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CROP PRODUCTION

Analysis of collaboration networks for scientific and technological research on passion Fruit

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ABSTRACT: Scientific research on passion fruit has been conducted in several institutions worldwide, and it is of interest to the productive sector, the scientific community, and science and technology managers to learn about current scientific advances and opportunities through metric studies of bibliographic information. A survey of publications indexed in the Web of Science and the Agricultural Research Database—BDPA, in European Patent Office – Espacenet, and Embrapa's technologies and projects were used as indicators to characterize research networks. This study analyzed the co-authorship and co-citation network of scientific production, the strength of connections among institutions, and a map of co-occurrence of keywords from 2001 to 2020. Brazil, the United States, Colombia, and France had the largest co-authorship networks for Passifloraceae. Brazilian institutions that are in a prominent position in the analysis of co-authorship networks and that produced the largest number of publications were Embrapa, University of São Paulo (USP), and State University of Campinas (Unicamp). The main themes studied were adsorption, antioxidant, clarification, evolution, flavonoid, flowering, growth, and somatic embryogenesis. Patents related to the use of passifloras were highest between 2015 and 2017 and were mainly focused on the production of food, beverages, cosmetics, and medicines. Brazil has relevant bibliographic production and technological development regarding passion fruit for the academic community and rural producers. These results integrated aspects of scientific activity that can help explore new research directions and explain the use and circulation of scientific production.
Key words: *Passiflora* L., bibliometrics, technological development, scientometrics.

Análise das redes de colaboração em ações de pesquisa científica e tecnológica sobre maracujá

RESUMO: As pesquisas sobre o maracujá são realizadas em diversas instituições ao redor do mundo e é de interesse do setor produtivo, da comunidade científica e dos gestores de ciência e tecnologia, conhecer a dinâmica da ciência por meio de estudos métricos das informações bibliográficas. O levantamento das publicações indexadas na *Web of Science* e na Base de Dados de Pesquisa Agropecuária da Embrapa (BDPA), os registros no Escritório Europeu de Patentes – *Espacenet*, as tecnologias e os projetos da Embrapa foram utilizados como indicadores para caracterizar as redes de pesquisa sobre os maracujás. Este estudo analisou a rede de coautoria e cocitação da produção científica, a força de conexão entre as instituições e o mapa de coocorrência de palavras-chave entre 2001 e 2020. Brasil, Estados Unidos, Colômbia e França tiveram as maiores redes de coautoria em *Passifloraceaes*. As instituições brasileiras em posição de destaque na análise das redes de coautoria e que produziram o maior número de publicações foram Embrapa, USP e Unicamp. Os principais temas estudados foram adsorção, antioxidante, clarificação, evolução, flavonoide, floração, crescimento e embriogênese somática. As patentes relacionadas ao uso do maracujá tiveram destaque entre 2015 e 2017 com foco na produção de alimentos, bebidas, cosméticos e medicamentos. O Brasil possui relevante produção bibliográfica e desenvolvimento tecnológico sobre o maracujá tanto para a comunidade acadêmica quanto para os produtores rurais. Estes resultados integram aspectos da atividade científica que poderão prospectar novos direcionamentos de pesquisa e tornar conhecidos o uso e a circulação da produção científica.
Palavras-chave: *Passiflora* L., bibliometria, desenvolvimento tecnológico, cientometria.

INTRODUCTION

The importance of passion fruit (Passiflora L.) in agribusiness is growing worldwide. Passion fruit is a plant native to Brazil and is generally marketed for fresh consumption or the pulp industry. Premium-quality fruits have a relatively high market value (GOMES et al. 2006, FALEIRO, 2022). Genetic improvement and passion fruit-related technologies developed in recent decades have contributed to the understanding and expansion of its cultivation in Brazil and worldwide (FALEIRO et al. 2020). According to data from the Food and Agricultural Organization (FAO) of the United Nations (2018), world passion fruit production was estimated at 1.5 million tons/year, approximately 65% of which was grown in Brazil. In 2020, Brazilian production reached 690,000 tons (IBGE, 2021). Colombia, Indonesia, Peru, Ecuador, Australia, and New Zealand are also important producers and exporters of the fruit.

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Scientific research on passion fruit has been conducted in several institutions worldwide. Parameters such as co-citation analysis, co-authorship, and number of patents demonstrate links and a scientific collaboration network through the link strengths of existing parameters and relationships (ZUPIC & CATER, 2015). These variables affect the complementarity among innovation activities from internal and external perspectives and are used as scientific and technological policies by several governments to encourage the formation of new scientific networks and links among countries, institutions, and researchers as well as to find out the impacts of the main programs in these organizations (KIDD, 1990).

CASSIMAN & VEUGELERS (2006) identified the dependence on basic research and importance of universities and research institutions as sources of information for the innovation process. Bibliometric historical analyses portray advances in research and provide a perspective of science networks. Therefore, these analyses are considered important tools for the scientific community in different thematic areas and serve as an introduction for those interested in knowing the trends, histories, subjects, and geographical distribution of specific themes (MACIAS-CHAPULA, 1998, CARUSO & TIGRE, 2004). The technological prospection of patents in international databases is useful for the development of new technologies. It includes recent performance analyses of the sector, the perception regarding companies' investment capacity, and the identification of technological trajectories that help clarify important market issues to guide new opportunities for research projects and prospect the continuity of growth (CARUSO & TIGRE, 2004).

This research analyzed scientometric indicators on the theme of Passiflora, based on the parameters of technical-scientific and technological collaboration among authors and educational and research institutions worldwide.

MATERIALS AND METHODS

To analyze co-citation and co-authorship, we used the Web of Science (WoS) database, with the main collection taking place on June 23, 2021. The research networks on passion fruit were mapped by educational and research institution, country, year of publication, and study themes. These data were used to construct measures of similarity and influence, generate structural images of scientific fields, and identify interconnection networks. The search terms and expressions used were "passion fruit", "passion-fruit", "passiflora" and "*maracujá*" (Portuguese for passion fruit). Due to orthographic variations in the abbreviation of authors' names and abbreviations and acronyms of educational and research institutions, the database was standardized to ensure accuracy in the generation of bibliometric indicators (GLÄNZEL, 2003). The publications cited in WoS and the Embrapa Agricultural Research Database (BDPA) and Embrapa's technological production were analyzed for four periods: P1 (2001–2005), P2 (2006–2010), P3 (2011–2015), and P4 (2016–2020).

Embrapa's bibliographic production data were extracted from the BDPA on June 10, 2021, and its technological production was extracted from the Asset Management System (EMBRAPA, 2021) on June 25, 2021. Technological monitoring of the expression "passion fruit OR passiflora" was carried out in the database maintained by the European Patent Office (Espacenet) on July 2, 2021.

The bibliometric statistical analysis was based on ZUPIC & CATER (2015) and VAN ECK & WALTMAN (2017) using VosViewer software version 1.6.18.Link strength is a measure of similarity represented by lines and spheres in bibliometric maps or by positive numerical values, which ranged from 0 to 107 in this study.

The sphere size represents the link strength between the co-authoring or co-occurring indicators. The thickness of the lines between the spheres illustrates the connection between the indicators; the thinner the lines and the smaller the spheres, the lesser the link strength, and the thicker the lines and the larger the spheres, the more relevance and proximity the items have. Clusters of spheres are represented by colors and positioned by similarity.

For the analyses of co-authorship and co-occurrence, the following criteria were established to generate the bibliometric maps: for co-authorship between institutions, at least 5 publications from the same educational and research institutions and 5 joint publications between institutions in the period; for co-authoring between countries, at least 10 publications in the same country in the period; and for keyword co-occurrence, at least 10 occurrences in the period.

For the co-citation analysis, the minimum criterion of occurrence was 10 citations per article, the same academic scoring system used to include articles in the calculation of Google's metric and time tracking (GOOGLE, 2011).

RESULTS AND DISCUSSION

The WoS database contained 40 papers published between the late 1940s and the 1970s, which addressed chemical, medicinal, agricultural, and food aspects of the Passifloraceae family. The total number of publications analyzed in this paper between 2001 and 2020 was 2,859. In the period from 2001 to 2005 (P1), 278 documents were published. This number doubled over the next five years, totaling 541 documents in P2. The number of publications increased over the years, reaching 864 and 1,176 in P3 and P4, respectively. This increase suggests that there was a need to fill gaps in knowledge regarding the cultivation of this crop, which has a privileged market position in fruit growing, with a view to providing an alternative that will diversity production systems, and also for its use as a functional, ornamental, and medicinal food.

The co-citation analysis of P1 and P2 showed a predominance of phytotherapeutic and pharmacological themes. Table 1 shows that in descending order, DHAWAN et al. (2004), SOULIMANI et al. (1997), and DHAWAN et al. (2001) had the highest number of citations. In P3, the most cited articles were those by DHAWAN et al. (2004), MUSCHNER et al. (2003), ULMER & MACDOUGAL (2004), and YOCKTENG & NADOT (2004) and were related to plant botany, biogeography, and phylogeny. In P4, the most cited articles were those of DHAWAN et al. (2004), ULMER & MACDOUGAL (2004), and FEUILLET and MACDOUGAL (2003) in relation to the classification of the Passifloraceae family. DHAWAN et al. (2004) described the morphological aspects and traditional, pharmacological, and toxicological uses of species of the genus Passsiflora. Due to the scope of discussion of this article, this study has been significantly used by the scientific community, with an average of 400 citations per year.

Table 2 shows the number of publications in WoS and the link strength of the 20 main educational and research institutions on passion fruit. The link strength ranged between 2 and 5 in P1, 15 and 55in P2, 22 and 111in P3, and 27and 107in P4. In P1, USP, Embrapa, and UFRGS published 18, 14, and 11 articles, respectively. Moreover, the USP and Embrapa had the highest link strengths in this period.

In P2, Embrapa was the institution with the highest link strength, followed by Unicamp, UnB, USP, and UFRGS with 49, 32, 26, 45, and 34 publications, respectively. In P3, Embrapa continued to be the institution with the highest link strength, followed by Unicamp, UFV, and USP, with a total of 240 publications. In P4, Embrapa remained the institution with the highest link strength, followed by USP, UFRB, UFV, and UNESP, which together published 272 documents. UFRB, founded in 2005, is located in the Brazilian state of Bahia, which is a major center for passion fruit production, and in P4, this institution had the third highest link strength and fifth highest number of publications. The strategy adopted by Embrapa for the development of research projects in partnership with graduate programs may explain the increase in link strength and passion fruit collaboration networks. The predominance of Brazilian institutions is consistent with the privileged market position of this crop in the country; passion fruit has a well-established marketing chain and a well-organized industrial sector with a good supply chain (FERNANDES et al., 2019).

From 2006, 2010, and 2016 onward, bibliographic production on Passiflora cited in WoS increased (Figure 1). Event sheld in Latin America, such as the IV Reunião Técnica de Pesquisas em Maracujazeiro (IV Technical Meeting for Research on

Table 1 - Publications most cited in periods P1, P2, P3, and P4.

Publications	P1	P2	P3	P4
	--------Number of citations-------			
DHAWAN et al. (2001): Anti-anxiety studies on extracts of *Passiflora* incarnata Linneaus.	17			
DHAWAN et al. (2004): *Passiflora*: a review update.		45	71	95
FEUILLET & MACDOUGAL (2003): A new infrageneric classification of *Passiflora* L. (*Passifloraceae*).				42
MUSCHNER et al. (2003): A first molecular phylogenetic analysis of *Passiflora* (*Passifloracae*).			26	
SOULIMANI et al. (1997): Behavioural effects of *Passifloraincarnata* L. and its indole alkaloid and flavonoid derivatives and maltol in the mouse.		25		
ULMER & MACDOUGAL (2004): *Passiflora*: Passionflowers of the world.			40	66
YOCKTENG & NADOT (2004): Phylogenetic relationships among *Passiflora* species based on the glutamine synthetase nuclear gene expressed in chloroplast (ncpGS).			20	

Table 2 - Number of publications in WoS and link strength of the first twenty institutions of education and research on Passiflora grouped into four periods between 2001 and 2020.

	----------P1----------		----------P2----------		----------P3----------		----------P4----------	
	--------(2001–2005)-------		-------(2006–2010)--------		--------(2011–2015)-------		--------(2016–2020)-------	
Institution	n	FL	n	FL	n	FL	n	FL
CIAT	5	2						
CIRAD	7	2						
Embrapa	14	5	49	55	84	111	87	107
UENF	8	2			36	32		
UESB			8	15	16	29		
UESC			14	16	32	42		
UFCG							24	28
UFLA			18	17				
UFPB					21	22	21	27
UFPE	6	3						
UFPR	6	4						
UFRB							38	57
UFRGS	11	3	34	20				
UFS							33	32
UFV			27	18	47	53	52	50
Un. Florida	7	2						
UnB			26	22	27	23	33	33
UNSP	7	2	29	17	39	32	28	36
Unicamp			32	33	50	56	50	34
USP	18	5	45	22	59	44	67	70

n = number of publications in the period.
FL = Link strength according to VAN ECK & WALTMAN (2017).

Passion Fruit) in 2005 in Brazil (EMBRAPA, 2005), the Latin American and World *Passiflora* Congress in Colombia (CEPASS, 2010, 2017), and the Internal Maracujá Congresses held in 2018, 2019, and 2022 in Peru (ADEX, 2022), fostered the exchange of knowledge and transfer of technology from research to the production of passion fruit. An important historical event related to technological development

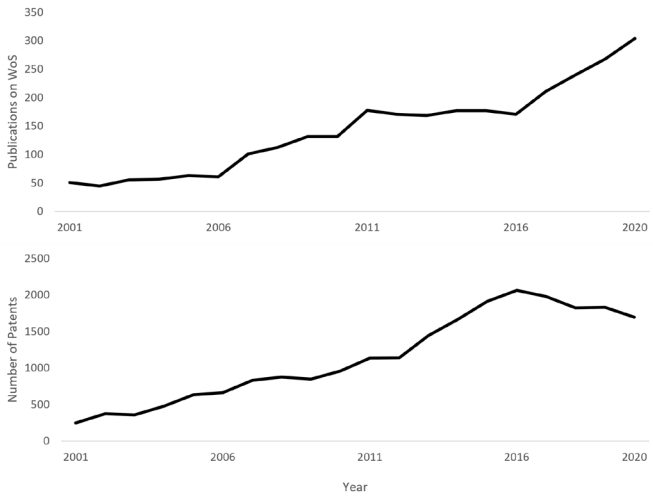

Figure 1 - Evolution of publications in WoS and evolution of patent deposits in the period 2001-2020.

was the launch of the world's first hybrid sour passion fruit cultivars in 2008 (EMBRAPA, 2008).

The number of technical publications in WoS increased alongside the number of patent applications, thereby suggesting that there was high technological demand in the 20 years (Figure 1). A total of 2,649 patent applications were filed with the World Intellectual Property Organization and 1,588 with the European Patent Office. These indicators showed the interest of the international market in the genus Passiflora as a raw material for food, beverages, cosmetics, and medicines. Most of the demand came from the United States and Germany. The highest numbers of patent applications were in 2015, 2016, and 2017 at1,916, 2,064, and 1,980, respectively.

The co-authorship analysis for the 2001–2020 period showed 105 countries composing the passion fruit thematic network, but of these, only 41 had over 10 publications in the period. Data that met the analysis criterion were grouped into seven clusters, with the majority of the publications coming from Brazil, the United States, Colombia, India, and France, with 1,587, 242, 144, 124, and 105 publications, respectively (Figure 2).

In P1, P2, P3, and P4, there were 256, 494, 753, and 1,261 institutions with publications in the network, respectively. Figure 3 shows the bibliometric maps of the evolution of the co-authorship network in the four periods considering the criterion established in the research. The networks formed in each period were composed of 15, 29, 54, and 82 institutions forming 2, 6, 9, and 9 clusters, respectively.

From 2001 to 2020, the interest in conducting research in the area of passifloras was evident, with the number of institutions that published together increasing five-fold. The production of knowledge and common technologies among institutions favored the formation of research arrangements and information flows for the production sector (PENTEADO FILHO et al., 2017).

The network of co-occurrence of keywords during 2001–2020 is shown in figure 4. There was a higher number of publications on biological and pharmacological aspects with flavonoids and antioxidant properties, especially in Brazil, the United States, and Colombia. The different species of Passifloracea are potential sources of molecules of pharmacological relevance and several other active components contained in the pulp, leaves, bark, and seeds (DHAWAN et al., 2001, 2004; ZERAIK et al., 2010). Works on aspects related to agricultural cultivation on growth and flowering, in which Brazilian authors were prominent, had greater link strength. These categories of subjects, related to production, were the most studied in the country, which is the main producer and consumer of the fruit (FAO, 2018). The most evident terms in the nine clusters formed on the map were adsorption, antioxidant, clarification,

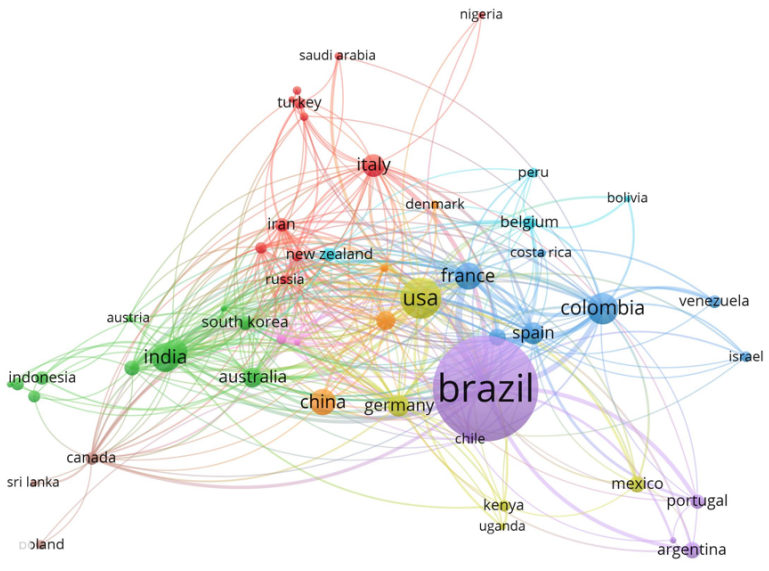

Figure 2 - Bibliometric map of co-authorship networks in the countries in the period 2001-2020. The size of the circles and the thickness of the lines indicate the greatest expression of the indicators. Colors indicate clusters among research teams.

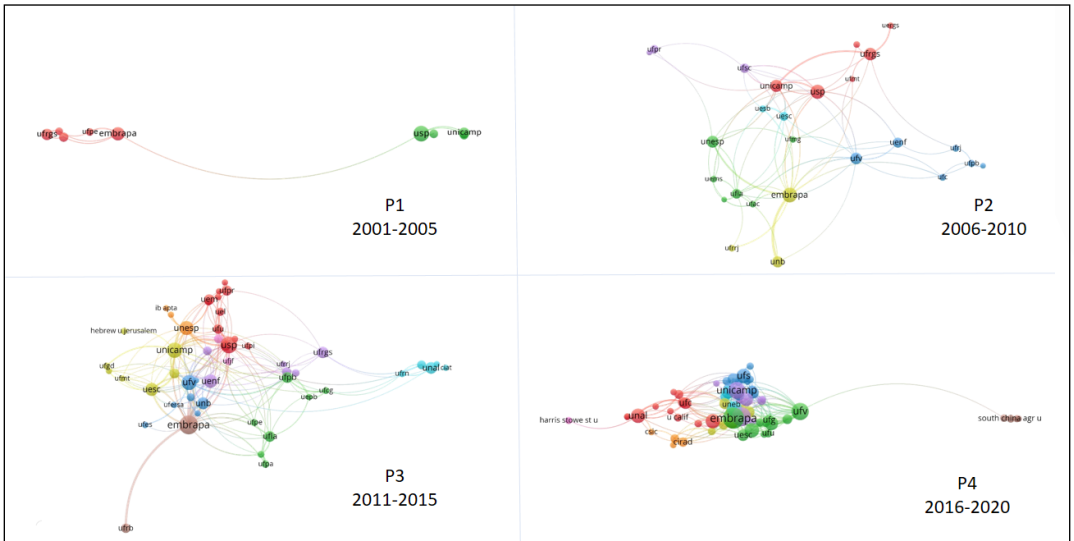

Figure 3 - Bibliometric maps of evolution of the co-authorship network of WoS publications by teaching and research institution in four periods (P1, P2, P3 and P4). The size of the circles and the thickness of the lines indicate the greatest expression of the indicators. Colors indicate clusters among research teams.

evolution, flavonoid, flowering, growth, and somatic embryogenesis. This diversity and interdisciplinarity of terms demonstrate that the scientific basis of Passifloracea has been extensively researched in Brazil and worldwide.

In terms of the number of publications on passion fruit, the main institution was Embrapa, for which the number of publications on WoS increased over the first three periods studied (P1, P2, and P3) and remained the same in P4 (Figure 5). Regarding the perspective of

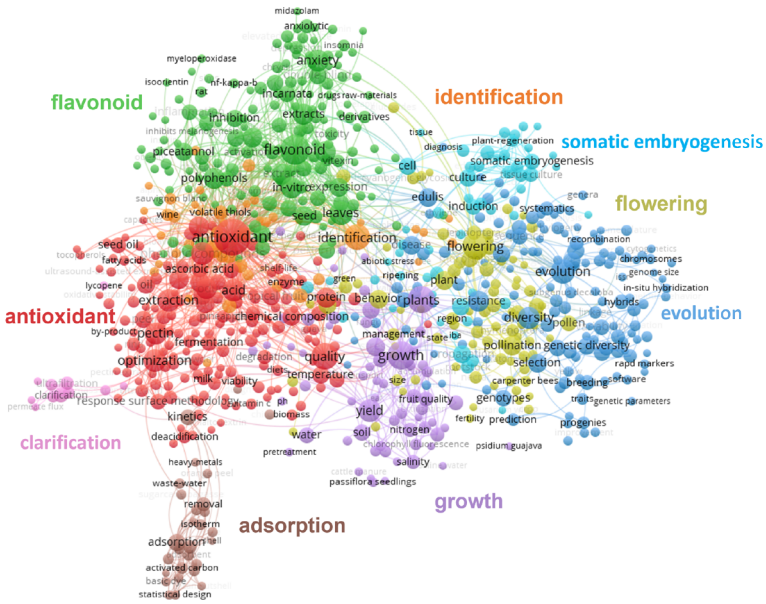

Figure 4 - Bibliometric map of co-occurrence of keywords in the period from 2001 to 2020. The size of the circles and the thickness of the lines indicate the greatest expression of the indicators. Colors indicate clusters among research teams.

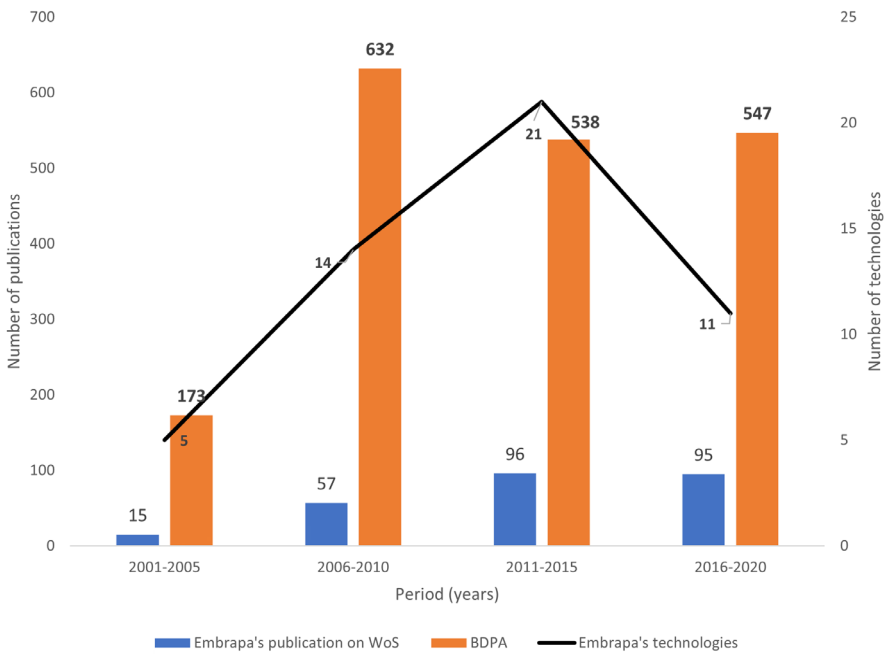

Figure 5 - Embrapa publications on WoS, on BDPA and technologies developed by Embrapa, related to passion fruit culture, grouped into four periods.

bibliographic production aimed at serving the production sector, the institution had 1,890 technical publications in the Agricultural Research Database (BDPA, 2021). This database followed the same pattern of a significant increase in publications between P1 and P2, with the number of publications remaining the same from P3 to P4. These bibliographic productions identified problems and demands related to rural producers focused on productive activity. In this context, there is a strengthening of ties between public research institutions and technology transfer and the productive sector, thereby filling gaps in knowledge on how to optimize rural producers' performance in the production chain.

The number of downloads of publications from the BDPA database showed society's interest in the information generated by the research. In the case of passion fruit, this value was significant from 2010 on ward, when the 6 publications of greatest interest together totaled 163,638 thousand downloads (Table 3). The topics of interest were related to the management practices of agricultural culture, focusing on rural producers as the target audience.

Table 3 - Technical publications and number of downloads from 2001 to 2020 related to passion fruit culture in the Agricultural Research Database.

Publication title	----------Nº downloads----------
Maracujá: o produtor pergunta, a Embrapa responde (Faleiro & Junqueira, 2016)	52.298
A cultura do maracujá (Lima et al., 1994)	38.257
Guia de identificação e controle de pragas na cultura do maracujazeiro (Machado et al., 2017)	24.163
Irrigação e fertirrigação na cultura do maracujá (Sousa & Borges, 2011)	18.059
Maracujá: sistema de produção convencional (Lima et al., 2011)	17.955
Principais doenças do maracujazeiro na Região Nordeste e seu controle (Viana et al., 2003)	12.906

Source: BDPA, 2021.

Between 2001 and 2020, Embrapa conducted 178 research projects and developed 51 production-related technologies; 11 ornamental, wild, sweet, and sour passion fruit cultivars; 16 agricultural practices; and 11 processes for food production (EMBRAPA, 2021a, EMBRAPA, 2021b). Most of these technological solutions were developed through partnerships with universities, state research entities, technical assistance companies, and the productive sector. The adoption of these technologies and their impacts on the passion fruit production system are routinely evaluated in the Embrapa research centers through a reference methodology described by AVILA et al. (2008). These evaluations include cultivars launched in 2008 that generated about 5,000 direct jobs, over 10,000 indirect jobs, and 400 million Brazilian reals on the wholesale market in 2016 (EMBRAPA, 2016). Besides improving crop production, the cultivars have benefited companies and research institutions, which have used the genetic material as the basis for several scientific and technological studies (EMBRAPA, 2022).

Understanding the technical-scientific collaboration network complements the sources of information for academics, managers, and public policy policymakers. This combination of indicators contributes to the implementation of research, development, and technology transfer strategies. Additionally, this information demonstrates the progress of the theme and contributions of the implementation and dissemination of knowledge for the production sector, bearing in mind the importance of joint efforts among the different stakeholders.

CONCLUSION

The study results show an increase in the production of technical and scientific publications on the genus Passiflora worldwide. Embrapa, USP, UFV, Unicamp, and UNESP were the educational and research institutions that published the most research between 2001 and 2020 worldwide.

In all the studied databases, the largest number of publications was from authors associated with Brazilian educational and research institutions. Embrapa was the institution with the highest number of publications in WoS and the strongest link strength across all four periods evaluated.

The number of downloads of technical publications aimed at rural producers, the number of research projects, and the number of technological solutions developed reinforce Embrapa's role in the generation and transfer of technology on the family Passifloraceae. Patents filed worldwide show trends and opportunities in the food, beverage, cosmetics, and medicine markets.

The information presented in this study is a source of knowledge for understanding the growth of production, research, and technologies related to passion fruit. The results showed the relationship between increased agricultural production and the time series of the development of the research network worldwide.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed to the conception and writing of the manuscript. All authors critically reviewed the manuscript and approved the final version.

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