
Biological Characteristics and Control Methods of Benghal Dayflower [*Commelina benghalensis* L.]

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To cite this article:

Xueli Wu, Kai Jiang, Yue Ma, Yongzhuo Zhao, Shenmiao Chen, Wenjie Lu, Juan Sun. Biological Characteristics and Control Methods of Benghal Dayflower [*Commelina benghalensis* L.]. *Journal of Plant Sciences*. Vol. 9, No. 6, 2021, pp. 280-288.

doi: 10.11648/j.jps.20210906.12

Received: October 4, 2021; **Accepted:** November 9, 2021; **Published:** November 12, 2021

Abstract: Benghal dayflower (*Commelina benghalensis* L.) widely distribute in the world and have strong and special reproductive methods. Benghal dayflower also possesses the ability to root at the nodes and can be propagated from cut stems. Under suitable environmental conditions, Benghal dayflower can reproduce very quickly and form invasive populations in crop planting areas that could cause outbreaks of crop pests and diseases as host of plant pathogens. Benghal dayflower is not sensitive to a variety of herbicides including glyphosate. Especially in recent years, with extensive promotion of glyphosate-resistant genetically modified crops and use of glyphosate, that has changed the species and composition of weeds in farmland systems. The control methods of Benghal dayflower mainly included chemical control, mechanical control and comprehensive management of crop production. But no comprehensive and effective control strategy has been developed. Benghal dayflower had become a malignant weed in agricultural production and caused serious agricultural economic losses. At present, the research on Benghal dayflower mainly focuses on biological characteristics, reproductive strategies, hazards and control methods. There are few studies on the physiological and ecological mechanism, the comparison of invasive community types, the process of invasion and diffusion in different species communities, and the dynamics of population response to the environment. and the ecological factors and efficient control methods are still unclear. In this review, our primary objective is designed to lay a theoretical foundation for the development of more economical and effective control technologies and preventative strategies via description of biological and ecological features, harms and formative mechanism of Benghal dayflower; that will help to devise new guidelines and technical approaches for effective prevention and control of Benghal dayflower.

Keywords: Benghal Dayflower, Reproductive Diversity, Biological Characteristics, Malignant Weed, Prevention Strategy

1. Introduction

Benghal dayflower (*Commelina benghalensis* L.) is native to tropical Asia, Africa, and the Pacific islands [1-3] and widely distribute in the world. It is a perennial weed in source area but acts as an annual weed in temperate regions of the United States [4]. At present, Benghal dayflower are attracting more and more attention as a weed that is difficult to control in the field [5, 6].

Benghal dayflower have become a malignant weed because of their special and strong reproductive methods [5, 7-8], but the distribution and hazard of Benghal dayflower vary greatly from place to place in the world [9-10]. In China, it is found throughout more than 17 provinces; the Qinling and the south

of Huaihe River Basin and Hebei Province are the main distribution areas. Although it is more common in potato (*Gossypium* spp.) and summer corn (*Zea mays*) growing areas in the North China Plain, but Benghal dayflower have not yet become a serious field weed in China [11]. In North America, South America and parts of Australia, Benghal dayflower have become a malignant weed [5, 7-8]. Especially in the southeast of United States, Benghal dayflower has aroused increasing concern due to its uncontrolled invasion and the difficulty in prevention and control in planting of glyphosate-resistant crops [12]. In Georgia and Florida, Benghal dayflower have been listed as one of the most difficult to preventable and controllable weeds in cotton and peanut cultivation. It is also an important host of plant

pathogens that could cause outbreaks of crop pests and diseases [13] and had caused serious economic losses. At present, although the biological characteristics, hazards and control methods of Benghal dayflower have been studied [14-18], but the ecological factors that make it difficult to control are still unclear, and efficient control methods need to be developed.

This paper is designed to lay a theoretical foundation for biological and ecological studies on and formative mechanism of this species on basis of progress of studies on Benghal dayflower in recent years, via description of biological and ecological features, harms and preventative strategies of Benghal dayflower; which will help to devise new guidelines and technical approaches for effective prevention and control of Benghal dayflower.

2. Biological Characteristics

2.1. Morphological Features

The leaves of Benghal dayflower are oval, 1.5-3.5 cm wide and 3-7 cm long. The tip of the leaf is sharp or blunt, nearly hairless; the petiole is obvious and short; the leaf sheath close the clasp and obvious which have a long fluff at the edge. The stems are thick and fleshy, and internodes are connected by enlarged nodes [15] (Figure 1A). The basal stem has highly growing offshoots so as to form large quantity of stolon. Height of its erect stem is about 35~40 cm. The nodes can regenerate branches and grow upward to form aerial branches; a large number of adventitious roots can be formed on the nodes, and if they are cut, they can be propagated into a large number of clonal plantlets (Figure 1B). It is consistent with Budd's conclusion that damaged stems of Benghal dayflower have vegetative and reproductive capacity [19]. Benghal dayflower is capable of growing three kinds of twigs [20]. Top and offshoots of aerial vegetative stem of Benghal dayflower is capable of forming aerial reproductive twig during reproductive/growing period. The aerial reproductive twig stands erect, growing with negative geotropism and containing 2~4 buds where seedlings are formed under one side. Sprouts on 3~4 nodes at base of the main stem are capable of breaking through the leaf sheath to grow with positive geotropism. If the soil texture is loose, the seedling is capable of going through under the ground surface to form subterranean reproductive twig with length of 15 cm; if the soil is harder, the sprouts will grow along the ground surface to form surface reproductive twig that is green, whereas the subterranean reproductive twig does not contain chlorophyll. The subterranean and surface reproductive twig do not have leaf blade but leaf sheath. A flower bud can be formed at the top and nodes of the reproductive twig, but the flower buds will not open during flowering [2].

The total bracts of Benghal dayflower are sessile or stalks very short, and the base of the bracts is connected into a funnel-shaped or hood-like shape, which is opposite to the leaves. Generally, several total bracts are gathered at the top of the branch and the lower edges are connate, about 8-12 mm

long, and the surface is sparse fluff. There is a significant difference between the total bracts of Benghal dayflower and *Commelina communis* L., which can be used as one of the distinguishing signs. The total bracts of *Commelina communis* L. have a relatively long stalk, and the base of the total bracts is not contiguous and unfolded in a heart shape (Figure 1C). Flowers of Benghal dayflower can be divided into five categories according to the growth environment and the characteristics of the male-female combination, that include male flower, aerial chasmogamous hermaphrodite, aerial cleistogamous hermaphrodite, subterranean hermaphrodite and surface cleistogamous hermaphrodite. Cyme inside spathe of aerial flower of Benghal dayflower usually has 2~4 flowers, of which the first flower is male and the other 2~3 flowers are hermaphrodite. The bud of the male flower blossoms in 30~35 min after coming out of spathe with small flower in shape of translucent petal; the second bud blooms in 40~45 min afterwards (with chasmogamous hermaphrodite) in three petals in blue-purple color [21]. Ovary of pistil ascends with one rather long style winding in flower in the shape of spiral. There are six stamens including three long stamens and three short stamens. The long stamen winds, wrap the style and head of style; whereas the short one is not capable of fecundity (Figure 1D). In rainy days, the blooming hour and the peak of blooming period of Benghal dayflower will be delayed in more than 1 h and the blooming period is extended [2]. The flower can bear fruits via cross pollination or via self-pollination after blooming. When flowering, the style aerial chasmogamous hermaphrodite is curved, slightly longer than the stamen filament. The style of cleistogamy-type hermaphrodite curls with length 3~4 times as filament. Aerial/surface cleistogamous hermaphrodite and subterranean hermaphrodite have identical flower composition and similar calyx and anther. The first two ones have identical color of petal as aerial chasmogamous hermaphrodite does whereas subterranean hermaphrodite has colorless petal [2, 6].

Benghal dayflower blooms and bears fruits via its aerial and subterranean reproductive shoots; Therefore, four seeds can be produced such as aerial large seed, aerial small seed, subterranean large seed and subterranean small seed [22]. Capsule of Benghal dayflower has three chambers, of which one chamber bears a large seed whereas the other two chambers bear 2~4 small seeds. The aerial and subterranean large seeds are in shape of ellipse with bulging back of net-like ridges and cut-smooth belly; hilum is slightly bulging and is parallel with major axis, located at belly of seed. The aerial large seed is smaller than the subterranean large seed but with longer hilum; the umbilical cord and the seed hole are connected by a small lateral groove, and the seed hole is depressed on the side of the seed; Micropyle sinks, covered with round/ovum-shaped and cap-like micropyle lid on the top. The aerial and subterranean small seeds are in shape of ellipse or long semicircle with one end cut smooth; caruncle-shaped bulging side and smooth-cut lateral end of the seed have net-like bulging ridges; the axis of the flat lateral side of the seed has micropyles with parallel major axis. The air-dry weight of the seed indicates that the

average weight per 100 subterranean large seed, subterranean small seed, aerial large seed and aerial small seed is respectively 1.0547g, 0.4400g, 0.5980g and 0.3145g. There are extremely significant differences among the four types of seeds, and the seed size is decreasing in turn [6, 22-23]. Benghal dayflower has large yield of seed. Field experiment conducted in Australia indicates that the potential yield of seeds for a single piece of Benghal dayflower reaches 9,740 while seed yield per square meters for Benghal dayflower reaches 12,000 [24].

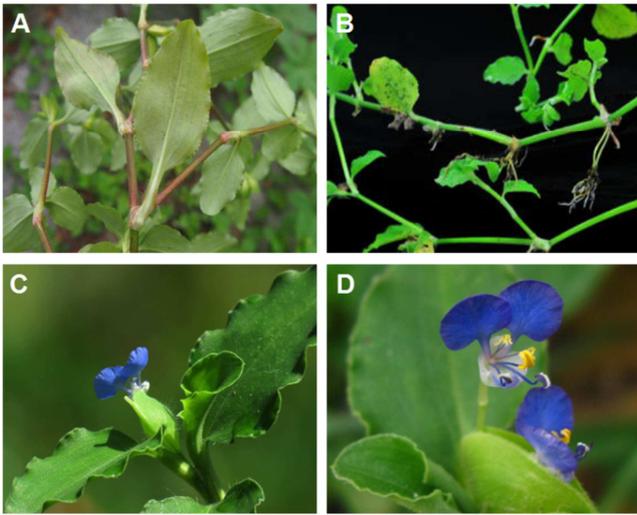


Figure 1. Morphological features of Benghal Dayflower. (A) Oval leaves with distinct short petiole. (B) Nodes have adventitious roots for asexual reproduction. (C) The total bracts are sessile or stalks very short, and its base is connected into a funnel-shaped or hood-like shape. (D) Purple-blue flowers grow in the leaf axils.

2.2. Features of Reproductive Biology

Seed of Benghal dayflower can sprout in soil when the temperature is higher than 15°C. Growing for about 3 weeks, Benghal dayflower can sprout, differentiate, blossom and bear fruits. The seed can come mature and dispersed in 2 weeks after blossoming. The blooming period of Benghal dayflower lasts as long as about 5 months from mid-to-late May to late October [25-26]. Theodore and Timothy point out that under the daily irrigation conditions in the greenhouse, Benghal dayflower began to appear aerial spathe in 7-8 weeks after planting. From the 11th week after planting, there were about 26 spathes ripe or have seeds dispersed each week [27]. 15% of total biomass of Benghal dayflower is used for reproduction, of which 68.9% is mainly supplied for aerial reproduction. Different proportion of biomass allocated to different types of reproductive twigs is linked to effectiveness of available biomass [28].

Benghal dayflower has a variety of reproductive methods, in addition to normal sexual reproduction to produce two types of seeds, both aerial and subterranean seeds, can also be vegetatively propagated through stolons [29-30]. The progeny population produced by asexual reproduction has higher survival rate, which is easy to form a high density aggregation group and occupy new growth space more easily. The progeny

population produced by sexual reproduction has higher genetic variability and higher ability superiority to adapt to environmental changes to a certain extent. In situ hybridization (ISH) was used to study whether the underground seeds were apomixis or sexual reproduction. The results showed that the subterranean seeds were produced by male and female gamete fertilization and belonged to normal self-fertilization rather than apomixis [28, 31].

The two reproductive strategies of sexual reproduction for Benghal dayflower are designed for aerial and subterranean effect. In the foreseeable normal growth environment, aerial seeds, especially aerial small seeds, are the main investment in the reproductive strategy, and only a little amount of resources are invested in subterranean seeds. In the unpredictable adverse environment, reproduction occurs in the early growing season [27]. The growth of reproductive branches to gravity was induced by stress, which increased the probability of flowering and Fruiting of reproductive branches in soil, thus increasing the yield of subterranean seeds [22]. Under adversity conditions, Benghal dayflower can reduce the risk of survival through subterranean seeds, especially subterranean large seeds, and maintain the reproductive capacity of the population [10]. The difference between the reproductive costs of seedlings from large seeds is not significant; but subterranean small seeds are significantly greater than that of aerial small seeds. Reproductive investment of seedlings from aerial large seeds is relatively large; while subterranean small seeds is the smallest [32].

2.3. Dormancy and Germination of Seeds

The dormancy characteristics of the seeds of Benghal dayflower are strong, and there are large differences in the dormancy and germination characteristics of different types of seeds [33]. In Queensland (Australia), the newly harvested seeds of Benghal dayflower vary greatly in terms of germination rate. The germination rate of aerial small seeds, aerial large seeds, subterranean small seed and subterranean large seeds is 0~3%, 20~35%, 33% and 90% respectively [24]. The fresh large seeds have certain germination ability while the small seed has a very low germination power and shows obvious dormancy characteristics. At the same storage time, the germination rate of aerial small seeds was the lowest; while that of subterranean large seeds was the highest, and aerial large seeds were slightly lower than it. With the prolongation of storage time, the germination rate of all kinds of seeds increased obviously, especially for small seeds [22]. Generally, most large seeds germinate after 24 h, but only a few small seeds begin to germinate after 48 h. The germination rates of aerial and subterranean large seeds were 82.50% and 88.33% respectively after 5 days, and the ultra-weak luminescence kinetics curve of the germination process was similar to that of other plants, showing a bimodal curve with good consistency. However, the germination rate of aerial and subterranean small seeds was only 8.33% and 11.67%, and the ultra-weak luminescence kinetic curve had no obvious characteristics, which was significantly different from that of large seeds [11, 34].

The seed of Benghal dayflower has at least two layers of seed coat, including thick and hard interior coat and thin exterior coat. Because seeds coat are impermeable to water and oxygen, seeds have dormancy characteristics [9, 23]. Abrading or cutting off partial seed coat, heat treatment or induction by sulphuric/hydrochloric acid or sodium hypochlorite can interrupt dormancy of the seed [19, 35]. Germination rate of aerial seeds of Benghal dayflower collected from crops and gizzards of American mourning doves. Results indicate that germination rate of aerial seeds of Benghal dayflower collected from crops of mourning doves is 92%, higher than germination rate of control seed 80%; germination rate of aerial seeds collected from gizzards of mourning doves is only 45% [23]. In the experiment of simulated rumen digestion, germination of Benghal dayflower seeds was increased at 48 h, and only a slight decrease occurred after 96 h [36]. Photoperiod treatment is capable of increasing germination rate of aerial seeds of Benghal dayflower obviously in the course of experiment. Light induction can increase the germination rate of seeds, and the sensitivity of subterranean seeds to light is higher than that of aerial seeds. The germination rate of above-ground seeds treated with light was 79%, which was significantly higher than that treated with darkness after 12 weeks. When the above-ground seeds treated with darkness were moved to light, the germination rate increased significantly to 87% [23]. Different kinds of seeds have different optimal germination temperature. Depth for germination of seeds is direct proportion to weight of seed. Optimal soil depth for germination of four kinds of seeds is 0~5 cm [24]; the results are similar to that optimal seedling depth of seeds is 0~4 cm. Optimal seedling depth of large seed is higher than that of small seed whereas seedling depth of subterranean seed is higher than that of aerial seed [34, 37].

Like most of seeds of weeds, seeds of Benghal dayflower germinate in a disordered manner for a long period of time particularly small seed, which germinates for 40~50 d. The final germination rate of big seeds (aerial and subterranean) was about 97%, and there was no significant difference between them. However, the germination coefficient and germination potential of subterranean large seeds were 41% and 81%, respectively, while the aerial large seeds were 27% and 70%. It can be seen that although the final germination rate is similar, but the germination activity of subterranean large seeds is significantly higher than that of aerial large seeds. The germination potential, coefficient and rate of subterranean small seeds were also significantly higher than those of aerial small seeds; but they were lower than large seeds. Through the germination law of four different types of seeds, it can be inferred that in the initial population formation period, large seeds occupy a dominant position, while small seeds supplement and expand the population by quantitative advantage and sustained germination rate, and under adverse conditions, new populations are re-formed to ensure the continuation of the population and to occupy a survival advantage in inter-species competition [22].

3. Distribution

In China, rice bales are widely distributed in 17 provinces such as Hebei, Shandong, Jiangsu, Zhejiang, and Fujian, and grow in the periphery of wetlands such as ponds and riverbeds. In summer, rice bales are commonly found in inter-row spaces such as corn, cotton, melons, and beans. In case of appropriate climate conditions in terms of water and heat, it grows very quickly with large quantity of offshoots, rapidly forming a single population which grabs sunlight, fertilizer and room from those of crops, so as to obviously affect growth of crops, reduce crop yield or quality. For several years, with use of farming machinery and large quantity of herbicide, Benghal dayflower is getting increasingly hazardous in China. As one of the destructive weeds of Chinese agriculture, however, Benghal dayflower has not caused serious economic loss as malicious, exotic and invasive weeds such as *Solidago Canadensis*, *Alternanthera philoxeroides* and *Eupatorium adenophorum*. However, in the southeast of the USA, Benghal dayflower is ranked as one of the most troublesome malicious and invasive weeds for planting of cotton and peanut [38].

In 1928, Benghal dayflower was found for the first time on American continent as a kind of weed. Reports about Benghal dayflower were published in 1930 and 1998 respectively in Florida and Georgia. But at that time, it was not considered that Benghal dayflower will become a malignant weed in agricultural production [1, 39]. Until 2001, when Benghal dayflower had become a kind of uncontrollable weed because of its quick expansion, then it was ranked as one of nine most troublesome weeds [40]. Benghal dayflower is a perennial weed in its native habitat but act as an annual in the more temperate regions of the USA [4]. The southeast of the USA has the most appropriate temperature conditions (30~35°C) for quick growth and reproduction of Benghal dayflower [41-42]. In Georgia and Florida, Benghal dayflower is ranked as one of the most troublesome weeds for planting of cotton and peanut (*Arachis hypogaea* L.) [43]. In 2009, Webster et al studied on the effect of cotton sowing dates on the key period of controlling Benghal dayflower. Results showed that The maximum yield loss of cotton planted in May due to Benghal dayflower is 21% to 30%, while the maximum yield loss of cotton planted in June is as high as 40% to 60% [44]. Benghal dayflower is a serious problem for planting of grains as well. The peak of growing period for Benghal dayflower comes out late in the growing season of grains; it has not brought considerable loss to yield of grains [4].

In 2005, Benghal dayflower expanded in Georgia within a range of about 80,000 hectares. Like other invasive weeds, Benghal dayflower expands quickly and usually reaches a very high density of plant population in infested regions. It has been expanding to 42 states of the USA [12]. Studies have shown that American Mourning Doves (*Zenaida macroura*) have a certain effect on the population spread of Benghal dayflower. most of American mourning doves feed on seeds of Benghal dayflower. The structurally reinforced seed coat of Benghal dayflower enables it to have a relatively high germination rate after it is fed on. Thus, American mourning

doves and other bird species may potentially aid in dispersal of seeds of Benghal dayflower as well as forming new Benghal dayflower population [23].

4. Hazards

In addition to its allelopathic effects on crops, the weeds appears to be an important virus pool, thus constituting a major constraint on efforts to increase and sustain food production [45]. As a key host for plant pathogens, Benghal dayflower is closely related to the outbreak of crop epidemics [13]. Research showed that Benghal dayflower is a key host for nematode and pathogenic fungi of major crops in the southeastern United States; nematode is one of the most damaging pathogens of cotton and one of major pathogens of peanut as well [46-48]. Southern and peanut root-knot nematodes reproduce well on Benghal dayflower with respective reproductive factors 15.5 and 7.2; reproductive factor of reniform nematode is 2.4~3.6. Fungal pathogen of stem rot can be parasitic in 40%~100% of Benghal dayflower plants. Therefore, large quantity of Benghal dayflower among plant population has greatly reduced the pathogen-suppressive effects of crop rotation [49-51].

Allelopathy, as an important ecological invasion mechanism widely existed in nature, plays an important role in species diversity and plant community succession [52-53]. The root exudates of matchhead have obvious allelopathic effects on seed germination and seedling growth of rape, sorghum, maize and mung bean [54]. The invasive range of Benghal dayflower is expanding, which may also be related to allelopathy. However, studies on allelochemicals and their mechanism of action have not been reported. In-depth study of its allelopathic mechanism will be of great significance in revealing its community distribution, succession evolution and biological invasion mechanism.

Benghal dayflower has become one of the most troublesome weeds in agricultural production, because it is not sensitive to a variety of herbicides including glyphosate. Especially in recent years, with extensive promotion of glyphosate-resistant genetically modified crops and use of glyphosate, that has changed the species and composition of weeds in farmland systems; Agricultural economic losses caused by Benghal dayflower are growing [55]. In ecosystem of cotton land in Georgia, factors causing rapid expansion of Benghal dayflower mainly include: use of large quantity of glyphosate for planting of glyphosate-resistant cotton; reduction of use of herbicide before and after seeding; Benghal dayflower is resistant to most of herbicides particularly glyphosate; and special growing and reproductive features of Benghal dayflower [12, 56]. Benghal dayflower has become a major problem in weed control in thousands of glyphosate-tolerant cotton growing areas in Georgia. Only less than 55% of Benghal dayflower can be controlled by glyphosate when height of Benghal dayflower is between 3 cm and 5 cm; up till now, the herbicide which is capable of controlling Benghal dayflower with height of more than 6cm has not been developed [56]. The financial cost for application

of herbicide to prevent and remove weeds during the whole growing season of crops is rather high [4, 14].

With change of ecological environment of the earth, concentration of atmospheric CO₂ concentration rises, which may enhance resistance of some weeds against herbicide [57-59]. Therefore, prevention and control of Benghal dayflower may become more difficult. Research showed that Benghal dayflower is a typical C₃ plant where nitrogen per unit produces larger quantity of biomass in case of high concentration of CO₂. Quantity of flowers and leaves and dry weight of aerial portion of Benghal dayflower obviously increase. Dry weight of leaves, flower, stem and total buds increase by 36%, 30%, 48% and 44% respectively; whereas height, root length and dry weight of root of Benghal dayflower are not affected [60]. Therefore, an in-depth study of the reproductive diversity of Benghal dayflower and its response to environmental conditions will have great significance in revealing the difference in hazard levels.

5. Prevention and Control

At present, the control methods of Benghal dayflower mainly focus on chemical control, mechanical control and comprehensive management of crop production. However, no comprehensive and effective control strategy has been developed at present, which has led to the continuous expansion of the invasion. Currently, chemical prevention and removal, as the main measure of Benghal dayflower control, has the characteristics of large use area, saving time and effort. when applied to small, actively growing plants, Several herbicides, such as MSMA, glyphosate, and 2,4-D provide effective postemergence control [16]. Because Benghal dayflower has the length of germination periods and the high germination rates of seeds, Dual Magnum (s-metolachlor) and other chloroacetamide herbicides, such as Outlook (dimethanamid) and Lasso (alachlor) are effective, which can provide residual preemergence control but the control rate is less than 50%. During 6 weeks of evaluation herbicides such as aminocyclopyrachlor (34-96%), flumioxazin (59-83%), saflufenacil (24-78%), and sulfentrazone (67-96%) provided higher variable control of Benghal dayflower [3]. Saflufenacil as a new protoporphyrinogen oxidaseinhibiting herbicide was ineffective for 5-10 cm plants of Benghal dayflower [61].

With the widespread planting of glyphosate-tolerant GM crops, production and management of crop have also changed, reducing the use of most herbicides which has soil residual activity. Glyphosate, one of the safest commercial broad-spectrum herbicides, is widely used in production and has gradually formed a management model that relies solely on glyphosate to control weeds [62-63]. Benghal dayflower is unsensitive to many herbicides, including glyphosate, and its tolerance is increasing [8, 55, 64-66]. Glyphosate was sprayed on the top of the grass in the early stage of emergence, and the control rate of rice grass was 53% after 21 days. The rice-covered plants less than 6 cm can be almost completely controlled by glyphosate. The growth of rice-planted plants with a height of 6-10 cm is inhibited by spraying glyphosate

for 3 to 4 weeks, and the subsequent growth is slow. Glyphosate is only capable of inhibiting growth of rather large seedling but it is not capable of inhibiting continued germination of Benghal dayflower in growing season. Therefore, activity of residual herbicide is obviously the most important factor for controlling and management system for Benghal dayflower with long germination period. Study had compared effect of combination use of different herbicides in terms of prevention and control, which indicates that application of glyphosate plus S-metolachlor during early seedling period and direct application of MSMA or flumioxazin during late seedling period have rather good effect on preventing and controlling [67]. Control rate reached 80% of Benghal dayflower in late period of time [68]. The control rate of Benghal dayflower by using glyphosate alone was only 68%, but by adding 2,4-D or a mixture of dicamba into glyphosate, that could be increased to 94% to 99% [69].

Because the unsatisfactory control effect of chemical herbicides on Benghal dayflower, the mechanical control method of manual eradication and tillage can be used as a supplement to the critical period. However, the mechanical control method is time-consuming and laborious, so it is difficult to be widely used. Benghal dayflower can use cutting stolons for vegetative reproduction. But mechanical control makes it difficult to clean up stolons thoroughly, so it cannot be completely prevented, but will cause a certain degree of spread. Temperatures higher than 25 °C favor regeneration of stem fragments of Benghal dayflower at both 2 and 6 cm depths. It can be seen that the efficiency of mechanical prevention is relatively low, and it can only be applied to the population with small density or new invasion, and the scope of application is relatively small [36].

Since chemical and mechanical control methods are not ideal for prevent and control of Benghal dayflower, studies on controlling weeds by improving crop production management methods has received increasing attention [18]. Studies have shown that crop-weed interactions can be affected by adjusting plant spacing, sowing date, fertilization and irrigation management, and critical periods for weed control can be determined [70-73]. Sowing cotton in the early growing season can greatly reduce the impact of Benghal dayflower on cotton yield. During the same time after the emergence of cotton, the biomass of Benghal dayflower in the cotton field planted in June was 2-6 times as much as that in May. Due to extensive growth of Benghal dayflower, the maximum yield loss rate of cotton planted in June was as high as 40% to 60%, which was significantly higher than 21%-30% in May. The critical period of weed control (maintain crop yield loss under 5%) for cotton planted in June started from 16th day after planting, and growing degree days ranged from 190 to 800 [44, 74]. The critical period for controlling Benghal dayflower in peanut planting is from May 30 to July 3; the growing degree days ranged from 185 to 607 [75]. By evaluating the periods of interference of Benghal dayflower in the initial growth of coffee seedlings, the critical periods of interference prevention were 15-88 and 22-38 days after coffee seedling sowing under winter and summer conditions, respectively [76]. Benghal dayflower

generally germinates in the late of the summer and grows poorly in low light environments. Therefore, the advance crop planting date is conducive to the formation of a dense canopy before the germination of Benghal dayflower, thereby inhibiting the growth and expansion of Benghal dayflower [2]. A short-day photoperiod can decrease time to flowering by several days and led to a 40 to 60% reduction in vegetative growth of Benghal dayflower [10]. Light restriction did not induce alterations in reproductive capacity of Benghal dayflower plants which have a certain shade tolerance [77]. In planting management, it is also effective to control the growth of meal weed by covering with blue or black mulch film [78-79]. Benghal dayflower has a lower drought tolerance than cotton, so it can be controlled by water management. During drought stress, the growth and reproductive processes of Benghal dayflower were inhibited, and the yield of subterranean seeds was less affected by water than that of aerial seeds. Therefore, reasonable water management is also an important part of Benghal dayflower diversity control system [27]. Recently, the methods of biological control have also made some progress, and research shows that *Lema praeusta* (Fab.) could be a potential biocontrol agent against Benghal dayflower in the fields of peanut, cotton, rice, maize, sorghum and soybean [17].

6. Conclusion

In world, Benghal dayflower is greatly different in distribution and hazards. At present, the research on Benghal dayflower mainly focuses on biological characteristics, reproductive strategies and control methods. There are few studies on the physiological and ecological mechanism, the comparison of invasive community types, the process of invasion and diffusion in different species communities, and the dynamics of population response to the environment. Much is unknown about how the invasive weed Benghal dayflower interacts with the environment [10]. By further researching the types of bio-community that are easy to invade in different growing environments and the key spreading period, we can further effectively reveal the key factors of Benghal dayflower invasion, find out the weak links of invasion and diffusion, and the key time for prevention and control. That can provide a theoretical basis for preventing the spread of rice bales from the source. Most herbicides are not ideal for the prevention and control of Benghal dayflower. Therefore, further study on the mechanism of different herbicides on Benghal dayflower and their control effects at different growth stages that will play an important role in guiding the development of more economical and effective prevention and control technologies.

Although Benghal dayflower is a serious weed in some agricultural production, its beneficial use cannot be ignored. It has widely used in medicine, pigments, food additives and other fields. In China, it has used as a medicinal herb with anti-inflammatory [80], febrifugal, and diuretic effects. In India, Kenya, Cameroon and other countries, it has used to treat leprosy or bedsores [81], menstrual pain [82], dystocia [83], male infertility [84]. At the same time, it has also used as

additives to mustard formulations [85], and flower juice is used as a pigment for painting on transparencies [86]. The highly potent activities of the extracts and constituent compounds of Benghal dayflower against dengue virus serotype 2 (DENV-2) infectivity highlight its potential as targets for further research to identify novel antiviral agents against dengue [87]. Therefore, while developing integrated herbicide control technology in agricultural system, it has important market value to further expand the application scope of Benghal dayflower.

Acknowledgements

This work was supported by National Natural Science Foundation of China (3210140418), Foundation Project of Shandong Natural Science Foundation (ZR202102280543), Fundamental Research Funds for the Universities (6631120002) and 'First Class Grassland Science Discipline' programme of Shandong Province.

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