EFFECTS OF UV RADIATION ON PLANT-INSECT RELATIONSHIPS: A BIBLIOMETRIC ANALYSIS

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Abstract. In the framework of global climate changes, the increase of UV radiation reaching the Earth's surface and impacting agroecosystems is a pressing concern. Most studies on this subject often focus only on plants; nevertheless, insects have a massive influence on plant growth and development. Therefore, we must assess the effect of increasing UV radiation on the plants-insects relationship and its implication on agroecosystems. UV manipulation in crop management practices has become a crucial area. Ultraviolet light plays a significant influence, especially on pollinators and herbivore insect behaviour. Visual cues are essential to insects for food plant finding, locating oviposition sites, and dispersion. Supplementation of UV-B radiation increase plant resistance to herbivory and may reduce transmission of different plant viruses. Our paper analysed a database of 148 articles from 1991-to 2021. We performed a bibliometric analysis of published articles emphasizing UV radiation effects on plant-insect relationships. The bibliometric study provided the research topics in this field and their evolution. According to author keywords, the bibliometric analysis revealed the topic research area: herbivores, UV-B, followed closely by aphids, flavonoids, Lepidoptera, and plant defence. We provide an international collaboration map that can be useful for identifying potential scientific collaborations. The journals with the highest number of published articles in this field are Oecologia, Environmental Entomology, Environmental and Experimental Botany, Journal of Chemical Ecology, and Plant Ecology. The bibliometric analysis of published articles is a powerful tool that offers an overview of this research area and the research trends.

Keywords: bibliometric analysis, UV, plants, insects.

Rezumat. Efectele radiației UV asupra relațiilor dintre plante și insect: o analiză bibliometrică. În contextul schimbărilor climatice globale, un interes deosebit îl ocupă impactul creșterii radiației UV asupra agrosistemelor. Manipularea radiației ultraviolete a devenit un domeniu important în planurile de management al culturilor agricole. Radiația ultravioletă are o influență semnificativă, în special asupra polenizatorilor și a insectelor fitofage. Indiciile vizuale sunt esențiale insectelor pentru găsirea plantelor gazdă, pentru localizarea locurilor de depunere a pontei și pentru dispersie. Suplimentarea radiațiilor UV crește rezistența plantelor la insectele fitofage și poate reduce transmiterea diferitelor virusuri ai plantelor. Cu toate că insectele au o influență majoră asupra creșterii și dezvoltării plantelor, cele mai multe cercetări se concentrează doar pe studierea plantelor. De aceea este necesară evaluarea efectului creșterii radiațiilor UV asupra relației plante-insecte și implicația acestui efect asupra agrosistemelor. Am realizat o analiză bibliometrică a publicațiilor care subliniază efectele radiațiilor UV asupra relațiilor plante-insecte. Studiul bibliometric efectuat pe o bază de date care cuprinde 148 de articole publicate în perioada 1991-2021, permite vizualizarea temelor de cercetare din acest domeniu și evoluția lor în timp. Potrivit cuvintelor cheie ale autorilor, analiza bibliometrică a evidențiat ca principale subiecte de cercetare: insectele fitofage, UV-B, afidele, flavonoizii, Lepidoptera și apărarea plantelor. Articolul include harta colaborărilor internaționale, hartă care poate fi utilă pentru identificarea potențialelor colaborări științifice în domeniu. Revistele cu cel mai mare număr de articole publicate în acest domeniu sunt: Oecologia, Environmental Entomology, Journal of Chemical Ecology, Environmental, Experimental Botany și Plant Ecology. Analiza bibliometrică a lucrărilor publicate este un instrument adecvat pentru a ne oferi o imagine de ansamblu asupra acestui domeniu de cercetare și a tendințelor cercetării.

Cuvinte cheie: analiza bibliometică, UV, plante, insecte.

INTRODUCTION

Rising UV radiation levels that reach the Earth's surface, caused by the stratospheric ozone depletion, increase scientific interest in its potential effects on biota. Due to the atmosphere, the UV radiation reaching the Earth's surface constitutes a large part of UV-A radiation and a small proportion of UV-B radiation. Even UV-B light (280–315 nm) is only 1.5% of the total spectrum (RAI & AGRAWAL, 2017); because it has higher energy than UV-A, it has more impact on living organisms.

The research on UV radiation often focuses on plants or insects. Plants and insect interactions may influence the UV radiation effect on them. Many studies focus on plants and their interaction with UV radiation, excluding the influence of insects. An elevated UV-B radiation generally has detrimental effects on plant development and reproduction since UV-A positively affect plant growth and yield (CHEN et al., 2019). Depending on the dose, UV-B radiation causes a reduction of food sources (plant biomass) for herbivores. Several researchers have reported decreases in plant size (REDDY et al., 2013), plant roots (ZHANG et al., 2019), the number of leaves (ZHAO et al., 2003) and leaf area (YAN et al., 2012; REDDY et al., 2013). Under elevated UV-B radiation, some plants develop thicker leaves (JOHANSON et al., 1995), a thicker wax cuticular layer (STEINMULLER & TEVINI, 1985) and increased trichome density (YAN et al., 2012). All these morphological changes decrease herbivores' attacks.

The research on UV implication on plant-insect relationships focuses on herbivorous insects and insect pollinators. These relationships are often separated, but in some cases, the same insect feeds on a plant in the larval stage and pollinates the same plants in the adult stage (REVILLA & ENCINAS-VISO, 2015). Therefore, cost and benefits should be carefully analysed.

UV manipulation is a friendly technique for crop pest control to reduce pesticides. UV-B radiation enhances plants' antioxidant capacity and phenolic compounds (YOUNIS et al., 2010: DEL VALLE et al., 2020). Unfortunately, many field studies report the change in total phenolics without identifying the specific compounds with implications for plant-herbivore interactions (ROBERTS & PAUL, 2006). Changes in plant tissue chemistry, such as furanocoumarins (McCLOUD & BERENBAUM, 1994) and nitrogen concentration (HATCHER & PAUL, 1994), have an essential role in determining herbivore responses. Specific compounds are induced in plants (such as chlorogenic acid and di-caffeoyl spermidine isomers) by elevated UV-B radiation and also by insect herbivores (IZAGUIRRE et al., 2007).

Visual cues are also important for insects. Thrips can detect host plants by UV-A reflectance (BALINT et al., 2013). Pollinators detect flower location and identity through a combination of sensory cues (CHITTKA & RAINE, 2006). Besides flower temperature patterns (HARRAP et al., 2017), colour (VAN der KOOI et al., 2019), odour (TURLINGS & ERB, 2018), petal micro-texture (KEVAN & LANE, 1985), the 'flowers' UV reflectance is a significant modulator of pollinators' activity. Approximately 25 % of angiosperms have flowers that reflect UV radiation (KLOMBERG et al., 2019). Different plant species have various UV reflectance. The highest reflectance is found in plant species with yellow flowers (PAPIOREK et al., 2015). Visual cues such as bullseye ultraviolet flower designs (PAPIOREK et al., 2015) give insects information about the landing sites and foraging section of flowers (LUNAU et al., 2017). The bullseye patterns found most notably in yellow flowers (PRIMACK, 1982) i's a nectar guide for pollinators. In the bullseye pattern, the apical petal parts reflect UV due to UV-reflecting yellow carotenoids (PAPIOREK et al., 2015), while the central flower parts absorb UV radiation due to quercetin glycosides or yellow flavonoids (HARBORNE & SMITH, 1978). The flowers' UV pigmentation increased by ~2% per year due to the enhancement of UV and temperature (KOSKI et al., 2020).

Besides flower location, UV radiation affects pollinators by delaying flowering time (YAN et al., 2012) and lifetime flower production (SAMPSON & CANE, 1999). Also, UV radiation has a deleterious effect on nectar sugar production (SAMPSON & CANE, 1999).

Information on the multifaceted interaction between UV light, plants and insects is vital for sustainable crop management practices and environmental plans management. Bibliometric analysis is a powerful tool that unveils an overview of the existing research on these interactions and the emerging research trends. Thus, in the current study, we analysed the available research articles on the effects of UV radiation on plant-insect relationships.

MATERIAL AND METHODS

On April 20, 2022, we retrieved two hundred and three articles from the database "Web of Science Core Collection Database". In our search strategy, we used the terms: "UV radiation", "plant", and "insect". The type of these publications was limited using the filter function "document type" to the article. The retrieved papers were published in the timeframe 1992 – 2021. We classified the documents into three categories: articles of interest, related to our subject and not associated with the issue. We analysed the first two categories, which include 148 articles. We performed a bibliometric analysis on the papers of interest category (92 documents) using VOSviewer 1.6.18 software (VAN ECK & WALTMAN, 2010).

In the bibliometric maps, the 'points' size represents the item's frequency, and the line width and the closeness of two points represent the correlation between these two items (VAN ECK & WALTMAN, 2022). In our analysis, the normalization of the strength of the links between items follows the association strength method (VAN ECK & WALTMAN, 2022). The minimum number of occurrences used was three. The clustering resolution of the maps was 0.5.

We use the VOSviewer to visualize the scientific collaboration between authors, research institutions and countries. The country of the corresponding author for each article was assigned to obtain the country's scientific collaboration map. Also, we create a co-occurrence matrix of author keywords and the evolution of keywords use over time. We performed author keywords grouping when two or more keywords have the same meaning or belong to the same group. We created thesaurus files to eliminate authors and keywords redundancy. We use VOSviewer to identify the most cited papers in this field. Analysis in Microsoft Excel 2016 included publications trend, number of authors per document and top journals.

RESULTS AND DISCUSSIONS

The bibliometric analysis of the papers of interest category revealed an overview of the implications of UV radiation on the plants-insects relationship. The evolution of research (number of publications per year) is detailed in figure 1 and has shown many signs of fluctuations in the publication rate. The research productivity, as number of published papers, varied over the last 29 years. The most productive was 2013 with seven publications, followed by 2012 and 2019 with six publications. The oldest article was from 1991. In 1992, 1993, 1995 and 2008, no document was registered.

There is a high collaboration between researchers in this field. Ninety-seven point eight per-cent of all documents have more than one author. Most of the papers have four authors (19%), three authors (18%), two authors (18%) and five authors (17%) (Fig. 2).

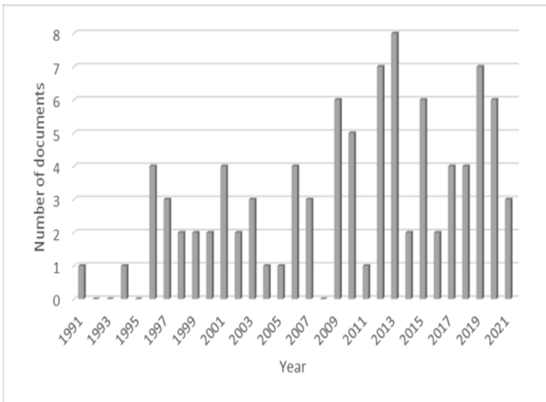

Figure 1. Publications trend.

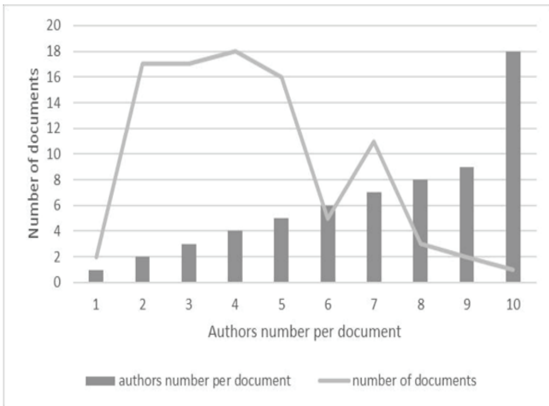

Figure 2. Number of authors per document.

All 92 papers were written by 270 authors and were published in 52 journals. The leading five journals with the most prolific publications were Oecologia, Environmental Entomology, Environmental and Experimental Botany, Journal of Chemical Ecology, and Plant Ecology. Most of the studies are included in the following research areas: Plant Sciences, Entomology and Environmental Sciences and Ecology.

In the analysis of the citation of the document (Table 1), we excluded the papers published in the last three years because, according to ABRAMO et al. (2011) and WANG (2013), a publication needs at least three years to accumulate enough citations. The older papers have more time to gather citations than recent ones. Therefore, an author who published recently will have fewer publications and citations than those published earlier. The paper of BALLARE et al. (1996) had the greatest number of citations, followed by MEWIS et al. (2012) and IZAGUIRRE et al. (2003).

Table 1. Documents citations.

Documents	Title	Journal	Total citations
Ballare et al., 1996	Solar Ultraviolet-B Radiation Affects Seedling Emergence, DNA Integrity, Plant Morphology, Growth Rate, and Attractiveness to Herbivore Insects in *Datura ferox*.	Plant Physiol. **112**(1):161-170.	155
Mewis et al., 2012	UV-B irradiation changes specifically the secondary metabolite profile in broccoli sprouts: induced signaling overlaps with defense response to biotic stressors.	Plant Cell Physiol. **53**(9): 1546-1560	153
Izaguirre et al., 2003	Convergent responses to stress. Solar ultraviolet-B radiation and *Manduca sexta* herbivory elicit overlapping transcriptional responses in field-grown plants of *Nicotiana longiflora*.	Plant Physiol. **132**(4):1755-67	145
Demkura et al., 2010	Jasmonate-dependent and -independent pathways mediate specific effects of solar ultraviolet B radiation on leaf phenolics and antiherbivore defense.	Plant Physiol. **152**(2):1084-1095.	133
Izaguirre et al., 2007	Solar ultraviolet-B radiation and insect herbivory trigger partially overlapping phenolic responses in *Nicotiana attenuata* and *Nicotiana longiflora*.	Ann Bot. Oxford **99**(1):103-109	131

Applying a minimum threshold of three in VOSviewer software, the co-authorship map includes thirty-four authors. The relatedness of authors is based on the number of documents they published together. The map revealed seven groups, from which two leading groups with higher cooperation (Fig. 3). In the first group (thirteen authors), Ballare C. L., Scopel A. L., and Zavala J. A. have the highest collaboration strength and the number of papers. In the timescale Scopel A. L has the earliest published articles and Zavala J. A. the newest. In the second bigger group (ten authors), Fereres A. have the highest collaboration strength and the highest number of documents.

Analysing the author's affiliations, VOSviewer revealed the fifteen most productive institutions, of which five have a strong co-authorship relationship (Fig. 4). The relatedness of the organization's map is based on the number of co-authored papers. The University of Buenos Aires and Consejo Nacional de Investigaciones Científicas y Tecnicas has strong co-authorship relationship. The Utah State University and the University of Joensuu had the earliest cooperation. The minimum number of an institution's documents is three, and the maximum is fourteen (University of Buenos Aires).

The publishing countries map relies on the number of publications counted by the corresponding author's country. The most prolific countries in publishing articles are highlighted in Fig. 5. The dark red colour is the world region with the highest productivity. The co-authorship countries map with a threshold of three is based on the number of co-authored documents. The map highlights the strong collaboration between Germany, USA and Argentina. The most prolific countries are Germany, the USA and Argentina, followed by Finland and Spain.

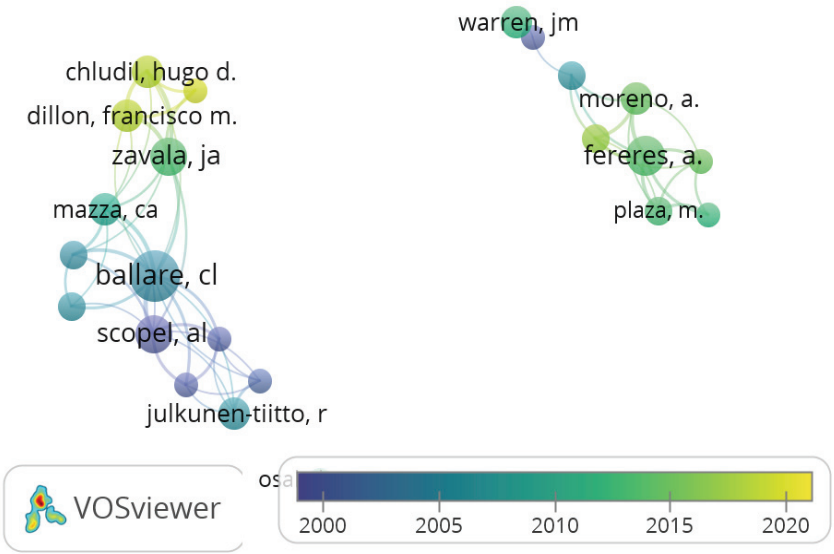

Figure 3. Researchers' collaboration network.

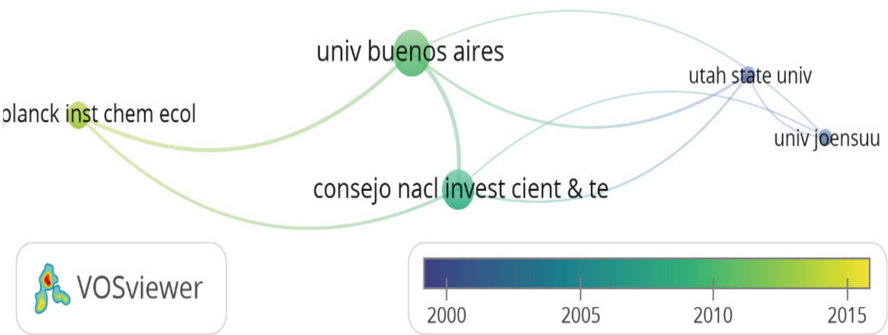

Figure 4. Collaboration between institutions.

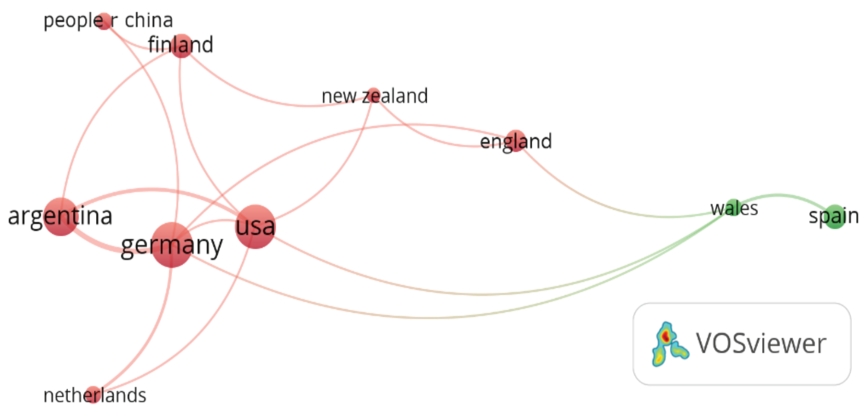

Figure 5. Cooperation network between countries.

The co-occurrence author keywords map (Fig. 6) has a threshold value of a minimum of three and a resolution of 0.5. From a total number of 198 keywords, only 28 meet the criteria. Colours indicate clusters of related terms grouped by the VOSviewer software.

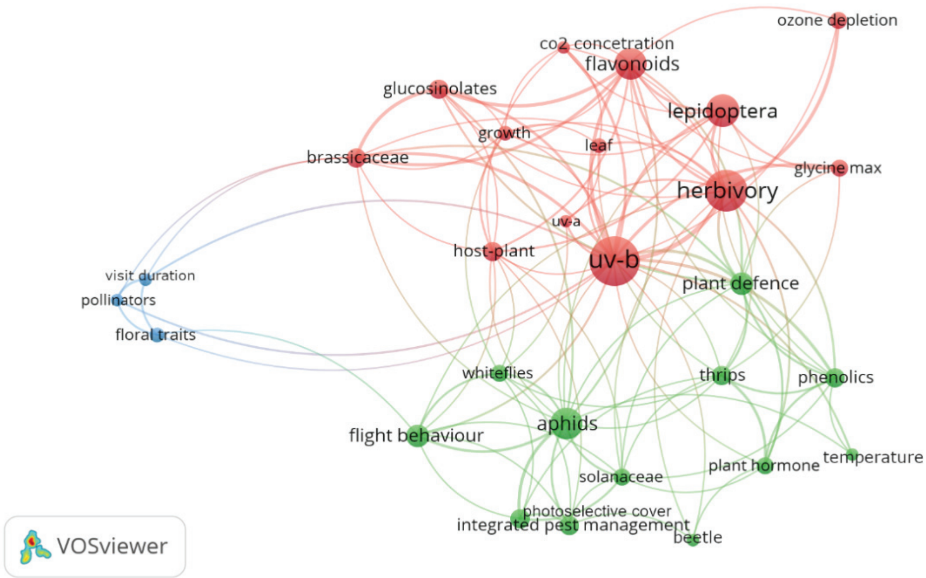

Figure 6. Author keywords co-occurrences map.

The red cluster includes four of the highest used keywords: herbivory, UV-B, flavonoids, and Lepidoptera. The Lepidoptera group consists of 12 species, most of which belong to the moth group.

The green cluster covers the important agricultural pest aphids, whitefly and trips. Integrated pest management is closest to photo-selective cover, indicating the increased use of UV manipulation in crop management practices.

The blue cluster is the pollinator keywords group and includes the pollinators, floral traits (nectar guide, nectar size, flower colour), and visit duration. Pollinators were less studied than herbivore insects.

According to author keywords, the research topics with the most significant frequency focused on herbivores, UV-B, followed closely by aphids, flavonoids, Lepidoptera, and plant defence. The plant family of Solanaceae and Brassicaceae were the best represented in these studies and comprise many species. The most studied plant was the economic important *Glycine max* (L.) Merr. (belonging to the Fabaceae family).

The overlay visualization map of keywords (Fig. 7) revealed the novelty of the scientific landscape. Herbivores, Lepidoptera, ozone depletion, leaf and pollinators (dark purple colour) were the oldest topics. In opposition, Solanaceae, integrated pest management, thrips and plant defence (brighter yellow colour) are currently attracting the researchers’ attention.

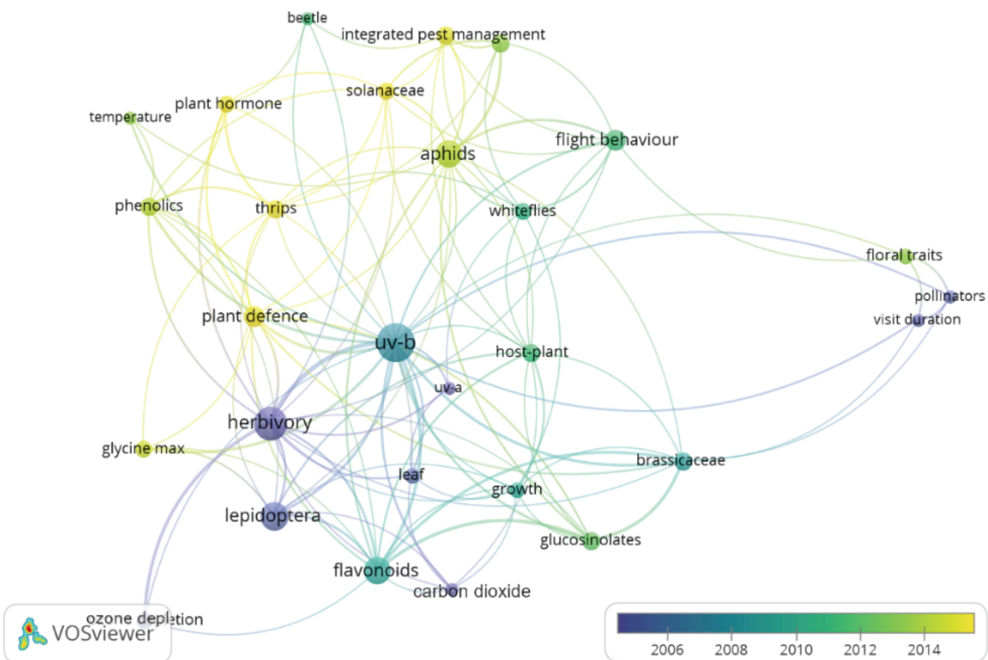

Figure 7. Author keywords co-occurrences map in the timeline-based visualization.

Along with the first category of papers, the second category (the documents related to our subject) gives us additional information. The main topics distinguished in this category are: microbial pesticide encapsulation to prevent UV degradation, the effect of UV-B and UV-A on insects (without including plants in the study), and the UV effect on entomopathogenic fungi.

This category consists of 57 papers written by 243 authors and published in 46 journals. The document with the highest citation rate is KARAGEORGOU & MANETAS (2006) (190 citations), followed by WANG et al. (2007) (183 citations). Most of the papers were written by three or four authors. The most prolific years were 2016, 2018, and 2020.

CONCLUSIONS

In this paper, we reviewed the scientific literature using bibliometric analysis. We pointed out the collaboration between researchers, institutions, and countries using VOSviewer bibliometric network maps.

The high number of authors and documents published in high-quality journals demonstrates the great interest in the UV radiation effect on the plant-insect relationship. Over the last 29 years, the research productivity and the number of published papers has fluctuated. Most of the documents have been written by two to five authors. The co-authorship map revealed two main groups of researchers with a high collaboration. The highest collaboration strength and number of papers is seen in Ballare C. L., Fereres A., Scopel A. L., and Zavala J. A.

Oecologia, Environmental Entomology, Environmental and Experimental Botany, Journal of Chemical Ecology, and Plant Ecology ranked first for productive journals.

The University of Buenos Aires has the highest number of published papers and a strong co-authorship relationship with other research institutions. Countries like Germany, the USA, and Argentina are leading the scientific research activity in this field.

The analysis of author keywords revealed that the main research focus is on herbivores, UV-B, followed closely by aphids, flavonoids, Lepidoptera, and plant defence. The latest research hotspots Solanaceae, integrated pest management, thrips and plant defence.

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