Journal of Polyphenols
2024, 6 (1): 33–41
journal homepage: http://jpolyph.syphu.edu.cn

Relationship between tea pigments and health: A bibliometric and visual analysis

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Abstract: Tea pigments have significant effects on human health. However, more attention have been paid to their physiological functions. The aim of this study was to analyze the quantitative and qualitative impact of tea pigments on human health, together with their current and potential future research directions. The study searched and screened 520 publications on WOS from January 2002 to December 2022. The article collected and collated literature published in the last 20 years and analyzed it bibliometrically for years, journals, countries, authors, topics, keywords and strongest citation bursts. The findings of keywords and strongest citation bursts revealed that the most discussed research topics were anticancer, black tea polyphenol, antioxidant, activator inhibitor, *in vivo*, gut microbiota, and summarize the relevant literature. As a reference for future research, the literature pointed out current shortcomings and speculated future development trend of tea pigments.

Keywords: tea pigment; health; visual; bioactivity

1 Introduction

Tea was the third most popular beverage in the world [1]. Tea contained a variety of active ingredients. These included polyphenols, alkaloids, lipids, amino acids, caffeine, vitamins and minerals. These combined ingredients gave tea many pharmacological effects, such as lowering blood lipid and blood sugar levels [2], combating fatigue [3] and antioxidant [4], anticancer [5, 6] and tumour growth [7]. Studies have reported that drinking tea was associated with positive human health [8]. Tea pigments significantly affected the quality [9-11]. With the research on the health functions of the components of tea, tea pigments have become a hot topic of research and received a tremendous amount of attention all over the world. Tea pigment was a type of plant pigment with various biological activities, derived from a class of catechin-based tea polyphenols that undergo enzymatic or non-enzymatic oxidation. Tea pigments shown various pharmacological effects, some of which were more effective than catechins, as a class of natural tea products with great potential for exploitation.

Tea pigments contained polyphenols, sugars, amino acids, flavonoids, alkaloids, steroids and other components. Three types of tea pigments were theaflavins (TFs), thearubigins (TRs), and theabrownins (TBs) [12]. The correlation analysis revealed that tea pigments had a greater influence on the taste and color of tea infusion. Theaflavins were primarily responsible for the brightness of tea soup, the taste and color of tea soup determined mainly by thearubigins, and the clarity of tea determined mainly by theabrownins [13].

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These authors have no conflict of interest to declare.

Theaflavins created during the fermentation of tea. It was known as theaflavins that the crystal's orange-yellow icicle color. Meanwhile, its parent nucleu was the structure of benzoophenone. Theaflavins formed by the oxidative coupling of catechin compounds under the action of polyphenol oxidase [14]. The term "thearubigin" referred to a class of complex phenolic compounds. Theabrownins were the pure natural product formed by further oxidation polymerization of phenolic substances [15]. Theabrownins' brown color in tea and tea soup turned the soup dark. Specifically, the variety and content of tea pigments changed as tea processing technology evolved. Tea could be classified into five categories based on fermentation levels: Unfermented, lightly fermented, semi-fermented, fully fermented, and post-fermented [16]. Alternatively, the type and content of tea pigments components in tea could change due to the different degrees of fermentation [17]. This resulted in the difference in tea soup color [18].

The primary objective of bibliometrics research quantitatively described academic information using mathematics, statistics. And it combined statistical analysis to reveal the quantitative characteristics and potential laws of researches [19]. It was conducive to the interpretation of a large amount of information and the investigation of research hotspots. It was crucial to apply these techniques to uncover the potential of tea pigments in current research and emerging trends. The investigation checked the general state of tea pigments research from a broad overview viewpoint in order to provide reference for the influence of tea pigments on human health.

2 Materials and methods

2.1 Search strategy and data collection

At first, data from Web of Science was gathered. The Web of Science database was commonly utilized in bibliometrics research, the study searched WoS from 2002 to 2022 to collect data comprehensively. The retrieval strategy was as follows: Topics (title, keywords, abstract) = ("theaflavin's effect") AND ("thearubigin's effect") AND ("theabrownin's effect") AND ("the effect of tea pigment"); Category = Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index Science (CPCI-S), Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH), Emerging Sources Citation Index (ESCI), Current Chemical Reactions (CCR-Expanded), Index Copernicus (IC); Document type = article; Language = English. The WoS search results were then filtered to contain peer-reviewed studies.

2.2 Visual analysis and software

CiteSpace V.6.1.R6 software was an interactive visualization application. It integrated bibliometrics, information visualization, and Java data mining algorithms. CiteSpace was created to support researchers by using science maps to spread information, replicating processes.

3 Results

3.1 Output and pattern analysis of publications

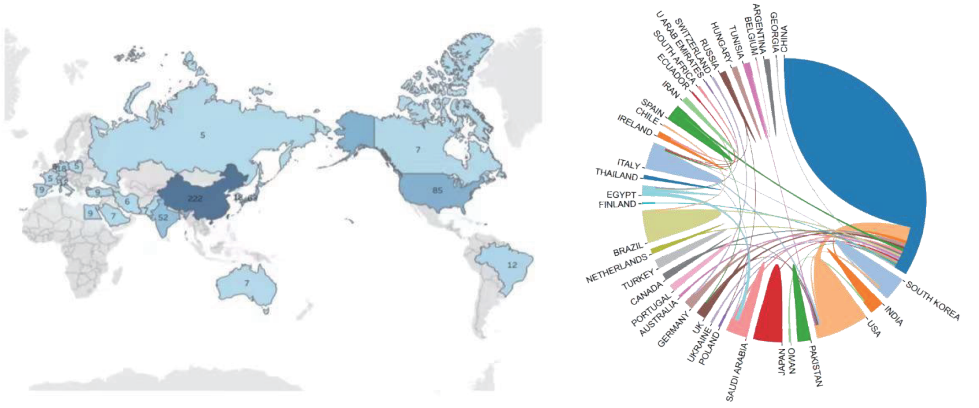
CiteSpace adjusted weight and interference, the number of publications was 520 between 2002 and 2022. The publications' countries had different impacts on the evolution of tea pigments by the visualization study of tea pigments. The most publications were published by the People's Republic of China (222, 42.308%). It clarified the remarkable contribution made by Chinese academics to the study of tea pigments. The next were the USA (85, 16.346%), Japan (63, 12.115%), India (52, 10.000%), Taiwan (23, 4.423%), and Germany (18, 3.462%), Brazil (12, 2.287%), England (12, 2.287%), Italy (12, 2.287%), Egypt (9, 1.715%), Netherlands (9, 1.715%), Spain (9, 1.715%), Turkey (9, 1.715%) (Fig. 1).

As the perspective of connected institutions (Fig. 2), Zhejiang University has 35 publications, and it represented 6.731% of the all. This was followed by the Chinese Academy of Agricultural Sciences (4.615%), Ministry of Agriculture and Rural Affairs (3.654%), The

Tea Research Institute (3.654%), Anhui Agricultural University (3.077%), Rutgers State University New Brunswick (3.077%), Yunnan Agricultural University (3.077%), Hunan Agricultural University (2.115%), the Council of Scientific and Industrial Research (1.923%), Kyushu University (1.923%), National Taiwan University (1.923%), Zhejiang Chinese Medical University (1.923%). Institutions of 3/4 were connected to China among the top 12 publications.

For publication research on tea pigments, the number of publications was below: Food Science and Technology (181), Food Chemistry (122), Biochemistry Molecular Biology (87), Agriculture (68), Pharmacology Pharmacy (67), Nutrition Dietetics (63), Biotechnology Applied Microbiology (33), Plant Sciences (29), Oncology (22), Cell Biology (20), Toxicology (20). According to the findings, chemistry, development, and application were the key areas of the impacts of tea pigments on health. Additionally, others had studied pharmacological characteristics, manufacturing, and molecular structure. The nutritional value of tea pigments had caught greater attention [20].

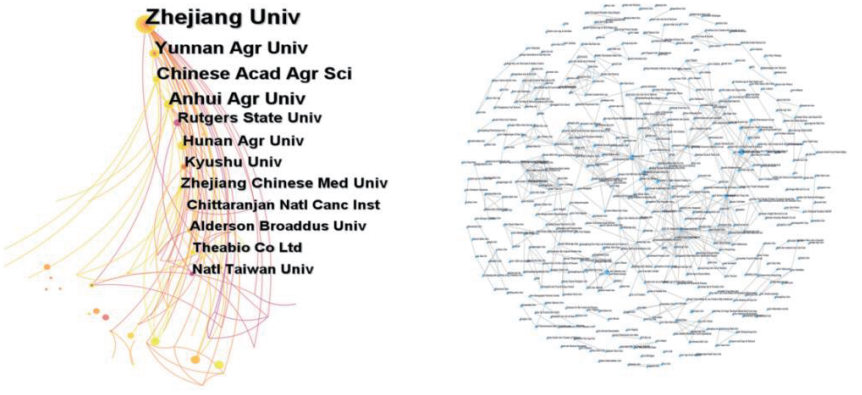
The articles of research were primarily published in Journal of Agricultural and Food Chemistry (35), Food Chemistry (24), Journal of Functional Foods (15), Frontiers in Pharmacology (11), Food & Function (10), Journal of Food Science (9), Bioscience Biotechnology and Biochemistry (8), Journal of the Science of Food and Agriculture (8), Molecules (8), International Journal of Molecular Sciences (7). The most of the top ten journals were from the food field.



(A) (B)

(A) − The top twenty countries by number of publications; (B) − The collaboration network of countries.

Fig. 1 Contributions of the countries



(A) (B)

(A) − The visualization of network and information on the top twelve publishing institutions; (B) − The collaboration network of the publishing institutions.

Fig. 2 Contributions of the institutions

3.2 Analysis of references, co-authors, co-journals

Based on the total number of citations, institutions and journals with high citations were screened out (Fig. 3, Table 1 and Table 2). On the one hand, among the TOP 3 co-authors in the journal, Yang had the largest number of co-citation frequency. Inhibition of 7, 12-dimethylbenz [a] anthracene (DMBA)-induced oral carcinogenesis in hamsters by tea and curcumin of Yang, the citation frequency was 178. Theaflavins in black tea and catechins in green tea were equally effective antioxidants of Leung, the citation frequency was 387. Multitargeted therapy of cancer by green tea polyphenols of Khan, it has a frequency of 291. On the other hand, the study discovered that Journal of Agricultural and Food Chemistry had the largest number of publications and the highest total citation frequency. The second was Food Chemistry and the third was Journal of Biological Chemistry.

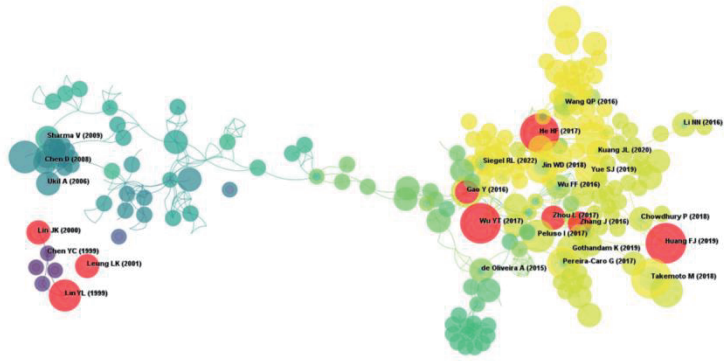


Fig. 3 The visualization of network and information on the references

Table 1 Top 10 authors cited in literatures

Co-authors	Country	The most cited article	Citations	Journal	IF	Year of publication
Yang CS, et al.	China	Inhibition of 7,12-dimethylbenz[a]anthracene (DMBA)-induced oral carcinogenesis in hamsters by tea and curcumin	178	Carcinogenesis	4.74	2002
Leung LK, et al.	China	Theaflavins in black tea and catechins in green tea are equally effective antioxidants	387	Journal of Nutrition	1.14	2001
Khan N, et al.	China	Multitargeted therapy of cancer by green tea polyphenols	291	Cancer Letters	9.76	2008
Tanaka T, et al.	Japan	Alpha-glucosidase inhibitory profile of catechins and theaflavins	258	Journal of Agricultural and Food Chemistry	5.92	2007
Gao Y, et al.	China	Theaflavin-3, 3'-digallate decreases human ovarian carcinoma OVCAR-3 cell-induced angiogenesis via Akt and Notch-1 pathways, not via MAPK pathways	59	International Journal of Oncology	5.88	2016
Sang SM, et al.	USA	The chemistry and biotransformation of tea constituents	330	Pharmacological Research	10.33	2011
Lin JK, et al.	China	Comparative studies on the hypolipidemic and growth suppressive effects of oolong, black, pu-erh, and green tea leaves in rats	209	Journal of Agricultural and Food Chemistry	5.89	2005
Lin YL, et al.	China	Suppression of extracellular signals and cell proliferation by the black tea polyphenol, theaflavin-3,3'-digallate	163	Carcinogenesis	4.74	1999
Wang QP, et al.	China	Effects of enzymatic action on the formation of theabrownin during solid state fermentation of Pu-erh tea	128	Journal of the Science of Food and Agriculture	4.13	2011
Gong JS, et al.	China	Effects of theabrownin from pu-erh tea on the metabolism of serum lipids in rats: Mechanism of action	110	Journal of Food Science	3.69	2006

Table 2 Top 10 journals cited in literatures

Co-journals	IF (2022)	Citation frequency	H-index	Country
Journal of Agricultural and Food Chemistry	5.92	320	262	USA
Food Chemistry	7.86	202	221	England
Journal of Biological Chemistry	5.49	143	477	USA
Journal of Nutrition	4.69	129	240	USA
Nutrition	4.89	122	128	USA
Journal of the Science of Food and Agriculture	4.13	122	121	England
PLOS ONE	3.75	103	268	USA
Proceedings of the National Academy of Sciences of the United States of America	12.78	100	699	USA
Critical Reviews in Food Science and Nutrition	11.21	96	135	USA
Food Research International	7.43	90	134	USA

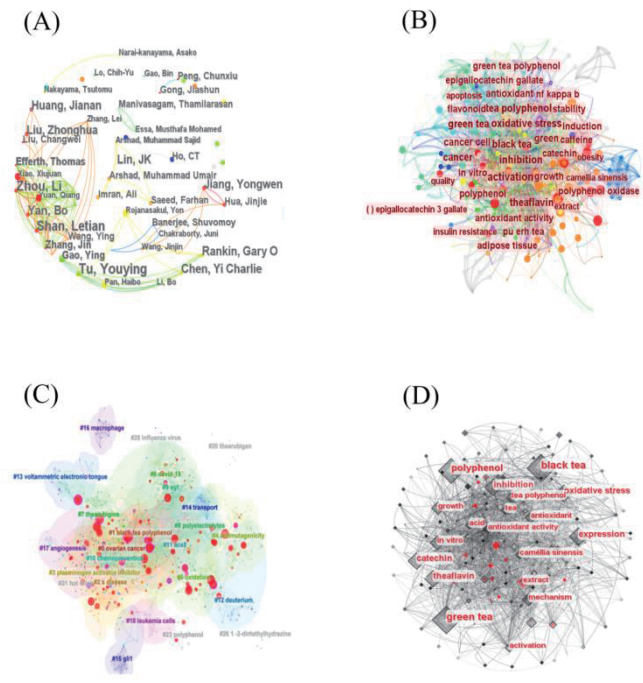
3.3 Authors, keywords and the strongest citation bursts analysis

Based on the analysis of the authors of the published research, it discovered (Fig. 4 A) that Tu YY (10) of Zhejiang University had made great contributions to the functional role of theaflavins; Zhou (9), Shen (9) and Yan (8) of Zhejiang Medical University mainly studied the prevention and treatment of theabrownins in tumor prevention, they had a large number of articles and high citation rate; Rankin (7), Chen (7) of Alderson Broaddus University had many breakthrough results in the inhibition of theaflavins on ovarian cancer cells; Huang (6) of Hunan Agricultural University had unique insights on the regulation of tea pigments on intestinal flora, and Jiang (6) of the Chinese Academy of Agricultural Sciences, Zhang (6) of Zhejiang University of Science and Technology and so on. In addition, Chinese scholars made great contributions to the research of articles on the effects of tea pigments. It was noteworthy that scholars from various units in Zhejiang Province had unique insights in this regard.

Meanwhile, the study conducted keywords clustering and prominence words emergence in the data, and found a total of 302 keywords. The top 10 categories (Fig. 4 B) were 0 # ovarian cancer, 1 # black tea polyphenol, 2 # disease, and 3 # plasminogen activator inhibitor, 4 # antimutagenicity, 5 # oxidation, 6 # COVID-19, 7 # thearubigins, 8 # polyelectroytes, 9 # epidermal growth factor, 10 # chemoprevention.

Strongest citation bursts (Fig. 4 C; Table 3) included mainly black tea, inhibition, tannin, apoptosis and cell. From 2018 to 2020, the study found that tea pigments on the cellular level was more prominent. In 2016, the study on tea pigment in vitro and its cancer pathways attracted more attention. And in 2020, tea pigments had contributed to the study of gut microbiota *in vivo*.

Researchers made the most advancements in green tea and dark tea by the analysis. Alternatively, it had the clear understanding of the precursors of tea pigments generation. The influence of tea pigments on the human was primarily reflected in studies of antioxidant, anti-cancer, hypoglycemic, and other studies. It was noteworthy that a few researchers have studied the antibacterial, antiviral, anti-inflammatory, and antidepressant effects. Moreover, the analysis of tea pigments' composition and the improvement of its extraction had recently taken center stage.



(A) − The collaboration network of the publishing authors; (B) − The collaboration network of the keywords; (C) − Top 28 the cluster mapping with keywords; (D) − The collaboration network of the strongest citation bursts.

Fig. 4 The collaboration network of the publishing authors, keyword visualization of frequency and centrality, strongest citation bursts, and cluster mapping

Table 3 Keywords with the strongest citation bursts of the effect of tea pigments

Keywords	Year	Strength	Begin	End	2002−2022
Black tea	2002	4.58	2002	2009	
Inhibition	2002	3.65	2002	2005	
Tannin	2005	3.06	2005	2011	
Apoptosis	2002	2.7	2008	2011	
Cell	2003	3.65	2010	2013	
Nf kappa b	2002	2.78	2010	2011	
Signaling pathway	2016	3.42	2016	2017	
Ovarian cancer	2016	2.65	2016	2019	
In vivo	2016	2.56	2016	2021	
Extract	2004	2.58	2018	2022	
Inflammation	2019	3.49	2019	2022	
Oxidation	2020	3.53	2020	2022	
Gut Microbiota	2020	3.14	2020	2022	
Metabolism	2015	2.74	2020	2022	

Note: Begin − Start time of keyword burst; End − End time of keyword burst; Legend: One year of no publication; One year; Burst year.

4 Discussion

Tea was a popular beverage all around the world. Tea Pigments, its compositions and identifications had all been the subject of extensive research due to concerns about the nutritional value and safety of tea [20]. Tea pigments had a significant impact on human health, more focuses had been placed on its physiological function.

The data on the effect of tea pigments were evaluated both quantitatively and qualitatively by using bibliometrics. There were 520 publications published between 2002 and 2022, with China, the United States, and India being the leader in term of countries. The majority of researchers in these nations were related to one another, regardless of national and regional influences. Chinese scholars dominated the effects of tea pigments on humans. Most of them had studied the antioxidant and anticancer effects of tea pigments, especially theaflavins. The publication trend was discovered to develop quickly after 2020 based on the tendency of the number of researches. The reason was that tea pigments play a significant role in the prevention and control of COVID-19 [21]. Thereby it absorbed the attention of researchers. Most of the researches conducted in prestigious journals such as Journal of Agricultural and Food Chemistry, Food Chemistry, Journal of Functional Foods, Frontiers in Pharmacology, Food Function, Journal of Food Science.

The use of keywords had revealed changes in tea pigment-related research over the past two decades. The strongest citation bursts had identified the research hotspots in this field. The study analyzed keywords and strongest citation bursts, the progress mainly focuses on antioxidant, hypoglycemic, separation and purification in recent years. It had been found that tea pigments was mainly present in black tea. Researchers had shown great interest in the antimutagenicity resistance, anticancer activity, and other health benefits of tea pigments. Tea pigments had been shown to play a significant role in the treatment of hypertension, reducing blood sugar levels, and preventing cancer and atherosclerosis. After conducting investigations on its antioxidant effects both *in vitro* and *in vivo*, it had been concluded that theaflavins and theaflavins had strong potential to act as antioxidants and counter the threat of lipid peroxidation in both scenarios. Additionally, tea pigment's antiviral activity had become a hot topic among researchers in recent years. Previous pharmacological studies have shown that theaflavins exhibit good antiviral activity against SARS-CoV-2 [22]. And while earlier research mainly focused on theaflavins, more and more scholars were now studying thearubigins and theabrownins.

Tea pigment has many health effects, but it also has many limitations. It was mostly evident in the following areas.

(1) The structural formulas of tea pigments were closely related to the target of disease treatment. Moreover, thearubigins and theabrownins had complex structures. There was still no conclusive answer to this question. Researchers would define their macromolecular structural formula, and would establish the groundwork for further application about the thorough investigation of therapeutic target.

(2) The anti-oxidation and anti-obesity effects of tea pigments were prominent. In contrast, they had done less research on calming, anti-depressive, and anti-epilepsy effects. Tea pigments stilled have a lot of potential, and investigations had not been widely reported in papers recently.

(3) Tea pigments applied sparingly and had little outcomes. The state and the rest of the world had shown a strong commitment to research and development, researchers should exploit potentialities detail to further develop drugs and health products.

5 Future directions

Regarding the limitations of tea pigments research, some suggestions are put forward as follows. In future studies, researchers should utilize modern analytical instruments to better understand the structure of thearubigins and theabrownins. Additionally, researchers should consider different possibilities and avoid repeating previous studies, when studying the pharmacological effects of tea

pigments. In China, theaflavins are considered food additives and can be added to food. It had broad application prospects in the food industry due to the variety of pharmacological effects. Furthermore, the development of new food delivery systems had become a popular research topic in recent years. Therefore, studying the combination of theaflavins with new delivery materials is a worthy research area.

6 Conclusion

The analysis showed that China was the biggest contributor among the world in the development and utilization of tea pigments. Additionally, most of the relevant studies were published in the journal of food field. They focused on anticancer, antioxidant, lipid lowering, hypoglycemic, *in vivo* and *in vitro* studies. Future research might continue to the differences in extract, gut microbiota and metabolism. Importantly, the bibliometrics identified research bases, current hotspots, and future trends in tea pigments area. The scientists would further be able to decide the direction of their research based on the emerging trends. In contrast, the use of bibliometrics analysis results had some limitations. The literature searching was not comprehensive enough, and the prediction results were limited to the literature contained in the WoS.

Acknowledgements

This project is funded by Livelihood Plan Project of Department of Science and Technology of Liaoning Province (2021JH2/10300069, 2019-ZD-0845); Department of Education of Liaoning Province (LJKZ0918); and National College Students' Innovation and Entrepreneurship Training Program (202210163013).

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