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A bibliometric assessment of ASEAN collaboration in plant biotechnology

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Abstract This study draws on publication and citation data related to plant biotechnology from a 10-year (2004–2013) period to assess the research performance, impact, and collaboration of member states of the Association of Southeast Asian Nations (ASEAN). Plant biotechnology is one of the main areas of cooperation between ASEAN member states and among the research areas promoted to achieve regional food security and sustainable development. In general, findings indicate increased scientific output, influence, and overall collaboration of ASEAN countries in plant biotechnology over time. Research performance and collaboration (domestic, regional, and international) of the region in plant biotechnology are linked to the status of the economic development of each member country. Thailand produced the most publications of the ASEAN member states while Singapore had the highest influence as indicated by its citation activity in plant biotechnology among the ASEAN countries. Domestic and international collaborations on plant biotechnology are numerous. Regional collaboration or partnership among ASEAN countries was, however, was found to be very limited, which is a concern for the region's goal of economic integration and science and technology cooperation. More studies using bibliometric data analysis need to be conducted to understand plant biotechnology cooperation and knowledge flows between ASEAN countries.

Keywords Bibliometrics · International research collaboration · Plant biotechnology · ASEAN · Scientific productivity

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Introduction and rationale

For more than three decades, organizations and individual scientists in many parts of the world have recognized the importance of working together in areas like plant biotechnology—a set of technologies used to achieve food security, sustainable development of agriculture, forestry, and the food industry, and feeding a growing global population (Cohen 2001; Food and Agriculture Organization 2013; World Food Prize 2013). The applications of plant biotechnology range from relatively straightforward and inexpensive procedures of tissue culture to advanced applications of molecular biology, including genetic engineering (Hautea and Escaler 2004). International collaborative efforts in plant biotechnology have been broad, ranging from implementing joint research projects in genomics and molecular-assisted selection to building human and institutional capacities, including training, information dissemination, and infrastructure development, in biosafety, bioinformatics, genetic engineering, and policy development activities. These partnerships have occurred within frameworks of formal intergovernmental, multilateral and bilateral agreements or a variety of less formal arrangements from handshakes between scientists to institutional cooperation. International collaborations have helped institutions and scientists monitor new developments and exchange technology and know-how in plant biotechnology research (Gibbons et al. 1994; Hagedoon et al. 2000; Royal Society 2011; National Science Board 2012), build capacity and develop research policy (Komen 1999).

Since 1983, member states of the Association of Southeast Asean Nations (ASEAN) have declared biotechnology as the main area of cooperation in science and technology. ASEAN, a regional association comprising Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar (Burma), Philippines, Singapore, Thailand, and Vietnam, has declared plant biotechnology as the next pillar of regional economic growth (Hautea and Escaler 2004; Erbisch and Maredia 1998; Karihaloo and Perera 2010) and the resolution to their food security issues. These countries have individually put investments in biotechnology research and its regulation (Cohen et al. 2004). However, because ASEAN member states are in different stages of development, only few of these countries are already reaping benefits from the development and commercialization of plant biotechnology (James 2012, 2013).

During the last two decades, bibliometric tools and indicators (e.g., publication and citation data) have been tapped to understand the evolution and collaborative nature of plant biotechnology in some countries. Dalpe (2002) used bibliometric tools to analyze the evolution of biotechnology research and did a case study of plant genetic research, with special emphasis on Canada. Pereira (2000) likewise did a bibliometric study on Portuguese biotechnology research while Gastrow (2008) focused on biotechnology research and development in South Africa. Sevukan et al. (2007) analyzed the research output and collaborative patterns in the plant sciences, including biotechnology, of 11 universities in India. Lo (2007) used bibliometric tools to analyze the patenting activities of genetic engineering research in Japan, Korea, and Taiwan.

The rapid economic growth of ASEAN member states as the major emerging economies of Asia and their future contributions to the generation of knowledge and innovation in the region and worldwide likewise attracted interest in bibliometric studies in the region (e.g., Hassan et al. 2012; Shari 2012; Moed and Halevi 2014; Kumar et al. 2014). However, studies on plant biotechnology coperation within ASEAN nations and their global partners using bibliometric tools have not been published. Most existing literature on ASEAN's plant biotechnology focused on the status and prospects of plant biotechnology in individual countries (e.g., Hautea and Escaler 2004) while reports on collaboration are mainly

focused on capacity building, policy development, and training (e.g., ASEAN 2009). By drawing on bibliometric data, this study will hence add to our understanding of the level and nature of collaboration, including research performance of ASEAN countries in plant biotechnology. The research questions addressed in the paper are as follows:

(1) What is the trend in knowledge production, quality of research, and collaboration of ASEAN and its member states in plant biotechnology? How do their profiles compare with each other? Which ASEAN countries are top generators of knowledge in plant biotechnology? How do ASEAN publications and citations in plant biotechnology compare with overall total of ASEAN publications and citations?
(2) Do the development stage of an economy and research investments contribute to the differences, if any, in the research output, impact, and the state of collaboration in plant biotechnology among ASEAN countries?
(3) Are ASEAN members collaborating among themselves in plant biotechnology?Which ASEAN country is co-publishing the most or least with other ASEAN nations? Is this linked with the status of economic development? How is regional collaboration affecting ASEAN's scientific output and quality of research?
(4) Do ASEAN countries actively seek global cooperation in plant biotechnology? Who are their most common international research partners? Do these collaborations contribute to increasing the influence and recognition of ASEAN's plant biotechnology research?

The target year for regional economic integration for ASEAN nations is 2015. Successful economic integration of the constituent countries of ASEAN will result to an ASEAN Economic Community that is expected to elevate the status of the region as a major economic growth force in Asia (ASEAN 2015). This study will help to provide evidence on if regional cooperation in plant biotechnology is truly occurring among the ASEAN countries. Our research questions and results are therefore relevant to the ASEAN secretariat, the member countries, and policy makers in charge of setting directions and designing strategies for research cooperation, and in planning research investments, especially in biotechnology, at the country, regional, and international levels.

The remainder of this paper is organized as follows. "Data sources and methods" section describes the different data sources and the methodology adopted in this study and the different indicators and indexes used to analyze ASEAN collaborations in plant biotechnology. Results and discussion section presents the results from our bibliometric analysis and a discussion of the implication of these results. Conclusion and recommendations section offers conclusions and recommendations from this study.

Data sources and methods

This bibliometric study is based on publications in plant biotechnology from 2004 to 2013 authored and co-authored by scientists in the 10 member states of ASEAN. The data were extracted from Elsevier's Scopus database, the world's largest abstract and citation database of peer-reviewed literature (Elsevier 2014). A basic search strategy was first used to locate plant biotechnology-related publications for the ASEAN countries: article title, abstract, keywords = "plant biotechnology", affiliation country = "Brunei"; date range = "2004–2013". Likewise, various keyword combinations drawn from the glossary of biotech terms by the US National Institute for Food and Agriculture (NIFA 2014) and

Table 1 Keywords used to search Scopus for plant-biotech related publications of ASEAN

	Keywords
A	*Agrobacterium tumefaciens*; Agrobacterium; agribiotechnology; agrobiotechnology
B	Biotech; biotechnology; biotechnologies; *Bacillus thuringiensis*; Bt;
C	Cell; clone; cloning; Cry1A; crop biotechnology
D	DNA; DNA marker(s); DNA shuffling
G	Gene(s); genetic(s); gene expression; genetic analysis; genetic engineering; genetic marker(s); genetically modified organism(s); genotype; GMO; genomic(s); genome
H	Hybridization
M	Mapping; molecular biology; molecular cloning; molecular marker(s); molecular mapping; molecular sequence; mutation
N	Nucleotide
P	Phage; plasmid(s); plant breeding; plant genetics; plant protein(s); plant science; plant transformation; Polymerase chain reaction; protein engineering
R	Recombinant DNA molecules; recombinant DNA technology; resistance; RNA
S	Selectable marker(s); site directed mutagenesis
T	Tissue; Tissue culture; Transgenic(s)
V	Vector(s); virus

the National Agricultural Library Agricultural Thesaurus (National Agricultural Library 2014) were used to locate more plant biotechnology-related publications for the region; see Table 1 for a list of keywords. The search strategy then included the use of the word "plant" and one of these keywords (e.g., "agribiotechnology"): "article title, abstract, keywords = plant and agribiotechnology; date range = 2004–2013. An additional filter was then set according to the affiliation country to include only the publications published by the 10 ASEAN countries. Scopus uses the location of the affiliation of at least one author of the published paper to identify publications originating from particular countries. No filter was set for the type of publication; all document types, including article, review, conference paper, short survey, note, editorial, letter, book chapter, book, and article in press were included. The citation information (author name, document title, publication year, source title, citation count, source and document type) and bibliographical information (affiliations) of these publications were then extracted from Scopus and saved as text files.

The resulting 'ASEAN' dataset, which was composed of 79 individual text files, represent the publication output of the 10 ASEAN countries in plant biotechnology for 2004–2013. These files were then loaded into a proprietary, non-commercial home-grown 'publication parser' tool (Sutton 2013). This publication parser tool, which was developed in-house at Washington State University, was useful in parsing the various text files for analysis of various indicators of interest at the country and institutional levels. The tool was also useful in helping to deconstruct unique authors per publication based on the authors' Scopus ID and the authors' names, linking these names to their current affiliation to determine countries of authorship. The tool was used to insert the Scopus author IDs and affiliation IDs into the dataset such that we can claim 99 % accuracy on disambiguation of authors. This process of inserting IDs into the dataset allowed us to determine within a 97 % confidence interval that Scopus is able to

provide 99 % accuracy in its disambiguation process (see e.g. Cheng 2006). The tool also has the capability to identify missing values and potential discrepancies in the dataset, such as multiple affiliation IDs of institutions. Some universities or institutes have multiple affiliation IDs, with some specific to a particular campus or department. Combining these multiple affiliation IDs was essential to creating a dataset that could be used to identify which universities or institutes were contributing the most publications. The tool was designed to combine affiliation IDs before the institutional analysis was conducted. Overall, this tool, which was also tested on other datasets, offered 97–98 % accuracy rates as compared with the total counts provided by Scopus, and was helpful in organizing and improving the Scopus data.

The methodology, including the interpretation of the different indicators, is built on best practices in indicators research (Moed et al. 2004). The analyses of bibliometric data are based on the following indicators:

a. Publication count—the number of research papers related to plant biotechnology written by ASEAN researchers.
b. Author count—the number of unique names of scientists involved in the total publication count by each ASEAN country.
c. Compound annual growth rate (CAGR)—a standard method to measure change over time. CAGR is the year-on-year constant growth rate over a specified period of time.
d. Type of publication—article, review, conference paper, short survey, note, editorial, letter, book chapter, book, and article in press.
e. Top producers—institutions with the highest number of publications per ASEAN country.
f. Citation count—the total number of citations received by each ASEAN country for all of their plant biotechnology-related articles.
g. Citation per publication (CPP)—the total number of citations divided by the total number of publications.
h. Collaboration rate—the intensity of collaboration of ASEAN nations at different levels (domestic, regional, and international) computed by dividing the number of co-authored papers with a collaborator by ASEAN's total publication output.

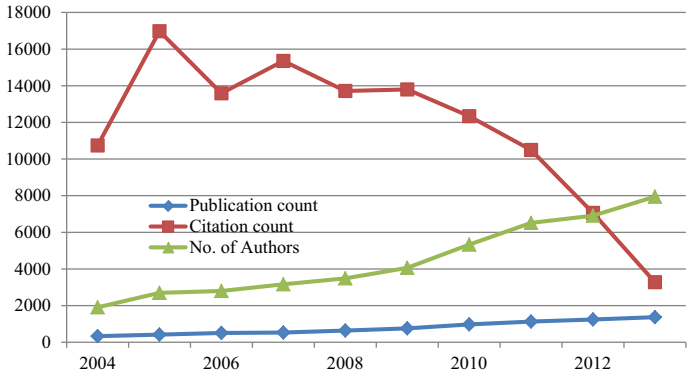

Fig. 1 Growth in the overall number of publications and citations for ASEAN countries in plant biotechnology, 2004–2013. *Source*: Scopus

Results and discussion

Publication output and citation impact

The quantity and quality of research output of ASEAN countries was assessed by publication output and citation impact, the two commonly used metrics to understand research performance and impact (Moed et al. 2004; Adams 2009; Rosas et al. 2011).

The scientific output of ASEAN nations in plant biotechnology, which represent 2 % of ASEAN's total publications (Elsevier 2015), shows a steady upward trend (Fig. 1). From 2004 to 2013, ASEAN researchers produced 7907 papers related to plant biotechnology with the annual output increasing by 15 % per year. The highest publication count in plant biotechnology for ASEAN nations was in 2013 while the lowest publication count was in 2004.

There were more than 13,170 unique authors identified for all ASEAN publications in this dataset. The number of authors publishing plant biotechnology in ASEAN countries strongly correlates ($r^2 = 0.98$) with the publication output and has increased steadily from 2004 to 2013 (Fig. 1) with numbers reaching close to 8,000 authors in 2013 compared with fewer than 2,000 authors in 2004.

The plant biotechnology literature produced by ASEAN scientists has appeared in different types of publication sources, with the majority of them published as articles in journals. Most of these articles have been published in less selective journals, such as Plos One, which is a peer-reviewed, online, open-access resource from the Public Library of Science. Plos One publishes a high number of papers online, making it less selective. By using open access journals, ASEAN plant biotechnology researchers are able to share their studies with a wide audience without restriction anywhere in the world, especially in less-developed nations where access to other journals may be too expensive.

Citation counts, a measure of the impact of scientific and scholarly work (Cole 2000; Garfield et al. 1983) indicate that the research output in plant biotechnology by ASEAN researchers is being used by their colleagues. ASEAN's plant biotechnology publications from 2004 to 2013 have been cited more than 117,000 times. Citation to ASEAN's publications was highest in 2007. Older publications are naturally cited more than newer publications because they have been in the public domain longer (Waltman et al. 2011; Colledge and Verlinde 2014). It is hence not surprising that the aggregate citation counts for all plant biotechnology publications from ASEAN countries followed a downward trend in the most recent years under study (Fig. 1). However, if we exclude the last three years in the analysis and cover only 2004–2010, the citation count for studies from ASEAN countries on plant biotechnology has a relatively stable pattern. The average citation per publication (CPP) for plant biotechnology publications of scientists from ASEAN countries (19.81) is likewise more than two times higher than the average CPP of all ASEAN publications (8.4) (Elsevier 2015), indicating higher influence of plant biotechnology publications than publications in other research areas.

Country output and research investments

We then classified the ASEAN countries into the following three groups based on expenditures on research and development (R&D) (UNESCO Institute for Statistics 2015) to understand the link between the quantity of research output and research investments: (1) high income countries with R&D spending greater than 1 % of gross domestic product

(GDP); (2) middle income countries with R&D spending of 0.1–0.9 % of GDP; and (2) lower-middle income countries with R&D spending of 0.0–0.09 % of GDP. Singapore is classified as a high income country; Malaysia, Philippines, Thailand, and Vietnam as middle income countries; and Brunei, Cambodia, Indonesia, Laos, and Myanmar are classified under lower-middle income countries.

There is an obvious difference in the publication output in plant biotechnology from higher income countries with larger investments in R&D compared with that of lower income countries with smaller research investments (Table 2). Thailand produced the highest number of publications ($n = 2489$). Malaysia and Singapore are the other top producers with more than 150 PPY and CAGR of 29 and 9 %, respectively. Philippines with a CAGR of 8 % and Vietnam with a CAGR of 19 % produced an average of 75 and 41 PPY, respectively. Lower middle-income countries, namely Brunei, Cambodia, Laos, and Myanmar experienced zero publication growth during the 10-year period and produced only an average of 1–2 papers per year. Interestingly, despite its low R&D investments and hence its classification as a lower-middle income country, Indonesia was able to produce 61 PPY and is growing at 12 % CAGR.

The number of authors contributing to the publications on plant biotechnology from most ASEAN countries, except for the lower-middle income countries of Brunei, Cambodia, and Laos, is growing (Fig. 2). An increase in the number of contributing authors is noted for Malaysia; the number of authors contributing to plant biotechnology publications in Malaysia from 2004 to 2013 has increased by almost 15 fold. This finding supports the increasing number of R&D personnel in Malaysia found in UNESCO Statistics (UNESCO Institute for Statistics 2015).

The institutions publishing plant biotechnology-related articles in the region are mostly local public research universities (Table 3). These include: University Brunei Darussalam (Brunei), Bogor Agricultural University (Indonesia), National University of Laos (Laos),

Table 2 Comparison of 2004 and 2013 article output, CAGR, and citation count for ASEAN (sorted by CAGR in declining order)

Country	Country classification based on research investments	Publication output	2004	2013	CAGR (%)	Citation count
Malaysia	Middle-income country	2,199	39	510	29	14,584
Vietnam	Middle-income country	418	14	83	19	3,957
Thailand	Middle-income country	2,489	108	377	13	27,863
Indonesia	Lower middle-income country	611	33	104	12	7,208
Myanmar	Lower middle-income country	23	1	3	12	180
Singapore	High-income country	1,594	101	234	9	49,094
Philippines	Middle-income country	757	46	104	8	14,492
Cambodia	Lower middle-income country	6	1	0	−100	135
Brunei	Lower middle-income country	35	0	0		157
Laos	Lower middle-income country	10	0	3		186
Total		7,907				11,7856

Source: Scopus

CAGR of Cambodia and Brunei resulted in undefined values and left blank in this table. The classification of country was based on gross domestic expenditure on research and development: (1) high income countries, >1 %; (2) middle income countries, 0.1–0.9 %; and (3) lower middle-income countries, 0.0–0.09 %. Source: UNESCO Institute for Statistics, 2015

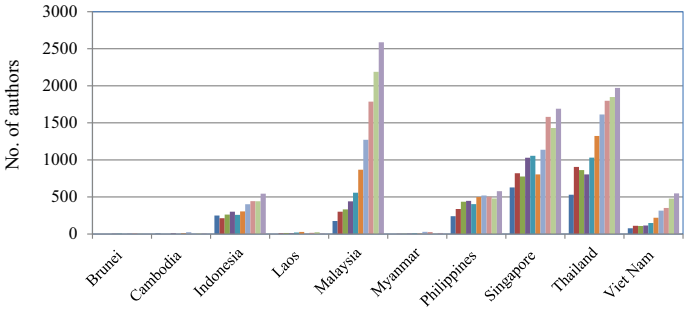

Fig. 2 Trends in the number of authors for ASEAN publications in plant biotechnology, 2004–2013. *Source*: Scopus

Table 3 Overview of ASEAN publications in plant biotechnology, 2004–2013

Country	No. of contributing authors	Top producer (no. of publications)	Top source type (%)
Thailand	12,688	Mahidol University (616)	Article (90.32 %)
Singapore	10,953	National University of Singapore (1261)	Article (85.73 %)
Malaysia	10,511	University of Malaya (391)	Article (86.80 %)
Brunei	30	University of Brunei Darussalam (3)	Article (100 %)
Philippines	4,444	International Rice Research Institute (774)	Article (82.57 %)
Indonesia	3,421	Bogor Agricultural University (89)	Article (85.71 %)
Vietnam	2,474	Institute of Biotechnology (37)	Article (91.37 %)
Laos	136	National University of Laos (6)	Article (87.50 %)
Myanmar	100	Yezin Agricultural University (6)	Article (100 %)
Cambodia	64	Cambodian Agricultural Research and Development Institute (3)	Article (100 %)

Sorted by number of contributing authors in declining order. *Source*: Scopus

University of Malaya (Malaysia), Yezin Agricultural University (Myanmar), National University of Singapore (Singapore), and Mahidol University (Thailand). The latter two universities were included in the top 100 Asian universities by the Times Higher Education Asia (Times Higher Education 2015). In Cambodia, Vietnam and Philippines, the top producers of publications on plant biotechnology were research institutions and include the Cambodian Agricultural Research and Development Institute, Institute of Biotechnology, and International Rice Research Institute (IRRI), respectively. The two former institutions are leading national research institutions in bioscience and plant biotechnology whereas IRRI is an international research organization.

With higher numbers of publications, the higher income countries received more total citations than did the lower income countries (Table 2). Singapore is the most highly cited in plant biotechnology followed by Thailand, Malaysia, and Philippines. With the exception of Indonesia, the lower income countries namely, Cambodia, Brunei, Myanmar, and Laos received the fewest citations for their plant biotechnology publications during the last two decades.

Collaboration

Co-authorship is a widely used proxy for measuring research collaboration. Studies by Abramo et al. (2009), Glanzel (2001), Glanzel and Schubert (2004) and Melin and Persson (1996) have established the use of co-authorship as indicators of collaborative trends at the institutional, national, or international levels, and these studies use co-authorship data to understand scientific networks and partnerships.

This paper distinguishes four types of research collaboration: (1) domestic—in which all authors are in the same country; (2) regional—in which one ASEAN author co-authored with another ASEAN author from another ASEAN country; and (3) international—in which authors in the ASEAN countries published together with at least one author (non-ASEAN) from another country (Jung 2012). Single authorship and publications that involved intra-institutional co-authorship are not classified as collaborations. These four types enabled identification of publications solely published by ASEAN researchers and research that involved international collaborative work. Figure 3 presents a decision tree adapted from Lan (2014) for classifying collaboration types. Figure 4 shows the collaboration levels of ASEAN countries for 2004–2013 in plant biotechnology for all collaboration types whereas Fig. 5 presents the different types of collaborations for individual ASEAN countries.

Single author publications and publications that involved intra-institutional co-authorship constitute only 15 % of ASEAN's total publications in plant biotechnology.

Eighty-five percent of ASEAN's total publications in plant biotechnology involved collaboration, which has a CAGR of 15 %. Interestingly, the most active institutions that engaged in collaborations in ASEAN are universities and institutions of higher education. This is an indication that these institutions are now actively seeking strategic research partnerships to produce and disseminate knowledge in addition to their primary role of educating future knowledge generators and users. The highest number of co-authored publications by ASEAN authors in plant biotechnology was recorded in 2013 ($n = 1169$) while the lowest number was recorded in 2004 ($n = 288$). These results confirm the observation that plant biotechnology research in ASEAN countries is increasingly

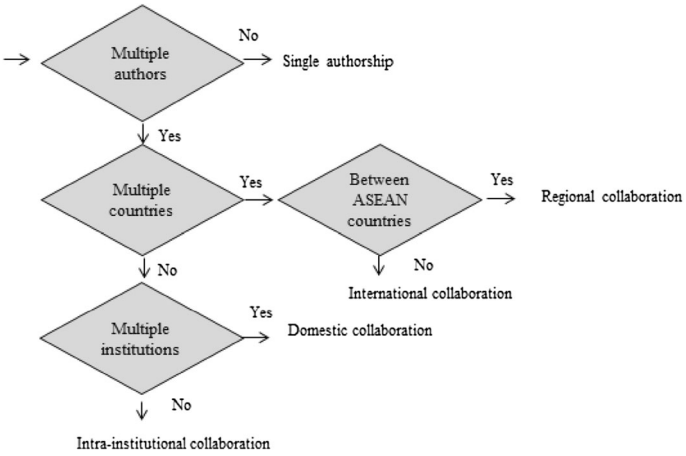

Fig. 3 Decision tree used to classify collaboration types. Adapted from Lan (2014)

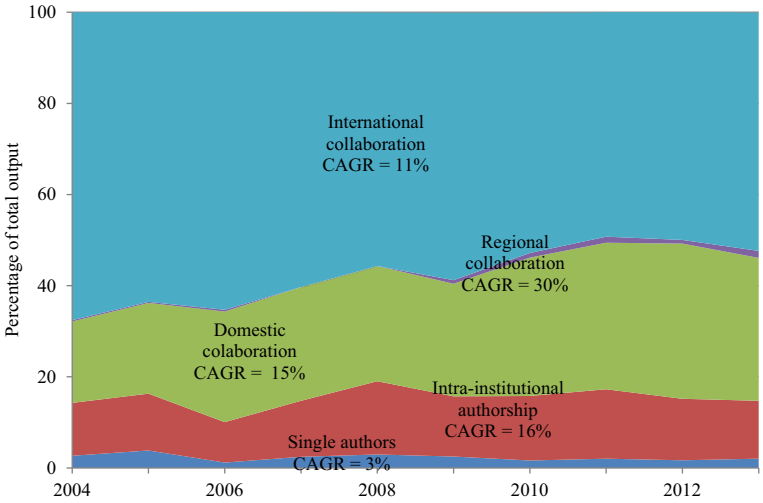

Fig. 4 Percentage of different types of collaboration for ASEAN countries combined in plant biotechnology, 2004–2013. *Source*: Scopus

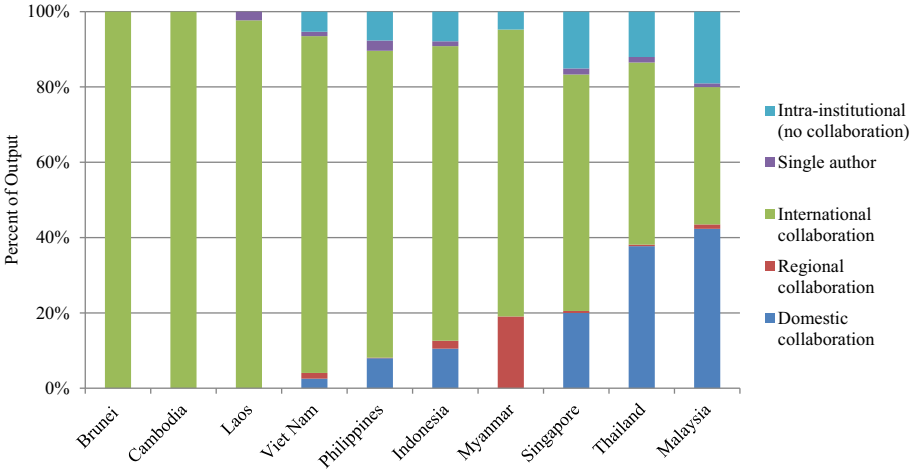

Fig. 5 Percentage of different types of collaboration for individual ASEAN countries in plant biotechnology, 2004–2013. *Source*: Scopus

conducted by a group of collaborating researchers rather than by single researchers (Glanzel 2001; Ding et al. 1998; Glänzel 2002). Price (1986) attributed the rise in shared authorship to Big Science—scientific experiments that require collaboration and specialization of many individuals (Galison and Hevly 1992). This collaborative culture is also increasingly encouraged especially in research areas that address scientific questions dealing with global challenges (Stvilia et al. 2011).

About 34 % of ASEAN publications involved domestic collaborations. The region's co-authored publications that involved domestic partnerships are growing at a CAGR of 15 %.

Table 4 Co-publication matrix and collaboration rate between ASEAN countries. *Source*: Scopus

	Brunei	Cambodia	Indonesia	Laos	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam
Brunei Darussalam	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cambodia	0.00	100.00	0.00	5.56	0.00	0.00	0.09	0.00	8.33	0.00
Indonesia	0.00	0.00	100.00	2.78	2.16	3.85	0.97	1.25	1.53	1.25
Laos	0.00	5.56	2.78	100.00	0.00	0.00	8.33	0.00	19.44	8.33
Malaysia	0.00	0.00	2.16	0.00	100.00	3.85	1.24	1.78	0.89	2.78
Myanmar	0.00	0.00	3.85	0.00	3.85	100.00	0.09	0.05	0.29	0.20
Philippines	0.00	0.09	0.97	8.33	1.24	0.09	100.00	0.67	2.30	3.98
Singapore	0.00	0.00	1.25	0.00	1.78	0.05	0.67	100.00	0.67	1.19
Thailand	0.00	8.33	1.53	19.44	0.89	0.29	2.30	0.67	100.00	0.71
Viet Nam	0.00	0.00	1.25	8.33	2.78	0.20	3.98	1.19	0.71	100.00

The highest number of publications that involved domestic collaborations was recorded in 2013 ($n = 430$) while the least was recorded in 2004 ($n = 60$). Six ASEAN members were engaged in domestic collaborations with the three higher income countries of Malaysia, Thailand, and Singapore having the highest percentage of domestic collaborations at 42, 37, and 20 %, respectively. The lower-middle income countries of Brunei, Cambodia, Laos, and Myanmar had no record of domestic collaborations.

ASEAN publications that involved regional collaboration are very limited with less than 1 % of the total collaborations. The highest number of publications that involved regional collaborations was recorded in 2013 ($n = 21$); there was no regional collaboration noted for 2007 and 2008. Ironically, 2007–2008 were the early years of the adoption of ASEAN's Economic Blueprint, which served as the guide for the establishment of the ASEAN Economic Community. All the higher income countries have co-authored with another ASEAN country although the numbers are quite limited (Table 4). Philippines and Thailand have collaborated with all of the ASEAN countries except Brunei. Among the lower income countries, Laos and Myanmar are two of the most active in regional collaborations despite their late membership to the regional association. Both countries have strong regional collaborations with Thailand, their closest ASEAN neighbor; Laos and Thailand used to be one country (Siam) and have basically the same language, making collaborations easy. Brunei has no record of collaborations with any of the ASEAN members.

Growing internationalization of plant biotechnology research is, however, noted for ASEAN nations. The region had a very high rate of international collaboration in plant biotechnology research during 2004–2013 at 65 % and the rate of collaboration is growing at a CAGR of 11 %. Similar to the domestic and regional collaborations, the highest number of publications that involved international collaborations was recorded in 2013 ($n = 227$) while the lowest was recorded in 2004 ($n = 717$). From 2004 to 2013, authors in ASEAN nations have partnered with 115 countries on plant biotechnology publication. These 115 nations were in varying stages of economic development. The United States, the country with the largest investment in biotechnology and a very close partner and large investor in Asia, remains the main international research partner of choice among ASEAN countries. ASEAN researchers in plant biotechnology are also tapping into the research expertise and resources of other Asian nations like Japan, China, South Korea, and India and advanced countries like the United Kingdom, France, Germany, Canada, and the Netherlands. This finding supports the observation of Arunachalam and Doss (2000) that Asian countries are quickly increasing their share of worldwide international collaboration in science and expanding collaborations beyond traditional collaborations with advanced nations such as the United States.

Lower income ASEAN countries are particularly noted for their very high international collaboration: 96–100 % of total publications from Brunei, Cambodia, and Laos were written with foreign partners. These collaborations could have been established in order for these countries to improve their research expertise, expand their visibility in the international plant biotechnology arena, and increase their research output despite limited research investments. Interestingly, the higher income countries and the top ASEAN producers, namely Malaysia, Thailand, and Singapore, have lower scientific output with the international community compared with other ASEAN countries, which validates the observation that these countries now have better domestic research capability and, hence, would not need as much international collaboration as the lower income countries need.

As expected, ASEAN publications that involved international partnerships received the highest citation count ($n = 86{,}423$) whereas publications that involved regional

collaborations received the lowest citation count ($n = 547$). These results support the observations of Katz and Hicks (1997) and Rigby (2009) that international collaborations tend to produce more highly cited papers than do collaborations of people in a single country. It is interesting to note that despite the regional collaborations involving more authors and one or more ASEAN countries, the citation count was lower compared to that for single-author publications or publications that did not involve collaborations (Fig. 6). This indicates the low quality of publications resulting from regional partnerships.

Conclusion and recommendations

Based on bibliometric data for the period 2004–2013 extracted from Scopus and deconstructed by a proprietary, non-commercial home-grown publication parser tool, this paper investigates the research collaborations of ten ASEAN member countries at the domestic, regional, and international levels in the area of plant biotechnology and ASEAN's contributions to advancing plant biotechnology research.

Analysis of the 10-year period indicated an increase in ASEAN plant biotechnology-related scientific output, which represents 2 % of total publications for ASEAN. The publication activity obviously varies from country to country but it is evident that this activity is linked with R&D investments. More publications came from countries that are classified as high income (Singapore) and middle income (e.g., Thailand) versus lower-middle-income (e.g., Brunei). It is also worth mentioning that except for the Philippines, the top generators of knowledge for the rest of ASEAN were all affiliated with local research institutions, indicating improvements in domestic research capability.

The scientific output on plant biotechnology from Singapore, Thailand, and Malaysia provides a good indication that more literature, especially scholarly or peer-reviewed articles, will be published on the subject from these countries. Generating more scholarly

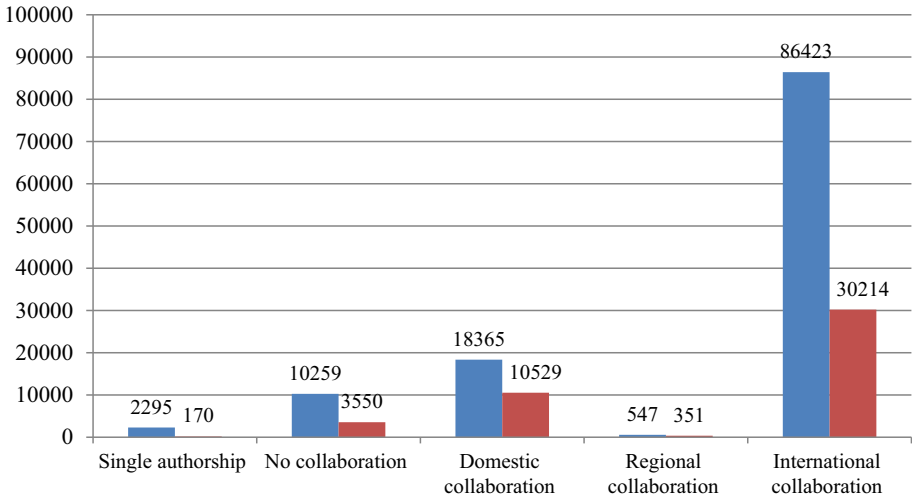

Fig. 6 Citation counts and number of authors for the different types of collaboration for ASEAN publications in plant biotechnology, 2004–2013. *Source*: Scopus

articles that are often referenced in academic research papers and publishing them in open access journals would help further increase ASEAN's visibility and influence in advancing the field of plant biotechnology. The growth in the publication records, especially of Indonesia and Viet Nam, supports the increasing commitment of these countries and their researchers to advancing the plant biotechnology field. Other ASEAN members need to further strengthen their R&D capability to improve productivity and impact in plant biotechnology. Philippines, for instance, needs to incentivize its local research and academic institutions to produce more output and to increase scientific output and not only rely on international institutions to boost the country's scientific productivity. Brunei, Cambodia, Laos, and Myanmar need to improve their research infrastructures and increase their research investments to show commitment to advancing the plant biotechnology field in their respective countries.

The increasing number of collaborative research teams and the number of contributing authors in ASEAN publications over the course of the 10-year period, however, is an encouraging result. These increases suggest an increase in the pool of researchers and a change in the balance of research focused more on collaborative teams among ASEAN researchers and their partners and not on lone scientists. This upward trend in multi-authorship is expected to continue given global priorities in agriculture, food security, and climate change using plant biotechnology tools.

Scientific collaborations are increasingly portrayed as important enablers of plant biotechnology research and the ASEAN nations are tapping into this potential to advance their plant biotechnology programs. All 10 ASEAN countries are actively engaged in research collaborations in plant biotechnology although to varying degrees. The publication output by countries in terms of the collaboration types—domestic, regional and international—differ and is linked with the status of economic development. Domestic collaborations are very strong among higher income countries with higher research investments while lower income countries with lower research investments tend to publish more with their international counterparts.

ASEAN's publications that involved international collaboration are contributing to the quickly increasing share of worldwide international collaboration in science. Preference for partnership with more advanced nations is noted but at least the region has expanded beyond collaboration only with the United States.

Partnerships among ASEAN members are very limited, which could be a concern for ASEAN's goal of integration. A higher regional collaboration rate is observed among countries that are in close proximity to each other, with common language, and with historical links. Kumar et al. (2014) made a similar observation after doing bibliometric work in the field of economics. The low regional collaboration was also mentioned in a recent report by the Asian Development Bank entitled, "Regional Cooperation and Cross-Border Collaboration in Higher Education in Asia: Ensuring that Everyone Wins".

ASEAN regional collaboration lags behind in terms of productivity and quality in plant biotechnology, which is very evident from the region's low research output and citation count for publications co-authored among ASEAN researchers. It remains to be seen whether regional collaboration will serve as a vehicle for continuing to modernize plant science in ASEAN and for sharing knowledge in plant biotechnology. More investments in research cooperation, funding mechanisms for regional plant biotechnology research, and other incentives need to be setup so ASEAN can make greater impact in the field of plant biotechnology. Regular quantitative monitoring of inputs and outcomes of research in ASEAN nations is likewise encouraged to help in developing research management and

science policies. Future studies can focus on the further assessment and mapping of research collaboration network among ASEAN researchers and their global partners and on a brain circulation study to understand the mobility of ASEAN researchers and whether such movement helps to increase regional productivity and collaborations and whether such benefits flow back to ASEAN. Furthermore, a qualitative study that would determine other factors that influence an ASEAN researcher to collaborate with another ASEAN researcher or with a global partner is suggested.

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