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Knowledge mapping of research on spectral technology in the fruit field using CiteSpace (1981-2021)

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Abstract

To explore the development process and trends of spectral technology in the fruit field, the quantitative and visual analysis of 849 documents from China National Knowledge Infrastructure (CNKI) and 4791 documents from Web of Science (WoS) in the fruit field was carried out in terms of the annual publication, authors and institutions, and keywords based on CiteSpace. According to the results of visual analysis and some important documents, the main research hotspots of spectral technology in the fruit field were discussed and summarized. The research based on the bibliometrics visualization tool CiteSpace expounds on the research of spectrum in the fruit field from a macroscopic and microscopic perspective. The document information is comprehensive and the results are intuitive, which can help researchers to understand the research progress, academic exchange, and grasp of the research in this field.

Keywords: spectrum; fruits; CiteSpace; visual analysis.

Practical Application: Knowledge mapping of research on spectral technology in the fruit field.

1 Introduction

In 1666, Newton decomposed the sunlight into red, orange, yellow, green, blue, indigo, and violet spectra through a glass prism, which opened the prelude of spectral research. In 1802, Wallaston discovered the existence of spectral lines. In 1859, Bunsen and Kirchhoff made the first prism spectrometer, which was mainly used to observe the flame reaction, and initiated the discipline of "spectral chemical analysis". Since then, spectral research has been rapidly developed and applied in many fields. With the continuous development of spectrum technology, visible spectrum, near-infrared spectrum, Raman spectrum and hyperspectral spectrum have been found one after another, and various detection models have been gradually established in combination with relevant algorithms. Spectral detection equipment with rich functions has been developed, which plays an important role in quality detection, variety identification and other fields (Fang et al., 2021; Liu et al., 2021; Su & Xue, 2021). Up to now, spectral technology has become one of the most important analytical methods in modern analytical chemistry. The research in the field of fruit has also made great progress, especially in fruit variety identification (Gaikwad & Tidke, 2022), sugar and acidity detection (Li et al., 2022), external and internal defect detection (Munera et al., 2021; Tian et al., 2022a). These studies are helpful to realize the rapid and accurate detection of fruits, which is of great significance to the improvement of fruit quality and the income of fruit farmers. With the development of computer technology, spectral detection technology has been mature, which is of great significance to countries with high fruit production, such as China, the United States, India and Brazil.

Among the previous research results of spectroscopy in the fruit field, the representative reviews are mainly based on the induction and summary of relevant literature, combing the research results and progress, and the research direction is single, only describing and revealing some laws and conclusions qualitatively. For example, some scholars pay attention to the application of hyperspectral imaging technology in fruit quality detection (Zhang et al., 2021), some scholars pay attention to the detection research of spectrum in fruit diseases and insect pests (El-Ghany et al., 2020; Ahmad et al., 2018), and some scholars pay attention to the detection research of spectrum on the external and internal quality of fruit (Sun et al., 2018). It cannot comprehensively and objectively reflect the whole picture of spectrum research in the fruit field, nor can it systematically display its development process. Although the existing reviews are very valuable for relevant scholars to understand part of the research in this field, these documents mainly rely on qualitative methods to describe the contents and topics of a limited number of documents. As a research method in scientific metrology, information metrology and other fields, the scientific knowledge atlas can reveal the knowledge source, development law and research characteristics of specific research fields, and can be quantitatively analyzed in visual form, which is more intuitive and reliable (Afuye et al., 2022; Xue et al., 2021; Yuan & Sun, 2022a). Based on the scientific knowledge map tool software CiteSpace, we analyzed the research documents on spectral technology in the fruit field, to make an objective sorting and evaluation of the development of spectral research, and provided

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a reference for the dynamic and development trend of spectral research in the fruit field.

2 Data source and research method

2.1 Data source

In this article, CNKI database and WoS database were used as data sources. Among them, we input “spectrum” + “fruit” search under the theme search setting in CNKI. The search deadline was December 31, 2021, and the cover introduction, journal message, seminar meeting and other documents that did not meet the requirements were excluded. Finally, 849 valid documents were obtained. All downloaded documents were exported in the format of “refworks”. The “WoS core collection retrieval” was selected for the retrieval of the WoS database, and the topics were set as “spectrum” and “fruits”. The retrieved results were further filtered by language (English) and literature type (review and papers). 4971 documents were finally obtained based on the CiteSpace data deduplication function.

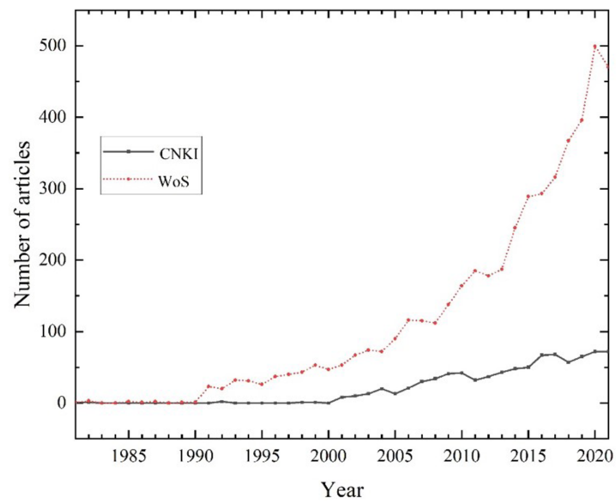


Figure 1. Statistics of documents issued.

2.2 Research methods

This article was mainly based on the CiteSpace software to comprehensively analyze the research of spectral technology in the fruit field. CiteSpace is a tool software for implementing bibliometrics, which needs to run in the Java environment (Ma et al., 2022). It can display the relevant information in a large number of documents (such as the publication and cooperation of authors and institutions, keyword co-occurrence, national cooperation, etc.) in a visual form, and trace the development trend of a research field to the map, which is more intuitive and clear. It is convenient for researchers to find effective information including the research development context, hotspots and trends of specific research fields, and help to further interpret and analyze the research status and dynamics of this field (Chu et al., 2022; Zong et al., 2022).

3 Research results and analysis

3.1 Document issuance analysis

The number of documents issued is an important indicator to evaluate the development of this field (Yuan & Sun, 2022b). Based on the spectrum calculated by CiteSpace, a line graph was drawn for analysis of the number of documents in the fruit research field. As shown in Figure 1, the number of documents published in WoS experienced a slow growth stage (before 2000), a stable growth stage (2001-2011) and a significant growth stage (2012-2021), while the number of documents published in CNKI increased slowly. In 2020, the number of documents published by both of them will reach the maximum (72 for CNKI and 499 for WoS). The above trends in the number of documents reflected that many scholars paid more and more attention to the research of spectroscopy in the fruit field.

3.2 Main research forces analysis

The number of documents included in the WoS database reflects a country’s scientific research strength in a certain research field to a certain extent (Che et al., 2022; Guo et al., 2022). Based on the country cooperation analysis function of CiteSpace, 4,791 search results were analyzed for the number of documents published in different countries. The node size, the connection between nodes, and the width of the connection represented the number of documents published by each country, and the cooperative relationship and cooperation intensity between the publishing countries. In addition, in the visualization graph, the betweenness centrality value represented the influence, and the outer edge of the node whose betweenness centrality value was higher than 0.1 was displayed in purple. It should be noted that since the authors of a document may involve multiple countries, the sum of the total number of published documents in each country was greater than the total number of documents retrieved. Based on the CiteSpace visual analysis, the cooperation situation of the countries that issued the documents was analyzed (Figure 2, Table 1). In the cooperation network, N = 205, E = 666, Density = 0.0319, and the cooperation between countries in the fruit research field based on spectral technology was close. The United States, in particular, had established cooperative relations with many countries in this field. China had close cooperative relations with the United States and the United Kingdom, and had the largest node, indicating that China published the most documents, and Chinese scholars paid more attention to the research in this field, which made great contributions internationally. Combined with the specific information listed in Table 1 for further analysis: China, the United States, India, Spain, and Germany were the main publishing countries, and the proportion of published documents was 20.14%, 11.46%, 4.96%, 4.57%, and 4.39%, respectively. The countries whose betweenness centrality value was higher than 0.1 were the United States, Germany, France, Spain, Italy and the United Kingdom from high to low, indicating that these countries had high-quality documents, and had greater contribution and influence to dissemination. Although China ranked first in the number of published documents, its intermediary centrality value was only 0.06, which was significantly lower than that of the above-mentioned countries, indicating that China’s research depth and document quality in this field

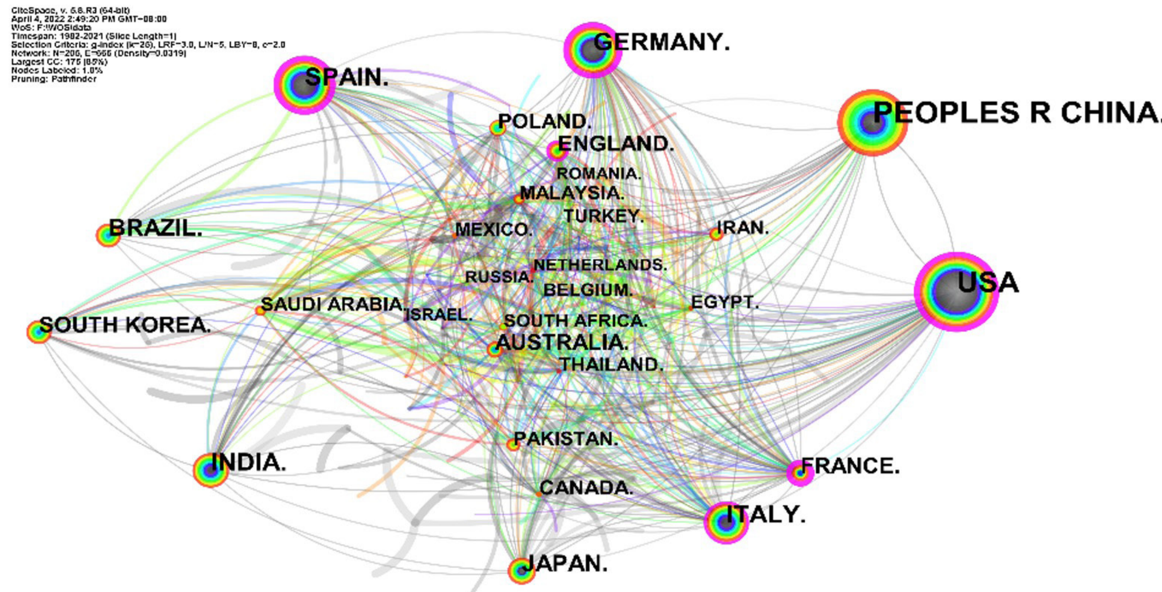
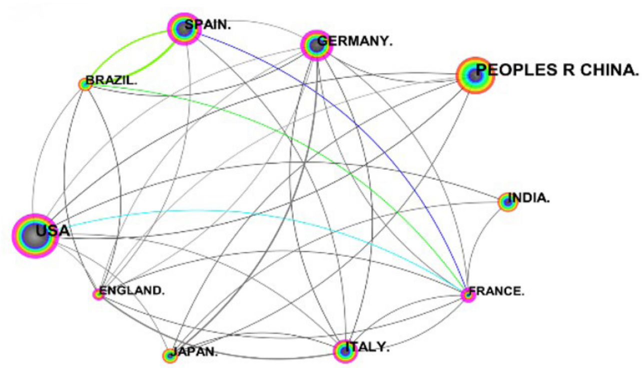


Figure 2. National cooperative relationship network.

Table 1. Top 10 high-yield countries in Fruit Research Based on spectral technology (1982-2021).

Rank	Country	Centrality	Count	Proportion	Top 10 national cooperation networks
1	China	0.06	1242	20.14%	
2	USA	0.33	707	11.46%	
3	India	0.09	306	4.96%	
4	Spain	0.21	282	4.57%	
5	Germany	0.24	271	4.39%	
6	Italy	0.16	249	4.04%	
7	Japan	0.06	210	3.40%	
8	Brazil	0.02	196	3.18%	
9	France	0.23	161	2.61%	
10	England	0.14	150	2.43%	

needed to be strengthened. In addition, most of these countries with high publication volume and high intermediary centrality were developed countries, which showed that the improvement of scientific research level was inseparable from strong financial support and was closely related to national economic strength.

3.3 Author cooperation network analysis

The author cooperation network can reflect the core authors in the research field and the cooperative relationship between them. Based on the author analysis function of CiteSpace, the author cooperation network of spectral research documents in the fruit field was obtained (Figure 3). The node size, the connecting line and the width of the lines represented the number of published documents, the cooperation relationship between the authors and the relationship strength. In CNKI database, there were 448 cooperative links among 554 authors, with a density of only 0.0032. The network was characterized by scattered points, sparse lines and uneven distribution. The top 5 authors in the number of documents were Jialin Xi, Yande Liu, Yingbin Ying, Meng Wang, Linxia Wu, etc. Jialin Xi from China agricultural product quality and safety risk assessment experimental station (Beijing) was the scholar with the largest number of documents in this research field, and had formed a research group with it as the core, gathering Linxia Wu, Meng Wang and Ling Li. Throughout the whole atlas, many document authors had formed about 5 research groups, including Jialin Xi research group, Yande Liu research group, Yingbin Ying research group, Xiaping Fu research group and Xudong Sun research group.

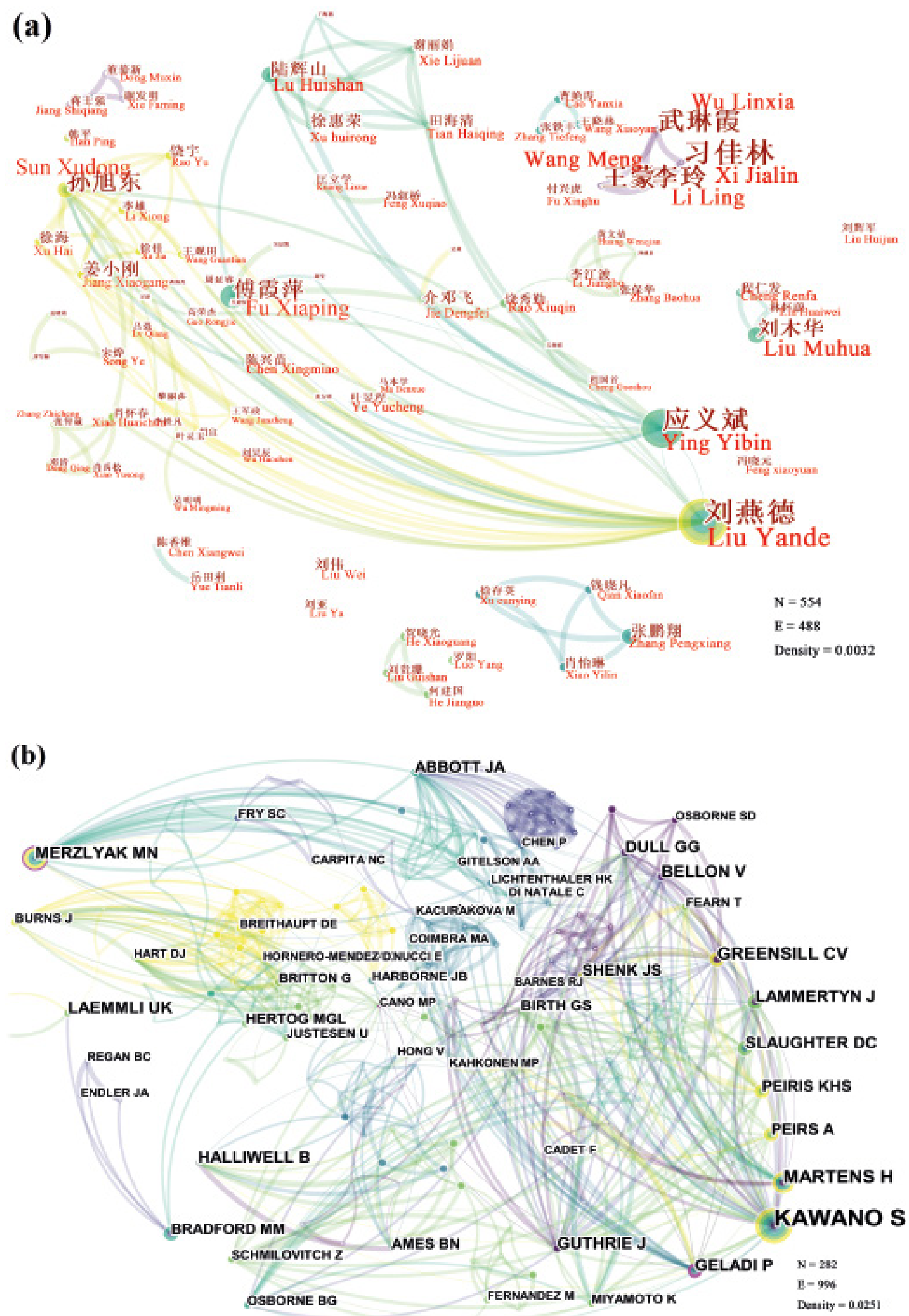


Figure 3. Author cooperation network map. (a) CNKI database. (b) WoS database.

In the WoS database, 282 authors had 996 cooperative links, with a density of 0.0251. There were many dense links among various research groups, forming many research groups of different sizes. As shown in Figure 3, a stable cooperative network had been formed in this field, which was conducive to the horizontal and vertical development of the research content to a certain extent. Kawano S from Kagoshima University had the largest number of documents and formed a stable team. In addition, MARTENS H team from Kassel University, GREENSILL CV team from Queensland University and GELADI P team from Swedish University of Agricultural Sciences followed closely (Table 2).

3.4 Keyword co-occurrence network analysis

Keywords are the condensation of the content of the documents. Keyword co-occurrence is to analyze the degree of keyword association in several documents and then get the research hotspots and evolution trends in the research field

(Che et al., 2022). The co-occurrence network of CNKI and WoS keywords was obtained based on CiteSpace (Figure 4), and the statistical analysis of the related information of the top 20 keywords in CNKI and WoS (Table 3 and Table 4) was conducted. Each node in the network represented a keyword, and the size of the node font, the size of the node ring, and the connection between nodes represented the frequency of keywords, the number of citations of the documents where the keyword was located, and the degree of connection between each keyword. As shown in Table 3 and Table 4, the network map density of CNKI database was 0.0058, which had 588 network nodes and 995 network connections.

'Nondestructive testing' had the highest frequency, which began to appear in 1981. And it appeared in 207 documents, accounting for 24.38% of the total. In 2021, the largest number

Table 2. Analysis of core authors of spectra in CNKI and WoS databases in the field of fruit.

CNKI database				WoS database			
Author	Institution	Count	Year	Author	Institution	Count	Year
Jialin Xi	Agricultural product quality and safety risk assessment experimental station	39	1981	KAWANO S	Kagoshima University	26	2000
Yande Liu	East China Jiaotong University	36	2003	MARTENS H	Kassel University	11	2000
Yibin Ying	Zhejiang University	29	2002	GREENSILL CV	Central Queensland University	10	2000
Meng Wang	Agricultural product quality and safety risk assessment experimental station	26	1981	GELADI P	Swedish University of Agricultural Sciences	9	2000
Linxia Wu	Agricultural product quality and safety risk assessment experimental station	26	1981	LAMMERTYN J	Katholieke Universiteit Leuven	9	2000

Table 3. Top 20 keywords CNKI database.

No.	Keyword	Frequency	Centrality	Year	No.	Keyword	Frequency	Centrality	Year
1	nondestructive testing	207	0.16	1981	11	Hyperspectral	18	0.01	2016
2	NIRS	97	0.13	2004	12	chemical composition	18	0.07	2003
3	hyperspectral imaging	36	0.04	2012	13	machine vision	16	0.02	2011
4	soluble solids	35	0.05	2007	14	agriculture products	15	0.01	1994
5	pesticide residues	33	0.19	2005	15	spectral analysis	15	0.04	2002
6	research progress	33	0.00	1981	16	PCA	13	0.03	2008
7	internal quality	31	0.02	2003	17	SSC	12	0.01	2007
8	VIS/NIR spectrum	27	0.04	2006	18	online detection	11	0.02	2010
9	Hyperspectral imaging technology	26	0.02	2013	19	quality detection	11	0.03	2002
10	near-infrared	26	0.13	2007	20	Atomic absorption spectrometry	10	0.09	1992

NIRS = near infrared spectroscopy; VIS/NIR = Visible Spectrum/Near Infrared Spectrum; PCA = principal component analysis; SSC = soluble solid content.

Table 4. Top 20 high-frequency keywords in WoS database.

No.	Keyword	Frequency	Centrality	Year	No.	Keyword	Frequency	Centrality	Year
1	fruit	1204	0.43	1991	11	vegetable	177	0.07	1991
2	identification	352	0.08	1991	12	prediction	174	0.01	2006
3	quality	348	0.03	1992	13	polysaccharide	163	0.03	1993
4	antioxidant	281	0.06	1998	14	Extraction	160	0.03	1996
5	spectroscopy	270	0.18	1991	15	NIR	159	0.00	2006
6	antioxidant activity	229	0.02	2006	16	leave	156	0.06	1995
7	apple	213	0.14	1991	17	food	155	0.10	1991
8	spectra	190	0.13	1991	18	acid	154	0.04	1991
9	extract	187	0.03	2002	19	flavonoid	149	0.05	1997
10	plant	183	0.33	1991	20	constitute	148	0.02	1992

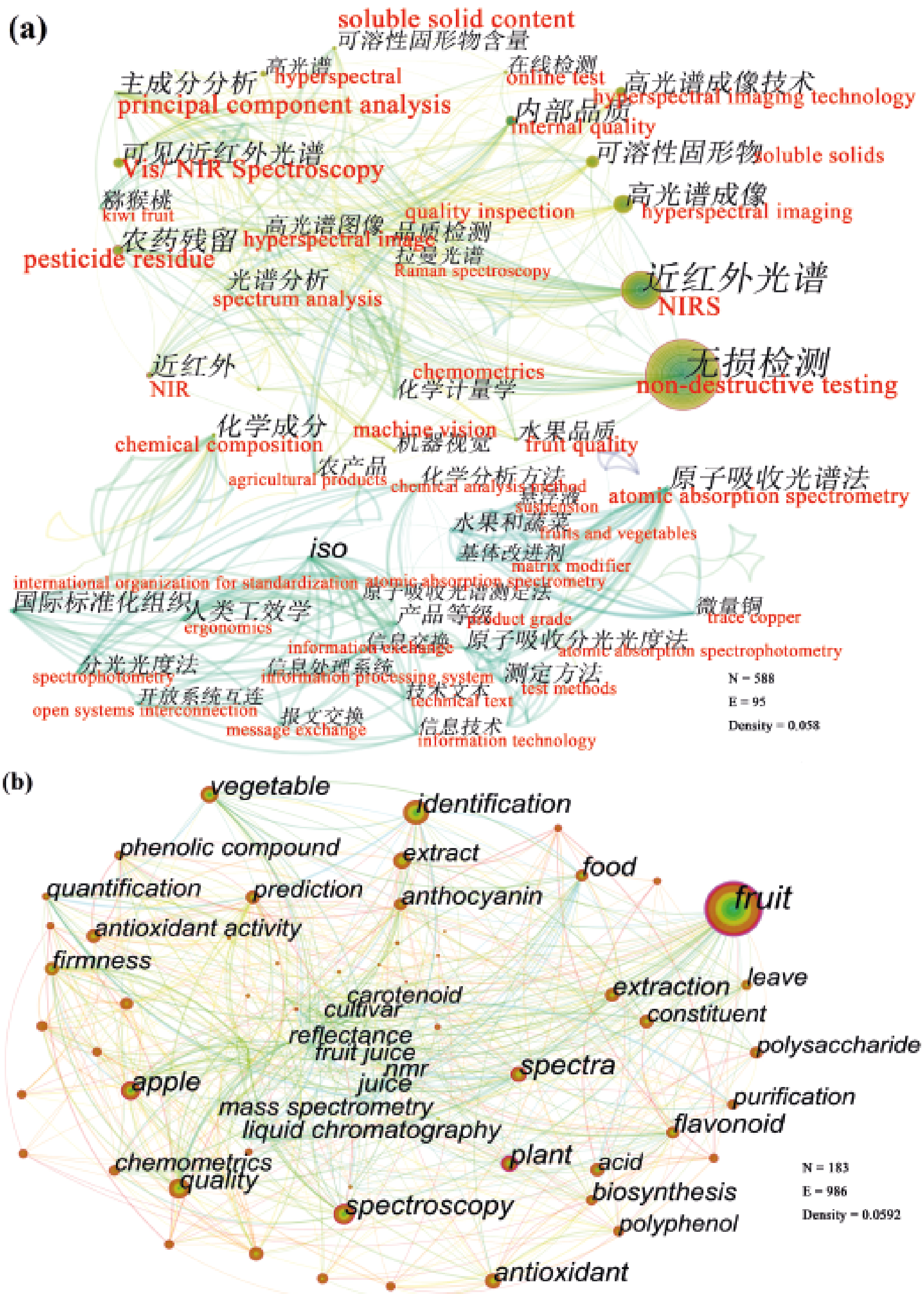


Figure 4. Keyword co-occurrence network. (a) CNKI database. (b) WoS database.

of documents was 22. The frequency of 'NIRS' ranked second. It first appeared in 2004, accounting for 11.43% of the total number of documents. The keywords such as 'hyperspectral imaging' (36 times), 'soluble solids' (35 times) and 'pesticide residues' (33 times) followed closely. Based on the analysis of relevant documents, it was concluded that the research of spectroscopy in the fruit field mainly focused on the selection of spectral species, the fruit quality evaluation (sugar content, pesticide residue, etc.), spectral processing algorithm, etc. The network map density of the WoS database was 0.0592, which had 183 network nodes and 986 network connections, indicating that the keywords were closely related. 'Fruit' appeared the most frequently, starting in 1991. And it appeared in 1204 documents, accounting for 25.14% of the total. The frequency of 'identification' ranked second, which first appeared in 1991. And it appeared in 352 documents, accounting for 7.35% of the total. Followed by keywords such as quality (348 times), antioxidant (281 times) and spectroscope (270 times), mainly involving the evaluation of fruit quality by spectroscopy. It can be seen that the detection and evaluation of the internal and external quality of fruits (such as soluble solids, acidity, pesticide residues, etc.) using different spectra (near-infrared spectroscopy, hyperspectral, etc.) was a research hotspot in this field.

4 Discussion

According to the existing documents on the research of spectra in the fruits field, the research characteristics involved in the documents in CNKI and WoS were the same, focusing on the research of detection technology related to fruit quality, mainly focusing on the selection of spectral species and modeling methods to detect the relevant quality of fruits (Malvandi et al., 2022; Raj et al., 2022; Tian et al., 2022b). According to the classification of specific applications, the research of spectra in fruits can be roughly divided into qualitative detection and quantitative detection (Table 5 and Table 6). Among them, qualitative detection includes pathogen detection, origin traceability, variety identification, etc. quantitative detection includes acidity detection, brittleness and hardness detection, shelf life detection, etc.

In addition, the maturity of theory and technology needs to be transformed into pleasant equipment before it can be implemented. With the development and maturity of spectrum

Table 5. Qualitative study on fruit detection by spectrum.

Research content	Significance	Example
Pathogen detection	The disease is one of the serious threats to the quality of fruit, which directly affects the grading of fruit. It is a powerful measure to prevent disease and remove disease fruit in time.	Qin et al. (2021) used visible and near/infrared spectral analysis technology to detect and study apple mold heart disease. Especially, the discriminative effect of the four kinds of apples in the online conveying posture (vertical handle up, vertical handle down, horizontal handle facing the conveying direction, and horizontal handle vertical conveying direction) was optimized and analyzed. The results show that PLS-DA can be used as an effective method to identify mold heart disease in apples, and placing the handle vertically can be used as an effective posture for online detection.
Origin traceability	The perfect traceability system of agricultural products can greatly guarantee the quality of fruits and promote the sales of fruits.	Lu et al. (2021) proposed a technology that combines long-term and short-term memory (LSTM) network and Raman spectroscopy technology to realize rapid and non-destructive identification of cherries from different regions. Taking cherries from the United States, Shandong and Sichuan as research samples, the spectral data of cherries from different places of origin were obtained by Raman spectrometer, and the discrimination model was built based on LSTM network, which provided a new idea for the origin tracing of cherries.
Variety identification	There are many varieties of the same kind of fruit, with different colors and tastes. Species identification based on spectral technology can easily provide raw materials for food production	Rong et al. (2020) constructed a one-dimensional convolutional neural network and established a visible/near-infrared spectrum database containing five kinds of peaches. This method can realize the identification of peach varieties, with an accuracy of 94.4% in the test data set.

Table 6. Quantitative study on fruit detection by spectrum.

Research content	Significance	Example
Sugar or acidity detection	Taste is one of the bases for people to choose fruit, thus sugar content and acidity are important factors that affect the taste. In recent years, it has been used as an important reference for fruit taste.	Wu et al. (2021) established a partial least squares regression (PLSR) model using a self-made NIRS detector and an improved variable selection algorithm to detect the SSC content of pears. It shows that the prediction model based on GA-BOSS selection variable and GA-VACAA selection variable is the best.
Brittle or hardness testing	Fruit texture mainly includes brittleness, hardness, etc., which reflect the physical properties and organizational structure of fruits and affect the taste of eating. Traditional fruit texture testing methods use destructive testing methods such as pressure hardness testers or texture analyzers, which are inefficient and damage the commodity value of apples after testing.	Sun et al. (2021) proposed a rapid nondestructive testing method for fig hardness based on VIS/NIR. The results show that using VIS/NIR diffuse reflectance spectroscopy combined with sample set partition based on joint X-Y distance (SPXY), RF and PLS algorithms can detect the hardness of figs without destroying them.
Shelf life testing	Shelf life is an important index to measure fruit life. Accurate judgment of the shelf life can better grasp the storage life and quality information of fruits, and provide an important reference for sales planning.	Li et al. (2019) took pears as the research object and used hyperspectral imaging technology combined with partial least squares discriminant (PLS) to determine the shelf life of pears. Through PCA compression on the original images of samples with different shelf-life, the weight coefficient data of three different shelf-life are obtained. The discrimination model is established with the average gray value of the characteristic image as the independent variable and the shelf-life as the dependent variable. The results showed that the method was effective in the determination of pear shelf life.
External damage detection	The skin of fruits is bruised or broken due to bumping and extrusion during picking and handling, and some minor damages are difficult to identify with the naked eye, resulting in discoloration and decay. Early detection and elimination are the main measures at present.	Chen et al. (2018) used Raman spectroscopy combined with chemometrics to quickly identify early minor damage to apples. The original Raman spectra were smoothed and denoised by Savitzky-Golay (SG) convolution, baseline corrected by adaptive iterative reweighted penalized least squares (airPLS) algorithm, and the classification discriminant model was established by nonlinear support vector machine (SVM) regression algorithm, with the 97.8% classification accuracy rate.

GA-BOSS = genetic algorithm- bootstrapping soft shrinkage; GA-VACAA = genetic algorithm- variable stability and cluster analysis algorithm; VIS/NIR = Visible Spectrum/Near Infrared Spectrum; SPXY = sample set partitioning based on joint x-y distance; RF = random forest; PCA = principal component analysis.

detection technology in the fruit field, many researchers have gradually developed various fruit quality detection equipment and put them into production, bringing many conveniences to fruit farmers and other related workers. Fan et al. (2021) developed a hand-held fruit sugar detection device based on the visible near/infrared spectrum analysis technology and used it for on-site real-time analysis of fruit sugar. The hardware system mainly includes a micro spectrometer, halogen lamp, OLED display screen, single chip microcomputer and drive circuit. The results showed that the device could meet the effective detection of the sugar content of apples and peach. With the help of the model transfer algorithm, the sharing and effective transfer of models among different devices were realized.

5 Conclusion

In this article, we took CNKI database and WoS database as data sources, and analyzed the annual publication volume, journals, authors, national cooperation, and research hotspots involved in the development of spectroscopy in the field of fruit based on CiteSpace. Combined with the results of the document visualization analysis and the corresponding key documents, a discussion was carried out, which showed that: (1) The research on spectroscopy in the fruit field had been paid more and more attention, and the number of publications of both WoS and CNKI was increasing. (2) The cooperation between countries in this field was close. Among them, the United States had established cooperative relations with many countries, and China had extensive cooperation with the United States and Japan. (3) China had the largest number of documents in this field, which indicated that China had done more work in this field, but the value of intermediary centrality was low, indicating that the depth of research and the quality of documents needed to be strengthened. The United States, Germany and other intermediary centrality values were large, indicating that they had great influence. (4) The use of different spectral types (NIRS, hyperspectral, etc.) for non-destructive testing and evaluation of internal and external fruit quality(such as soluble solids, acidity, pesticide residues, etc.) had become research hotspots in recent years.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest

The authors declare no conflict of interest.

Availability of data and material

The data used in this article all came from the WoS and CNKI.

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