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EDUCATION AND RESEARCH OF WEED SCIENCE IN BANGLADESH: PRESENT STATUS AND DIRECTIONS FOR IMPROVEMENTS

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ABSTRACT

Weed science is a sub- discipline of agriculture that deals with spontaneously grown species in crop fields and their management. It is an important discipline in agriculture production systems as weed causes a significant reduction in crop yield. Management of weeds in crop fields requires an in-depth understanding of morphology, distribution and dispersal behavior of their propagules and their nature of interaction with crops. Several management options including physical, mechanical, chemical, and biological methods are applied to achieve a good harvest by reducing the negative effects of weeds. Although significant improvements were attained in different aspects of weed management, a lot of research needs remained unexplored in Bangladesh. Here, we applied a scientometric analysis to compare the research status and trend in Bangladesh with the global research progress to focus on our present needs. In total, 14,275 articles with appropriate keywords related to weeds were collected and analyzed under different categories. The research on weed science in Bangladesh needs to be updated with particular emphasis on documentation of weed species with their ecology, understanding of crop-weed-soil-environment interactions, herbicide chemistry, herbicide formulation, development of bioherbicides, efficient use and right application of herbicides and advanced weed management techniques (e.g., robotic weed management). This paper has highlighted all these issues and thus, carries significant implications for the development of weed science in Bangladesh.

Keywords: Scientometric analysis, herbicide uses, weed ecology, crop-weed interactions, invasive species, interdisciplinarity in weed science.

INTRODUCTION

Bangladesh is an agriculture-based country, and its economy is largely dependent on agricultural production. Crop, by nature, grows in association with different kinds of weeds depending on the environment of crop growth. Since the requirement of crops and weeds are similar, crop growth cannot be considered without weeds, and therefore, a significant competition for resources occurs between the two groups of plants if the resources are limited, resulting in the poor performance of crop biomass and yield. The yield reduction varies with the magnitude of crop-weed competition with estimates between 5% and 100%.

Weed management is one of the major aspects of weed science, which requires in-depth knowledge and understanding of the behavior of competing species. In a crop field, weed and crop species compete for the available resources (e.g., light, space, water, nutrients etc.) and thus, crop plants may face severe competition for one of the resources although the other resources may be present in abundant. For instance, a crop species

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may compel to reduce its growth due to the limitation of a single nutrient element although it may appear that the above ground canopy coverage is far below the competition for solar radiation. Moreover, there are many species that exudate biochemicals (known as allelochemicals) that are harmful to the growth of the standing neighbouring crop although there might be no visible evidence of competition. Therefore, weed management needs a fundamental understanding of crop-weed interactions on the issues related to those aspects of competition.

Weeds are managed following different methods including- a) physical/mechanical such as stale seedbed, hand weeding, hoeing, robotic weeding etc., b) chemical application (e.g., organic and inorganic herbicides), and biological (e.g. use of bio-herbicide, bio-agents including insects and pathogens, plant ecology intensification etc.) or the combinations of several methods. In Bangladesh, weeds are generally managed using physical and mechanical methods while in recent years chemical weed management strategies are evolving due to labour shortage. Comprehensive research is needed to make a paradigm shift in weed management from the physical method (mostly manual) to the advanced mechanical method (e.g. robotic weed management), chemical and biological methods and a combination of different methods, i.e., integrated weed management (IWM) system.

Weed infestation and their nature (occurrence and extent) have been changing with the changes with production systems (cropping systems, land type ecologies, crop and livestock integration), cultivation practices (e.g. dryland cultivation to irrigated cultivation), use of chemicals (e.g., fertilizers and herbicides) and change in growth conditions (i.e., climate change). For instance, in the last few decades in Bangladesh, the application of large amount of chemical fertilizers significantly changed the aquatic weeds diversity and their occurrence. Moreover, introduction of invasive species, e.g., parthenium weeds has also changed crop weed interactions and the agro-ecosystems.

Despite significant changes in weed science have been made in elsewhere, the research and education in weed science have not been progressed at the level to manage the weeds efficiently and sustainably. The scientometric analysis is a method applied to identify the education and research priority in any field of science. For instance, Wu *et al.* (2020) applied scientometric analysis to visualize the research progress in biochar science. As far as we know, there is no such scientometric analysis yet been done on weed science in Bangladesh. The current study was, therefore, conducted with aims at identifying the research needs, and the future strategies of actions, that are required to include in the curricula of weed science in Bangladesh.

MATERIALS AND METHODS

A comprehensive survey of literature was made using Web of Science to collect articles published between 2010 and 2021 using the key word "Weed". A total of 14, 275 articles were collected along with all information (e.g., titles, keywords, abstracts) for performing scientometric analysis. The collected data were then processed with Mendeley to remove duplication while articles related to specific fields of weed science were separated. Scientometric analysis was performed using Vosviewer (Van Eck *et al*., 2010; Waltman *et al.*, 2010). Moreover, the curricula of different universities of south Asian countries were also analyzed after collection of major contents following similar methods and compared with Bangladesh to find out the education and research needs in the country.

RESULTS AND DISCUSSION

Weeds in Bangladesh- Necessity of preparing a national compendium

Understanding the morphology and ecology of weeds are the key aspects for determining the proper weed management strategies and the policy making related to weed science. Hundreds of weed species are grown

in Bangladesh, but proper recording of these weed species is not available in the country. According to Banglapedia, the number is as high as 350 species, which was reported to grow in crop fields. However, little effort is given in developing a national compendium of weeds grown in Bangladesh. It is important to mention that there are several books, articles and open sources that reports weeds grow in Bangladesh. For instance, Karim and Kabir (1993) wrote a book on major weeds in Bangladesh in which identifying characters of major along with hand-drawn figures of the weed species have been included. Karim (2014) has also published another book on Important Tropical Weeds, where he described more than 300 tropical weed species with identifying characters and full taxonomy with their infield photographs. He has also compiled all research findings on weeds in Bangladesh from 1946 to 2012, which has been arranged under different crops (Karim, 2012). Caton *et al*. (2010), a group of researchers when working for International Rice Research Institute, have developed a practical guidebook on weeds grown in rice fields. Similarly, Islam (2014) identified the major weeds grown in jute fields in Bangladesh. Karim (2013a) also written a book, published by Universiti Malaysia Kelantan, Malaysia on effects of weeds on crops and human being. Open and unpublished resources are also available on weed species grow in Bangladesh. However, there is a need to combine and compile for having a national treasury of weed species grown in Bangladesh.

Weed science research in Bangladesh in comparison to the global context

There are five different clusters, made with the keywords collected from the existing literature. The first cluster (represented with red colors) included 189 keywords. The major areas of research were abundance, agro-ecology, biodiversity, biological invasion, community, and climate change. The second cluster included 50 items and majority of them are different crops. Cluster 3 includes 42 items with allelopathy, adsorption, and growth. Cluster 4 included 40 items and the most dominant keywords were competition and competitive ability, crop-weed competition. The cluster 5 was about cultivation practices that included cover crops, conservation agriculture, and crop rotation. The sixth cluster is about classification, and it included 24 items. The most frequent keywords are also included in Fig. 2. Compared to global context, the weed science education and research are not well developed (Table 1 and Fig. 1 & 2). The major areas of education included the understanding of the importance of weed, weed morphology, agro-ecology and fewer management strategies. The major areas to be focused on herbicide chemistry, advanced weed management techniques (e.g., robotic weed management) and fundamental understanding of crop-weed-soil-environment interactions. All these are discussed in the later sections under different sub-headings.

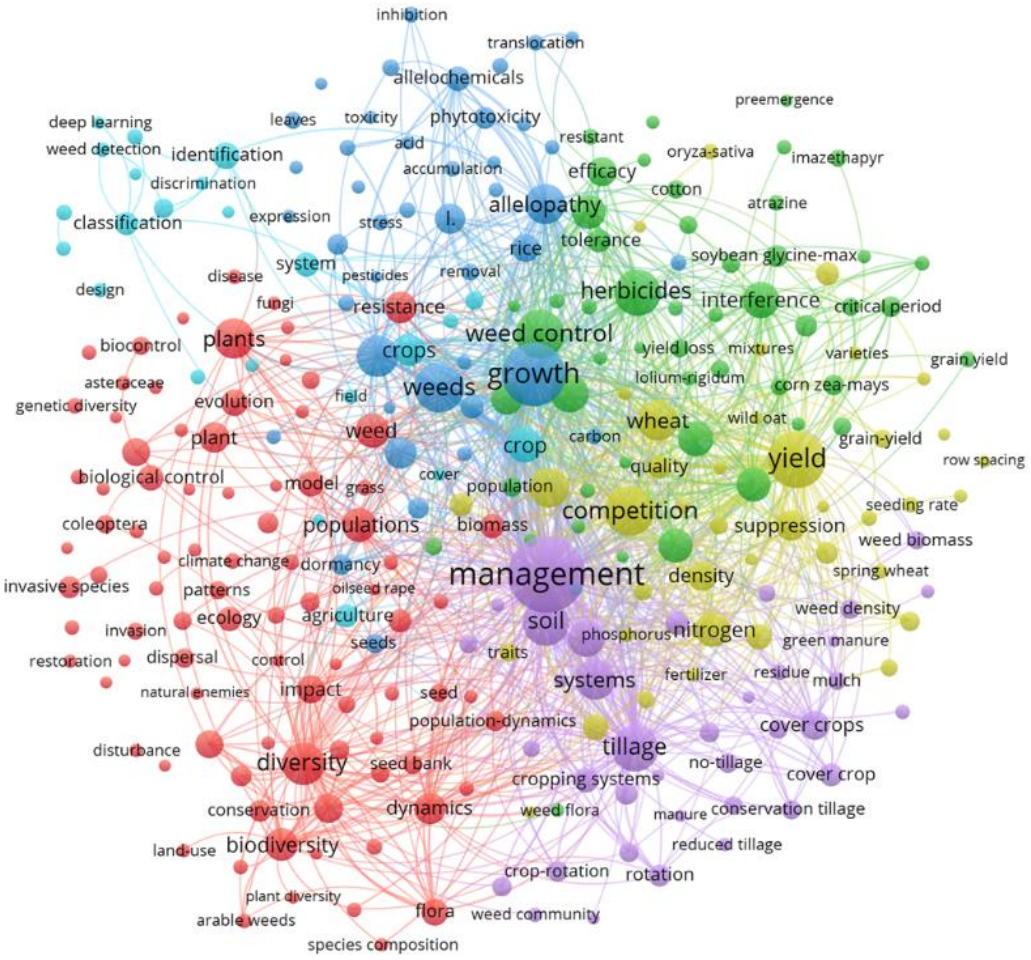


Fig. 1. Network map showing major areas of research in weed science. The figure was developed with 14275 articles, collected from web of science. Note that most of the important aspects are not touched in Bangladesh.

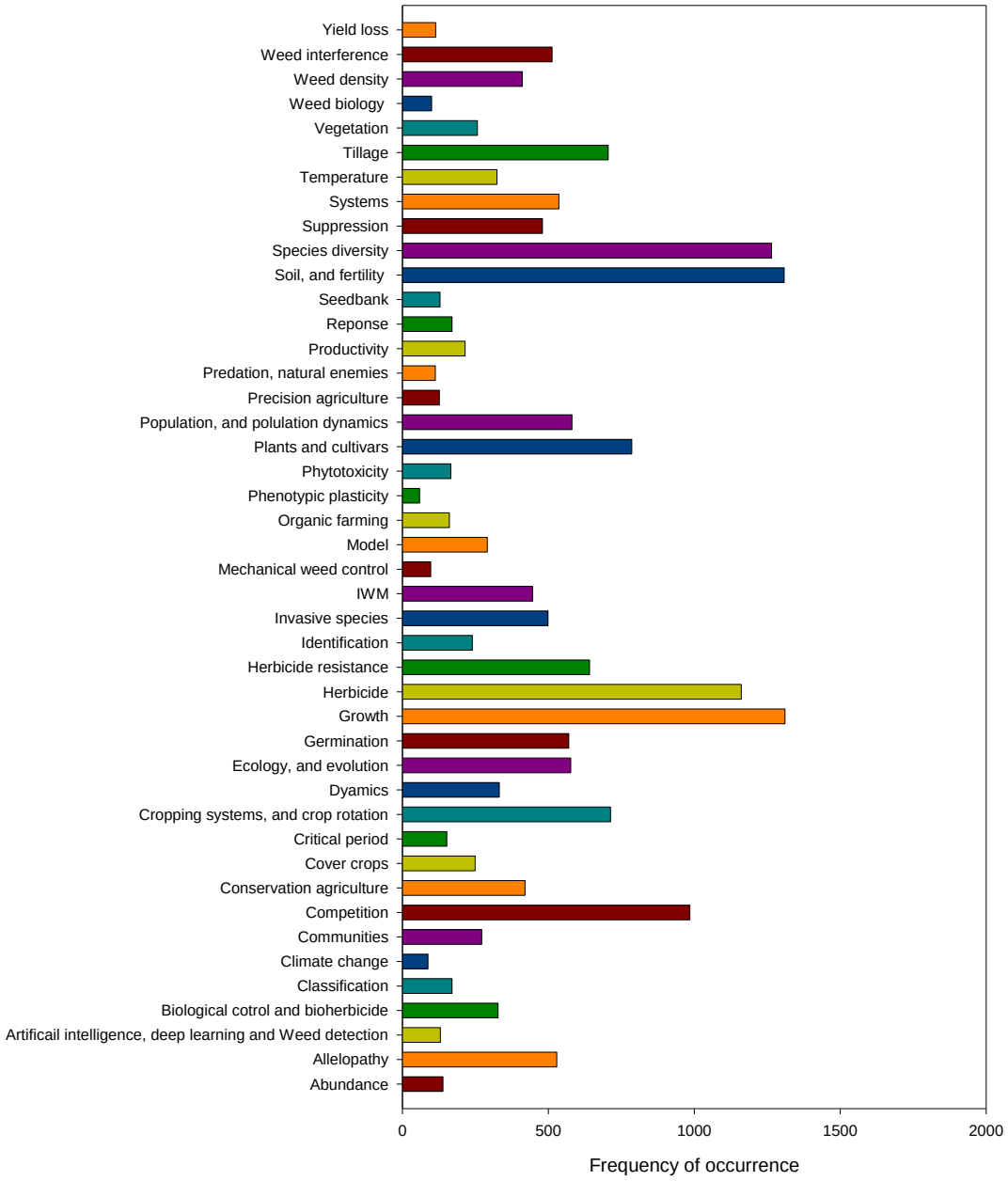


Fig. 2. Major areas of research (keywords) in weed science in the world.

Table 1. Major areas of education and research in weed science in Bangladesh

Major topic of education in Bangladesh[#]	Major of areas of research in Bangladesh[#]	Global research focus	Actions and strategies to bridge the gap
Weed concept and importance	Determination of yield loss	Compendium (online) of all possible weed species	Identification and documentation of all weed species with their importance
Weed morphology and biology	Identification of weeds grown in different agro-ecological zones and in different crop fields	How and why weed changes their habitat with changing climate and understanding the interactions at molecular level.	A comprehensive understanding of weeds behavior needs to be documented.
Weed ecology and its concept, crop weed association, crop-weed interactions, crop weed competition	a) Determination of critical period of crop weed competition b) Allelopathic effect of weeds on crops and vice-versa.	Advanced methods to determine crop – weed competition and critical period of competition for administering weed management practices.	Similar advanced techniques can be applied in Bangladesh.
Weed management strategies by different methods (e.g., cultural, physical, mechanical, biological and chemical)	a) Effectiveness of different weed management practices b) Determination of appropriate rates of herbicides for control weeds in crop fields	a) Introduction of novel weed management techniques including new generation herbicides, use of bioherbicides, robotic weed control measures. b) Herbicide resistance in weeds and crops c) Fate of herbicide in the environment	Similar techniques can be applied in Bangladesh while bio-herbicide can be explored from native species. Mode of actions of herbicides, application, use, timings, and amounts of herbicides, herbicide resistance and residual effects need to be included in research and education.
Integrated weed management	Determination of effectiveness of	a) Advanced management	Similar techniques can be applied in Bangladesh.

Major topic of education in Bangladesh[#]	**Major of areas of research in Bangladesh[#]**	**Global research focus**	**Actions and strategies to bridge the gap**
	different weed management practices in combination.	practices including insects, pathogens and development of weed-suppressive crop varieties, are applied. b) Model based assessment has been introduced.	
Tradeoffs of livestock, human beings and weed species	Limited information and knowledge are available	Advance research has been conducted in developed and developing countries	Interaction of livestock, human beings and weed species, their dependency in rural communities and uses of weed species
Chemical weed control (herbicides) impact on environment, human beings and both livestock and water bodies	Limited information and knowledge are available	Advance research has been conducted in developed and developing countries	This is important area should be undertaken in Bangladesh to understand the impact of herbicide use on human health, soil health, water bodies and environment.

[#]Based on expert judgment and literature survey.

Crop weed interactions

When two species are grown together, both positive and negative interactions take place. Crop and weed, when grown in the same field, both compete for growth resources including nutrients, light, and water while weeds can also release allelochemicals (Fig. 3). There are allelopathic crop species that may also release allelochemicals to suppress weed growth but there are also crop- associated weed species in existence to compete for available resources. However, there a number of positive feedbacks of weed to crop plants. These are addition of organic carbon and nutrient after death, supply of N under symbiotic association, release of growth promoting substances and hosting beneficial microorganisms. Given that the interactions can be positive and negative, it is important to understand the level of competition.

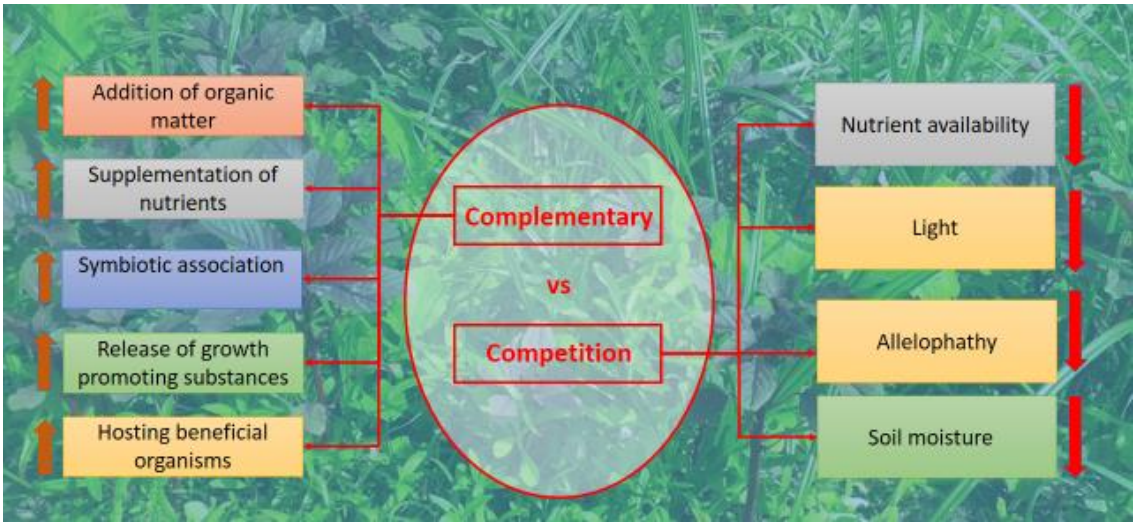


Fig. 3. Schematic presentation of crop-weed interactions

Crop-weed competition is a common phenomenon in the cropland ecosystems resulting in poor crop growth and yield loss in most of the cases. Usually crops and weeds struggle for their existence and/or superiority. Weeds compete with crops in both direct ways (by sharing limited resources like nutrients, moisture, space, and light) and indirect (by exuding allelochemicals) ways. Since weeds are much more adapted to an agro-ecosystem than the cultivated species, the ultimate sufferer is always the crop. Therefore, estimating the magnitude of crop weed competition as well as minimizing its consequences on crop productivity is remained a key challenge in agriculture.

Crop-weed competition study is essential to provide valuable information on the economic weed threshold and optimal timing to weed control for cost effective weed management (Swanton *et al.*, 2015). Weed species, time of weed emergence, weed density and critical crop growth competition period are among the major variables that determine the degree of crop yield losses due to weed competition. Competition can be viewed as a series of interrelated physiological and morphological changes as the consequence of both resource-dependent and resource-independent processes (Harper, 1977). Most of the published articles have focused on resource-dependent processes such as competition for limiting resources such as water, nutrients, and light. The competitive ability of crops and weeds is governed by morpho-physiological attributes that allow them to explore, capture, and exploit available natural resources. On the other hand, resource-independent effects such as hormonal and light quality signals can also play an important role in determining the outcome of crop–weed competition (Swanton *et al.*, 2015).

Determining the critical period of crop-weed competition (CPWC) is another approach to effective weed control in integrated weed management (Anwar *et al.*, 2012a). During CPWC weeds must be controlled to prevent unacceptable or economic crop yield loss (Zimdahl, 1980). In theory, presence of weeds before CPWC will not cause significant yield loss. Thus, crop yield obtained by weeding during CPWC is almost similar to that obtained by the full season weed- free conditions (Knezevic *et al.*, 2002). The CPWC has got a beginning and an end as well. The CPWC is determined by calculating the time interval between critical time for weed removal (CTWR) and the critical weed-free period (CWFP). The critical period of weed competition has commonly been reported as day after planting (sowing/transplanting), but due to differences in planting dates and environment, this may generate results with more variability among locations, seasons, and cultivars. Therefore, in recent studies, CPWC has been reported as growing degree days (GDDs) because

it is a biologically meaningful measure of time required for plant growth and development (Gilmore and Rogers, 1958), and therefore, it would be applicable for comparing critical period across different agro-climatic conditions (Evans *et al*., 2003).

Invasive weeds in Bangladesh

There are many invasive species in Bangladesh. However, our research and education on why these species are invasive (i.e., mechanisms for their dominance and hazardous over other species) has not been explored yet. In contrast to Bangladesh, the research and education on invasive species is quite developed in other developed countries (Fig. 4). The major areas of research are, the causes of dominance, effects of invasive species on native species and ecosystems, and sustainable management of invasive species including introduction and enforcement of plant quarantine laws. Karim (2008. 2013b) has identified the occurrence of an important invasive species in Bangladesh (in 2008) and Malaysia (2013), the parthenium weed (*Pathenium hysterophorus* L.) which allergenic to human and livestock health, and hazardous to our agro-ecosystem, especially in dryland conditions.

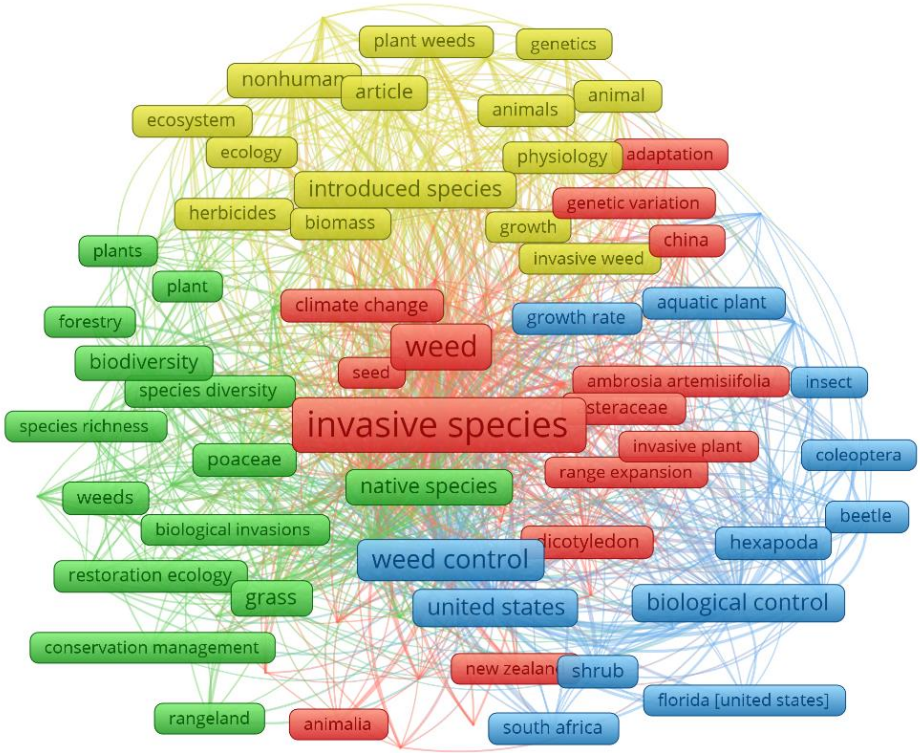


Fig. 4. Research in invasive weeds in the world represented with scientometric-based network map. Note that most of the aspects of invasive weed was not studied in Bangladesh.

Changes in weeds with climate and land use

Bangladesh has been experiencing the impacts of climate change while there are drastic changes in land uses. Both of the drivers are changing the growing conditions of crops and the weeds. Given those facts, there may be a large change in weed biology (e.g., changes in species life cycles, and population dynamics) with consequences for changes in structure and composition of weed communities within both natural and managed ecosystems (Peters and Gerowitt, 2014). Changes in weed biology, ecology, and interference potential, in the wake of climate change, will result in complex crop-weed interactions that necessitate

alternative adaptive mechanisms. There is a general perception that climate change will result in a differential growth pattern between crops and weeds as major weeds of the globe have the C4 pathway, and they will become more competitive in the era of climate change. Invasion with the worst weed of the planet (e.g. *P. hysterophorus*) is a major concern for many countries including Bangladesh, which needs proper research and policy implementation by the government. Moreover, the changes in cropping systems over time from more diversified cropping systems to monotonous cropping systems (e.g., rice-rice and rice-wheat) increases the dominance of crop associated weed species (e.g., *Colona spp*. and *Phalaris minor*). Therefore, research should be undertaken to address these issues.

Seaweed cultivation in Bangladesh-an opportunity yet to explore

Seaweeds have significant economic importance in the world and are widely cultivated. Although seaweed cultivation is a common practice in many south-east Asian countries, in Bangladesh, however, the seaweed industry, has not been developed yet. Researchers and policy-makers in Bangladesh are still not aware of the potentials of seaweed. Since Bangladesh has a large coastal zone with 480 km coastline and 25,000 km^2 of the coastal area. These areas have diverse ecosystems including sandy and muddy beaches, estuaries, and mangrove swamps which can be used to cultivate a large number of seaweeds. Although 133 seaweed species were identified, this number can be even larger since many of the species have not been explored yet. Given that seaweed carries ingredients for manufacturing bio-chemicals, pharmaceuticals, and cosmetics industries, they have high values in many countries in the world. Efforts are needed to increase production through improving cultivating and harvesting techniques, creation of artificial habitats and seeding of suitable coastal areas. The technology for the cultivation of different commercially important seed stocks and their improvements should be done through research. In addition, extensive surveys need to be conducted to identify suitable sites for large-scale seaweed culture in the country.

Medicinal weeds in Bangladesh and research needs

There are hundreds of weed species including invasive weeds that have medical values (Table 2). Many of these weeds have been used in Bangladesh for traditional medicine. However, very few studies were so far carried out solely on the status, diversity, and traditional usage of these species for medicinal purposes. Moreover, advanced research on identifying the active ingredient in the medical weeds that have not been studied yet.

Table 2. Weeds having medicinal properties and used for different diseases

Botanical name	Family	Local name	Parts used	Medicinal uses
Argemone mexicana Linn.	Papaveraceae	Pivla Dhotra	Roots, Latex, Seeds	Jaundice, Expectorant, Stomachache, Skin diseases, Blood purifier.
Abutilon indicum Linn.	Malvaceae	Tapari	Whole plants	Boils, ulcers, bronchitis, diarrhea, gonorrhea, urethritis and fever.
Acalypha indica Linn.	Euphorbiaceae	Kuppi	Whole plants	Bronchitis asthma, pneumonia and rheumatism.
Bacopa monnieri (Linn). Pennell	Scrophulariaceae	Brahmi	Leaves	Chronic fever, enhance memory and as a tonic for nervous disorder.
Biophytum sensitivum (Linn.) DC.	Oxalidaceae	Lajri	Entire plant	Wounds, Insect bites, Vaginal disorders, Piles,

Botanical name	Family	Local name	Parts used	Medicinal uses
				Cough, Kidney stones, Skin disorders.
Boerhaavia diffusa Linn.	Nyctaginaceae	Punarnava	Whole plant	Intestinal colic, kidney disorders, cough, hemorrhoids, skin diseases, alcoholism, insomnia, eye diseases, asthma and jaundice.
Cleome viscosa Linn.	Cleomaceae	Pivli Tilvan, Jakhya	Leaves, seeds	Fever, Dysentery, Headache, Earache and seeds are anthelmintic and carminative.
Cannabis sativa Linn.	Cannabinaceae	Ganja or Charas or Bhang	Leaves, seeds, and flowers	Dyspepsia, gonorrhea and nervine stimulant.
Cynodon dactylon (Linn.) Pers.	Poaceae	Durva	Entire plant	Piles, dysentery, wounds, Pain reliever, Skin disorders.
Cyperus scariosus R.Br.	Cyperaceae	Nagarmot-ha	Roots	Indigestion, Fever, Lactation, Vermicide
Cyprus rotundus Linn.	Cyperaceae	Nagarmot-ha	Rhizome	Indigestion, dysentery and stomach disorder.
Centella asiatica (Linn.) Urb.	Apiaceae	Thankuni	Whole plant	Dysentery, Gastritis, Minor wounds, Contact dermatitis
Desmodium gangeticum (Linn.) DC	Fabaceae	Salparni	Whole plant	Fever, Digestive, Diuretic, Urinary disorders.
Euphorbia hirta Linn.	Euphorbiaceae	Dudhani	Whole plant	Wound healer, Cold, Asthma, Stomachache, Skin disorders.
Euphorbia thymifolia Linn.	Euphorbiaceae	Chhoti Dudhi	Whole plant	Cough, Acidity, Baldness, Purgative, Skin disorders.
Eclipta prostrata Linn.	Asteraceae	Bhingraj	Whole plant	Skin diseases, dysentery, headache and toothache.
Leucas cephalotes (Roth.) Spreng.	Lamiaceae	Dronapu-shpi	Whole plant	Plant juice used in scabies. Leaves for blood purifier. Flowers for cough and cold.
Phyllanthus niruri Linn.	Phyllanthaceae	Bhuiamla	Whole plant	Jaundice and genito-urinary diseases.
Solanum nigrum Linn.	Solanaceae	Kakmac-hi	Whole plant	inflammation of the kidney and bladder, swollen and painful scortum and testicles, fever, diarrhea, and heart diseases, enlargement of liver.

Botanical name	Family	Local name	Parts used	Medicinal uses
Sida cordifolia Linn.	Malavaceae	Bala	Whole plant	Nerve tonic, healing for post child delivery trouble.
Sida rombifolia Linn.	Malavaceae	Atibala	Whole plant	Healing sores and aphrodisiac.
Tridax procumbens Linn.	Asteraceae	Coatbutto-n	Leaves	Kidney stones, Bronchial disorders, Wound healer.
Tribulus terrestris Linn.	Zygophyllaceae	Gokhrurka-ta	Fruits	Various types of urinary diseases, kidney diseases.
Vetiveria zizaniodes (Linn.) Nash.	Poaceae	Khus	Leaves	Anthelmintic for children.
Xanthium strumarium Linn.	Asteraceae	Clothbur	Leaves	Fever, Malarial fever, Chronic fever, Diuretic, Diaphoretic, Skin diseases, Blood purifier, anthelmintic, Cooling, Laxative, Tonic, digestive

Weed management

Physical weed management

Physical weed control is one most common practice followed in weed control strategies in South Asian countries including Bangladesh. It includes intensive tillage before crop establishment to eliminate the existing weeds and hand or mechanical weeding using nirani, harrow, hoe or a weeder during crop season. With the time many mechanical weeder and artificial intelligence driven weeding machines or techniques (e.g., camera-guided weed hoeing, sensor-based patch and spot spraying, robotic weeding and weed scouting, sensor-based electrical weed control, drone (unmanned aerial vehicle)-based weed mapping and patch spraying, targeted weed control with direct injection of herbicides) have been developed and used for weed control (Gerhards *et al.,* 2022). Specifically, sensor technologies including 3D cameras, and multispectral imaging used to take photographs which were then classified based on computer-based decision algorithms and artificial intelligence (Esposito *et al.,* 2021; Gerhards *et al.,* 2022). Those treatments are targeted for patches of weeds or individual weed plants. Cameras can also guide inter-row hoes precisely in the centre between two crop rows at a much higher driving speed. In a recent review, Gerhards *et al.* (2022) mentioned that spraying of herbicide in patches reduced herbicide use at least by 50% in various crops without causing additional costs for weed control in the following years. In Bangladesh no such research yet been started.

Chemical weed management

The farmers of Bangladesh mainly practice conventional/manual methods of weeding, which are laborious and time- consuming. In recent decades, the manual methods of weed controls are getting difficult and very expensive due to the scarcity of agricultural laborers as a consequence of rapid industrialization, which results in severe crop yield loss. Therefore, farmers of the country are more to be dependent on chemical (herbicides) weed control, which is quick, cost-effective, and less laborious. As a result, the use of herbicides in the country has been experienced a 37- fold increase in the last three decades (BBS, 2017) and it is increasing exponentially (Fig. 5) with the recent use of about 7800 metric tons. Herbicidal weed control is now considered as a viable alternative or supplement to conventional weeding (Anwar *et al.,* 2012). About 68

herbicides from different groups have been registered in Bangladesh. Among these herbicides, the most commonly used herbicides in Bangladesh are listed in Table 3. It is important to understand the effects and limitations of those herbicides on noxious weeds. Herbicides are categorized based on crop and weed species safety as selective or non-selective. Selective herbicides kill a specific type of plant and are safe to use for main crop while non-selective herbicides kill all plants that come into contact with it. There are three basic principles that need to be fundamentally addressed for successful applications of herbicides; the choice of proper herbicides and their mode of action, the timing of herbicides applications and the proper application technique (Kashem *et al.*, 2009). Additional factors such as soil type, slope, existing vegetation (target and non-target plants) may also need to be considered to assure the most effective herbicide application outcomes.

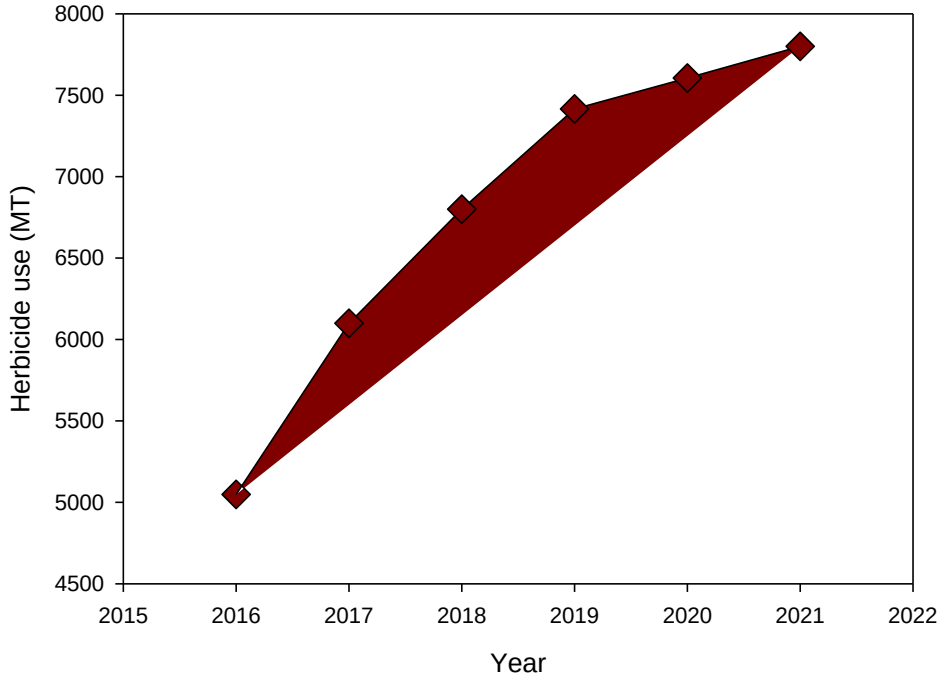


Fig. 5. Uses of herbicide in the recent years in Bangladesh (source- Bayer Crop Science, 2022).

Uses of these chemical herbicides to control weeds have negative impacts on human, soil, and environmental health. Islam *et al.* (2016) conducted a survey on pesticides used in Patuakhali and Comilla region and found that 16-38% of the farmers felled vomiting and headache due to the mild poisoning of pesticide during application. Rahman (2003) and Aktar *et al.* (2009) also reported that pesticide application affects human health, causes fish destruction and death of livestock/poultry, destroy soil fertility, and pollutes water body. Botanical herbicides will be suitable alternatives of synthetic chemical herbicides to control weeds through utilizing the allelopathic potentials of these materials (Motmainna *et al.* 2021). Natural botanical herbicides are friendly both to the environment and human health and also less costly due to the availability of raw materials. A pot experiment has been conducted by Islam *et al.* (2021) to evaluate the botanical herbicidal properties of fresh *Mikania micrantha* H.B.K and *Samanea saman* Jacq. Merr. leaf extract on two commonly grown weeds *Physalis heterophylla* and *Chenopodium album*, and it was concluded that *M. micrantha* leaf extract causes chlorosis on leaves and has high potentiality as botanical herbicide to control both *C. album* and *P. heterophylla* in terms of weed control efficiency. So, advance research should be focused to develop eco-friendly botanical herbicides and reduce the dependency on chemical herbicides for environmental protection and sustainable weed management for safe agricultural production.

Major problems in herbicide education, research & development in Bangladesh

There are a number of problems associated with the adoption of chemical weed control measures in Bangladesh. These includes-

- Lack of knowledge on the yield loss caused by weeds
- Limited knowledge on and awareness of the herbicide selection, use, and their mode of action under different chemical groups & brand names available in the market making it difficult to choose a good herbicide
- Diversity and variability in herbicides, application windows & methods of application etc. for different crops and cropping systems
- Lack of understanding of how herbicide works (mode of action) in soil or plant tissue
- Lack of collaboration and experience sharing between companies, research organizations, and universities
- Lack of knowledge on right application techniques

Table 3. Commonly used herbicides in Bangladesh with their brand numbers, target weeds and crops field

Sl. No.	Name of herbicides	Total brand name in the markets	Major target weeds	Recommended crop
1.	2,4-D Amine	35	Dicot weeds	Tea
2.	Bensulfuron methyl (4%) + Acetochlor (14%)	119	*E. crus-galli, Monochoria vaginalis, Sporobolus maritimus, Cyperus difformis*	Rice
3.	Bensulfuron methyl (4%) + Quinclorac (28%)	9	*C. difformis, E. crus-galli, M. vaginalis, C. dectylon*	Rice
4.	Bensulfuron methyl (18%) + Bispyribac Sodium (12%)	17	*C. album, E. crus-galli, D. sangunalis, C. rotondus, C. difformis, M. vaginalis, B. hispida, I. cylindrica*	Rice, onion, tea
5.	Bispyribac Sodium	15	*C. difformis, M. vaginalis, E. crus-galli, S. zeylanica, N. nouchali, S. maritiums, C. dactylon*	Rice
6.	Butachlor	24	Broad leaf weed and sedge	Rice, tea
7.	Ethoxysulfuron	24	Broad leaf weed and sedge, *C. rotundus*	Rice, jute, tea
8.	Fenoxaprop-p-Ethyl	32	*E. colonum, E. cursgalli, Eleusine indica, D. sanguinalis, C. dactylon, C. rotundus*	Brinjal, onion, jute
9.	Fluazifop-p-butyl	5	*E. Colonum, D. sanguinalis*	Jute, maize
10.	Glyphosate	72	Dicot and monocot weeds	Tea, rubber, sugarcane, banana
11.	Glyphosate (41%) + Paraquat (20%)	14	*B. hispida, I. cylindrica*	Tea

Sl. No.	Name of herbicides	Total brand name in the markets	Major target weeds	Recommended crop
12.	Metribuzin	10	Broad leaf weeds	Potato, maize
13.	Atrazine (25%) + Mesotrione (2.5%)	14	*A. spinosus, D. sangunalis, C. colonum, E. indica, C. dactilon, C. rotundus, C. iria*	Maize
14.	Oxadiazon (25%)	22	Broad Lead and Sedge	Rice, potato, onion
15.	Paraquat	98	*B. hispida, I. cylindrica, C. rotundus, C. dactylon, Ratoon rice, C. sculenus, S. juncoides, M. vaginalis, P. debris, L. adscendens*	Tea, rubber, rice, banana
16.	Pendimethalin	55	*C. rotundus, C. dactylon, B. hispida, S. maririmus, E. crus-galli, M. vagilais*	Rice, onion, potato, tea
17.	Pretilachlor	77	*E. crus-galli, S. maritimus, C. difformis, M. minuta, D. trifolium*	Rice
18.	Pyrazosulfuron Ethyl	89	*S. maritimus, M. vaginalis, C. difformis, E. crus-galli*	Rice
19.	Quizalofop-p-Ethyl	47	*E. colonum, D. canguinal, P. distichum*	Jute, cotton, onion
20.	Triasulfuron	1	*C. difformis, E. fluctuans M. vaginals, I. adscendens R. scleratus, S. zeylanica E. crus-galli, A. sessilis, M. Minuta*	Rice

Herbicide resistance in weeds

Globally, the resistance of herbicides against weeds has become one of the most stressing challenges in crop production. In Bangladesh, use of herbicides has been increasing and therefore, herbicide resistance can be a major challenge in the future. However, the education and research on herbicide resistance are not developed while the policy makers are also not aware of this issue. Globally, a total of 2886 articles reported herbicide resistance. In those articles, the key research areas were genetics and breeding (genetics, gene expression), chemistry and biochemistry of herbicide and plants including metabolism, dose-response relationships, evolution, and botany of plants (Fig. 6). To address these new herbicides are required to manage weeds that have evolved resistance to the existing herbicides. However, relatively few herbicides with new modes of action (MOAs) have been developed in the last 40 years suggesting a need to discover new MOAs for sustainable crop production (Qu *et al.,* 2021). Understanding the mechanism of resistance and development of strategies for breaking this cycle (e.g. use of natural MOAs that has not used in commercial herbicide) are explored across the globe (Duke and Dayan, 2022). Phenyl-urea herbicides (metoxuron, methabenzthiazuron, and isoproturon) were used in wheat to control Phalaris minor in India during early post green revolution which resulted in high wheat yield production for 10-15 years. The continuous single use of Isoproturon for 10–15 years resulted in the evolution of resistance in *P. minor* in wheat in the rice-wheat cropping system in the early 1990s (Malik and Singh, 1993, 1995). This herbicide resistance caused the serious concern in wheat production in the region, resulting in total crop failure from heavy weed infestations (2000–3000 plants m^{-2})

(Malik and Singh, 1995). But recently, the development of multiple levels of resistance against multiple herbicides has been evolved in *Phalaris minor* and becoming now a serious challenge in wheat production (Yadav *et al.*, 2016). For instance, in a recent review, Jin *et al.* (2022) synthesized the current state of knowledge on herbicide resistance mechanisms in weeds grown in rice fields and suggested the breeding strategy of rice to overcome this problem.

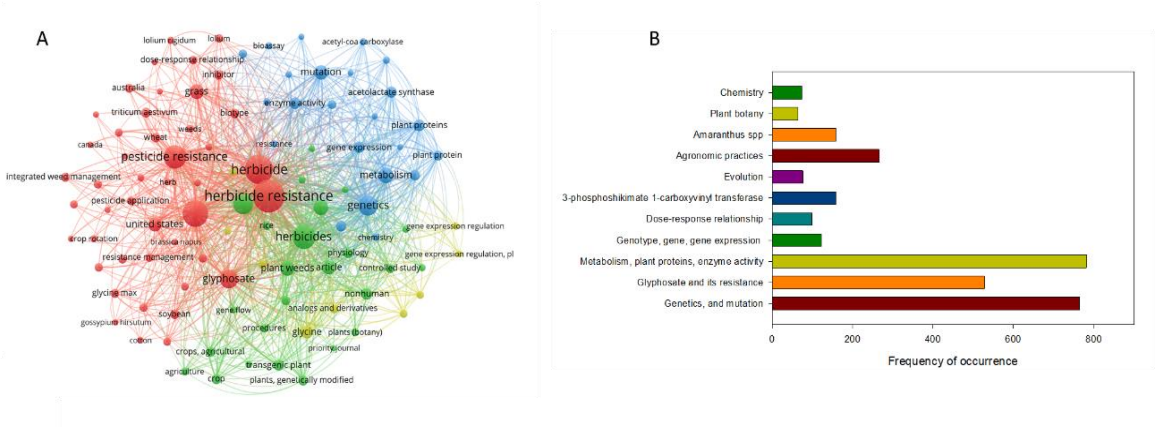


Fig. 6. Keywords of research in the area of herbicide resistance. Panel A represent network map of keywords and panel B represent frequency of major of occurrence.

Biological weed management

Biological weed control involves the use different biological agents including bacterial, fungal, and insect to control weeds, either as natural introduction or as bioherbicides prepared form different inoculum (e.g., fungal spores, bacterial preparations, insect eggs). Our global data analysis showed that the most dominant keywords of research in biological weed management were fungi, and mycoherbicide; Coleptera, Lepidoptera, Hexapoda and beetle; host specificity; biocontrol agent, host range; animal and herbivory, and allelopathy (Fig. 7). In North America, fungi (e.g., *Colletotrichum*, *Sclerotinia* and *Phoma*) and bacteria (e.g., *Xanthomonas* and *Pseudomonas*) are been shown to be potential genera (Harding and Raizada, 2015). Compared to the global context, there are no specific efforts have been found in Bangladesh.

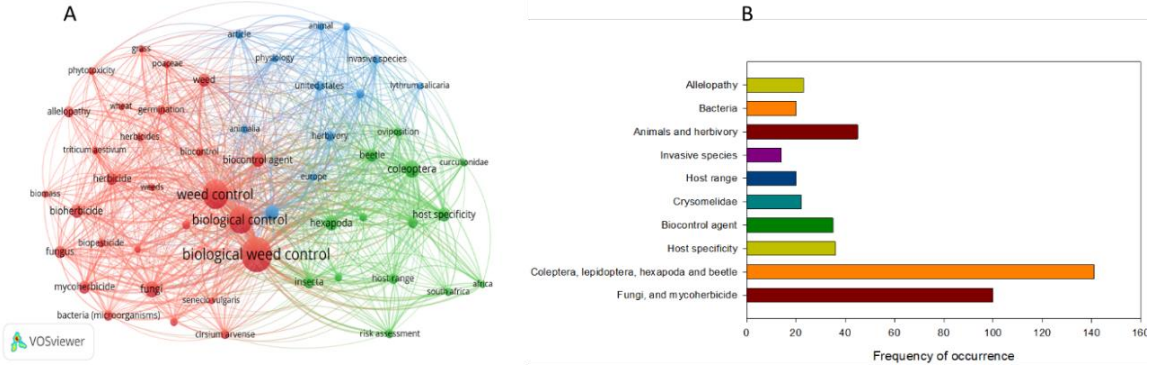


Fig. 7. Keywords of research in the area of biological control of weeds. Panel A represent network map of keywords and panel B represent frequency of major of occurrence.

Ecological weed control

Given that weed management is one of the important challenges for crop production, a range of weed management strategies are evolved and practices including herbicide application, the use of ecological weed management strategies. However, evidence of negative environmental impacts from both tools is growing, and herbicide resistance is increasingly prevalent. These challenges emerge from a lack of attention to how weeds interact with and are regulated by the agroecosystem as a whole. Novel technological tools proposed for weed control, such as new herbicides, gene editing, and seed destructors, do not address these systemic challenges and thus are unlikely to provide truly sustainable solutions. The major points are the following: (1) the diversity and type of crops, management actions and limiting resources can be manipulated to limit weed competitiveness while promoting weed diversity; (2) in contrast to technological tools, ecological approaches to weed management tend to be synergistic with other agroecosystem functions; and (3) there are many existing practices compatible with this approach that could be integrated into current systems, alongside new options to explore. A number of means are suggested for ecological control of weeds. These include prevention of the spread of weeds, management of weed seedbank, adoption of crop rotations, use of tillage and cover crops, use of competitive crop cultivars, and many more (Gage and Schwartz-Lazaro, 2019). Given a large area of research in ecological weed management, a total of 946 articles included this topic with major keywords ecology, biodiversity, population dynamics, agronomic management, seed bank, invasive and introduced species (Fig. 9). Compared to the global context, the education and research in Bangladesh is minimal with only a basic introduction to the topic. Recently, there is an increasing trend in research on ecological weed control, specifically on crop rotation, relay cropping, mulching, dryland agriculture or aerobic rice culture etc.

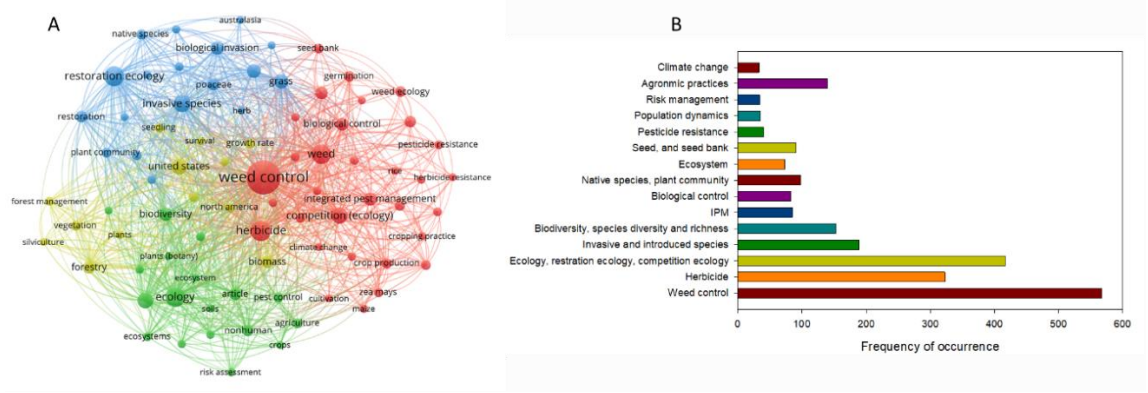


Fig. 9. Keywords of research in the area of ecological control of weeds. Panel A represent network map of keywords and panel B represent frequency of major of occurrence.

Integration of disciplines for development of weed science

Although weed science is sub-disciple of agriculture, many other fields are inter-related including different disciplines including botany, vegetation systems analysis, chemistry/agricultural chemistry, agronomists, software and mechanical engineers, and environmental scientists which can make a complete and proper weed science research to bring fruitful results. However, these integrations or interdisciplinarity have not been started yet in Bangladesh.

CONCLUSIONS

Weed science, a major discipline in agricultural science, has been receiving increasing attention across the globe. However, there education and research has not been developed in Bangladesh with a pace of the global science. This article identified the need of major areas of research and education in Bangladesh. The key

areas of research can include herbicide chemistry, herbicide formulation and mode of action, and development of bioherbicides, advanced weed management techniques (e.g., robotic weed management) and fundamental understanding of crop-weed-soil-environment interactions.

REFERENCES

Aktar, M. W., Sengupta, D. and Chowdhury, A. 2009. Impact of pesticides use in agriculture: their benefits and hazards. *Interdisc. Toxicol*. 2(1): 1–12.

Anwar, M. P., Juraimi, A. S., Samedani, B., Puteh, A. and Man, A. 2012a. Critical period of weed control in aerobic rice. *Sci. World J*. 1-10.

Anwar, M. P., Juraimi, A. S., Puteh, A., Man, A. and Rahman, M. M. 2012b. Efficacy, phytotoxicity and economics of different herbicides in aerobic rice. *Acta Agric. Scand. B Soil Plant Sci.* 62(7): 604–615.

BBS (Bangladesh Bureau of Statistics). 2017. Statistical Yearbook of Bangladesh. Bangladesh Bureau of Statistics, Ministry of Planning. Dhaka. Bangladesh

Caton, B. P., Mortimer, M., Hill, J. and Johnson, D. 2010. A practical field guide to weeds of rice in Aisa. Second Edition. Los Banos (the Philippines); International Rice Research Institute. p. 118.

Duke, S. O. and Dayan, F. E. 2022. The search for new herbicide mechanisms of action: Is there a 'holy grail'? *Pest Manag. Sci*. 78: 1303–1313.

Esposito, M., Crimaldi, M., Cirillo, V., Sarghini, F. and Maggio, A. 2021. Drone and sensor technology for sustainable weed management: A review. *Chem. Biol. Technol. Agric.* 8: 18.

Evans, S. P., Knezevic, S. Z., Lindquist, J. L., Shapiro, C. A. and Blankenship, E. E. 2003. Nitrogen application influences the critical period for weed control in corn. *Weed Sci.* 51(3): 408–417.

Gage, K. L. and Schwartz-Lazaro, L. M. 2019. Shifting the Paradigm: An Ecological Systems Approach to *Weed Manag. Agric*. 9:179.

Gerhards, R., Andújar, S. D., Hamouz P, Peteinatos, G. G., Christensen, S. and Quintanilla, C. F. 2022. Advances in site-specific weed management in agriculture—A review. *Weed Res.* 62:123–133.

Gilmore, E. C. and R. S. Rogers. 1958. Heat units as a method of measuring maturity in corn. *J. Agron*. 50: 611–615.

Harding, D. P. and Raizada, M.N. 2015. Controlling weeds with fungi, bacteria and viruses: A review. *Front Plant Sci*. 6: 659.

Harper, J.L. 1977. The Population Biology of Plants. Academic Press, London. pp. 892.

Islam, M. 2014. Research Advances of Jute Field Weeds in Bangladesh: A Review. *ARPN J. Sci. Technol.* 4:254–268.

Islam, M. S., Alam, M. S., Uddin, M. N., Zabir, A. A., Islam, M. S., Haque, K. A., Islam S. M. A. and Hossain, S. A. A. M. 2016. Farm Level Pesticides Use in Patuakhali and Comilla Region of Bangladesh and Associated Health Risk. *J. Environ. Health.* 2(4): 20-26.

Islam, S., Khatun, M., Uddin, N., Rahman, S., Islam, A. S. M. and Saifullah, M. K. 202. Evaluation of herbicidal properties of Mikania (*Mikania micrantha* H.B.K) and rain tree (*Samanea saman* jacq. Merr.) leaf extract. *Matrix Sci. Pharma.* 25: 89-95.

Jin, M., Chen, L., Deng, X. W. and Tang, X. 2022. Development of herbicide resistance genes and their application in rice. *Crop J*. 10: 26–35.

Kashem, M. A., Faroque, M. A. and Bilkis, S. E. 2009. Weed Management in Bangladesh: Policy issues to better way out. *J. Sci. Foundation.* 7(2): 59 -67

Karim, S. M. R. and Kabir, M.S. 1993. Bangladesher Agacha Porichiti (An Introduction to Weeds of Bangladesh). Bangla Academy, Dhaka. pp. 350.

Karim, S. M. R. 2008. Parthenium weed (*Parthenium hysterophorus* L.): A threat for Bangladesh. Paper presented in a seminar at the Bangladesh Agricultural University, Mymensingh on 29 October 2008.

Karim, S. M. R. 2013a. How do weeds affect us all and what is the way-out? Published by UMK Library, Universiti Malaysia Kelantan. pp. 21.

Karim, S. M. R. 2013b. Parthenium invasion: Weed it out before its too late. NewStraites Times, 25 October, 2013.

Karim, S. M. R. 2012. Review on Weed Research with Special Reference to Bangladesh and Malaysia. Published by UMK Library, Universiti Malaysia Kelantan. pp. 368.

Karim, S. M. R. 2014. Important Tropical Weeds. Published by UMK Library, Universiti Malaysia Kelantan. pp. 362.

Knezevic, S. Z., Evans, S. P., Blankenship, E. E., Van Acker, R. C. and Lindquist, J. L. 2002. Critical period for weed control: The concept and data analysis. *Weed Sci.* 50:(6) 773–776.

Malik, R. K. and Singh, S. 1993. Evolving strategies for herbicide use in wheat. Resistance and integrated weed management. Proceedings of Indian Society of Weed Science International symposium on Integrated Weed management for Sustainable Agriculture, 18-20 November,1993, Hisar. India. 1: 225-238.

Malik, R. K. and Singh, S.1995. Little seed canary grass (*Phalaris minor* Retz.) resistance to isoproturon in India. *Weed Technol.* 9: 419-425.

Motmainna, M., Juraimi, A. S., Uddin, M. K., Asib, N. B., Islam, A. K. M. M. and Hasan, M. 2021. Bioherbicidal Properties of *Parthenium hysterophorus*, *Cleome rutidosperma* and *Borreria alata* Extracts on Selected Crop and Weed Species. *Agronomy*. 11: 643.

Peters, K. and Gerowitt, B. 2014. Important maize weeds profit in growth and reproduction from climate change conditions represented by higher temperatures and reduced humidity. *J. Appl. Bot. Food Qual.* 87: 234–242.

Qu, R., He, B., Yang, J., Lin, H., Yang, W., Wu, Q. and Li, Q. X. 2021. Where are the new herbicides? *Pest Manag. Sci.* 77: 2620–2625.

Rahman, S. 2003. Farm-level pesticide uses in Bangladesh: Determinants and awareness. *Agric. Ecosyst. Environ.* 95: 241–252.

Swanton, C. J., Roger, N. and Robert, E. B. 2015. Experimental methods for crop-weed competition studies. *Weed Sci*. 63(1): 2–11.

Van Eck, N. J. and Waltman, L. 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*. *84*(2): 523-538.

Waltman, L., Van Eck, N. J. and Noyons, E. C. M. 2010. A unified approach to mapping and clustering of bibliometric networks. *J. Informetr.* 4(4): 629-635.

Wu, P., Wang, Z., Wang, H., Bolan, N.S., Wang, Y. and Chen, W. 2020. Visualizing the emerging trends of biochar research and applications in 2019: A scientometric analysis and review. *Biochar*. 2: 135–150.

Yadav, D. B., Yadav, A. K., Punia, S. and Chauhan, B. S. 2016. Management of herbicide-resistant *Phalaris minor* in wheat by sequential or tank-mix applications of pre- and post-emergence herbicides in north-western Indo-Gangetic Plains. *J. Crop Prot*. 89: 239-247

Zimdahl, R. L. 1980. Weed-crop competition: A review, Wiley-Blackwell; 2nd edition, New York. pp. 220