

Bibliometric Mapping of Rambutan (*Nephelium lappaceum* L.) Research: Trends and Directions

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ABSTRACT

This study presents a comprehensive bibliometric analysis of 551 journal articles retrieved from the Web of Science (WoS) database to evaluate the biological and pharmacological potential of rambutan (*Nephelium lappaceum* L.). Using co-citation and co-word analyses, the research identifies key thematic clusters and emerging trends. Bibliographic mapping highlights four dominant themes: (1) valorization of rambutan byproducts, (2) its role as a functional food source, (3) investigation of different plant parts for diverse applications, and (4) utilization of rambutan peel in nanomaterial synthesis. Co-word analysis further emphasizes four critical research directions: (i) applications of rambutan-derived compounds, (ii) biological activities of their constituents, (iii) sustainable extraction and production methods, and (iv) fruit waste valorization for environmental sustainability. Overall, the findings provide a holistic understanding of rambutan's multifaceted significance across food science, pharmacology, and environmental domains. The study also identifies existing research gaps and future opportunities, offering valuable insights into advancing both scientific inquiry and industrial applications.

Keywords: Bibliometric analysis; biological activity; co-word analysis; *Nephelium lappaceum* L.; Rambutan

1. Introduction

Rambutan (*Nephelium lappaceum* L.) is a tropical fruit primarily cultivated in

Southeast Asian countries such as Malaysia, Indonesia, and Thailand, belonging to the Sapindaceae family [1, 2]. While it is native to

Malaysia, the species has been introduced and is now grown in various tropical regions worldwide. Traditionally, rambutan has been used for a wide range of medicinal purposes. Different parts of the plant, including the leaves, peel, and seeds are known to be rich sources of bioactive compounds like anthocyanins, phenolics, and flavonoids, which contribute to their health-promoting properties. Studies have shown that these plant components possess notable biological activities such as antioxidant, antibacterial, antidiabetic, and cytotoxic effects [3]. Among the identified phytochemicals, phenolic compounds are particularly prominent due to their significant role in biological functions. In addition to this, phytochemical screening has revealed the presence of various other constituents, including reducing sugars, monosaccharides, carbohydrates, proteins, tannins, alkaloids, steroids, saponins, glycosides, and flavonoids [4], all of which support the plant's medicinal value.

Recent studies have highlighted the promising potential of rambutan byproducts, such as the peel, seed, and rind for a variety of sustainable applications. Notably, the peel and seed together account for over half of the fruit's total weight, representing a significant portion of waste generated during processing [5]. These waste materials offer valuable opportunities for repurposing, including the use of rambutan seed oil and peel as packing fillers, bio-coagulants, bio-sorbents, and even as a biodiesel alternative. Despite their promising applications, research evaluating the full potential of these byproducts remains limited and further validation is necessary [6].

Rambutan byproducts are rich in beneficial bioactive compounds, including proteins, vitamins, minerals, antioxidants, and aromatic oils, which can be recovered and used in functional food production [7]. Incorporating extracts from these materials into food products could enhance nutritional profiles and offer potential health benefits [8]. Moreover, these bioactive components have been found to exhibit various pharmacological

activities, supporting their use in health-promoting formulations. Sustainable and eco-friendly extraction technologies have been developed to isolate these compounds in an environmentally conscious manner [9]. Rambutan-derived extracts, particularly due to their antioxidant and antimicrobial properties, also hold promise as ingredients in cosmetic and pharmaceutical products [7, 10]. Additionally, specific compounds such as phenolics and flavonoids found in rambutan byproducts may serve as natural stabilizing and reducing agents in the green synthesis of nanomaterials [11].

Environmentally friendly extraction techniques, including supercritical fluid extraction, microwave-assisted extraction, and ultrasonic-assisted extraction, are currently being explored to enhance the recovery of valuable bioactive compounds from rambutan processing waste. These innovative methods reduce the reliance on harmful solvents and minimize waste generation, making them both efficient and eco-conscious [12, 13]. By improving the extraction yield of key bioactive components, such approaches not only support sustainable agricultural practices but also promote the effective utilization of rambutan byproducts. The process of converting waste materials into valuable products is referred to as "valorization." In the context of rambutan, valorizing its byproducts, such as peels and seeds, offers a promising approach to producing high-value goods while significantly reducing food waste. By extracting and utilizing the bioactive compounds present in these byproducts, industries can support circular economic principles in food production and open new revenue streams [14]. This approach not only addresses waste management challenges but also encourages more sustainable agricultural practices. The present bibliographic coupling study emphasizes the value-added potential of rambutan byproducts, highlighting their role in the green synthesis of functional nanomaterials and the development of nutrient-rich food

ingredients through environmentally sustainable methods [11, 15].

This bibliometric study investigates current and emerging research trends associated with different parts of the rambutan plant, including the synthesis of nanomaterials, the biological activities of its bioactive compounds, and the valorization of byproducts for functional food applications. Using a systematic approach, this study maps scholarly developments by examining the scope, focus, and evolution of existing literature. Through the analysis of publication patterns and research trajectories, it highlights major areas of scientific attention and outlines potential directions for the sustainable utilization of rambutan-derived resources.

Applying bibliometric techniques to literature published up to 2023, this study evaluates the progression and dynamics of research in the field while identifying key trends, influential works, and knowledge gaps. Co-citation analysis was used to determine highly referenced and impactful publications, whereas co-word analysis revealed thematic structures and emerging research topics. By uncovering intellectual linkages and developing themes, this work provides valuable insights for researchers and industry stakeholders, supporting informed decision-making and guiding future investigations into innovative applications of rambutan-based materials.

2. Materials and Methods

Bibliometric analysis is a quantitative research method that examines bibliographic data using science mapping techniques to uncover patterns within a research domain [16]. In this study, bibliometric visualizations and network maps were generated using VOSviewer (version 1.6.20.0), focusing on recurring terms, contributing countries, institutions, and journals. This methodology aligns with previous bibliometric investigations in related fields, such as active packaging [17]. Bibliometric analysis complements traditional review approaches by

bridging the narrative synthesis of systematic literature reviews with the statistical depth of meta-analyses [18].

The analysis operates across two principal dimensions: performance analysis and science mapping [16, 19]. Performance analysis evaluates the productivity and impact of scholarly output through metrics like publication and citation counts, typically aggregated by authors, journals, institutions, or countries. In contrast, science mapping explores the relationships between these bibliometric entities to elucidate the intellectual and conceptual structure of a research field.

Guided by the study's objectives, two specific science mapping techniques are employed. First, Bibliographic Coupling Analysis assesses the degree of similarity between publications that share common references [20]. The clusters generated through this method reveal groups of recent publications, offering insights into the development and convergence of contemporary research themes [16]. Second, Co-word Analysis examines the frequency and co-occurrence of keywords derived from article titles, abstracts, and author-defined terms [21, 22]. This technique helps identify dominant topics and emerging themes within literature and complements bibliographic coupling by forecasting future research directions [23].

2.1 Research design and data collection procedure

To retrieve relevant publications, we used a targeted search strategy outlined in Table 1, applying it to the Web of Science (WoS) Core Collection database. The search terms were primarily based on "rambutan" and its scientific name, *N. lappaceum*. The WoS topic search function was employed, which scans for keywords within the title, abstract, and author-provided keywords excluding terms found solely within the full text. This approach ensures that the retrieved terms reflect a central focus of each publication.

Only peer-reviewed journal articles were considered, while other types of publications, such as conference proceedings, books, book chapters, editorials, and white papers were excluded. This selection criterion was adopted to maintain the quality and credibility of the dataset, as journal articles typically undergo more rigorous peer-review processes compared to other publication formats [24].

Table 1. Search string in WoS database.

"Keyword"	Justification
"Rambutan" OR	To identify the specific
" <i>Nephelium lappaceum</i> L."	name for the plant.

Table 1 presents the search strategy employed for this bibliometric analysis. The WoS database was queried using the topic search function, with search parameters limited to titles, abstracts, and keywords. The search string included the terms "rambutan" OR "*Nephelium lappaceum* L." and was executed on May 5, 2024. This preliminary search yielded 551 publications. To ensure reliability, only peer-reviewed journal articles were considered, as they represent the most credible and relevant sources for bibliometric evaluation [25]. Each record was carefully screened for errors and duplicates to maintain data integrity. Furthermore, only articles published in English were included to ensure consistency and standardization. Finally, the WoS Core Collection database was used as the primary source for comparison and reference.

3. Results and Discussion

Fig. 1 illustrates the annual distribution of publications and citations related to rambutan research. The earliest article was published in 1971; however, it had limited impact as no subsequent publications appeared over the following nine years. A noticeable upward trend in scholarly output began in 1994, reflecting growing scientific interest in rambutan. Publication activity peaked in 2023, marking the highest number of annual contributions to the field. Although citation counts have shown a slight decline in recent years, the overall trend suggests sustained research attention. Given the diverse applications and beneficial properties of

rambutan, the number of publications is expected to remain consistently significant in the coming years.

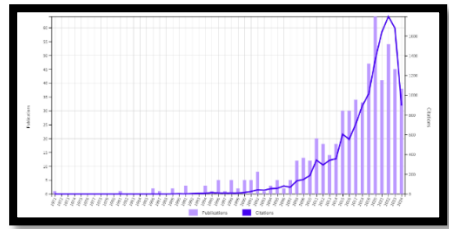


Fig. 1. Number of publications and citations of rambutan research (Source: Web of Science).

3.1 Bibliographic coupling

Out of the 551 retrieved documents, 55 satisfied the minimum citation threshold, which resulted in the formation of four clusters. The threshold value was carefully optimized, as a lower threshold could lead to overlapping or redundant themes (under-filtering), while a higher threshold might exclude essential core themes (over-filtering). The most influential studies based on total link strength (TLS) were identified as Yuvakumar et al., [26] with 33 TLS, Thiltildetacha et al., [27] with 33 TLS, and Maran et al., [28], with 32 TLS. The top 10 influential documents obtained through bibliographic coupling analysis are listed in Table 2.

Table 2. Top 10 documents in bibliographic coupling analysis of rambutan research study.

Rank	Publication	Citation	TLS
1	Yuvakumar et al., 2014 [26]	201	33
2	Thiltildetacha et al., 2010 [27]	126	33
3	Maran et al., 2017 [28]	165	32
4	Yuvakumar et al., 2015 [40]	118	29
5	Thiltildetacha et al., 2008 [60]	129	18
6	Palanisamay et al., 2011 [42]	133	17
7	Okonogi et al., 2007 [61]	178	16
8	Khorkhan et al., 2010 [62]	70	16
9	Tachakittirungrod et al., 2007 [63]	233	15
10	Zhuang et al., 2017 [64]	107	11

The bibliographic coupling analysis revealed four distinct and independent clusters, each representing different thematic directions in rambutan research. These clusters not only reflect current scientific trends but

also indicate promising avenues for future applications and activities. The labeling of clusters was carried out through inductive interpretation by examining representative articles within each group and synthesizing their common themes and research streams. The overall network visualization of these clusters is presented in Fig. 2.

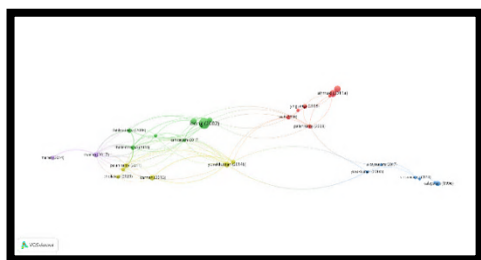


Fig. 2. Bibliographic coupling of *Nephelium lappaceum* L. studies.

Cluster 1 (red): Cluster 1 with seven items is labeled “The valorization of rambutan byproducts”. Ahmad and Alrozi [29], conducted the experiment, which involved the adsorption of malachite green (MG) dye onto activated carbon based on rambutan peel (RPAC). The effects of several reaction parameters on MG adsorption were investigated, including the beginning MG concentration, contact time, solution temperature, and initial pH. Njoku et al., [30], stated that peel from rambutan, a unique agricultural waste, was a precursor to prepare activated carbon through chemically assisted potassium hydroxide (KOH) activation. The activation time was significantly shortened because microwave heating was used for activation. Palanisamy et al., [31], for the first time, studied the extract from the rind of rambutan, which has a high phenolic content, a low pro-oxidant capacity, and good antioxidant activity. There are applications for this extract in the pharmaceutical, nutraceutical, and cosmetic fields. It can be used alone or in conjunction with other active components. Wall [32], studied cultivars of rambutan collected from various parts of Hawaii, and their mineral and ascorbic acid (vitamin C) contents. The average ascorbic

acid concentration for rambutan was 36.4 mg/100 g. The fruit was also found to contain 20% of the daily recommended intake for copper and 8–10% for magnesium.

Cluster 2 (green): Cluster 2 has seven items labeled “Rambutan as a functional food source”. Can-Cauich et al., [33], stated that fruit peels and other byproducts frequently have more beneficial chemicals than the edible parts of the plant. Some tropical fruit peel extracts were discovered to have potent antioxidant activity and high bioactive component concentrations. Leong and Shui, [34], measured the ability of fruit pulps to scavenge the free radical 2,2'-casino-bis-(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS) to determine overall antioxidant capability for 27 different fruits. Using RP-HPLC, the contribution of l-ascorbic acid (AA) to the overall antioxidant activity of fruits was examined. Among fruit species, the amount of AA contributing to l-ascorbic acid equivalent antioxidant capacity (AEAC) ranged widely, from 0.06% in ciku to 70.2% in rambutan. Besides that, Thitilertdech et al., [27], also supported the idea that rambutan peel has antioxidant qualities. Experiments were carried out using a lipid peroxidation inhibition test to isolate, identify, and determine the active ingredients' antioxidant activity. The methanolic extract of rambutan peels showed potent antioxidant qualities. Khonkarn et al., [35], evaluated the cytotoxic and antioxidant activity of fruit peel extracts from coconut, mangosteen, and rambutan against human cell lines. The rambutan peel crude extract exhibited the highest level of antioxidant activity. The ethyl acetate fraction showed the highest radical scavenging capacity via the ABTS assay, with a Trolox equivalent antioxidant capacity value of 23.0 mM/mg.

Cluster 3 (blue): Cluster 3 with four items is labeled as “Potential uses of rambutan parts”. Witayaudom and Klinkesorn, [36], used rambutan kernel fat stabilized with Tween-80 to create nanostructured lipid carriers (NLCs). The effects of solidification

temperature (5 and 25 °C) and Tween 80 concentration (0.025, 0.05, 0.1, 0.2, 0.5, and 1.0 wt%) on the properties and stability of the NLC were examined. The findings indicated that while there was no discernible impact on the polydispersity index, an increase in Tween-80 concentration led to a decrease in particle size (Z-average) and zeta-potential (ζ -potential). Yuvakkumar et al., [26], studied the sustainable biosynthesis of NiO nanocrystals using peel extract from rambutan as a natural ligation agent. Utilizing the byproduct of rambutans, a nickel-delegate complex was formed to conduct the green synthesis of NiO nanocrystals. It was confirmed that NiO nanocrystals have formed successfully. Solís-Fuentes et al., [37], examined the yield, content, physical, chemical, and thermal characteristics of the fat extracted from the rambutan seed to assess the fruit byproduct's potential as a natural edible fat source that might be used in industry [38]. Out of the 364 plant seeds evaluated, 51 had fatty acid levels higher than 15% (dry weight), and the cetane index of their methyl esters was more significant than 50. An exception was rambutan seed, which had a high cetane index (67.1) and a low lipid content of only 14.7%. In addition to having high cetane indices, three seed oils from the Sapindaceae family also included long-chain fatty acids with 20 carbon atoms. As a result, there is much potential for these plant seed oils to be developed as diesel fuel.

Cluster 4 (yellow): Cluster 4 with five items is labeled as "Rambutan peel for nanomaterial synthesis". Phongtongpasuk et al., [39], created a new, low-cost method for the biosynthesis of zinc oxide nanoparticles from rambutan peel extract, with the extract functioning as a natural ligation agent throughout the synthesis. Yuvakkumar et al., [40], synthesized bioinspired zinc oxide nano chains from naturally occurring rambutan peel waste. The extensive polyphenolic system of rambutan peels allows them to naturally ligate zinc ions, forming zinc oxide nano chains throughout the incubation phase. Transmission

electron microscopy studies confirmed the successful production of these zinc oxide nano chains. Chollakup et al., [41], found that when cassava starch and whey protein isolate were blended with plant extracts, the resulting films displayed altered characteristics and release patterns. The effects of acetylated starch and native starch on antioxidant and antibacterial activities and film characteristics were studied. The antioxidant and antibacterial activity of the mixed films was controlled by the food components and phenolic release, respectively, and varied between in vitro (disc diffusion method) and actual food (salami). Palanisamy et al., [31], studied the anti-hyperglycemic properties of ethanolic rambutan rind extract. The primary bioactive substances that were separated from this extract were geraniin or ellagitannin. Thus, geraniin may one day be used as an anti-hyperglycemic medication. Table 3 summarizes the bibliographic coupling analysis, including cluster number and color, cluster labels, number of publications, and representative publications.

Table 3. Bibliographic coupling analysis on rambutan.

Cluster No. and color	Cluster label	Number of publications	Representative publication
1 (red)	Valorization of rambutan byproducts	7	[30-32]
2 (green)	Rambutan as a functional food source	7	[28, 33-35]
3 (blue)	Potential uses of rambutan parts	6	[36-38]
4 (yellow)	Rambutan peel for nanomaterial synthesis	6	[40-42]

3.2 Co-word analysis

The co-word analysis applied to the same database. Of the 3055 keywords, 117 met with the minimum of 6 occurrences, resulting in four clusters. This makes the resulting map easier to interpret and ensures that the four clusters represent the most dominant and established themes in the field. Similar to bibliographic coupling, the threshold was tested several times to ensure the network map

produced was robust and represents the research streams accurately. The highest co-occurrence keywords were rambutan (97 occurrences), antioxidant (30 occurrences), and *N. lappaceum* (30 occurrences). Table 4 summarizes the top 15 co-occurred keywords with their number of occurrences and TLS.

Table 4. Top 15 keywords in the co-occurrence of keywords analysis.

Rank	Keyword	Occurrences	Total link strength
1	rambutan	97	236
2	antioxidant	58	218
3	<i>Nephelium lappaceum</i>	60	137
4	nanoparticles	38	124
5	<i>In vitro</i>	26	109
6	Phenolics compound	24	95
7	<i>Linnaeus</i> (L.)	23	89
8	performances	28	86
9	<i>Nephelium-lappaceum</i>	23	82
10	geraniin	18	81
11	identification	24	80
12	polyphenols	18	78
13	acid	22	76
14	<i>Nephelium-lappaceum</i> L.	19	76
15	Ellagic acid	14	74

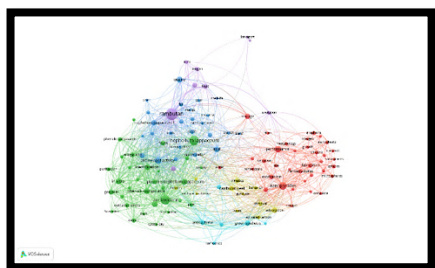


Fig. 3. Co-word analysis on rambutan studies.

Fig. 3. presents the network structure of co-word analysis. It shows that five clusters were produced in the scientific network. After an in-depth analysis, it was deduced that only four clusters were significant, with the appropriate number of words representing four different themes. The four clusters were assigned the proper labels. The reduction from five to four clusters in the co-word analysis was a refinement step intended to align keyword-based themes with the stable document-based themes identified through

bibliographic coupling for better comparative accuracy.

Cluster 1 (red): With 35 keywords, this cluster was labeled as "The application of compounds from *N. lappaceum* L.". Ahmad and Alrozi, [43], investigated the best ways to prepare rambutan peel-based activated carbon (RPAC) so that the reactive dye Remazol Brilliant Blue R (RBBR) could be removed from aqueous solution. The physiochemical activation approach was used to create the RPAC; it involved gasifying carbon dioxide and treating with KOH. The effects of the preparation variable, activation temperature, activation time, and KOH impregnation ratio on the RPAC yield and RBBR percentage elimination were ascertained using the central composite design. Lestari et al., [44], suggested that chemical or physical methods can synthesize Ag nanoparticles (AgNPs). The physical approach uses techniques like laser ablation and evaporation/condensation. Strong reductants like borohydrate, citrate, ascorbate, and elemental hydrogen are used in the chemical method. The reduction of silver ions (Ag^+) to their elemental form (Ag^0) by the reductants will lead to the formation of colloidal particles. To minimize the use of harmful chemicals needed to decrease the concentration of silver ions, a variety of plant extracts, microbes, and fungi are used in the green synthesis of AgNPs.

Plant extract is most commonly used since RPEs demonstrates higher antibacterial efficacy against *Staphylococcus aureus* than *Streptococcus mutans*, with nanoparticle formulations achieving significant growth inhibition and bactericidal effects ($\geq 99.9\%$ reduction) at lower concentrations than traditional microparticle extracts. Florenly et al., [45], evaluated the effectiveness of RPEs in micro- and nanoparticles against oral bacteria, specifically *Streptococcus mutans* and *Staphylococcus aureus*. This study used RPEs in microparticles (62.5 mg/mL and 250 mg/mL) and nanoparticles (26.5 mg/mL) in a post-test-only laboratory experiment. A variety of inflammatory illnesses and oral

infections are brought on by mouth biofilm that contains microorganisms. The antibacterial effects of rambutan peel extracts are attributed to bioactive components. Urena-Saborio et al., [46], used Electrospun nanofiber (ESNF) templates, including multiple components, to encapsulate rambutan peel polyphenolics (RPP). AgNPs were applied to these nanofibers using in situ electrochemical reduction. The results showed that hydrophilicity, cell adhesion, and proliferation in vitro improve when RPP is added to synthetic polycaprolactone (PCL) ESNF. Additionally, when AgNPs and RPP were combined in the multi-functionalized ESNF system, a synergistic antibacterial and cell proliferation impact was seen. AgNPs/RPP-PCL ESNF's potency as an antimicrobial and antioxidant matrix may facilitate wound healing and operate as a hybrid scaffold for tissue engineering.

Cluster 2 (green): With 31 keywords, this cluster is labeled "Biological activities of *N. lappaceum* L.". Monrroy et al., [47], used a variety of extraction solvents, boiling, and ultrasonic extraction techniques to identify the active components in extracts of rambutan peel and assess their antioxidant qualities. The chemical analysis of rambutan peel revealed 2% and 12 grams of reducing sugar. Besides that, Rakariyatham et al., [48], suggest focusing on biological activity, health-promoting properties, safety assessment, and possible uses of these byproducts in the food and pharmaceutical industries. A comparison of the benefits and drawbacks of contemporary and traditional extraction methods for recovering these phenolics was also covered. Sulistiyansih et al., [49], studied nosocomial infection, infections contracted in a hospital that can lead to several serious illnesses. *Pseudomonas aeruginosa* multi-resistant (PAMR) is the primary bacterium that causes nosocomial infections. The leaf of the rambutan plant is suspected of containing flavonoids, polyphenols, and tannins, which are known to have antibacterial properties. The findings of the study demonstrated that the

rambutan leaf ethanolic extract, ethyl acetate fraction, and water fraction exhibited antibacterial activity against PAMR, with the ethyl acetate fraction being the most active. Putri et al., [50], evaluated the antioxidant and antibacterial properties of rambutan-ake leaf extract using three distinct extraction solvents. N-hexane, ethyl acetate, and ethanol solvent were used in a sequential solvent extraction process, yielding the maceration method's extracts. Antioxidant activity was examined using the (2,2-diphenyl-1-picrylhydrazyl) DPPH radical scavenging assay compared to ascorbic acid. DPPH free radicals could be scavenged by all extracts at concentrations of 25, 50, and 100 parts per million. Additionally, these plant extracts displayed inhibitory activity against every microbe examined in the study.

Cluster 3 (blue): With 25 keywords, this cluster was labeled "Sustainable techniques for compound production". Chai et al., [51], have proved the value of recycling rambutan seed, as the seed has a good deal of crude fat. Therefore, this study aimed to examine the seed's lipid characteristics and antinutrient content during the rambutan fruit's fermentation process. Cerda-Cejudo et al., [52], studied the extraction of ellagic acid (EA) from Mexican rambutan peel using solid-state fermentation (SSF) assistance. The effects of moisture, temperature, and *Aspergillus niger* inoculum on the recovered chemicals were assessed. Testing was done to determine the ideal fermentation conditions and the maximum accumulation of EA, radial development of *A. niger*, and water absorption capacity of the rambutan peel. De León-Medina et al., [53], found that the rambutan peel has many ellagitannin byproducts. Ellagic acid is produced during the biodegradation of ellagitannins. This experiment aimed to isolate ellagitannins from rambutan peel and perform SSF to determine which enzymes are responsible for the ellagitannins' biodegradation. Microwave/ultrasound technology was used to extract rambutan ellagitannins, which were then separated using

column chromatography and Amberlite XAD-16 resin and identified using HPLC-MS.

Cluster 4 (yellow): With 11 keywords, this cluster was labeled "Valorization of fruit waste for environmental applications". Chen et al., [54], conducted a comparative investigation of the chloroplast genomes of nine *Sapindaceae* species. They found that the IR sections and the large single-copy and small single-copy regions were more comparable in conservation. The results of the phylogenetic analysis indicate that the chloroplast genome of rambutan and *Pometia tomentosa* are closely related. Future studies on rambutan breeding and *Sapindaceae* evolutionary studies could benefit from understanding the chloroplast genomics of rambutan and a comparative examination of *Sapindaceae* species. Choudhury et al., [55], stated that fruit waste in the processing industry is primarily made up of seed, skin, rind, and pomace, all of which have fair amounts of potentially bioactive compounds that can be used as substrates. Fruit waste can make activated carbon, an inexpensive and efficient CO₂ adsorbent with a large surface area. Heavy elements like arsenic, hexavalent chromium, cadmium, lead, and dyes like methylene blue and alcian blue, among others, can be absorbed by these valorized waste products. Despite having a smaller capacity than complex adsorbents, the cost-benefit ratio of these adsorbents makes their application more widespread and competitive. Ahmad et al., [56], produced resin-derived spherical activated carbon based on rambutan seeds by gasifying CO₂ and activating KOH. Then, using proximate analysis, Brunauer-Emmett-Teller method, scanning electron microscopy, and Fourier transform infrared spectroscopy, the seed-based activated carbon adsorbent was characterized.

4. Challenges, Limitations, and Future Perspectives

Accumulating research studies on rambutan parts is a promising area of research that must be further explored. Most of the

research focuses on the bioactive compounds present in rambutan parts. However, of these studies, most focus on the peel. It is challenging to produce rambutan peel extracts on an industrial scale that are high quality, consistent, and taste good enough for consumers. There are also limitations on the stability of phenolic compounds derived from rambutan peels during manufacturing and storage.

New extraction techniques, such as instantaneous controlled pressure, may improve the effectiveness of extracting bioactive chemicals from rambutan peels. Further investigation is required into the fate of the rambutan peel-derived phenolics in the gastrointestinal system, and their absorption, bioavailability, and mode of action within the body to determine their effectiveness. Additionally, meta-analyses of the available scientific data on their health benefits might be productive. One potential solution to the problem of leaf vulnerability is the development of rambutan cultivars resistant to leaf spot disease. The market generally sees increased demand for rambutan fruits, which bodes well for the crop's future.

The main difficulties are in large-scale rambutan peel component extraction and stabilization and in determining the safety and bioavailability of these compounds.

Overcoming these constraints through technical advancements and additional study may facilitate future rambutan-based product development.

5. Conclusion

This bibliometric analysis provides a novel perspective on the multifaceted applications of rambutan by identifying core research themes through bibliographic mapping and co-word analysis. The study reveals that the most significant therapeutic potential is concentrated in key bioactive compounds such as geraniin, ellagic acid, and corilagin. These polyphenols have demonstrated a high percentage reduction in the growth of pathogens like *Streptococcus*

mutans and *Staphylococcus aureus*, particularly when formulated through green synthesis as nanomaterials. Thus, to facilitate the translation of these findings into practical applications, future development should focus on integrating these extracts into functional foods and nutraceuticals for oxidative stress management. Furthermore, the potent antimicrobial properties of these compounds offer promising clinical applications, specifically in the development of natural dental disinfectants and topical agents. Ultimately, the transition from agricultural waste to high-value bioactives underscores a sustainable path for both environmental valorization and pharmaceutical innovation.

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