Bibliometric analysis of biochemical and sensory characteristics of mangosteen using virtual reality technology

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Abstract. Mangosteen is a tropical fruit native to Southeast Asia. This study aimed to examine mangosteen's biochemical and sensory characteristics using virtual reality (VR) technology with bibliometric analysis. The bibliometric analysis method used VOSviewer and biblioshiny to identify patterns of author collaboration, research topic trends, and publication dynamics from year to year. The data of 101 journal articles (2009-2025) used the Scopus database with the keywords "biochemical mangosteen" and "virtual reality sensory science". The analysis revealed that although the number of publications integrating biochemical and sensory studies of mangosteen with VR technology is still limited, this trend indicates that research in this field has grown with an average annual expansion of 11.85%. The analysis revealed that China is the main contributor in the number of publications produced and international collaborations, especially the City University of Hong Kong. This study provides an initial contribution to describing the opportunities for using VR technology in the study of mangosteen. Interdisciplinary collaboration between food science, digital technology, and sensory perception studies has great potential to drive innovation in analysing mangosteen fruit quality.

1 Introduction

Mangosteen (*Garcinia mangostana* L.) is one of an exotic fruit native to Indonesia. Mangosteen is referred to as the "*Queen of Tropical Fruits*" due to its uniqueness. The bioactive compound that is the primary component of the fruit is xanthone, a polyphenolic compound that is a secondary metabolite not possessed by other fruit commodities. The xanthone compounds in mangosteen fruit peel contain alpha, beta, and gamma mangostin [1]. The dominant component in mangosteen fruit is the peel, which accounts for 83%, the pulp 15%, and the seeds 2%. Mangosteen is often consumed fresh [2]. Product development utilizing mangosteen has included mangosteen fruit beverages [3] and peel extracts [1]. Notably, no attempt has been made to build a lexicon relating to the sensory aspects of the mangosteen's distinguished features.

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Furthermore, virtual reality (VR) in sensory evaluations is highly discussed. VR, or virtual reality, replaces an environment made or taken from the real one. Moreover, VR encapsulates the user in an artificial environment where one or more senses can be used, providing an experience resembling the actual, tangible physical world. Virtual reality sensory testing in Ireland was conducted on chocolate and beef steak samples [4]. The findings indicated that VR significantly influenced the hedonic responses of panelists to both samples. The development of VR technologies offers new opportunities for food scientists to assess different dimensions of food products. It opens new avenues for engaging and participatory systems that are sophisticated enough to record and analyze the complexities of human sensory interpretation [5].

Bibliometric analysis, a powerful tool for examining publications, collaboration networks, and citation dynamics of scientific research, implements quantification for analysis [6]. A bibliometric study illustrates the international scope of the literature related to the biochemistry of mangosteen and its sensory characteristics by identifying the author collaboration, the most active scholars, publications, and participating countries. Analyzing such studies is paramount for exploring the deficiencies in the available literature and emerging topics, which shape the appropriate focus of research for the future. Moreover, a bibliometric correlation of how VR technology can assess and enhance the understanding of mangosteen's biochemical properties and sensory qualities remains underexplored. This study aimed to examine these properties using VR technology with bibliometric analysis.

2 Methods

2.1 Search strategy and data retrieval process

In this study, bibliographic information was sourced from the Scopus database. Scopus is one of the most prominent and utilized databases in quantitative studies [6]. The keywords used to retrieve all relevant documents were "biochemical mangosteen" and "virtual reality sensory science". These keywords were chosen based on their relevance to the subject of interest, encompassing both biochemical aspects of mangosteen and its applications within virtual reality sensory science. The inclusion criteria were that the documents of interest for this analysis were exclusively written in English to maintain linguistic consistency and avoid biases that could arise from translations and included research articles and reviews. Additionally, the initial search period, from 2009 onward until 2025, returned a total of 101 publications. Review papers are essential in this context, since they thoroughly review specific subjects, highlight deficiencies in the current literature, and establish a solid conceptual framework. Given the ever-evolving nature of research methodologies and technologies, limiting the publication timeline of research is one way to ensure the relevance and recency of the findings. The only criterion for exclusion was if the paper was written in a language other than English to ensure that all included papers could be comprehensively analyzed. Studies that did not address both domains (biochemical mangosteen and virtual reality sensory science) in a meaningful way were excluded to maintain the focus on research bridging these two distinct areas. Therefore, more recent research is generally viewed as more accurate and representative.

The data cleaning and merging process for the literature search focuses on the biochemical study of mangosteen and virtual reality sensory science, as well as the interdisciplinary connections between these topics. Starting with literature extraction from Scopus and keyword searches, several sequential steps were performed. First, duplicates were removed based on the title, author, and publication year to ensure data consistency. Second, separate searches are conducted for each keyword within the scope of the topics in

Scopus. Third, a thorough review of each document's abstract and main text was conducted to assess its relevance to biochemical studies of mangosteen and virtual reality sensory science. Lastly, two different keywords were merged by assuming that authors and researchers considering both areas, even indirectly, would contribute relevant papers. For instance, research on the biochemical properties of mangosteen related to health and wellness that mentions aspects of virtual reality sensory science would be included, even if the connection is indirect.

2.2 Data analysis

This study utilized VOSviewer, RStudio (Biblioshiny), and Microsoft Excel to investigate and visually depict scientific collaboration, potential research paths, and trends within this field. The bibliometric analysis incorporated citation metrics, keywords co-occurrence, publication year, author information, contributing country, and affiliation to identify collaboration patterns among authors, emerging trends in the research focus, geographic distribution, contributing institutions, and changes in publications over the years.

3 Results and discussion

3.1 Analysis of keyword co-occurrence

The analysis results using VOSviewer, as shown in Fig. 1, show three main clusters: "*Garcinia mangostana"*, "human", and "virtual reality". The relationship lines demonstrate that each cluster is closely related. The keywords in each cluster show research trends and are indicated by the emergence of various specific and rarely discussed topics in each cluster. This is also shown by the collaboration lines between keywords and descriptors in each field. The more lines between descriptors there are, the closer the relationship between the research is [6]. Older research keywords are purple, newer topics are visualized in yellow, and green represents researchable topics.

Specific terminology associated with *Garcinia mangostana*, like "biochemical composition," "alpha mangostin," "mangostin", "drug effect," and "clinical effectiveness," is linked to the influence of mangosteen. Research on identifying metabolite profiles in mangosteen fruit, especially at the maturity level [7,8]. It was concluded that different metabolites are major contributors to the color change at the maturity level, depending on the mangosteen part. Primary metabolites found in the pericarp: fructose, psicose, glucose, and galacturonic acid; in the flesh: xylose, glucuronate, 2-aminoisobutyric acid, tryptophan, and xylulose; and in the seeds: phenylalanine, valine, tyrosine, isoleucine, and serine [7]. The content of alpha mangostin found in the flesh of ripe mangosteen fruit is higher than that in the mangosteen pericarp. Furthermore, phenolics, especially flavonoids, contribute to the flavor and aroma of ripe fruits, combined with sugars, acids, and volatile compounds [8].

Another study on *Garcinia mangostana* supplementation to high-fat diet induced obese rats for seven weeks noted an improvement in total antioxidant capacity and the level of glutathione peroxidase. In these studies, subjects also experienced reduced body weight as well as improvements in lipid profiles and plasma pro-inflammatory markers (TNF-α and IL-6), indicating a reduction in inflammation. Moreover, the supplementation reduced diet-induced hepatic and renal tissue damage associated with high-fat diets [9].

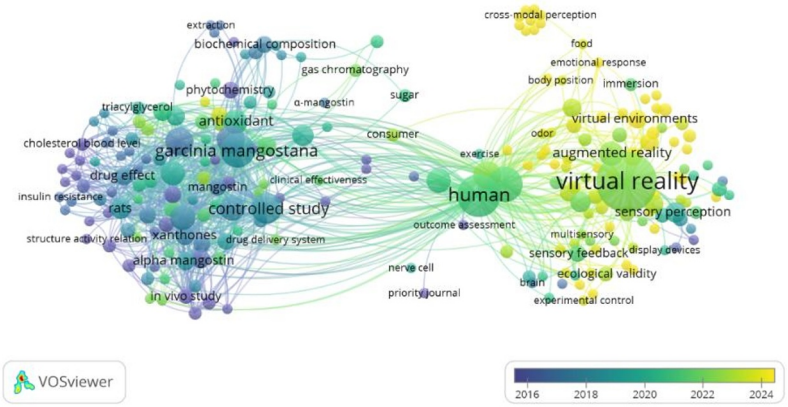

Fig. 1. Overlay visualization

The relationship between *Garcinia mangostana* and virtual reality (VR), such as "human," indicates additional investigation into the potential of VR technology for humans. Specific terminology associated with VR, like "sensory perception," "augmented reality," and "virtual environments," is linked to the influence of VR. VR is revolutionizing the food industry by transforming how it interacts with its customers and even impacting how customers experience the taste of the food through multi-sensory engagement. Some benefits of using virtual reality for people include realistic sensory experiences, greater control over factors, heightened efficiency, and cost-effectiveness. VR can enhance the user's sensory perception, such as sight, hearing, and touch [5].

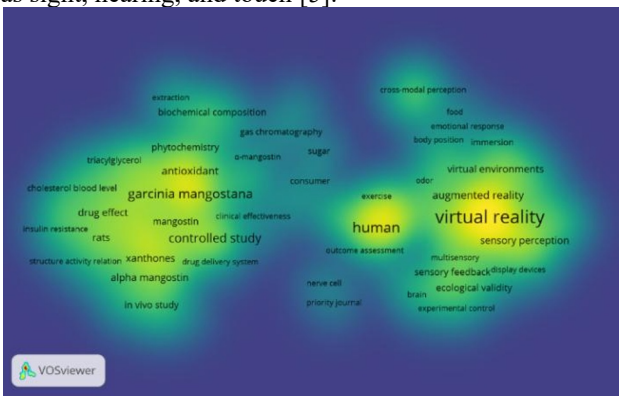

Fig. 2. Density visualization

The density in Fig. 2 shows the density/emphasis of the research groups. Density can be used to see the parts of the research that are still rarely done. Based on Fig.2, many topics have not been widely researched and still require further study and research. The scattered keywords (research variables) show that implementing *Garcinia mangostana* research, biochemical composition, virtual reality, human, emotional response, and sensory perception are comprehensive research topics that require further study.

3.2 Analysis of annual scientific production

The annual growth rate from RStudio (Biblioshiny) was 11.85%. The analysis results from Biblioshiny, shown in Fig. 3, show that the published paper trends indicate changes in scientific yearly production. This technique is essential to assess the milestones achieved in scientific publications throughout the years and why there are shifts in academic productivity. The graph substantiates that there have been considerable changes over the years. However, there is an undeniable upward trend in scientific output in recent years.

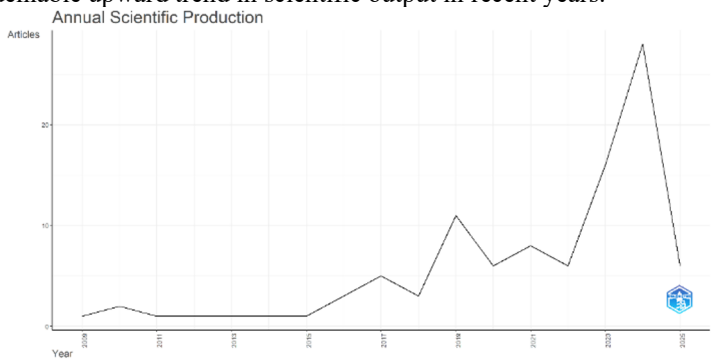

Fig. 3. Annual scientific production

From 2009 to 2018, the productivity in scientific articles was restricted, with the generation of 1 to 5 articles each year. This increased to 11 articles in 2019, and peaked at 28 articles in 2024, which is projected to remain the peak from 2020 to 2025. 2025 is still early, but it is currently at six articles. The improvement in the number of articles produced may be due to better international integration and technological advances. International collaboration often acts as a major driver for growth in the volume of publications, particularly in clinically expensive fields like clinical trials. Furthermore, the growing research on mangosteen's health benefits and the sensory applications of VR highlight an increasing awareness of the positive impact of consuming mangosteen fruit and exploring new food consumption methods.

3.3 Analysis of contributing country

The data in Fig. 4, Fig. 5, and Table 1 demonstrate that China and the United States led worldwide scientific research contributions.

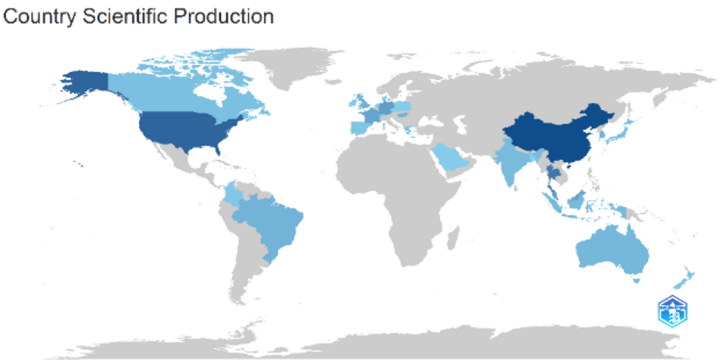

Fig. 4. Country scientific production

The frequency value in China was 88 (Table 1), the MCP and SCP values were 26.7% and 11 (Fig. 5). Research on audio, visual, and olfactory with virtual reality indicated that the prototype device surpassed the subjective usability test by integrating visual, auditory, and olfactory stimuli. Effectively, the prototype device enhances medical VR applications. In the future, the device will be used in diverse populations, such as surgery patients, those with eating disorders, obesity, and patients with anorexia who are unable to take food orally [10].

In the USA, the frequency value was 71 (Table 1), the MCP and SCP values were 0% and 13 (Fig. 5). According to [11], on the application of immersive mixed-reality to enhance the ecological validity of sensory behavior and eating. The study's results from consumer acceptance tests showed that trained panelists rated the VR restaurant environment as more acceptable than the panel booth. However, the highest acceptance rating was for the actual restaurant environment. This could be a new method for evaluating the influence of the environment on eating behavior and may be promising for further research.

Table 1. Top 10 Country Production

Country	Freq
China	88
USA	71
Thailand	58
Germany	32
Malaysia	29
France	28
UK	19
Brazil	18
Hungary	18
South korea	18

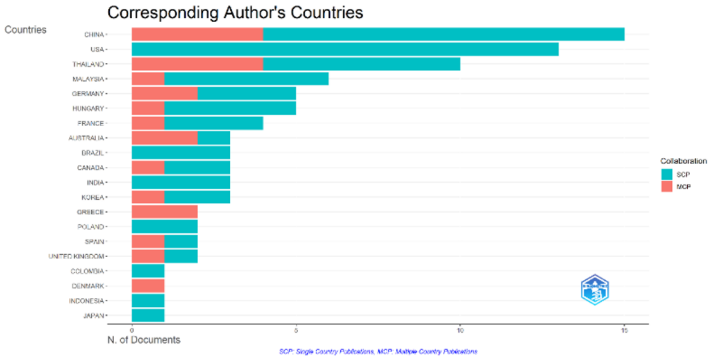

Fig. 5. Most productive countries (SCP: single country publications, MCP: multiple country publications)

The frequency values in Malaysia and Thailand were 29 and 58 (Table 1). The MCP and SCP values consecutively were 16.7% and 5, 40% and 6 (Fig. 5). As in the tropical countries in Southeast Asia, Malaysia and Thailand led the research on mangosteen fruit. For example, Malaysia has researched metabolite profiles at mangosteen fruit maturity levels [8]. Another study focused on research on mangosteen pericarp extract with microwave extraction. As the results compared to the water bath-maceration method, microwave extraction led to approximately the same antioxidant capacity and higher extraction of alpha mangostin, a primary xanthone found in the pericarp of the mangosteen [12]. In addition, Thailand has also conducted research on mangosteen peel extract supplementation for clinical health [13].

3.4 Analysis of top 10 author production

Table 2 shows the number of articles produced by the top ten authors. From first to third place were Gere, Attila, Kókai, Zoltán, Zulkarnain, and Abdul Hannan bin, with five articles each. These authors appear to be more productive than the others. The three of them conducted collaborative research specifically on sensory perception with VR technology [5,14]. The results suggest that a virtual sensory booth could be a significant asset for sensory scientists and those interested in investigating VR's new possibilities. Furthermore, this study's achievements could represent a considerable improvement in analysis and cost efficiency, increasing the study's potential influence in optimizing research methodologies.

Table 2. Top 10 Author Production

Authors	Sum of Articles
Gere, Attila	5
Kókai, Zoltán	5
Zulkarnain, Abdul Hannan bin	5
Brennan, Charles	2
Chandrapala, Jayani	2
Kantono, Kevin	2
Aizat, Wan Mohd	2
Azizan, Kamalrul Azlan	2
Baharum, Syarul Nataqain	2
Johnson, Jeremy J.	2

3.5 Analysis of top 10 most cited article and relevant affiliation

Table 3 demonstrates the top ten most-cited articles, allowing an understanding of the impact and reach of each publication within the scientific community's documents. The articles are scored based on complete citations, citations annually, and normalized total citations based on an equitable age of publication comparison amongst peers. This value demonstrates the scientific literature, the contribution of each publication, and the extent of its impact over time.

Table 3. Top 10 most cited articles

Paper	Total Citations (TC)	TC per Year	Normalized TC
Lebedev MA, 2017, Physiol Rev	412	45.78	4.06
Papanastasiou G, 2019, Virtual Reality	271	38.71	5.86
Kwon O-H, 2016, IEEE Trans Visual Comput Graphics	161	16.10	2.49
Johnson JJ, 2012, Carcinogenesis	131	9.36	1.00
Melo M, 2022, IEEE Trans Visual Comput Graphics	116	29.00	3.91
Cheok CY, 2013, Ind Crops Prod	83	6.38	1.00
Laiju AR, 2014, Environ Sci Pollut Res	62	5.17	1.00
Udani JK, 2009, Nutr J	61	3.59	1.00
Ammann J, 2020, Food Qual Preference	51	8.50	1.97
Watanapokasin R, 2010, Appl Biochem Biotechnol	51	3.19	1.36

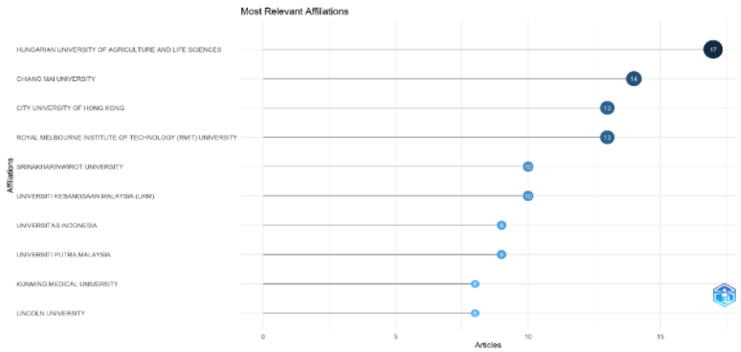

Fig. 6. Most relevant affiliation

Fig. 6 shows that the Hungarian University of Agriculture and Life Sciences, Chiang Mai University, and the City University of Hong Kong were the leaders for relevant affiliation. These three universities published 17, 14, and 13 papers in total. They are known for their agriculture and life sciences research, which is relevant to biochemical mangosteen and the use of virtual reality in sensory evaluation.

Research in the Institute of Food Science and Technology, Hungarian University of Agriculture and Life Sciences, Hungary, focused on using VR technology to study human sensory perception. The research included the assessment of the virtual sensory laboratory, which integrates conventional sensory practices (booth panels) into the virtual world to explore differences in consumer responses [5]. Moreover, VR sensory booths can reproduce some real-life settings, including cafes, restaurants, parks, and many others. Such adaptability gives scientists and researchers access to specific environments they might otherwise be unable to recreate [14]. The City University of Hong Kong also researched developing miniaturized VR technology for the taste generators in gustatory VR applications [10]. The research aimed to address the issue of insufficient sensory stimulation from the colors and aromas of food in patients receiving enteral nutrition via tube feeding. An immersive VR sham feeding device, incorporating audio, visual, and olfactory sensory perceptions, was independently developed, and its usability was evaluated. Overall, the equipment was user-friendly, and all users perceived it had a clear interface and operated reliably and efficiently. No adverse responses, including dizziness, were reported among any participants [10].

Between research in the Hungarian University of Agriculture and Life Sciences, Chiang Mai University, and the City University of Hong Kong indicated that the implementation of VR technology in consuming food products had many benefits, especially in the exploration of methods and the environment virtual space of consuming food as well as its application to surgical patients, patients with eating disorders, and other patients who couldn't receive food through the mouth.

4 Conclusion

Mangosteen (*Garcinia mangostana* L.), abundant in bioactive chemicals like xanthones, is recognized for its essential pharmacological qualities, including anti-oxidative, anti-inflammatory, and preventive benefits against diabetes. Virtual Reality (VR) in sensory perception research has illustrated the capability of VR technology to generate authentic and immersive sensory experiences, enabling researchers to examine the impact of diverse factors on sensory perception. Few publications have merged mangosteen's biochemical and sensory analyses with VR technology. The research subjects of *Garcinia mangostana*, biochemical

composition, virtual reality, human, emotional response, and sensory experience are broad and necessitate further exploration, especially the integration of VR in future sensory testing of tropical fruits.

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References

1. P. Suvarnakuta, C. Chaweerungrat, S. Devahastin, Effects of drying methods on assay and antioxidant activity of xanthones in mangosteen rind. Food. Chem. **125**, 240 (2011). https://doi.org/10.1016/J.FOODCHEM.2010.09.015
2. F. Nur'azizah, D. Hunaefi, T. Muhandri, Analysis of consumer preferences for instant mangosteen (*Garcinia mangostana* L.) powder drink in Bogor Regency and City. AgriTECH. **43**, 141 (2023). https://doi.org/10.22146/AGRITECH.69865
3. F. Nur'azizah, N. Andarwulan, S. Koswara, Development of Ready to Drink from Frozen Mangosteen (*Garcinia mangostana* L.). Indones. J. Food. Qual. **7**, 1 (2020). https://doi.org/10.29244/jmpi.2020.7.1.1
4. E. Crofton, N. Murray, C. Botinestean, Exploring the Effects of Immersive Virtual Reality Environments on Sensory Perception of Beef Steaks and Chocolate. Foods. **10**, 1154 (2021). https://doi.org/10.3390/FOODS10061154
5. A.H.B. Zulkarnain, Z. Kókai, A. Gere, Assessment of a virtual sensory laboratory for consumer sensory evaluations. Heliyon. **10**, 1 (2024). https://doi.org/10.1016/J.HELIYON.2024.E25498
6. N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, W.M. Lim, How to conduct a bibliometric analysis: An overview and guidelines. J. Bus. Res. **133**, 285 (2021). https://doi.org/10.1016/J.JBUSRES.2021.04.070
7. Parijadi AAR, Putri SP, Ridwani S, Dwivany FM, Fukusaki E, Metabolic profiling of *Garcinia mangostana* (mangosteen) based on ripening stages. J. Biosci. Bioeng. **125**, 238 (2018). https://doi.org/10.1016/J.JBIOSC.2017.08.013
8. S.F. Mamat, K.A. Azizan, S.N. Baharum, N.M. Noor, W.M. Aizat, GC-MS and LC-MS analyses reveal the distribution of primary and secondary metabolites in mangosteen (*Garcinia mangostana* Linn.) fruit during ripening. Sci. Hortic. **262**, 1 (2020). https://doi.org/10.1016/j.scienta.2019.109004
9. N. S. M. Adyab, A. Rahmat, N.A.A.A. Kadir, H. Jaafar, R. Shukri, N.S. Ramli, Mangosteen (*Garcinia mangostana*) flesh supplementation attenuates biochemical and morphological changes in the liver and kidney of high fat diet-induced obese rats. BMC. Complement. Altern. Med. **19**, 1 (2019). https://doi.org/10.1186/s12906-019-2764-5
10. K. Li, X. Yuan, Y. Hu, W. Zhang, Y. Chen, R. Hong, et al, An Integrated Audio-Visual-Olfactory Virtual Reality False Feeding Device: Research, Development, and Design. J. Sichuan. Univ. **54**, 792 (2023). https://doi.org/10.12182/20230760204
11. J.W. Long, B. Masters, P. Sajjadi, C. Simons, T.D. Masterson, The development of an immersive mixed-reality application to improve the ecological validity of eating and sensory behavior research. Front. Nutr. **10**, 1 (2023). https://doi.org/10.3389/fnut.2023.1170311
12. N.A. Mohammad, Z.D.N. Abang, I.I. Muhamad, M.H. Abdul, H. Yaakob, J.Y.M. Mohd, Optimization of the antioxidant-rich xanthone extract from mangosteen (*Garcinia mangostana* L.) pericarp via microwave-assisted extraction. Heliyon. **5**, 1 (2019). https://doi.org/10.1016/j.heliyon.2019.e02571
13. N. Hutadilok-Towatana, W. Reanmongkol, C. Wattanapiromsakul, R.

Bunkrongcheap, Acute and subchronic toxicity evaluation of the hydroethanolic extract of mangosteen pericarp. J. Med. Plants. Res. **4**, 969 (2010).

14. A.H.B. Zulkarnain, Z. Kókai, A. Gere, Immersive sensory evaluation: Practical use of virtual reality sensory booth. MethodsX. **12**, 6 (2024). https://doi.org/10.1016/J.MEX.2024.102631
15. M.A. Lebedev, M.A.L. Nicolelis, Brain-machine interfaces: From basic science to neuroprostheses and neurorehabilitation. Physiol. Rev. **97**, 767 (2017). https://doi.org/10.1152/physrev.00027.2016