability and in vitro bioaccessibility" by Altin, G; Gultekin-Ozguven, M; and Ozcelik, B. This article has been cited 44 times in WoS Core and was published in 2018. The article focuses on the use of chitosan as a coating material to encapsulate cacao hull waste extract in liposome dispersions. The researchers investigated the effects of spray drying on the physico-chemical stability and in vitro bioaccessibility of the encapsulated extract.

The second most cited article is "Solid lipid nanoparticles comprising internal Compritol 888 ATO, tripalmitin and cacao butter for encapsulating and releasing stavudine, delavirdine and saquinavir" by Kuo, YC and Chung, CY. This article has been cited 37 times in WoS Core and was published in 2011. The article focuses on the use of solid lipid nanoparticles to encapsulate and release stavudine, delavirdine, and saquinavir. The third most cited article is "Encapsulation of vegetable organogels for controlled delivery applications" by Sagiri, SS; Sethy, J; Pal, K; Banerjee, I; Pramanik, K; and Maiti, TK. This article has been cited 22 times in WoS Core and was published in 2013. The article focuses on the encapsulation of vegetable organogels for controlled delivery applications.

The remaining articles have been cited fewer than 15 times in WoS Core. Nonetheless, they cover a diverse range of applications for micro-encapsulation of cocoa, such as the valorization of cocoa husk, the microencapsulation of *Theobroma cacao* L. waste extract, and the microencapsulation of phenolic-enriched extract from cocoa pod husk. In summary, the table provides a comprehensive overview of the search results for articles on micro-encapsulation of cocoa in the Web of Science database. The top cited article is "Chitosan coated liposome dispersions loaded with cacao hull waste extract: Effect of spray drying on physico-chemical stability and in vitro bioaccessibility" by Altin, G; Gultekin-Ozguven, M; and Ozcelik, B, which has been cited 44 times in WoS Core. This article centers on using chitosan as a coating material to encapsulate cacao hull waste extract in liposome dispersions. Its substantial citation count signifies a significant contribution to the field of cocoa micro-encapsulation research.

Although the search result shows a total of 15 articles in micro-encapsulation of cocoa, the result publication pattern indicates that there is more opportunity in the micro-encapsulation of cocoa research especially in food technology applications and shelf-preservations. The lack of research on this area also provide opportunity for Malaysian researchers to excel in this area in the future and potentially become a centre of references for micro-encapsulating technology for cocoa product.

CONCLUSIONS

The article discusses the potential of micro-encapsulation technology in cocoa research and the development of functional foods and nutraceuticals. The use of natural polymers such as alginate, chitosan, and pectin as coating materials in micro-encapsulation has gained widespread attention due to their excellent encapsulating properties and biocompatibility. The scoping review mentioned in the document provides an overview of the existing literature on micro-encapsulation of cocoa, while the thematic review focuses on specific areas of interest, such as the use of natural polymers and the controlled release of cocoa compounds.

The article suggests that future research in cocoa micro-encapsulation could explore the use of other natural polymers as coating materials and investigate the controlled release of cocoa compounds. Such research could help to identify key themes and trends in the literature, providing a more comprehensive understanding of the topic and contributing to the development of new applications of micro-encapsulation in the food industry.

The article is several limitations of this study that are include the selection of database, due to the

limitation of selected database, although the quality of articles is concise, the limitation of selected manuscript from web of science hinders the progression of research by excluding potentially significant research output that may exists in other database. Next, the specification of topic search as mention in Table 1 could potentially reduce the inclusion of other materials that are related to this research. However, the inclusion and exclusion criteria for the search strategy were necessary to maintain the rigor of the review. Additionally, the search was limited to articles published in English between 2004 and 2022, which may have excluded relevant studies published in other languages or outside of this time frame. It is important to note that this scoping review provides an overview of the existing literature on micro-encapsulation of cocoa, but it is not a comprehensive analysis of the topic. Further research could expand on the findings of this review and explore new applications of micro-encapsulation in the food industry.

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