



## Global biopesticide research trends: a bibliometric assessment

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### ABSTRACT

Combined realization of the negative effects of chemical pesticides and the positive attributes of biopesticide led to intensive research programmes on the later by both public and private institutions across nations. This has generated a knowledge pool and accumulated vast scientific literature. This paper tries to capture the nature of basic research in biopesticide and growth of the discipline during the last four decades. Bibliometric methods such as analysis of title-word and author keywords have been used to capture direction of research and to identify thrust areas of research. Growth of biopesticide research output has been encouraging, particularly since 1996. Microbial pesticides, particularly *Bacillus thuringiensis*-related research has dominated the discipline so far. The paper also identifies the leading institutes, countries, and the nature of inter-country as well as inter-institutional collaboration. As in most other disciplines of science, United States had an upper hand in biopesticide research, followed distantly by India. Two aspects that need immediate attention are the decline in participation of industry and international collaboration in biopesticide research, both of which are critical for developing cost-effective and environment-friendly pesticides having world-wide application.

**Key words:** Agriculture, *Bacillus thuringiensis*, Biological control, Biopesticides, Botanical pesticides, Environment

There has been growing concern in recent years about excessive usage of chemical pesticide and its impact on nature and natural resources (Pimentel 1996) including human (Margni *et al.* 2002). The notion, 'pesticide as panacea' has changed over the years. Recognition of the negative effects of chemical pesticides buttressed by the reported advantages of biopesticide, led to intensive biopesticide research programmes on the later by both public and private institutions across the globe (Rossel *et al.* 2008). This has resulted in an avalanche of scientific literature reporting attempts to discover and develop newer and safer pesticides, particularly in the last three decades (Koul and Dhaliwal 2001, 2002). A comprehensive list and classification of formulation types of different mycoinsecticides and mycoacaricides are given by de Faria and Wraight (2007). Development and use of *Bt* as a successful bioinsecticide has been reviewed by Bravo *et al.* (2011).

The term biopesticide in *sensu stricto* implies any pest control agent which is of biological origin, ie derived from plants, animals or microbes. The United States Environmental Protection Agency (EPA) recognizes three major classes of

biopesticides namely microbial pesticides, plant-incorporated protectants (PIPs), and biochemical pesticides. Besides, biopesticides also include entomopathogenic nematodes, parasites and predators, plant extracts and secondary metabolites etc. Biopesticides may also be classified according to the target organism such as bioinsecticides, bioherbicides, and biofungicides.

Despite the increasing interest on biopesticide, virtually no attempts have been made to capture the nature and trend of biopesticide research. For that matter, the only study of its kind even in conventional insecticide research is that of Rothman and Lester (1985). Recent research focus of a discipline is usually reflected on its publication output (Garfield 1970), and bibliometric method is the most commonly used tool for research evaluation. In this study, bibliometric methods have been used to assess the growth of scientific literature on biopesticide since 1971, current state of publication patterns, research priorities, and patterns of collaboration etc. Hopefully, this paper would be of assistance to future policy planners.

The most crucial and tricky step in publication-based studies is the selection of right combination of keywords (Zitt and Bassecoulard 2006). Selection of a proper keyword combination is more difficult for newer, multidisciplinary and evolving disciplines like biopesticide; even experts were unable to agree on a particular outline. Takeda and his

associates used a simple query, “nano\* and bio\*” to define nano-biotechnology in studying the emergence of the discipline (Takeda *et al.* 2009). A similar query, “bio\* and pest\*” was used in the present study to define biopesticide and searched in the Scopus search engine for publications between 1971 and 2008. This query returned very few records.

For a comprehensive coverage of global biopesticide research, combination of keywords from three aspects was used, viz. (i) two variations of the word biopesticide, (ii) three major types of biopesticide, and (iii) three keywords suggested by most of the subject experts.

All the keywords (Table 1) were connected with ‘OR’ Boolean operator and two-word keywords were enclosed with Boolean strings. The query was run in Scopus search engine<sup>1</sup>. This generated a dataset of 30,626 records, however, with a lot of noise such as unidentified documents, articles from irrelevant subject areas like dentistry etc. To clean the data, document types were restricted to articles and reviews which reduced the data set to 28,484 records. Then the query was run again, but this time looked for matching text in the title, abstract and keywords fields of the three main document types: articles, reviews, and conference proceedings published between 1971 and 2008.

Table 1 Keywords used to extract biopesticide publication records from Scopus

| Word variation | Biopesticide types | Expert keywords |
|----------------|--------------------|-----------------|
| Biopest*       | Microbial pest*    | Biofung*        |
| Biopest*       | Biochemical pest*  | Bioinsect*      |
|                | Botanical pest*    | Mycopest*       |

<sup>1</sup> Running the query in Web of Science (WoS) returned only around 500 articles which were essentially included in the output from the Scopus database. Hence, Scopus was used instead of WoS to embrace as many as biopesticide related publications despite the fact that the later is normally used in this type of studies

SCIENTIFIC OUTPUT

Biopesticide research has developed steadily over the last 38 years, from just 10 articles in 1971 to 387 articles in 2008. Altogether, 3 539 papers were published during the last four decades. The starting of publication during 1970s reflected the beginning of scientific studies on biopesticide around that time. This might have been triggered by highlighting of the detrimental effects of chemical pesticides through revolutionary works such as by Rachel Carson’s *Silent Spring* (Carson 1962). It could be seen that the global academic publication had a rapid growth from 1996 onwards; sharper since 2004. In fact, during 1971–1995, 535 articles were published which accounted for only 15% of the total publication in the study period.

A correlation analysis between the yearly cumulative number of publications and the year revealed low coefficient of determination in the period 1971 to 1995 ( $r^2 = 0.611$ ). However, the correlation coefficient for the period 1996 to 2008 was higher ( $r^2=0.957$ ). Publication growth during the later period was high as compared to the period from 1971 to 1995. Further, it was more consistent and hovered around the mean annual publication (Fig 1). Thus, it can be assumed that scientific output on biopesticide will grow at a higher rate in the near future.

PUBLICATION PATTERNS

An indicator of maturity of a discipline is the number of subject categories under which its research publications are dispersed because the more mature a discipline the more detail and deeper it would be studied (Palmer *et al.* 2005). In 1971, biopesticide research had publications in only four subjects which increased to 28 subjects by 2008 indicating its gradual maturity. The discipline of biopesticide has emerged to address the twin major issues of crop protection while ensuring environmental sustainability. This is evident from the categorization of about 75% of the research output

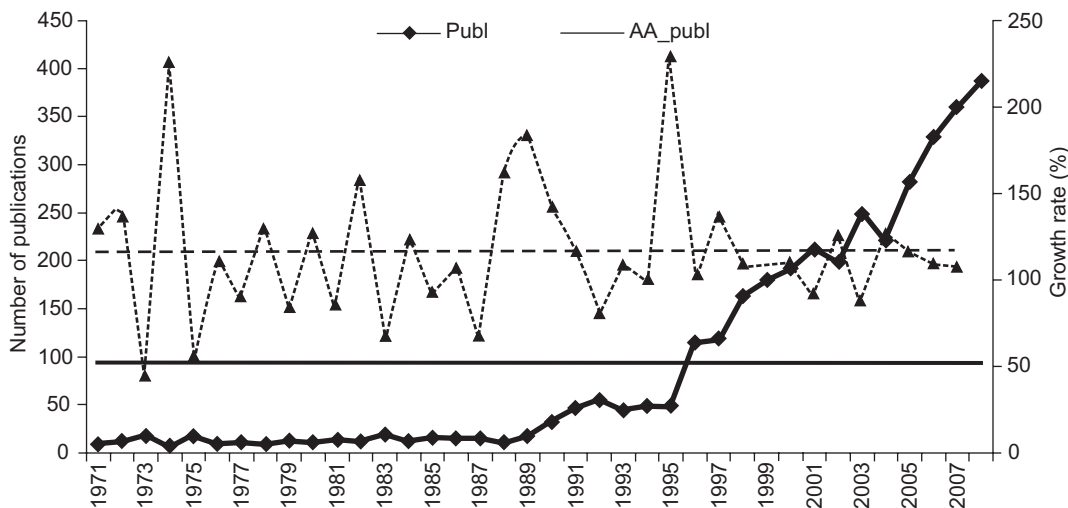


Fig 1 Publication output of global biopesticide research. AA\_publ: Average annual publication; AGR: annual growth rate; AAGR: average annual growth rate

Table 2 Top nine subject categories of global biopesticide research publication

| Subject category                                | 1971–2008 |         |     | 1971–1995 |     | 1996–2008 |     |
|---|-----------|---------|-----|-----------|-----|-----------|-----|
|   | TA        | R (%)   | A/Y | R (%)     | A/Y | R (%)     | A/Y |
| Agricultural and Biological Sciences            | 1 543     | 1 (44)  | 41  | 3 (24)    | 5   | 1 (47)    | 109 |
| Environmental Science                           | 1 090     | 2 (31)  | 29  | 1 (36)    | 8   | 2 (30)    | 69  |
| Biochemistry, Genetics<br>and Molecular Biology | 879       | 3 (25)  | 23  | 5 (18)    | 3.8 | 3 (26)    | 60  |
| Immunology and Microbiology                     | 851       | 4 (24)  | 22  | 4 (21)    | 4   | 4 (25)    | 57  |
| Medicine  | 429       | 5 (12)  | 11  | 2 (28)    | 6   | 5 (9)     | 22  |
| Pharmacology, Toxicology and<br>Pharmaceutics   | 252       | 6 (7.1) | 6.6 | 6 (13)    | 2.8 | 6 (6)     | 14  |
| Chemical Engineering                            | 186       | 7 (5.3) | 4.9 | 10 (2.2)  | 0.5 | 7 (5.8)   | 13  |
| Earth and Planetary Sciences                    | 170       | 8 (4.8) | 4.5 | 7 (1)     | 2.4 | 9 (3.7)   | 9   |
| Chemistry                                       | 167       | 9 (4.7) | 4.4 | 9 (6.2)   | 1.3 | 8 (4.5)   | 10  |

TA, Total articles published in 38 years; R (%), ranking (percentage of all articles published in these years); A/Y, articles/year

in the two subjects: agricultural and biological sciences and environmental sciences. Table 2 shows categories which had at least 100 articles, including the ranking and number of articles per year. During 1996–2008, agriculture and biological sciences (47%) accounted for highest share of the total publication, almost twice the percentage share in the previous block of years.

Global biopesticide publication came from five different document sources. Journals (3,382) were the dominant source comprising around 96% of the total output (Fig 2), followed distantly by book series (2.2%). As journal articles constituted majority of the biopesticide publication, growth pattern of journals and the top publishing journals were studied. According to Bradford's law (Bradford 1985), growth in number of papers on a subject requires a certain degree of growth in number of journals. The number of journals has increased from 9 in 1971 to 202 journals in 2008; it grew by about 16% per annum. The number of articles published per journal has also increased steadily.

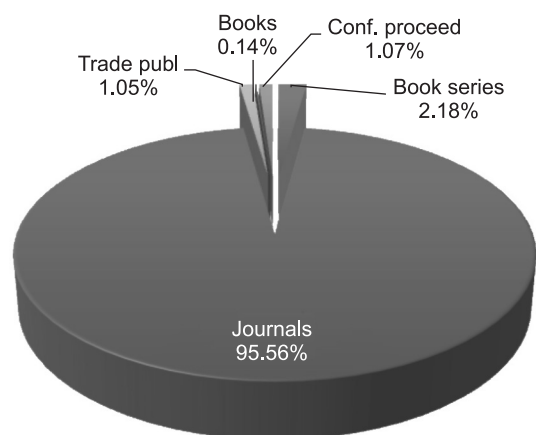


Fig. 2 Medium of communication in world biopesticide research

Table 3 presents the top nine journals (>50 articles) publishing biopesticide-related research during the study

Table 3 Top nine journals publishing global biopesticide research

| Journal   | 1971–2008 |       |     |           | 1971–95 |     | 1996–2008 |     |
|---|-----------|-------|-----|-----------|---------|-----|-----------|-----|
|   | TA        | R (%) | A/Y | AIF±SE*   | R (%)   | A/Y | R (%)     | A/Y |
| Applied and Environmental Microbiology                    | 115       | 1     | 3.0 | 3.77±0.05 | 3       | 0.8 | 2         | 7.3 |
| Pest Management Science                                   | 106       | 2     | 2.7 | 1.42±0.12 | 41      | 0.1 | 1         | 7.8 |
| Journal of Applied Microbiology                           | 69        | 3     | 1.8 | 2.02±0.09 | 60      | 0.1 | 3         | 5.2 |
| Journal of Environmental Science and<br>Health Part B     | 68        | 4     | 1.8 | 0.69±0.08 | 2       | 0.8 | 8         | 3.7 |
| Journal of Invertebrate Pathology                         | 64        | 5     | 1.7 | 1.23±0.14 | 5       | 0.6 | 6         | 3.8 |
| Soil Biology and Biochemistry                             | 64        | 6     | 1.7 | 2.31±0.14 | 6       | 0.5 | 5         | 3.9 |
| Biocontrol Science and Technology                         | 58        | 7     | 1.5 | 0.98±0.09 | 100     | 0.1 | 4         | 4.4 |
| Journal of Agricultural and Food Chemistry                | 55        | 8     | 1.4 | 2.27±0.09 |         |     | 14        | 2.8 |
| Bulletin of Environmental<br>Contamination and Toxicology | 54        | 9     | 1.4 | 0.56±0.02 | 1       | 1.2 | 20        | 1.9 |

TA, Total articles published in 38 years; R (%), ranking; A/Y, articles/year; AIF, average impact factor. \* average of 2001–08 with standard error of mean

period. Articles published in the top nine journals accounted for 18% of the total articles published over the period. As flagship journals of this particular field, the two journals: Applied and Environmental Microbiology and Pest Management Science published the most articles. Upper edge of broader journals like Applied and Environmental Microbiology indicates emphasis on microbial biopesticides which is also apparent in the next paragraphs. A direct correlation between the emphasis on microbial biopesticide research is apparent in the dominance of the biopesticide market by microbial pesticides (Rodgers 2006).

It also appeared that journals with higher impact factors have received more articles. The number of articles published per year by these top nine journals showed a remarkable increase during 1996–2008 as compared to 1971–95. Prior to 1995, journals dealing with contamination of environment and food by pesticide residues occupied the top positions indicating the thrust on analyzing the negative impacts of chemical pesticides. On the other hand, improvements in the ranking of biopesticide-related journals like Biocontrol Science and Technology, Journal of Applied Microbiology, Pest Management Science, Applied and Environmental Microbiology is a pointer towards application orientated research to develop newer and safer pesticides.

**PRIORITY AREAS IN BIOPESTICIDE RESEARCH**

Statistical analysis of author keywords and title-words gives valuable clue about the direction of research (Garfield 1990), and also helps in identifying subjective focus (Xie *et al.* 2008). In the analysis of words-in-title, singular and plural forms of a word were considered independently as each form indicates different connotation. Further, in case of living organisms, subspecies and variants were considered separately. A look at the top 22 most frequently occurring keywords (> 100 times) indicates the exploratory nature of biopesticide research (Fig 3). This was supported by the presence of more investigative terms like ‘effects’ (257), ‘effect’ (255), ‘against’ (209) and ‘evaluation’ (106). Occurrence of words such as ‘*Bacillus thuringiensis*’ (277), ‘microbial’ (253), ‘bacteria’ (130), and ‘bacterial’ (123) indicated the dominance of microbial pesticides. This is evident in the representation of over 90% of biopesticide sale by a single product type containing *Bt* (Rodgers 2006).

Analysis of author keywords revealed that altogether 6,444 unique keywords were used. Among them, 5,004 (78%) appeared only once, and 712 (11%) keywords appeared twice. Large number of once-only author keywords probably indicates lack of continuity in research and a wide disparity in research focuses (Xie *et al.* 2008). This was in consistence with the trend observed with title-words. The thrust on microbial biopesticides was also apparent in the author keyword frequencies (Table 4). However, it should be noted here that comparison of keyword frequency as well as the fluctuation in keyword ranking may not be a true reflection

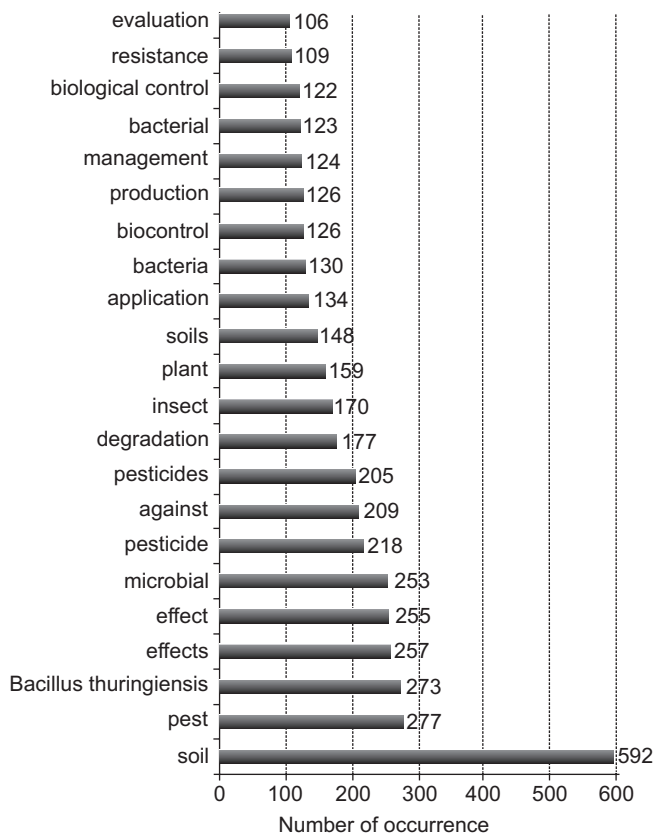


Fig 3 Top 22 title-words in biopesticide research appearing more than 100 times

of the state of affairs. This is because of two inherent characteristics of the keywords. Firstly, some terms have more than one expressible form. For instance, the term

Table 4 Frequency of keywords (> 50 times) used in global biopesticide research publications

| Author keyword                | 1971–2008 |          | 1971–95  | 1996–2008 |
|-------------------------------|-----------|----------|----------|-----------|
|                               | TA        | R (%)    | R (%)    | R (%)     |
| Biological control            | 188       | 1 (8.8)  | 4 (9.3)  | 1 (8.6)   |
| <i>Bacillus thuringiensis</i> | 165       | 2 (7.7)  | 5 (6.7)  | 2 (7.4)   |
| Microbial control             | 125       | 3 (5.8)  | 1 (12)   | 3 (5.5)   |
| Pesticides                    | 121       | 4 (5.6)  | 2 (12)   | 4 (5.3)   |
| Biopesticide                  | 112       | 5 (5.2)  | 19 (2.7) | 5 (5.2)   |
| Biodegradation                | 91        | 6 (4.2)  | 3 (10.7) | 6 (4.0)   |
| Biocontrol                    | 83        | 7 (3.9)  | 73 (1.3) | 7 (3.9)   |
| <i>Beauveria bassiana</i>     | 79        | 8 (3.7)  | 70 (1.3) | 8 (3.7)   |
| Degradation                   | 72        | 9 (3.4)  | 7 (5.3)  | 10 (3.2)  |
| Soil                          | 72        | 10 (3.4) | 6 (6.7)  | 11 (3.2)  |
| Biopesticides                 | 71        | 11 (3.3) | 77 (1.3) | 9 (3.3)   |
| Pesticide                     | 67        | 12 (3.1) | 8 (5.3)  | 12 (3.0)  |
| Integrated pest management    | 65        | 13 (3.0) | 9 (5.3)  | 13 (2.9)  |

TA, Total articles published in 38 years; R (%), ranking (percentage of all articles with keywords in the respective years)

*Bacillus thuringiensis*, in addition was expressed in three other forms: *B. thuringiensis*, *Bt*, *B.t*. Similar is the case with other generic terms like biopesticide, biocontrol etc. Secondly, the analysis was only for a total of 2,175 articles with author keywords information. Hence, the findings might be just approximate reflection of the scientific attention. Besides, during 1971–95, a total of 75 articles had author keywords, accounting for only 14% of the publications in those 25 years. In contrast, 70% of the publications made during 1996–2008 had author keywords. Thus, fluctuation in keyword ranking between these two periods might not be an indication of shift in biopesticide research thrust as such.

### RESEARCH PERFORMANCE

The common practice of judging the quality of research with citations/paper (cpp) rules out the influence of time. In general, a recent paper would receive fewer citations than a paper published 5 or 10 years back; except extraordinary papers. Citations received by a paper/year (cpppy) appeared to be a more accurate indicator of the quality of a paper. Total citations of each paper published during 1996 were divided by 13 because till 2008 each paper got 13 years for citation. The denominator was reduced by one unit for every subsequent year. Articles published in 2008 were excluded from the citation analysis, and also self citations of all the authors were excluded.

Altogether 9 828 authors were involved in biopesticide research during 1971–2008. The number of contributing authors have increased from 16 authors in 1971 to 1 544 authors in 2008; a growth of 20% per annum. However, the growth during 1996–2008 (27%) was higher as compared to that during 1971–95 (16%). During 1971–2008, altogether 2 176 institutes participated in biopesticide research. The numbers of participating institutes have reached to 512 institutes by 2008 at the rate of 33%. Among the 101 countries involved over the study period, 61 countries had no publication till 1995. Further, 29 countries just began to publish only after

2001; and only 14 countries have been continuously publishing since 1975. Though the numbers of authors, institutes and countries involved in biopesticide research have increased over the time, productivity has remained almost static. However, quality of biopesticide research appeared to be improving over the time; mean cpppy has increased from 1.8 in 1996 to 2.8 cpppy in 2007 (Table 5).

As only 2,943 articles had affiliation information, 29 articles (1%) have been set as benchmark for highly productive institutes. Agriculture Research Service division of the United States Department Agriculture (USDA-ARS) shared about 5.4% of the world publication and occupied the highest position in the list of most active global institutes (Table 6).

Table 5 Authors, institutes and countries engaged in biopesticide research during 1996–2008

| Year | A (Au) | Au   | A/Au | In  | A/In | C  | A/C | TC    | cpppy |
|------|--------|------|------|-----|------|----|-----|-------|-------|
| 1996 | 114    | 341  | 0.3  | 122 | 0.9  | 29 | 3.9 | 2 372 | 1.8   |
| 1997 | 118    | 366  | 0.3  | 153 | 0.7  | 35 | 3.2 | 1 804 | 1.5   |
| 1998 | 161    | 524  | 0.3  | 194 | 0.8  | 37 | 4.3 | 2 762 | 1.7   |
| 1999 | 179    | 564  | 0.3  | 211 | 0.8  | 38 | 4.6 | 4 101 | 2.6   |
| 2000 | 191    | 624  | 0.3  | 222 | 0.9  | 44 | 4.3 | 3 767 | 2.5   |
| 2001 | 211    | 763  | 0.3  | 246 | 0.8  | 44 | 4.8 | 3 262 | 2.2   |
| 2002 | 197    | 740  | 0.3  | 231 | 0.8  | 42 | 4.6 | 2 543 | 2.2   |
| 2003 | 249    | 881  | 0.3  | 350 | 0.7  | 52 | 4.7 | 2 611 | 2.1   |
| 2004 | 220    | 805  | 0.3  | 300 | 0.7  | 48 | 4.4 | 1 669 | 2.0   |
| 2005 | 280    | 989  | 0.3  | 363 | 0.8  | 57 | 4.8 | 2 111 | 2.5   |
| 2006 | 328    | 1196 | 0.3  | 426 | 0.8  | 56 | 5.8 | 1 513 | 2.3   |
| 2007 | 360    | 1444 | 0.2  | 495 | 0.7  | 57 | 6.2 | 1 003 | 2.8   |
| 2008 | 386    | 1544 | 0.3  | 512 | 0.7  | 58 | 6.6 |       |       |

Top institutes: 1996–2008

A (Au): Articles with author information; Au, no. of authors; A/Au, articles/authors; In, no. of institutes; A/In, articles/institute; C, no. of countries; A/C, articles/country; TC, total citations; cpppy, citations/paper/year

Table 6 World's top11 prolific institutes in biopesticide research during 1996–2008

| Institute                                     | Article | R (%)    | A/Y mean±SE | TC    | cpppy mean±SE |
|---|---------|----------|-------------|-------|---------------|
| USDA Agricultural Research Service            | 160     | 1 (5.4)  | 12.3±1.0    | 1 531 | 1.85±0.2      |
| University of California, Riverside           | 56      | 2 (1.9)  | 4.3±0.7     | 677   | 1.78±0.3      |
| Indian Council of Agricultural Research       | 50      | 3 (1.7)  | 3.8±1.3     | 142   | 0.64±0.5      |
| Zhejiang University                           | 48      | 4 (1.6)  | 3.7±1.2     | 269   | 0.73±0.3      |
| Council of Scientific and Industrial Research | 42      | 5 (1.4)  | 3.2±1       | 488   | 2.56±0.4      |
| Chinese Academy of Sciences                   | 39      | 6 (1.3)  | 3.0±1.8     | 96    | 1.01±0.4      |
| Agriculture and Agri-Food Canada              | 36      | 7 (1.2)  | 2.8±0.4     | 207   | 1.23±0.2      |
| Embrapa, Brazil                               | 32      | 8 (1.1)  | 2.5±0.6     | 369   | 2.58±1.6      |
| UC Davis                                      | 31      | 9 (1.1)  | 2.4±0.5     | 287   | 1.42±0.3      |
| Cornell University                            | 30      | 10 (1.0) | 2.3±0.6     | 257   | 2.36±0.9      |
| University of Florida                         | 29      | 11 (1.0) | 2.2±0.4     | 231   | 2.24±1.1      |

Top countries: 1996–2008

R (%): Rank (per cent share of world publication); A/Y: Articles/year; TC: Total citations; cpppy: Citations/paper/year

The second position was also occupied by an American Institute, University of California. Indian Council of Agricultural Research (3<sup>rd</sup>) and Council of Scientific and Industrial Research (5<sup>th</sup>) are two Indian institutes in the list of top contributors to global biopesticide research. However, in terms of quality of research output as judged from the cppy value, Embrapa, Brazil tops the list with 2.58 points followed closely by CSIR, India with 2.56 points. This indicates that the quality of biopesticide research done by Embrapa and CSIR is best among the contemporary institutes. Cornell University (2.36) and University of Florida (2.24) are another two institutes doing high-quality biopesticide research.

Among the countries, United States of America was the leader with 863 publications over the period 1996–2008 (Table 7). India came second in position in the list, however, with 64% less publication than those of USA. However, in terms of research quality, Switzerland overpowered others with a highest cppy of 3.1. England and Netherlands were following closely, each with 2.9 citations/paper/year.

#### RESEARCH COLLABORATION

In contemporary research, collaboration has been playing an ever increasing role. This is manifested usually in the form of internationally co-authored papers or domestic inter-institutionally-authored papers. This collaboration pattern can easily be tracked by bibliometric method (Schubert and Braun 1990). Among the 2,943 articles with affiliation

Table 7 World's top 20 prolific countries in biopesticide research during 1996–2008

| Countries      | Articles | R (%)    | A/Y<br>mean±SE | TC     | cpyy<br>mean±SE |
|----------------|----------|----------|----------------|--------|-----------------|
| United States  | 863      | 1 (29.3) | 66±3.1         | 11 313 | 2.4±0.2         |
| India          | 317      | 2 (10.8) | 24±3.7         | 1 076  | 0.8±0.1         |
| United Kingdom | 240      | 3 (8.2)  | 18±1.8         | 4 043  | 2.9±0.3         |
| China          | 188      | 4 (6.4)  | 14±4.2         | 473    | 1.2±0.3         |
| Canada         | 174      | 5 (5.9)  | 13±1.5         | 1 285  | 1.6±0.2         |
| Germany        | 155      | 6 (5.3)  | 12±1.6         | 1 737  | 2.4±0.3         |
| France         | 139      | 7(4.7)   | 11±1.3         | 1 824  | 2.5±0.3         |
| Australia      | 117      | 8 (4.0)  | 9±1.1          | 1 161  | 2.0±0.3         |
| Spain          | 100      | 9 (3.4)  | 8±1.7          | 690    | 2.1±0.6         |
| Brazil         | 97       | 10 (3.3) | 7±1.2          | 772    | 1.9±1.0         |
| Italy          | 90       | 11 (3.1) | 7±1.6          | 522    | 1.4±0.3         |
| Japan          | 80       | 12 (2.7) | 6±1.0          | 335    | 1.0±0.2         |
| Netherlands    | 65       | 13 (2.2) | 5±0.9          | 1 336  | 2.9±0.5         |
| South Korea    | 60       | 14 (2.0) | 5±1.0          | 202    | 0.9±0.2         |
| Denmark        | 57       | 15 (1.9) | 4±1.1          | 530    | 1.5±0.3         |
| Switzerland    | 54       | 16 (1.8) | 4±0.6          | 694    | 3.1±0.7         |
| Mexico         | 48       | 17 (1.6) | 4±0.7          | 218    | 1.2±0.2         |
| Belgium        | 38       | 18 (1.3) | 3±0.8          | 382    | 2.8±0.9         |
| Sweden         | 36       | 19 (1.2) | 3±0.8          | 185    | 1.7±0.5         |
| Turkey         | 31       | 20 (1.1) | 2±0.5          | 197    | 1.1±0.7         |

R (%), Rank (per cent share of world publication); A/Y, articles/year; TC, total citations; cppy, citations/paper/year

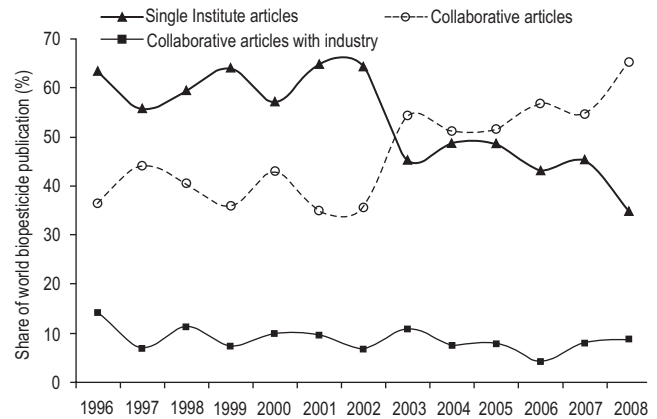


Fig 4 Trend in collaborative biopesticide research publication during 1996–2008

information, 53% were publications by single institute, and the rest were inter-institutional collaborative output, both national and international. Single institute articles were more prevalent during the earlier years and started declining continuously after 2003. In contrast, collaborative articles have increased steadily over the years (Fig 4). The number of inter-institutional articles have increased from 37% of world publication in 1996 to 65% in 2008. On the other hand, numbers of single institute articles have decreased from a share of 63% of the total publication in 1996 to 35% in 2008. It was obvious that increasing proportion of collaborative articles to world publication was somewhat owing to the rising number of institutes and countries that engaged in biopesticide research as evident earlier. During the study period, single institute output showed an overall negative average annual growth of 4% as compared to collaborative articles which increased at the rate of 6% per annum.

The domain of biopesticide is a product-oriented field of research. Industry is one of the important stakeholders in this area, who bring the findings of research to the end-users; and industry academia partnership in the research process is critical in the successful commercialization of research findings. As evident from Fig 4, participation of industry in global biopesticide research had been declining steadily which is not a good sign at all for world agriculture.

Among the world collaborative articles, 65% were domestic inter-institutional articles, and the remaining were international collaborative articles. As could be seen from Fig 5, national inter-institutional articles were more prevalent in recent years than earlier years; increasing its share of world collaborative articles from 68% in 1996 to 77% in 2008. On the contrary, share of international collaborative articles have decreased from 32% in 1996 to 23% in 2008. A higher scientific productivity from national inter-institutional collaboration indicates a stronger network of biopesticide research groups within the national boundary. This might have been influenced by the ease in establishing networks with similar national institutes and also the role of IPR and

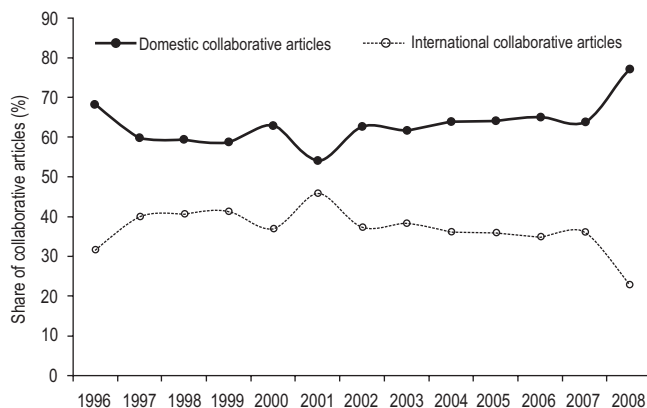


Fig 5 Localization of global biopesticide research

royalty that could be generated by commercializing the research products might not be ruled out totally.

### CONCLUSION

The study has provided significant insights into trends in biopesticide research. Virtually there were no scientific publications on biopesticide until 1970. However, significant growth was observed in biopesticide research, particularly in the period 1996–2008. Further, as the field matured, the focus has shifted towards development of newer and safer pesticides for agricultural use. Research on biopesticide has been dominated by microbial pesticides, particularly *Bacillus thuringiensis* research. Among the countries, United States was leading the path, followed distantly by India. Research collaboration has also increased more conspicuously in the recent years. However, the collaboration was more between national institutes. Collaborative research with industries, however, has seen 5% decline over the 12 years of observations.

Biopesticide, man's new found answer against pests and diseases appears to be responding well with time which is evident from the fact that the share of biopesticide in the global pesticide market has increased substantially from just 0.2% in 2000 to 2.5% in 2005 (Lerner 2005). In 2009, the global biopesticide market has reached worth US\$ 1.6 billion accounting about 3.9% of the global pesticide market (BCC 2010). In the next five years, the biopesticide market is expected to grow by compound annual growth rate (CARG) of 15.6% and is valued at US\$ 3.3 billion by 2014. In contrast, the overall pesticide market is expected to increase at a much slower rate (3%). The increasing market share has been possible due to development of cost-effective biopesticides which naturally is a direct impact of the global surge in biopesticide research. Thus, with the current pace of research and development, one could be optimistic of a much higher market share of biopesticide in the near future buttressed by tightening regulatory norms against chemical pesticides across nations as well as the growing demand of organically produced food.

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