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Mapping biological control research: A systematic review of 20 years of research in Indonesia

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Mapping biological control research: A systematic review of 20 years of research in Indonesia

R Novita[1], D Buchori[1,3], B Istiaji[1], and AU Seminar[2,3]

[1] Departement of Plant Protection, Faculty of Agriculture, IPB University, Bogor, Indonesia.
[2] Departement of Communication Science and Community Development, Faculty of Human Ecology, IPB University, Bogor, Indonesia.
[3] Center for Transdisciplinary and Sustainability Sciences (CTSS), IPB University, Bogor, Indonesia.

*Corresponding email: damayanti@apps.ipb.ac.id

Abstract. Biological control research in Indonesia has a long history since it was started by Dutch scientists more than 100 years ago. Currently, the number of research has arisen, but there has been no systematic analysis of how this research produces technology that can be practiced in the field. This analysis is essential since it provides baseline information about biocontrol research and provides future research direction. This study aims to conduct a systematic review of biocontrol research conducted in Indonesia over the past 20 years. All articles were obtained from various databases using keywords related to biocontrol. A total of 437 articles were analyzed. We focussed our research on predators and parasitoids and found 269 articles related to parasitoids and predators. We found that biocontrol research in Indonesia was dominated by research on insect pathogens. Further analyses showed that research on identification and biology dominated most of the studies on predators and parasitoids. Almost all the research that was conducted addressed the basic biology of different types of natural enemies for different crops' pests but has not addressed the full-scale host-parasitoid research that is needed to develop natural enemies that are ready to be released on a large scale. Four natural enemies have been reported in large-scale applications: *Anagyrus lopezi*, *Lanius schach*, *Trichogramma* spp., and *Tetrastichus brontispae*. There is limited research on the mass release of parasitoids or predators in the field. Most of the research on releases was focussed on the short-term establishment without long-term evaluation and measure of success. It leads to a knowledge gap in biological control research and should become one of the future research directions.

Keywords: parasitoid, predator, measure of success, natural enemies, agriculture, systematic literature review

1. Introduction

Biological control or biocontrol is defined as using natural enemies to combat pests, weeds, or pathogens, directly or indirectly, for human good. Natural enemies in the terminology of biological control of pests refer to three groups: parasitoids, pathogens, and predators [1]. Globally, pests were the most researched target organisms compared to weeds and pathogens [2].

Biological control has been practiced around the world. One of the biological control approaches is introducing natural enemies from other countries. BIOCAT, a database documenting global insect introductions for the biocontrol of other insects, reported that 5715 introductions were recorded from the 1890s until the end of 2010. Those introductions involved 2384 natural enemies against 588 insect species in 148 countries [3]. Based on these cases, as many as 620 natural enemies (10,1%) resulted in success against 172 pest species. One example of a successful case was the introduction of *Anagyrus lopezi* (Hymenoptera: Encyrtidae) to control cassava mealybug in Africa in 1981. The decline in pest populations was reported by 95%, and productivity increases reached 2.5 tons/ha [4]. In addition to successful stories, several cases also failed or remain unknown. Based on 5715 introduction cases, only 1823 cases reported natural enemies' establishments, while 3892 cases were natural enemies that failed to establish (including no report of establishment) or establish but did not contribute to control (including no report of impact). Many unsatisfied introductions remain unreported [3].

Researchers are likely to publish basic knowledge (e.g., the taxonomy and biology of natural enemies) rather than the application results. A global analysis in 2004 reported that research on biological control dominantly reported an experimental approach under laboratory conditions (66,9% of 878 articles reviewed). The most examined studies focused on the natural enemy's biology, such as efficacy, oviposition, feeding behavior, host specificity, and life history. On the other hand, studies addressing agent establishment were just 9% of articles reviewed [5].

In Indonesia, even though biological control research was started very early, during the Dutch occupancy period [6], the numbers seem to dwindle over the years. There was scattered research on various crops. Some research on the invasive species *Spodoptera frugiperda* (Lepidoptera: Noctuidae) did gain some attraction [7-8]. Nevertheless, there has been no systematic analysis of how the research produces technology that can be applied in the field. This analysis is essential since it provides baseline information that is important for future research direction on biological control. The objective of the research is to study the biological control research in the past 20 years in Indonesia with emphasis on what are the natural enemies studied, what crops, what are the target organisms, and what biological control agent has been successfully practiced in Indonesia.

2. Methods

This research is a systematic literature review. Various databases were used, such as the Directory of Open Access Journals (DOAJ), Google Scholar, ProQuest, and Scopus. Articles were searched using the following keyword strings: 1) “Pengendalian hayati” OR “musuh alami” OR parasitoid hama OR predator hama OR entomopatogen, and 2) "Biological control" OR biocontrol OR "natural enem*" OR parasitoid* OR predator* OR entomopathogen*

The selected articles in the databases were filtered by country "Indonesia". The time of publication was limited between 2000 and May 2021. The selected articles then went through the subject screening stage to remove the article from the unsuitable subject. The next stage was entering the articles into *Mendeley* to go through a screening and eligibility assessment that included the following:

1. Screening the titles with inclusion criteria, i.e., (a) in Indonesian or English and (b) related to pests’ biological control.
2. Assessment of the full-text article with inclusion criteria, i.e., (a) primary research, (b) journal articles or conference papers, (c) related to pests and natural enemies in Indonesia, and (d) the full-text is available on the internet.
3. Assessment based on the index, articles were indexed on Sinta (sinta.ristekbrin.go.id/journals) and or Scopus (www.scimagojr.com) are selected to be research samples.

The selected articles were then grouped into several categories. First, the articles were grouped based on the year of publication and types of natural enemies (insect pathogens, parasitoids, predators, and combination). Next, the articles about parasitoids or predators were grouped by research topics, and the crops studied. Finally, the articles on each crop studied were grouped by natural enemies used, target pests, and their research topics. Data analysis used *QSR Nvivo 12* and *R studio.*

3. Results and discussion

As many as 10036 articles were initially identified through search terms in the databases. A total of 9599 articles were eliminated according to the literature eligibility criteria, so 437 articles were selected as research samples (Figure 1). Research samples were almost 87% derived from national publications. Based on the index, it was mostly indexed by S2 Sinta (62%) and 22% indexed by Scopus.

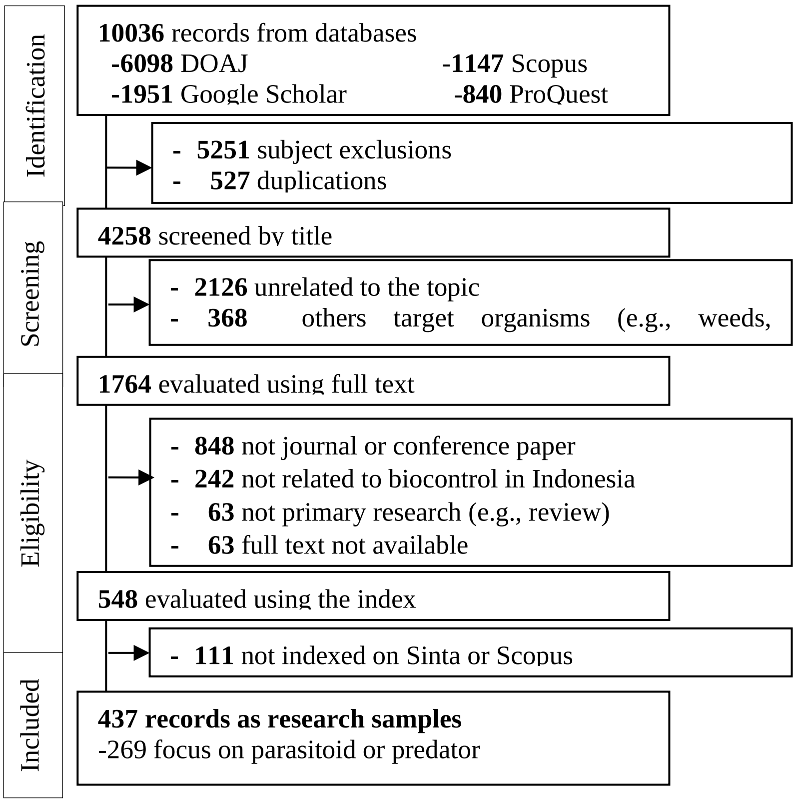


Figure 1. Flow chart detailing the process of getting research samples.

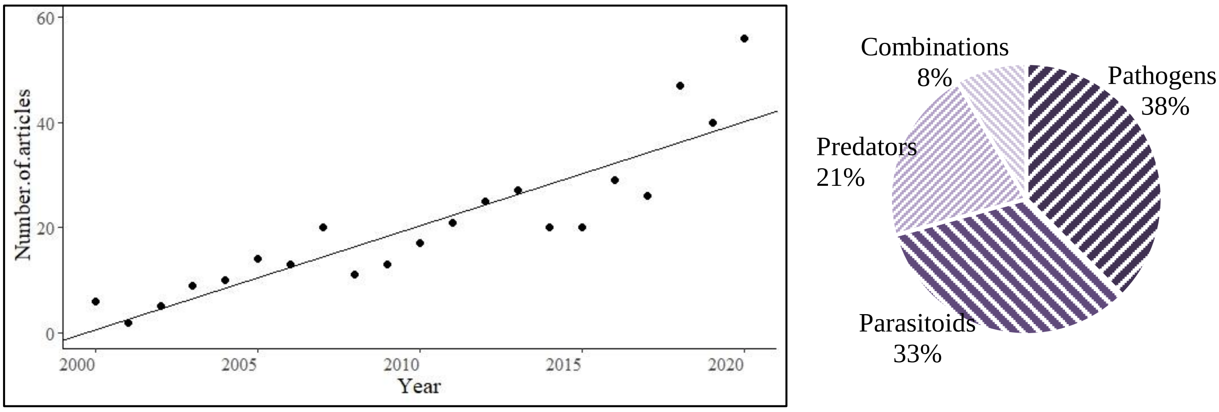
Research on biological control has increased significantly in the past 20 years (Figure 2a). However, the global proportion of publications on pest biological control has decreased, and the proportion of pathogen biological control has increased [1-2]. It illustrates an increased interest in pathogen biological control research. However, it cannot be analyzed in this study because research on pathogen biological control is not the scope of this research.

Insect pathogens became the most studied natural enemies (38%), followed by parasitoids (33%), predators (21%), and combinations (8%) (Figure 2b). The findings differ from global biological control research that was dominated by parasitoids (41%) and predators (27%) [2]. This information showed that insect pathogens are quite popular in Indonesia. However, the high number of insect pathogen research is not comparable to biopesticide products commercially available. Insect pathogens registered as biopesticides in Indonesia have just included *Bacillus thuringiensis* (8 trademarks), *Beauveria bassiana* (3 trademarks), and *Metarhizium anisopliae* (2 trademarks) [9]. Although insect pathogens dominate biological control research in Indonesia, our study focuses on parasitoids and predators' role in biocontrol research. A global meta-analysis showed that predators and parasitoids could reduce pest populations by up to 130% and increase parasitization by 139% compared to controls. It proves that both natural enemies have excellent performance and promise to be applied as biological control agents [5].

Although insect pathogens dominated biocontrol research in Indonesia, this study only examined articles focusing on parasitoids and predators. A total of 269 articles focused on parasitoids or predators as natural enemies. Based on the research topics, Figure 3a shows that most research topics were focused on identifying natural enemies. The second topic was the study of natural enemies' biology, while natural enemies' release and evaluation were only ten out of 269 articles filtered.

Research on natural enemy identification is the first step. The output resulting from this identification is still around basic sciences such as taxonomy. Natural enemies that have been identified still have to go through more research focusing on biology. Research on the biology of natural enemies was dominated by research on the ability to prey or parasitize and the biological ability of natural enemies. The development of natural enemies ready to be used for large-scale release has just been the research of propagation techniques. Research on propagation techniques was also still very little researched. So far, five researchers have been reported for propagation techniques, namely for *Anagrus nilaparvatae* (Hymenoptera: Mymaridae), *Menochilus semaculatus* (Coleoptera: Coccinellidae), *Anastatus dasyni* (Hymenoptera: Eupelmidae), *Gryon nixoni* (Hymenoptera: Scelionidae), *Sycanus annulicornis* (Hemiptera: Reduviidae) [10-14]. This shows that the output of biological studies is also still related to the basic sciences and has not further led to the development of natural enemies that are ready to be used for large-scale releases.

Over the past 20 years, four natural enemies have been reported in large-scale releases: *A. lopezi* released in cassava plantations, *Tetrastichus brontispae* (Hymenoptera: Encyrtidae) and *Lanius schach* (Passeriformes: Laniidae) in coconut fields, and *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) in the sugarcane plantation. Research on releases in Indonesia has not been comprehensively conducted. Research topics were still limited to the establishment of natural enemies or the mortality of target pests due to the release. Research has not led to measuring success. In measuring success, information about the establishment of natural enemies and or mortality of target pests is not enough. There must also be information on the effect of release on crop productivity and control costs [15]. Both topics have not been found in natural enemy release research in Indonesia.



a b

Figure 2. Frequency of research based on time of publication (y=1.98x-3962.93, R^2 = 0.78, p<0.01) (a) percentage based on natural enemies studied (b).

3.1. Rice and other secondary crops

Rice and secondary crops were the most researched crops (Figure 3b). A total of 105 articles were focused on the biological control of those crops. As many as 60% or up to 62 articles were the study of biological control in rice plants. This number is the highest among all plants studied. It is not surprising because rice is a staple food of Indonesian. This commodity is widely grown in various regions, with the harvest area recorded at 10.66 million ha in 2020 [16]. Although there have been many studies on rice plants, none have reported the release of natural enemies. The research was still dominated by identification. In the past five years, there has been an increase in research on the influence of refugia on the abundance and diversity of natural enemies. It is likely to be influenced by the program to grow refugia around rice cultivation triggered by the Decree of the Directorate General of Food Crops Number 53 / Hk.310 / C / 8/2012 concerning Guidelines for Recommendations for Control of Plant Pest Organisms Cereal Plants. So far, the research on the influence of refugia plants is still related to identifying natural enemies who inhabit the land planted with refugia and those that do not. Research has not been directed at what kind of refugia is effective at increasing the activity of natural enemies and suppressing pest populations. This knowledge can be a step in natural enemies conservation in rice fields.

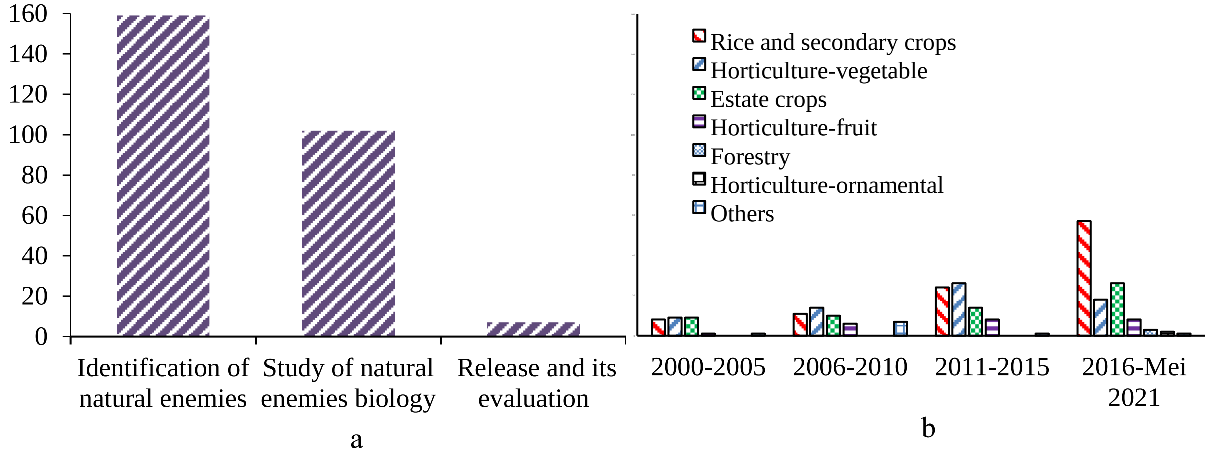


Figure 3. Frequency of research based on (a) topics and (b) crops studied.

The following crops were cassava (15%) and soybeans (11%). Research on biological control of cassava plants focused on predators from the family Phytosiidae and parasitoid *A. lopezi*. *A. lopezi* as a parasitoid of *P. manihoti* was introduced in 2014. The release of the parasitoid occurred in September 2014, with the release point located in Bogor, West Java. Three years later reported that the parasitoid had spread to West Java, Banten, Lampung, Central Java, East Java, and West Nusa Tenggara but had not been detected in East Nusa Tenggara. The parasitization rate varies from 1.50% in West Nusa Tenggara to 59.19% in East Java [17]. Based on history, Africa became the area that reported the successful introduction of *A. lopezi*. The decline in pest populations in the region was reported to reach 95%, and productivity increases reached 2.5 tons/ha [4]. These results make the introduction of *A. lopezi* to Africa one of the world's most successful cases of biological control [18]. One factor that supports the successful release of the parasitoid is the spreading ability. *A. lopezi* had a spreading speed of 50-100 km in 5-8 months. Based on this speed, *A. lopezi* spread over 1.5 million km^2 seven years after the first release in Nigeria [19].

Monitoring continuously is the next direction of research on *A. lopezi*. This step is needed to confirm the success of releases in Java and to find out the establishment in other regions of Indonesia. Another research direction is the study of non-target impact because the parasitoid result from introduction. *A. lopezi* has a high preference towards *P. manihoti* compared to other mealybugs species [20]. However, the influence of *A. lopezi* on the useful insects that inhabit cassava crops has not been studied.

3.2. Vegetable crops
Biological control in vegetable crops became the second most researched study. A total of 67 articles focused on the biological control of these crops. The most studied plants were Brassicaceae (36%), chili and tomato (29%), and leaf miner hosts plants (17%). A total of 25 articles discussed biological control in Brassicaceae plants. The most studied pest was *Plutella xylostella* (Lepidoptera: Plutellidae). Research on *P. xylostella* was still dominated by identifying its natural enemies. *Diadegma semiclausum* (Hymenoptera: Ichneumonidae), as the introduced natural enemy, had been quite effective in parasitizing *P. xylostella* but required low temperatures for its lives development;

hence the high population was found in highlands [21]. Therefore, identifying other natural enemies continues to be carried out to obtain effective natural enemies in the highlands and the lowlands. Based on observations in various locations, researchers found *Trichogrammatoidea cojuangcoi* (Hymenoptera: Trichogrammatidae) and *Cotesia plutellae* (Hymenoptera: Braconidae). However, the research on the two parasitoids has only been the identification, so measuring their effectiveness in controlling *P. xylostella* becomes a research prospect in the future.

3.3. Estate crops

A total of 60 articles focused on biocontrol in estate crops. Oil palm and coconut were the most researched crops. Although the pests that affect the two plants are almost the same, the research topic was different. Oil palm research focuses more on identifying natural enemies. While in coconut, research on releases has been carried out. Similar to the coconut research, sugarcane research has also reported the release results. There were six reports of releases in estate crops involving three natural enemies.

The natural enemies released in coconut plantations were parasitoid *T. brontispae* to control *Brontispa longissima* and a predatory bird *Lanius schach* (Passeriformes: Laniidae) to control *Sexava* spp. The release of *T. brontispae* has been carried out in coconut plantations in East Nusa Tenggara. The parasitoid had been previously introduced from North Sulawesi in 2005. The parasitoid parasitized *B. longissima*, with the highest level of parasitization reaching 38.09% [22]. Meanwhile, the rate of pest damage was still relatively high, which was between 21.92% to 35.20%. It happened because the pest population was high enough, so parasitoids could not control it. However, there are no reports examining the continuation of the release in the years that followed.

The release of *L. schach* birds was carried out in 2011 in Salibabu Island, North Sulawesi. The bird had been introduced from Yogyakarta. Three months later reported that the bird was well-established in the field. In addition, there were also positive results from aspects of pest populations. The pest population was recorded as 11% lower than before the release. The results indicate that the release of *L. schach* might control *Sexava* spp. in the field [23]. The next challenge of this release is its conservation efforts. *L. schach* is also sold in the market to be a pet. Therefore, the most important step of this conservation is protecting against hunting the community might carry out. In addition to conservation, non-target impact research is also needed because this bird results from an introduction.

The target pests in the biological control of sugarcane plants are the shoot borer *Scirpophaga* spp. (Lepidoptera: Crambidae) and stem borer *Chilo* spp. (Lepidoptera: Crambidae). Over the past 20 years, research has focused on evaluating the mass release of *Trichogramma* spp., which are parasitoid eggs of both pests. The oldest literature reported this evaluation was in 2000, while the latest was reported in 2019 [24-25]. This shows that the release of *Trichogramma* spp. has been done for the past 20 years.

Observations were carried out at several sugarcane plantations with release or without treatment. After release reported that *Scirpophaga* spp. was not parasitized by *Trichogramma* spp [24-26]. Unlike *Scirpophaga* spp., *Chilo* spp. reported could be parasitized by *Trichogramma* spp. Two evaluations observed the level of parasitization after release compared to several plantations without release treatment [25-26]. The evaluation reported that the highest level of parasitization by *Trichogramma* spp. occurred in Malang (50%), which is a natural occurrence (without release). They also observed the level of parasitization by other *Chilo* spp. egg parasitoids that were established in the field. It found that the rate of parasitization of *Telenomus* spp. and *Tetrastichus* spp. is between 43% to 87% (Figure 4).

The release of *Trichogramma* spp. was based on its successful cases in several countries, such as China and Pakistan [27-28]. However, the release of *Trichogramma* spp. in Indonesia has not shown satisfactory results. *Scirpophaga* spp. was not parasitized by *Trichogramma* spp. Meanwhile, *Chilo* spp. was parasitized by *Trichogramma* spp., but the level of parasitization always shows equal to or lower than the level of parasitization by *Tetrastichus* spp. and *Telenomus* spp. that are already established in the field. Low levels of parasitization were caused by their low fitness. Therefore evaluation is required regarding the biology of *Trichogramma* spp. and its propagation techniques [25-

26]. Another strategy to consider is the conservation of *Tetrastichus* spp. and *Telenomus* spp. Both strategies are the prospects of future biological control research in sugarcane plantations.

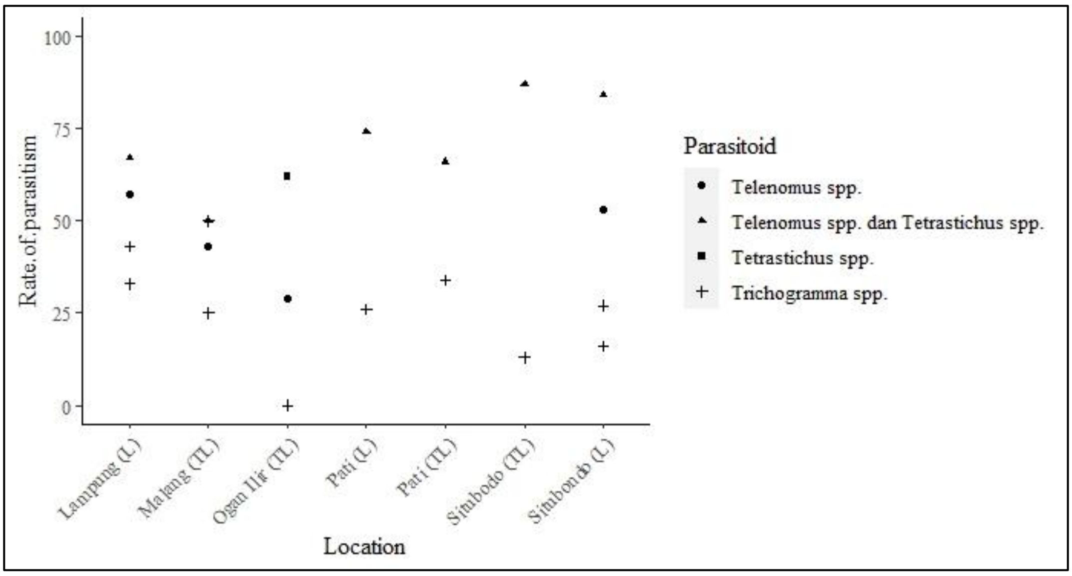


Figure 4. Parasitization level of *Chilo* spp. egg groups in various region: L = with release, TL = without release.

3.4. Fruit crops

There are 23 articles on biological control research in fruit crops. The fruit crops studied included bananas (35%), oranges (26%), fruit crops that were the host of fruit flies (26%), and papaya (13%). Based on its focus, research was dominated by identification, followed by studying natural enemies' biology. So far, not a single article has reported releases.

4. Conclusion

Research on biological control in Indonesia showed a significant increase over the past 20 years. Studies were dominated by research on insect pathogens (38%). Research on predators and parasitoids was mainly conducted on rice plants (23%), with the research focusing mainly on the identification (59%) and biology of natural enemies (38%). Almost all the research that was conducted addressed the basic biology of different types of natural enemies for different crop pests but has not addressed the full-scale host-parasitoid research that is needed to develop biocontrol agents that are ready to be released on a large scale. Mass releases have reported four natural enemies: *Anagyrus lopezi, Lanius schach*, *Trichogramma* spp., and *Tetrastichus brontispae*. Research on the releases has not led to a measure of their success. The opportunity for future biological control research is the development of potential natural enemy technologies that are ready for mass release. Research has to continue until the success of the release is reported.

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