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A new species of comb-footed spider from Bangladesh

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Abstract

A comb-footed spider of the genus *Theridion* Walckenaer was identified as new to science. The species was collected from village Teroshri, district Manikganj, Bangladesh. Taxonomic description of the species together with its generic diagnosis and distribution are presented here.

Keywords: Comb-footed spider, *Theridion*, Araneae, Theridiidae, Theridinae

Introduction

Comb-footed spiders are members of the family Theridiidae, a group of small sized, colorful spiders' majority of which are parasitic on the webs of araneid spiders. These are commonly found in the garden and forests of Bangladesh. These spiders are cosmopolitan in distribution but majority of the species are found in the tropical and subtropical regions of the world. The family is a large with widespread members and at present it contains a total of 3028 species belonging to 124 genera in the world fauna (World Spider Catalog 2025, Mikhailov 1997, Buchar and Ruzicka 2002). In the Indian Subcontinent, this number is very poor and till date, total 76 species under 26 genera in India (Tikader 1963, Tikader 1970, Patel 1973, Keswani *et al.* 2012) and only 10 species under 6 genera are recorded in Bangladesh (Chowdhury and Nagari 1981, Chowdhury and Pal 1984, Okuma *et al.* 1993, Biswas 2009, 2019, 2021). But in other Asian countries, these numbers are satisfactory, viz. in China (Chen and Zhang 1991, Zhao 1993, Zhu 1998, Song *et al.* 1999), Japan (Yaginuma 1986, Yoshida 1993, 2003, Malayasia (Murphy and Murphy 2000), Singapore (Koh 1989), the Philippines (Barrion and Litsinger 1995), Israel (Levy 1998, Levy and Amitai 1982) etc.

Members of the genus *Theridion* Walckenaer are widely distributed worldwide. These are commonly found in the gardens, forests and crop-fields in Bangladesh. The genus is cosmopolitan and was first established by Walckenaer in 1805 with the type-species *Aranea picta* and till date, it contains a total of about 600 species throughout the world (World Spider Catalog 2025).

Spiders of the genus *Theridion* are one of the potential predators and help in biological pest control of some insect pests of garden and field-crops. Considering both the taxonomic and economic importance of these spiders, the present study was undertaken to know their taxonomic position, diversity and distribution in different places of the country. The present paper represents an illustrated description of a new species *Theridion teroshriensis* n. sp. collected from Teroshri College campus under Manikganj district of Bangladesh, together with its generic diagnosis and distribution.

Materials and methods

Collection and preservation: The specimens were collected by hand from the webs of araneid spiders and from the shrubs by jarking on the inverted umbrella placed underneath the plants. Collected specimens after paralyzing in the jar with chloroform are preserved in 70% ethyl alcohol temporarily for identification.

Identification and deposition: The specimens thus preserve, were identified following different books and literatures of home and abroad. Some of those are– Tikader (1963, 1970, 1987), Levi (1963), Levi and Levi (1962), Barrion and Litsinger (1995), Zhu (1998), Yoshida (2003), Song *et al.* (1999), Okuma *et al.* (1993), Yaginuma (1986) and Levy (1998).

Dissection and study: Taxonomically important body-parts of specimens were dissected out under the Stereo zoom Binocular Microscope placed on a alcohol filled petri dish. Female epigynum after dissected placed in clove oil for 12-18 hours (Levi 1965, Tikader 1987). After dissection, the female epigynum placed in separate micro-vials and later put it in a large vial along with the parent spider within audemans' Preservatives.

Illustration and photograph: Body of spider and its different body-parts were illustrated with Camera lucida under a Stereozoom Binocular Microscope. Leg measurements were taken in the following sequences: femur, patella, tibia, metatarsus, tarsus and total length. All measurements were taken in millimeters (mm).

Results and discussion

Systematics

Family: THERIDIIDAE Sundevall, 1833

Subfamily: Theridinae Sundevall, 1833

Genus: *Theridion* Walckenaer, 1805

Type-species: *Aranea picta* Walckenaer, 1802

1805. *Theridion*Walckenaer, *Tabl. Araneides*: 72.

1895. *Theridion* : Simon, *Hist. Nat. Araignees,* 1: 550.

1942. *Theridion* : Roewer, *Catalog der Araneae*, **1**: 459.

1948. *Theridion* : Kaston, *Bull. Conn. St. Geol. Nat. Hist. Surv.,* 70: 100.

1963. *Theridion* : Levi, *Bull. Mus. Comp. Zool. Harv.,* 129 (10): 483.

1965. *Theridion* : Comstock, *The Spider Book*: 359.

1970. *Theridion* : Tikader, *Rec. zool. Surv. India*, 64 (1-4): 8.

1986. *Theridion* : Yaginuma, *Spiders of Japan in color*: 34.

1991. *Theridion* : Chen & Zhang, *Fauna of Zhejiang, Araneida*: 154.

1993. *Theridion* : Zhao, *Spiders of cotton fields in China*: 219.

1995. *Theridion* : Barrion & Litsinger, *Riceland spiders South &S.east Asia*: 441.

1997. *Theridion* : Platnick, *Advances in Spider Taxonomy*: 289.

1997. *Theridion* : Mikhailov, *Cat. Spiders of former Soviet Union*: 40.

1998. *Theridion* : Zhu, *Fauna Sinica, Araneae, Theridiidae*: 119.

1999. *Theridion* : Song *et al., The Spiders of China*: 137.

2004. *Theridion* : Majumder, *Mem. Zool. Surv. India*, 20 (2): 41.

2006. *Theridion* : Platnick, *World Spider Catalog,* Version 6.5: 829.

2009. *Theridion* : Biswas, *Encycl. flora & fauna of Bangladesh*, 18 (1): 343.

2019. *Theridion* : *World Spider Catalog,* Version 19.5, Nat. Hist. Mus. Bern., http ://www.wsc.nmbe.ch (accessed 17th Jan., 2019).

2021. *Theridion* : Biswas & Uddin, *J. Noakhali Govt. College,* **1** (1): 7.

2025. *Theridion* : *World Spider Catalog,* Version 25.0, Nat. Hist. Mus. Bern., http ://www.wsc.nmbe.ch (accessed on 14th Feb., 2025).

Diagnosis: Spiders of this genus are small in size. Cephalothorax oval or nearly so, flat. Anteromedian eyes equal to or smaller than posteromedians; lateral eyes contiguous. Chelicerae usually weak, sometimes larger. Sternum rounded, projecting almost up to coxae IV, narrower in smaller species and more narrowly rounded (Kaston 1948). Legs relatively long and slender clothed with sharp spines**.**

Abdomen oval, globular in female, sometimes triangular but in male, it is narrower.

Biological note: These spiders are usually found on their own small webs but some members are parasitic on the webs of other spiders of the family Araneidae. They are usually found to move on the foliages of plants on the garden and crop-fields. These are good predators of small insect pests in the crop-fields and gardens.

Distribution: Asia; Africa; America; Europe And Australia.

Description of the species

1. *Theridion teroshriensis* n. sp. (Figs. 1a–1e; 2a)

Material examined: 1 female (Holotype), Teroshri College campus, District Manikganj, 18.05.1992, Coll. V. Biswas. 1 female (Paratype), Agricultural Diploma Institute campus, Faridpur, 12.X.1993, Coll. V. Biswas.

General: Body small, light brown in color. Cephalothorax and legs brown, abdomen dirty-white. Total body length 3.80 mm. Carapace 1.50 mm long, 1.50 mm wide; abdomen 2.60 mm long and 2.40 mm wide with nearly equal width.

Cephalothorax: Broad, longer than wide, marginally constricted; cephalic region raised. Eyes pearly- white, equal, ringed with black basal band; lateral eye close; anterior row of eyes recurved and posterior row nearly

Table 1. Measurements (mm) of leg segments of *T. teroshriensis* n. sp.

Leg	Femur	Patella	Tibia	Metatarsus	Tarsus	Total
I	1.20/1.20	0.40/0.40	0.90/0.90	0.90/0.90	0.40/0.40	3.80/3.80
II	1.00/1.00	0.30/0.30	0.80/0.80	0.80/0.80	0.30/0.30	3.20/3.20
III	0.90/0.90	0.30/0.30	0.70/0.70	0.60/0.60	0.30/0.30	2.80/2.80
IV	1.30/1.30	0.50/0.50	0.90/0.90	1.00/1.00	0.50/0.50	4.20/4.20

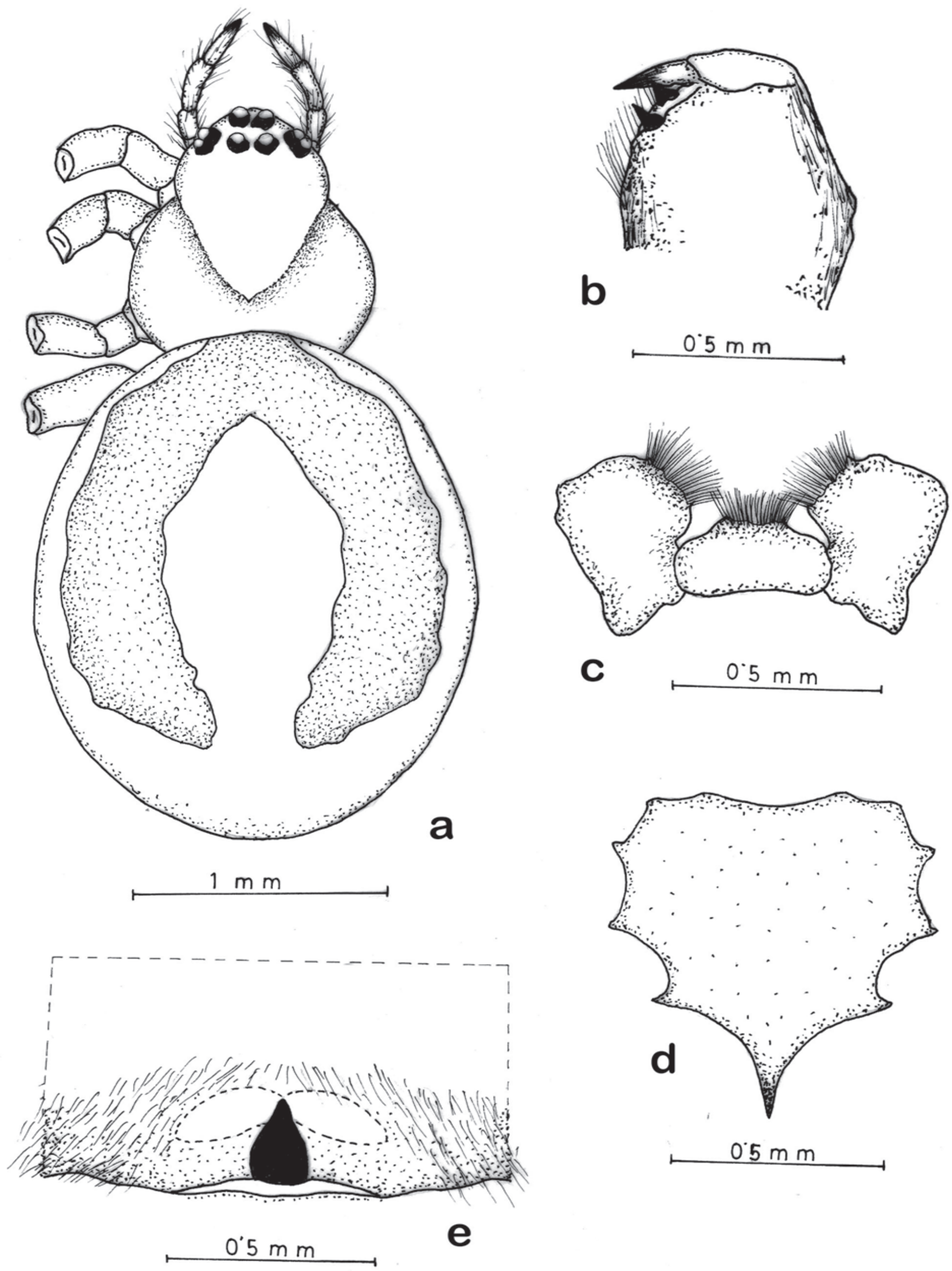

Figure 1 (a-e): *Theridion teroshriensis* n. sp. a. Whole body (dorsal view); b. Chelicerae; c. Maxillae and Labium; d. Sternum; e. Female epigynum.

straight; cervical furrows deeply distinct; thoracic broad, marginally rounded (Fig. 1a). Chelicerae brown, little longer than wide, each of inner and outer margins with 1 tooth (Fig. 1b). Maxillae brown, longer than wide, anteriorly broad and scopulate (Fig. 1c). Labium brown, wider than long, anteriorly scopulate (Fig. 1c). Sternum nearly apple-shaped, posteriorly narrowed and pointed (Fig. 1d). Legs long and slender; leg formula 4123 and the measurements (in mm) are shown in Table 1.

Abdomen: Broadly oval, posteriorly wide, dorsum decorated with blackish longitudinal band; ventrally pale; epigynum as in fig. 1e.

Male: Unknown.

Holotype: Female in spirit.

Paratype: Female in spirit (otherwise data same as for the holotype).

Etymology: The species is named after the name of the type-locality from where the holotype was collected for study.

Distribution: Bangladesh: Manikganj and Faridpur. A whole body dorsal view of the *T. teroshriensis* n. sp. is given Figure 2.

Remarks: The species *T. teroshriensis* n. sp. does not show any similarity to its Indian congeners. However, it shows a little similarity with *T. maijdiensis* Biswas & Uddin (Biswas & Uddin 2021) in general appearance and structure of maxillae and labium but it stands distinct in having the following important characters –

- Structure of cephalothorax and abdominal decoration much different.
- Presence of only 1 tooth on each cheliceral margin.
- Sternum and legs are much different in structure and decoration and
- Structure of epigynum much different with that of *T. maijdiensis* Biswas & Uddin.

Considering the above-mentioned characters of the present species, it may conclude that this species is with distinct and specialized characters. Therefore, the species,

Figure 2. ***Theridion teroshriensis* n. sp. (Whole body dorsal view).**

is described as new to science.

Conclusion

In the taxonomic history of the study of spiders of Bangladesh (Chowdhury and Nagar 1981, Chowdhury and Pal 1984, Okuma *et al.* 1993, Biswas 1995, 2009, 2019, 2021, Begum and Biswas 1997), it is found that studies on the comb-footed spiders (family Theridiidae) are very poorly known and the present study is the second record in the study of theridiids (after Biswas and Uddin 2021) of Bangladesh. In this study, it is observed that there are some marked differences exist in the present species with those of the previous ones.

But there are many similarities found in the biology and behavior with the previous ones. For example– all these are potential predators of small insect pests of fields and gardens crops. The preying of both present and previous ones took place on the plant leaves and webs where they stay. Therefore, all these web-inhabiting members are called '*kleptoparasitic species*' or the kleptoparasites of the web-building spiders (Araneidae). But all these species are helping in the biological pest management system of garden, forests and field-crops.

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The author is grateful to late Dr. S. C. Majumder, Scientist-SD, Zoological Survey of India, Kolkata, for the confirmation of the identity of the species and Professor Herbert W. Levi, Museum of Comparative Zoology, Harvard University, for sending several papers of this study. The author also thankful to the Principal, Government Profulla Chandra College, Bagerhat, for his kind permission to carry-out this study.

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Impact of COVID-19 pandemic on cultivation of potato in Bangladesh

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Abstract

COVID-19 pandemic was a serious catastrophe which affected the people worldwide. The study was carried out to assess the impact of COVID-19 pandemic on cultivation of potato variety BARI Alu-25 in Bangladesh. The study sites were Sirajdikhan and Tongibari upazilas under Munshiganj district and Pirgacha and Mithapukur upazilas under Rangpur district. Data were collected from 80 BARI Alu-25 growers. Descriptive statistics were used for data analyses. About one-fifths (13.8%) of the respondents were very highly affected in marketing BARI Alu-25 and 10.0 percent of them were very highly affected in getting market price due to COVID-19 pandemic. The highest portion of the respondents suggested to give incentives, subsidies, inputs, marketing support, labourer financial grants, credit at a reduced rate of interest and transport facilities for carrying potato farming during lock down with government initiative.

Keywords: *Solanum tuberosum*, COVID-19, labourer, market price

Introduction

COVID-19 pandemic was an adversity originated from Wuhan, China which gradually devoured the whole world. It was a pandemic having adverse effects on both human lives causing deaths and serious health hazards as well as on economic and agricultural activities. About seven million people died due to COVID-19 pandemic throughout the world which is a serious loss (Worldometer 2025). The COVID-19 was the fifth documented pandemic since the 1918 flu pandemic. The first report of COVID-19 was observed in Wuhan, China at the end of 2019 and from there it was spread all over the world. Extensive precautions like extensive hygiene protocol (e.g., regular hand washing, avoidance of face-to-face interaction etc.), social distancing, wearing of masks etc. and banning gatherings of people, locking the population, enforcement of strict quarantine were adopted by many countries to control the spread of COVID-19. The daily life of people, businesses, the world trade and movements were seriously affected by COVID-19 (Haleem *et al.* 2020).

The access to inputs such as seeds, fertilizers and agrochemicals by the farmers were greatly affected by the lock downs and border closure (Roubík *et al*. 2022). The first COVID-19 patient was reported on March 11, 2020 in Bangladesh. The COVID-19 pandemic put the agriculture sector at risk and 66% farmers obtained lower price than normal situation in Bangladesh. The price of vegetables, fruits and nearly all agricultural products were lowered due to reduced market demand. Thirty four percent of respondents reported damages of their products (Gautam *et al*. 2022).

Potato is the most important non-cereal food crop worldwide and ranked the world's fourth most vital food crop after rice, wheat, and maize. The productivity of potato was decreased during COVID-19 pandemic. The accessibility of farmers to the market was difficult. Sometimes they were not able to go to the market due to the large-scale social restrictions. The frequency of the presence of collectors was also decreased (Pujiharto and Wahyuni 2023). An unprecedented rise in price of potato was reported during the months of lock down in India. It might be due to the decrease in arrivals because of transportation and labour unavailability. The prices decreased at the end of lock down due to the relaxations in lock down and reduced demand (Rajpoot *et al*. 2022).

Many researches were conducted on the impact of COVID-19 pandemic on agriculture worldwide. Several researches on this issue were also carried out in Bangladesh, though limited carried out on the impact of COVID-19 pandemic on potato production especially in the context of Bangladesh. Therefore, this research was conducted on impact of COVID-19 pandemic on cultivation of a Bangladesh Agricultural Research Institute released

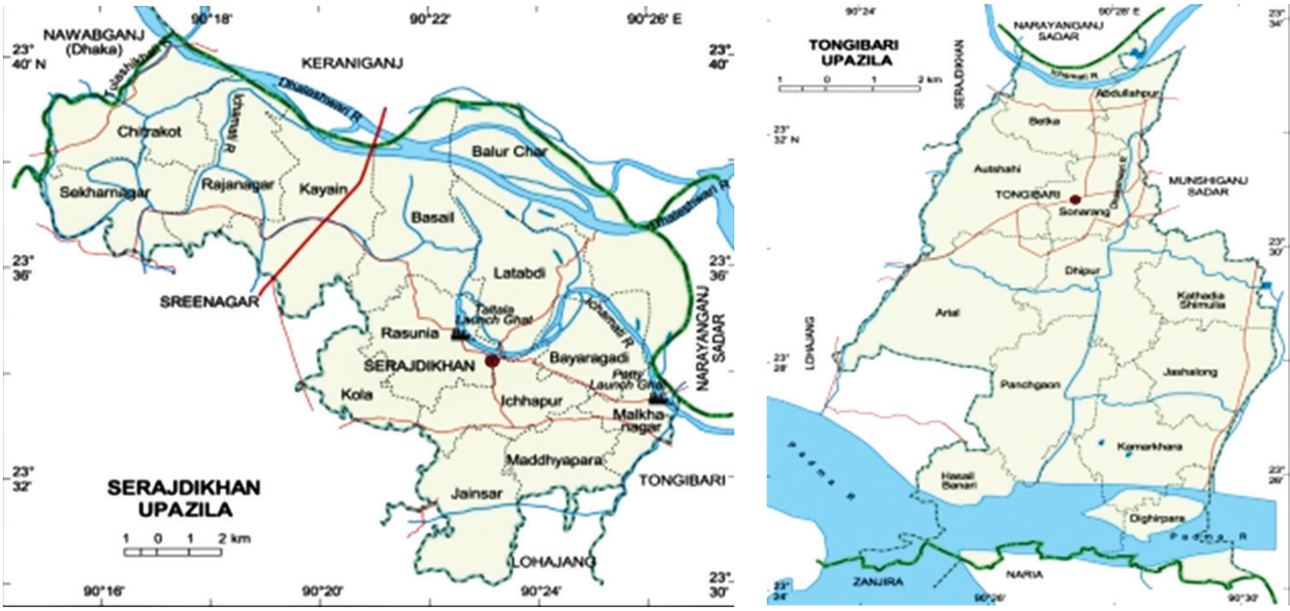

Figure 1. Map showing Sirajdikhan and Tongibari upazilas under Munshiganj district

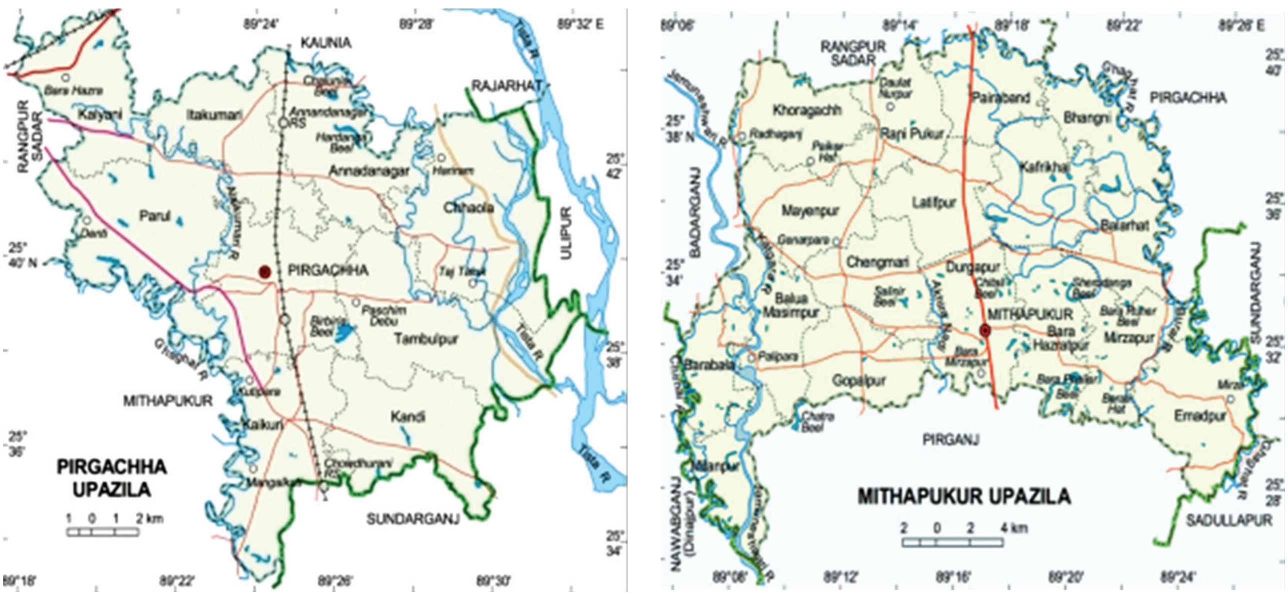

Figure 2. Map showing Pirgacha and Mithapukur upazilas under Rangpur district.

potato variety, BARI Alu-25 considering all the aspects of cultivation and marketing.

Methodology

The study was carried out in Sirajdikhan and Tongibari upazilas under Munshiganj district and Pirgacha and Mithapukur upazilas under Rangpur district (DAE 2019a, DAE 2020a, DAE 2020b, DAE 2020c).

The population of the study was the growers who cultivated BARI Alu-25 for at least three years. The sampling population was 330 and 100 in Sirajdikhan and Tongibari upazila, respectively under Munshiganj district and 220 and 150 in Pirgacha and Mithapukur upazila, respectively under Rangpur district. Sampling was done following Hossain and Rahman (2001) where the respondents were 80. The data were collected during December, 2020 to

November, 2021. Fifteen selected characteristics of the respondent were the independent variables of the study. Age of the respondent was measured in terms of years. Level of education was measured in terms of years of schooling. Family size was measured by counting the total number of family members of the respondent comprising the head of the household, his wife, children, parents and other dependents who jointly lived and ate together. Farm size was measured in terms of hectares. Annual income was measured in terms of thousand BDT. Training experience was measured in terms of number of days. Extension contact was measured in terms of scores. Farming experience was measured in terms of years. Access to credit, off-farm activities and availability of irrigation water were measured in ordinal scale where if the respondent had access to credit, it was coded as one (1) and if he/she had no access to credit, it was coded as zero (0). Similarly, if the respondent had off farm activities, it was coded as one (1) and if he/she had no off-farm activities, it was coded as zero (0). In case of availability of irrigation water, if the respondent had available irrigation water, it was coded as one (1) and if he/she did not have available irrigation water, it was coded as zero (0). Organizational membership, cosmopoliteness, innovativeness and knowledge on cultivation of potato were measured in terms of scores. The impact of COVID-19 pandemic on cultivation of potato variety BARI Alu-25 was the focus variable of the study. Impact of COVID-19 pandemic on cultivation of BARI Alu-25 was measured by using five-point rating scale. The extents of impact were 'very highly affected', 'highly affected', 'moderately affected', 'poorly affected', and 'not affected at all', with the corresponding scores assigned '4', '3', '2', '1' and '0', respectively. The issues considered for measuring impact of COVID-19 were: production, harvest, market price, marketing, transport, labourer, availability of seed, high cold storage charge, and input price. The suggestions to cope with the challenges of COVID-19 pandemic in cultivation of potato variety BARI Alu-25 were collected from the respondents' responses. Then the suggestions were listed based on the percentage. Data were coded, compiled, tabulated and analyzed according to the objectives of the study using SPSS v20. Descriptive statistical measures like number and percentage distribution, range, rank order, mean etc. were used.

Results and discussion

Results presented in Table 1 show that about half (46.3%) of the respondents were old aged. Majority (82.5%) of them were literate and the highest percentage (42.5%) of them belonged to secondary education level. The majority of them (45.0%) had small family. More than half (51.3%) of the respondents had medium farm and there were no landless farmers. Their average annual income was BDT 649.4 thousand which was much higher than the national average (BDT 137.8 thousand) (BBS 2021) and most of the growers (81.2%) belonged to medium to low annual income category. About half (40.0%) of the respondents had high training experience. The large majority of them (73.8%) received agricultural training. The highest portion of the respondents (63.8%) had medium extension contact. Most of them (66.3%) had medium farming experience. Most of the respondents (86.3%) had access to credit. More than half (55.0%) of them had no off-farm activities. All the respondents (100.0%) had available irrigation water. Majority of them (48.8%) had medium organizational membership. Majority of them (71.3%) had medium cosmopoliteness. About half of the respondents (43.7%) had low innovativeness. Most of them (71.2%) had low to medium innovativeness. Majority of them (75.0%) had moderate knowledge on potato cultivation.

About one-fifths (13.8%) of the BARI Alu-25 respondents were very highly affected in marketing BARI Alu-25 and 10.0 percent of them were very highly affected in getting market price (Table 2) due to COVID-19 pandemic. It was also found that 8.8 percent of them were very highly affected in getting transport, 5.0 percent of them were very highly affected in getting labourer, 5.0 percent of them were very highly affected in availability of seed and 2.5 percent of them were moderately affected in input price due to COVID-19 pandemic. It might be due to the reason that because of lock down caused by COVID-19 pandemic growers were very highly affected in marketing BARI Alu-25 and getting the market price, transport availability, labourer availability and seed availability. Their input price was also moderately affected. During lock down they could not sell potatoes due to market closure. They also did not get reasonable market price due to reduced demand, panic and market closure since potato is perishable crop. Therefore, they sold the potatoes at

Table 1. Characteristics of the respondents

Characteristics (Measurement unit)	Possible and observed range	Respondents (n=80)		Mean
		Categories	%	
Age (Year)	Unknown (24-78)	Young (up to 35)	26.2	47.5
		Middle aged (36-50)	27.5	
		Old (above 50)	46.3	
Level of education (Years of schooling)	Unknown (0.5-18)	Illiterate (0)	0.0	7.8
		Can sign only (0.5)	17.5	
		Primary (1-5)	20.0	
		Secondary (6-10)	42.5	
		Higher secondary (>10)	20.0	
Family size (Number)	Unknown (2-16)	Small family (up to 4)	45.0	5.3
		Medium family (5-6)	32.5	
		Large family (above 6)	22.5	
Farm size (Hectare)	Unknown (0.2-13.5)	Marginal (up to 0.2)	1.3	2.4
		Small (0.21-1.00)	23.7	
		Medium (1.01-3.00)	51.3	
		Large (above 3.00)	23.7	
Annual income ('000' BDT)	Unknown (10-3900)	Low (up to 291)	38.7	649.4
		Medium (292-1008)	42.5	
		High (above 1008)	18.8	
Training experience (Number of days)	Unknown (0-330)	No training (0)	26.2	39.8
		Low (1-5)	26.3	
		Medium (6-10)	7.5	
		High (above 10)	40.0	
Extension contact (Score)	0 to 80 (11-56)	Low (up to 21)	20.0	31.7
		Medium (22-42)	63.8	
		High (above 42)	16.2	
Farming experience (Years)	Unknown (4-65)	Low (up to 13)	17.5	26.6
		Medium (14-40)	66.3	
		High (above 40)	16.2	
Access to credit	-	No	13.8	-
		Yes	86.3	
Off farm activities	-	No	55.0	-
		Yes	45.0	
Availability of irrigation water	-	No	0.0	-
		Yes	100.0	
Organizational membership (Score)	Unknown (0-216)	Low (up to 11)	36.2	37.7
		Medium (12-64)	48.8	
		High (above 64)	15.0	
Cosmopoliteness (Score)	0 to 15 (3-15)	Low (up to 8)	18.7	10.9
		Medium (9-14)	71.3	
		High (above 14)	10.0	
Innovativeness (Score)	0 to 21 (0-15)	Low (up to 3)	43.7	5.4
		Medium (4-7)	27.5	
		High (above 7)	28.8	
Knowledge on potato cultivation (Score)	0 to 30 (14-28)	Low (up to 19)	18.7	22.4
		Medium (20-26)	75.0	
		High (above 26)	6.3	

reduced price.

The potato farmers did not get transport for carrying products and did not get labourer during lock down. They also faced difficulties in input availability. Inputs especially seeds were not available due to lock down and input price was also high in some cases. Gatto and Islam (2021) revealed that agricultural production was reduced after COVID-19 hit in Bangladesh. But significant reductions were not observed in case of potato. Slight reduction was observed in the share sold at markets in case of potato in 2020. It was also observed in their study that to compensate for the reduction in male family labourer, households hired slightly more male and female labourer. The consumption of potato was reduced in 2020. COVID-19 had no significant effect on potato sales but the coefficients had the expected negative sign which might be due to the fact that the potato is an important cash crop. Talukder *et al*. (2021) reported that the agri-food systems were disrupted at the farm, value chain and market levels in Bangladesh due to COVID-19 pandemic.

The Lock down led to loss of income among people across the country, with lowered purchasing power and demand for fresh produce which affected both producers and suppliers. Farmers could not sell their products after harvest in many cases. Some farmers had let their crops rot in the fields, leading to great loss. Some farmers could sell perishable produces locally at significantly discounted rates. Rahman *et al*. (2021) also reported that the lock down due to COVID-19 pandemic caused restrictions on the access to agricultural products, materials, markets and advisory services in Bangladesh and farming activities were greatly affected by those. Gautam *et al*. (2022) reported that 53% crop and vegetables farmers obtained lower price during COVID-19 than normal situation in Bangladesh. The price of vegetables, fruits and nearly all agricultural products were lowered due to reduced market demand. Thirty four percent of respondents reported damages of their products. Haque *et al*. (2022) also reported that the availability of labourer for the time bounding farming such as vegetable, crops and fruit picking was seriously affected by quarantine measures in Bangladesh. Perishable products like fruits, vegetables and milks were spoiled due to transportation restriction. The movement of workers were impeded due to transport restriction which seriously affected horticultural, livestock, and food processing industries. Plantation and harvesting operations were hindered because of unavailability of expert workers. In their study it was also reported that the marketing and shipping of fruits, vegetables, eggs, chicken meat, and milk were seriously affected. Khan *et al*. (2021) reported that the shortage of adequate storage facilities, along with transport disruptions and reduced demand due to lock down to prevent the spread of COVID-19 caused wastage of perishable goods. It was also found in their study that labourers could not move

Table 2. Impact of COVID-19 pandemic on potato variety BARI Alu-25 cultivation in Bangladesh

Item	Extent of impact				
	*VHA (%)	HA (%)	MA (%)	PA (%)	NAAA (%)
Production	0.0	1.3	0.0	0.0	98.8
Harvest	1.3	2.5	0.0	1.3	95.0
Market price	10.0	3.8	1.3	0.0	85.0
Marketing	13.8	1.3	1.3	0.0	83.8
Transport	8.8	0.0	3.8	2.5	85.0
Labourer	5.0	1.3	3.8	5.0	85.0
Availability of seed	5.0	0.0	1.3	0.0	93.8
High cold storage charge	1.3	0.0	0.0	0.0	98.8
Input price	1.3	0.0	2.5	1.3	95.0

*VHA=Very highly affected, HA= Highly affected, MA=Moderately affected, PA=Poorly affected, NAAA= Not affected at all

Table 3. Rank order of the suggestions to cope with the challenges of COVID-19 pandemic in potato variety BARI Alu-25 cultivation

	Suggestions	Respondents (%)	Rank
1.	The government may rehabilitate the affected growers through incentives, subsidies, quality inputs, labourer and marketing support, financial grants, and credit at a reduced rate of interest	37.5	1st
2.	Transport facilities for carrying agricultural products in lock down with government initiative	37.5	1st
3.	The government may provide labourer support in lock down situation and arrange easy transport and movement facilities for labourer at low cost in lock down	31.3	2nd
4.	Reasonable market price of potato can be ensured through regular monitoring	31.3	2nd
5.	Market of perishable agricultural products may be kept open in compliance with health regulations and maintaining social distance in lock down situation with government initiative	25.0	3rd
6.	Export of potato can be increased with government initiative	18.8	4th
7.	Government may purchase potato and arrange marketing and export	12.5	5th
8.	Vaccination of growers for COVID-19 and creating awareness	12.5	5th
9.	Timely input supply in lock down situation	6.3	6th
10.	Import of potato can be reduced during harvesting of potato	6.3	6th
11.	Proper training may be arranged for growers	6.3	6th
12.	Government cold storage facilities are essential	6.3	6th

due to social distancing and decreased transportation. It was also reported that agricultural inputs are imported by most of the countries from other parts of the world. The shipment of agricultural inputs became expensive because of the closing of the international border and restriction on commercial flights in lock down situation. Farmers experienced the scarcity of agricultural inputs such as seeds, fertilizer, and pesticides.

To cope with the challenges of COVID-19, the highest portion (37.5%) of the respondents suggested that the government may rehabilitate the affected growers through incentives, subsidies, quality inputs, labourer and marketing support, financial grants, and credit at a reduced rate of interest and about 'transport facilities for carrying agricultural products in lock down with government initiative' (Table 3). It might be due to the fact that the affected growers needed rehabilitation through incentive, subsidy, financial grants and agricultural credit support. The incentives, subsidies, free distribution of quality inputs, labourer and marketing support, financial grants, and credit at a reduced rate of interest provided by the government help the affected farmers, especially small and marginal farmers, for rehabilitation in any calamities. Haque *et al*. (2022) also reported that the loans should be given on easy terms among the marginal farmers so that their poor financial condition due to lock down can be overcome since the small and marginal farmers were affected most due to the lock down. In their study, it was also reported that there can be provision for free distribution of agricultural inputs. Getting agricultural loans by the farmers can be made easy. They also suggested about the consideration of the decision to reduce interest on previous loans. They also reported that it is essential to create an accurate database to reach the facilities and subsidies provided by the government at the marginal farmer level. They also suggested that the supply of irrigation facilities, crop-protecting equipment, seed, and fertilizer needs to be ensured in a lock down situation. The capacity of BADC needs to be expanded to increase irrigation. Amjath-Babu *et al*. (2020) also suggested about adequate credit facilities and innovative labourer management tools.

The respondents also suggested about transport facilities. It might be due to that they could not sell their agricultural products timely because of transport unavailability in lock down. If there are provision of transport for carrying agricultural products in lock down situation farmers can easily sell their agricultural products to markets and the products can be carried throughout the country. Jhajhria *et al*. (2020) also suggested that transportation logistics are essential for the movement of farm produce which can be arranged by farmers' groups or traders during lock down due to COVID-19. Mottaleb *et al*. (2020) also reported that the government can issue movement passes to persons and carriers of agricultural input and output in very strict lock down situation to support smallholder agriculture, wage workers and agricultural value chains in Bangladesh.

About one-third (31.3%) of the respondents' major suggestions were 'the government may provide labourer support in lock down situation and arrange easy transport and movement facilities for labourer at low cost in lock down' and 'reasonable market price of potato can be ensured through regular monitoring' (Table 3). It might be due to the fact that they could not get labourer due to lock down, restrictions on movement and transport unavailability. It is very essential to ensure labourer availability in lock down situation and easy transport and movement facilities for labourers to execute agricultural activities. Mottaleb *et al*. (2020) also reported that the government can issue movement passes to persons and carriers of agricultural input and output in very strict lock down situation to support smallholder agriculture, wage workers and agricultural value chains in Bangladesh. They also might not get reasonable market price of potato due to lock down situation and closing of market. If regular monitoring can be ensured by the government, then reasonable market price of potato can be obtained by farmers. Haque *et al*. (2022) also reported that market monitoring is very essential to maintain a sound marketing chain after COVID-19 pandemic. Syndicate is a serious problem for distribution of profit among all stakeholders associated with supply chain. Syndicate and illegal stocking affect profit distribution. Proper monitoring can reduce these problems and proper distribution of profit can be ensured among all stakeholders.

One-fourths (25.0%) of the respondents suggested that the market of perishable agricultural products may be kept open in compliance with health regulations and maintaining social distance in lock down situation with government initiative (Table 3). It might be due to the fact they could not sell their agricultural products timely because of closing of market in lock down. As a result, their potatoes were wasted. Therefore, markets of perishable agricultural products are essential to be kept open in lock down situation maintaining health regulations properly. Rahman *et al*. (2021) reported that any distortions in the supply chain during harvest needs to be avoided in the COVID-19 pandemic. Mottaleb *et al*. (2020) also reported that the government can issue movement passes to persons and carriers of agricultural input and output in very strict lock down situation to support smallholder agriculture, wage workers and agricultural value chains in Bangladesh.

Conclusion

COVID-19 pandemic negatively impacted human lives as well as global economy all over the world. About one-fifths (13.8%) of the respondents were very highly affected in marketing BARI Alu-25 and 10.0 percent of them were very highly affected in getting market price due to COVID-19 pandemic. Their transport, labourer and seed availability were also affected. The highest portion of the respondents suggested the government about rehabilitation of the affected growers through incentives, subsidies, inputs, labourer and marketing support, financial grants, and credit at a reduced rate of interest and transport facilities for carrying agricultural products in lock down with government initiative.

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Present status and future scenario of water security in the Barind area of Bangladesh

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Abstract

The present study assessed the spatial and temporal dynamics of water security from 1988 to 2021 and projected the future scenarios for 2026 and 2031 in the Barind area of Bangladesh. Geospatial techniques such as, weighted overlay method with composite weight levels ranging from 1 to 5 (representing very low to very high water security), were applied to delineate and identify water security conditions across specific locations within the Barind area. A total influence of 100 was distributed among key variables based on their relative importance. Using GIS and remote sensing software, rainfall, temperature, groundwater, and surface water conditions were processed, estimated, and predicted based on collected datasets. The findings reveal a significant deterioration in water security from 1988 to 2021, with a noticeable expansion of both very low and low water security conditions. Very low water security, nearly negligible in 1988, affected 17.08% of the region by 2021. Low water security increased from 12.22% in 1988 to 27.39% in 2021. Moderate water security, initially covering a substantial portion of the region, declined to 41.06% by 2021, while high water security areas dropped sharply from 44.06% in 1988 to just 12.29% by 2021. Throughout this period, very high water security conditions remained consistently limited, covering only 2.18% of the region by 2021. Projections for 2026 and 2031 suggest a further decline in water security, with very low water security predicted to affect 30.42% of the region by 2031 and low water security expected to cover 36.72%. High water security is projected to shrink to just 4.47% of the region, while very high water security will remain stable but limited, covering only 1.43%. These trends signify the pressing needs for improved water management strategies such as surface water conservation, sustainable irrigation practices, managed aquifer recharge and afforestation to mitigate increasing water scarcity and ensure sustainable resource use in the Barind area.

Keywords: Climate change, future prediction, ground water, water security, weighted overlay

Introduction

Water is a critical natural resource that sustains life and is integral to socio-economic development across regions (UN 2021, FAO 2020, IPCC 2022). It is essential for agriculture, energy production, and ecosystems, making it fundamental for both human well-being and economic stability (Ahmad *et al*. 2023). The negative impacts of climate change, especially global warming, have significantly exacerbated the global reduction in water resources (IPCC 2022, UN 2021). Similarly, these effects have been observed and documented at the regional level. However, water security, which indicates the capacity of a population to access adequate water of acceptable quality for human well-being, socio-economic development, and environmental sustainability (UN-Water 2013), is increasingly at risk in Bangladesh (Adeel 2017) it is ambitious as it aims to fix major global problems in a 15-year span. It signifies a paradigm shift in international development that emphasizes the role of national governments and other domestic stakeholders. Water security is a keystone element in achieving the 2030 Agenda – not just for Sustainable Development Goal (SDG. The broader implications of climate change, including altered precipitation patterns, higher temperatures, and rising sea levels, have serious consequences for Bangladesh's water resources (Hossain *et al.* 2012) Government of People' Republic of Bangladesh. Climate Change Cell, Dhaka, 2007. The country ranked 7th in the Global Climate Risk Index 2020, is one of the most climate-vulnerable regions globally (Eckstein *et al.* 2020). With frequent floods, cyclones, and droughts, the nation's hydrological risks are compounded by desertification, riverbank erosion, and salinization, further straining agriculture and food security (Rahman 2015). These challenges necessitate robust policy responses, as reflected in the government's efforts through various frameworks such as the National Adaptation Programme of Action (NAPA) 2005 and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) 2009 (MoEF 2009). More recent policies include the Bangladesh Climate Change Action Plan (BCCAP) 2021-2025, which extends the BCCSAP and provides updated strategies for managing climate impacts and enhancing resilience (MoEFCC 2023). Additionally, the National Adaptation Plan (NAP) 2021 builds on the NAPA 2005 to outline long-term adaptation strategies for managing climate risks and improving resilience across various sectors, including water management (MoEFCC 2023). Furthermore, the Delta Plan 2100 addresses long-term water management and climate change challenges in the delta region, focusing on sustainable water use and resilience-building (Bangladesh Delta Plan 2018).

There is substantial research evidence of reduced surface and groundwater levels across different regions of Bangladesh (Shaw *et al.* 2013). In particular, the Barind area of northwestern Bangladesh is experiencing the brunt of these changes, with rising temperatures, droughts, and depleting groundwater supplies (Hossain *et al.* 2020, Ahmed *et al.* 2022, Rahman *et al.* 2023). Studies have documented that groundwater abstraction has rapidly increased in Bangladesh, depleting reserves and pushing the water table further down (Basharat 2014, Zahid 2015, BGS 2015). The impacts of such over-extraction are particularly felt in water-stressed regions such as Barind area, where agriculture, which consumes nearly 90% of the country's water, depends heavily on groundwater (Reza *et al.* 2020b, UNDP 2017). As one of the climate-induced hotspots designated in the Bangladesh Delta Plan 2100, the Barind area exemplifies the growing threat of water insecurity exacerbated by climate change (Bangladesh Delta Plan 2018). The groundwater and surface water levels in Bangladesh, particularly in regions like the Barind Tract, have been continuously declining due to both climatic and anthropogenic factors (Sujan *et al.* 2023). Recent studies have confirmed these trends. For example, the Bangladesh Water Development Board (BWDB) has reported ongoing groundwater depletion, primarily driven by intensive agricultural irrigation (Islam *et al.* 2021). Additionally, global data from NASA's GRACE satellites highlight a significant drop in terrestrial water storage across the country, particularly over the last two decades, reinforcing the role of climate change in exacerbating water scarcity (Ahmed *et al.* 2020). Furthermore, a comprehensive analysis by the Asian Development Bank (2022) underscores the link between increased demand for irrigation water and declining aquifer levels in the region. The Barind Multipurpose Development Authority (BMDA), established to alleviate these water challenges, has made strides in afforestation and water extraction through deep and shallow tube wells (Reza *et al.* 2020a). Despite these interventions, groundwater depletion continues, posing a major concern for long-term water security in the region (Islam *et al.* 2017, Ahmed *et al.* 2020 and Rahman *et al.* 2022). The Barind area, marked by erratic rainfall, over-extraction of groundwater, and poor water management, faces exacerbated water stress due to both population growth and climate change (Hosenuzzaman *et al.* 2024, Raza and Khan 2022) untreated industrial effluents, improper disposal of domestic waste, and agricultural runoffs. Furthermore, the availability of surface water is not consistent because of seasonal variation. Due to shortage and inconsistencies in surface water supplies, groundwater acts as the mainstay for agriculture, industrial use, and household consumptions. The depleting groundwater level and contamination from different sources have become a great challenge for Bangladesh. This chapter will highlight the major causes of surface and groundwater contamination along with the potential water management strategies through human and policy intervention nexus.

A complete scenario of recent water pollution status, challenges of safe water, and management approaches will provide insights and help in policy-making to address water scarcity c7hallenges in the delta region of Bangladesh. The population of the Barind area is projected to increase from 18.9 million in 2019 to 23.3 million by 2030. This growing demand for water, combined with climate-induced stressors, is expected to worsen existing challenges (BBS 2020). Moreover, the intensifying impacts of climate change, such as prolonged dry spells, increased evaporation, and saline intrusion, are likely to further deplete groundwater resources (Islam *et al.* 2017). The literature review indicates that water security in the Barind area has not been covered extensively in previous research. Hence, the present study is an endeavor to evaluate the current and future water security in the Barind area of Bangladesh by examining the changes in climatic parameters in the study area.

Study area

The Barind area, encompassing the districts of Rajshahi, Chapai Nawabganj, Naogaon, Joypurhat, Bogra, Sirajganj, Pabna, and Natore in the Rajshahi Division, as well as Thakurgaon, Dinajpur, Panchagar, Rangpur, Kurigram, Nilphamari, Lalmonirhat, and Gaibandha in the Rangpur Division, features a diverse topography. Predominantly a flat plateau with gentle slopes, the region's elevation ranges from 20 to 30 meters above sea level. This elevated terrain is interspersed with small hills and undulating areas. The soil varies from sandy loam to clayey loam, supporting extensive agricultural activities. The drainage system, characterized by a network of rivers, canals, and natural depressions, plays a crucial role in flood management and irrigation. The region's subtropical climate, with distinct wet and dry seasons, impacts water availability and agricultural productivity. Understanding these spatial features is essential for addressing water security challenges and implementing effective policies for the Barind area (Figure 1).

Materials and methods

Modelling current water security: The study used geospatial approach to identify the trends of water security conditions in the study area. Hence, a weighted overlay method was applied in ArcMap (Version: ArcMap 10.3) in which a set of climatic and hydrological parameters was used (Figure 2). The parameters were selected based on a through literature review and adopting opinions from experts in the relevant fields. Previous data on rainfall, temperature, groundwater levels, and surface water in the Barind area have provided valuable insights into the region's water availability, quality, and overall environmental dynamics over the studied periods. Using a weighted overlay method, these variables were combined to produce annual assessments of water security in the Barind area of Bangladesh.

The following weighted overlay method was applied to assess water security for the years 1988, 1997, 2006, 2016 and 2021, using composite weight levels ranging from 1 to 5 (very low to very high) for each variable. The total influence of 100 was distributed among the variables based on their importance, as established by previous research. A total of four variables—rainfall, temperature, groundwater, and surface water—were considered to delineate and identify the water security conditions and the specific locations within the Barind region (Figure 2).

$$\text{Composite Weight} = \text{Weight}_{\text{Temperature}} \times \text{Influence of Temperature} + \text{Weight}_{\text{Rainfall}} \times \text{Influence of Rainfall} + \text{Weight}_{\text{Groundwater}} \times \text{Influence of Groundwater} + \text{Weight}_{\text{SurfaceWater}} \times \text{Influence of Surface Water} + \text{Weight}_{\text{Vegetation}} \times \text{Influence of Vegetation.}$$

Prediction of future water security: For the prediction of water security, data from 2016 and 2021, along with spatial variables, were utilized. A change matrix was developed to illustrate the differences in water security indicators between those years. A relational transition model was established to identify patterns and correlations between the change matrix and spatial variables. Using an Artificial Neural Network (ANN), water security for 2026 was simulated and validated. This process was iterated for 2021 and 2026 to predict water security for 2031. Finally, the results for 2026 and 2031 were visualized in maps.

Data used in the study: The study incorporated meteorological data (i.e. rainfall and temperature)

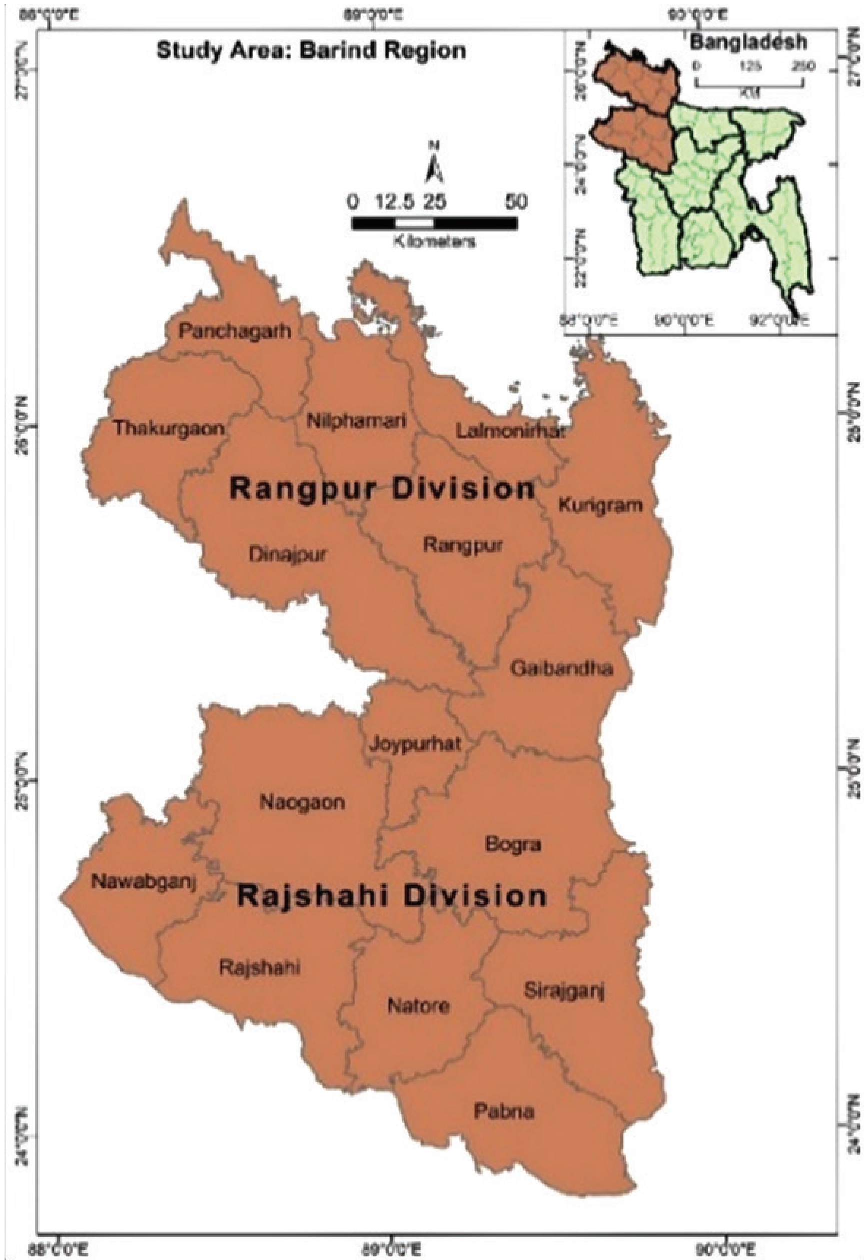


Figure 1. Location of the study area (Barind area) in Bangladesh.

from Bangladesh Meteorological Department for a period spanning 40 years, from 1977 to 2017, as well as groundwater data from the Bangladesh Water Development Board (BWDB) for the years 1997 to 2021. Additionally, USGS GloVis satellite data from 1988 to 2021 were utilized as key variables. The rainfall and temperature variables offer insights into the historical patterns of rainfall and temperature in the Barind area during the selected timeframe. Variations in these variables can impact water availability and quality within the region. Data on groundwater levels measure the depth of underground water in the Barind area over the selected period. Changes in groundwater levels indicate shifts in water availability and storage in the region. Surface water measurements in the Barind area were determined using the modified normalized difference water index (MNDWI)

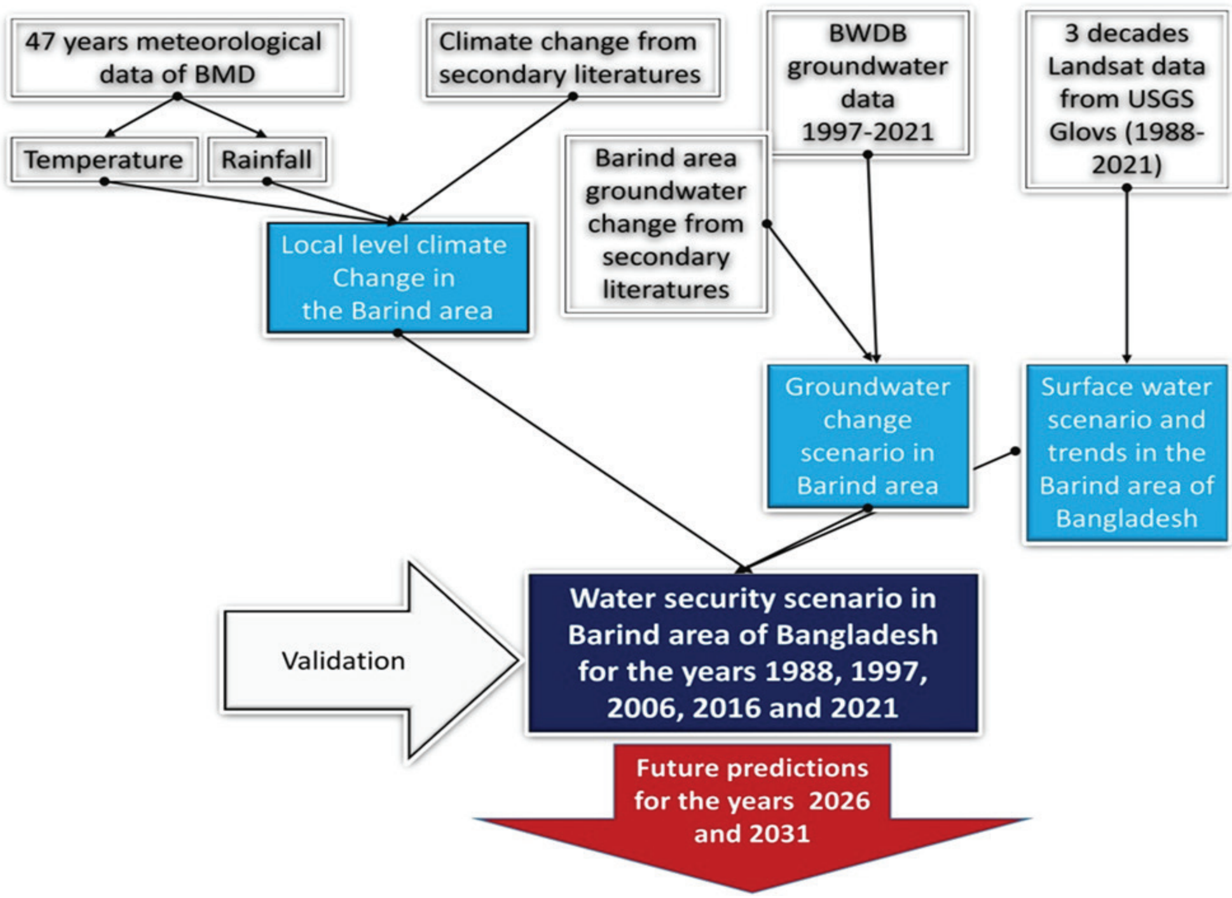


Figure 2. **Methodological flow chart of the study.**

by analyzing Landsat satellite images from 1988 to 2021. These measurements provide an accurate assessment of surface water availability in the region from 1989 to 2022, serving crucial needs for irrigation, industrial applications, and domestic use. Analyzing trends in surface water offers valuable insights into water security and the overall status of the region.

Validation of the results: The study conducted an accuracy assessment for the variables of surface water and vegetation coverage changes in Google Earth Engine. Among the datasets, temperature, rainfall, and groundwater were observed data collected from the government agency. However, the final model results were thoroughly validated by consulting relevant stakeholders, such as the Water Resources Planning Organisation (WARRPO), Bangladesh Water Development Board (BWDB), Bangladesh Agricultural Development Corporation (BADC), Soil Resource Development Institute (SRDI), Department of Agricultural Extension (DAE) and local communities.

Results

Condition of present water security : The water security across the Barind area, measured to pixel/cell values on a scale of 1-5, reveals a significant downward trend between 1988 and 2021. Districts such as Pabna, Natore, and Lalmonirhat with strong negative correlations close to -1.00, show sharp declines in water security, as reflected in their mean pixel values. For instance, a reduction of pixel value for Pabna district from 3.45 in 1988 to 2.27 in 2021, indicates a significant reduction in water availability. This consistent decline is strongly supported by the perfect negative regression (-1.00), indicating a steady worsening of water availability over time (Table 1). Water security was also moderately worsening in districts such as Rajshahi, Joypurhat, and Nawabganj, with negative correlation values ranging between -0.70 and -0.90. These districts exhibit substantial drop in water security. Rajshahi, for example, experienced a decline from 2.45 in 1988 to 1.42 in 2021, marking severe deterioration, as reflected by its correlation coefficient of -0.86. The regression trends in these districts suggest an overall declining trend in the area.

In contrast, districts such as Kurigram, Dinajpur, and Gaibandha are also facing water security challenges, but with weaker negative correlations between -0.50 and -0.70, indicating a slower decline in water security, as shown by their relatively higher pixel values. Kurigram, for instance, obtained a mean pixel value of 4.06 in 1988 and showed a relatively stable water security condition (i.e. 3.77) in 2021. Although the decline is present, the slower pace suggests these districts may have experienced less severe stress on water resources compared to other districts.

Overall, the regression trends and pixel values on the scale of 1-5 highlight widespread degradation of water security in the Barind area (Table 2 and Figure 3). Districts with higher negative correlations and lower pixel values have faced more severe water scarcity, while areas with weaker correlations have shown more resilience but still reflect a general downward trend. The combination of urbanization, deforestation, and climate change appears to be driving these regional declines, leading to critical impacts on water availability.

Table 1. Water security condition on a scale of 1-5 in the Barind area of Bangladesh

District Name	Mean Pixel Value (1988)	Mean Pixel Value (1997)	Mean Pixel Value (2006)	Mean Pixel Value (2016)	Mean Pixel Value (2021)	Regression
Pabna	3.45	3.14	2.95	2.58	2.27	-1.00
Natore	2.89	2.66	2.66	2.25	2.03	-0.97
Lalmonirhat	3.97	3.61	3.6	3.39	3.31	-0.95
Bogra	3.09	2.94	2.98	2.73	2.69	-0.94
Sirajganj	3.73	3.47	3.54	3.25	2.82	-0.93
Rangpur	3.83	3.6	3.56	3.56	3.39	-0.92
Rajshahi	2.45	1.89	2.25	1.7	1.42	-0.86
Joypurhat	2.9	2.25	1.79	1.92	1.85	-0.84
Nawabganj	2.59	1.47	1.68	1.54	1.32	-0.78
Nilphamari	3.98	3.25	3.48	3.38	3.12	-0.76
Panchagarh	3.79	3.06	3.51	3.3	2.73	-0.73
Naogaon	2.75	1.53	1.61	1.61	1.51	-0.71
Kurigram	4.06	3.81	3.75	3.85	3.77	-0.69
Dinajpur	3.42	2.97	3.25	3.25	2.89	-0.56
Thakurgaon	3.33	2.74	3.27	3.08	2.6	-0.55
Gaibandha	3.51	3.5	3.5	3.59	3.26	-0.52

Table 2. Trends of aerial coverage of different categories of water security conditions from 1988 to 2021 in the Barind area of Bangladesh

Condition of Water Security	1988		1997		2006		2016		2021	
	Area (in sq. km)	%	Area (in sq. km)	%	Area (in sq. km)	%	Area (in sq. km)	%	Area (in sq. km)	%
Very low	7.07	0.02	3793.7	11.09	3010.59	8.80	4930.99	14.42	5841.88	17.08
low	4180.7	12.22	6195.44	18.12	6520.05	19.07	7730.91	22.61	9364.68	27.39
Moderate	14774.63	43.17	16220.95	47.44	14638.07	42.81	11474.53	33.56	14040.9	41.06
High	15080.2	44.06	7488.88	21.90	9300.78	27.20	9419.22	27.55	4204.1	12.29
Very High	182.19	0.53	496.58	1.45	726.05	2.12	639.9	1.87	743.99	2.18

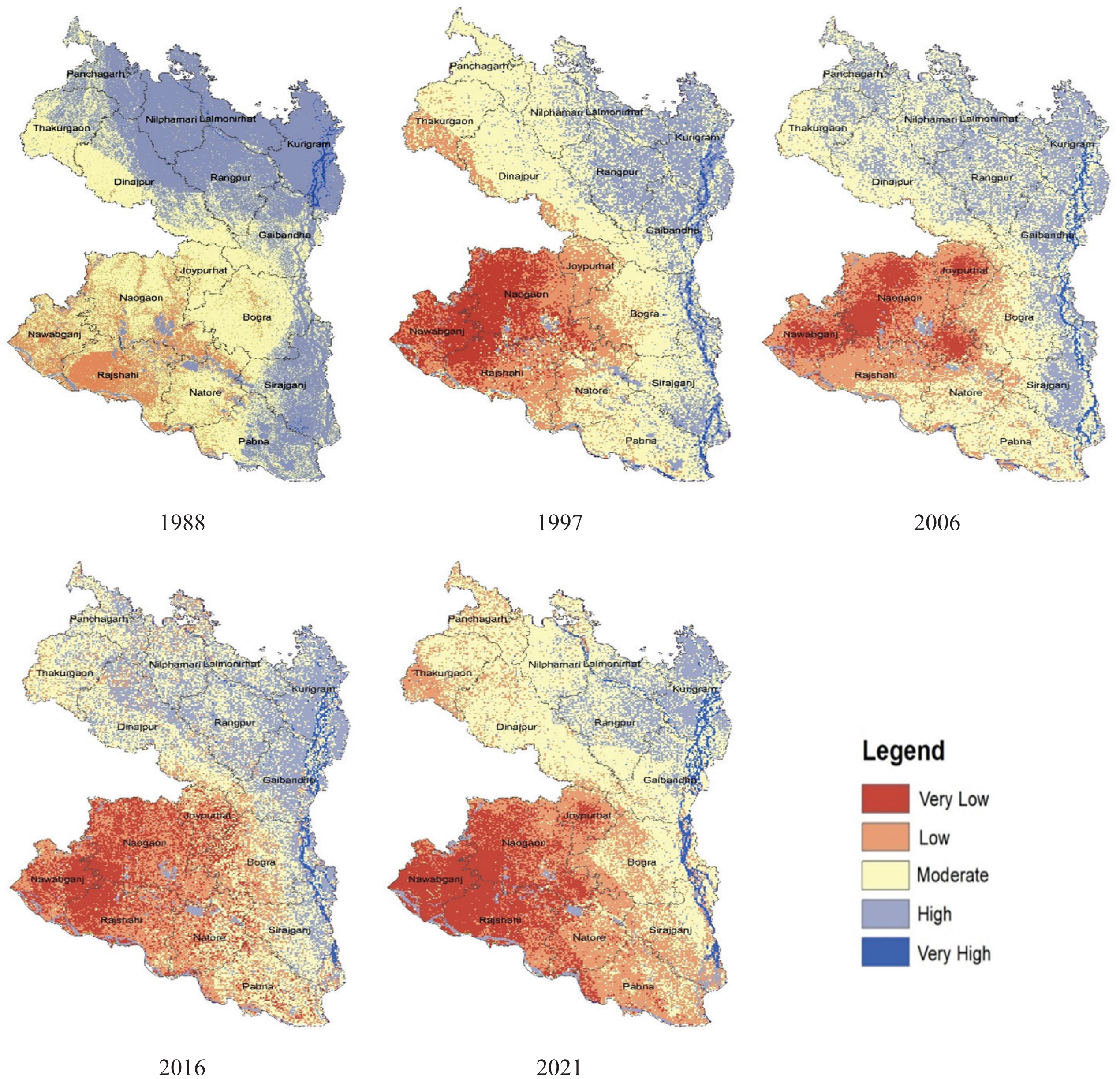


Figure 3. **Potential water security condition in the Barind region of Bangladesh from 1988 to 2021.**

Scenario of future water security : By 2026 and 2031, water security in the Barind area is expected to worsen, with the "very low" and "low" categories expanding significantly. The "high" category would be shrink, while the "very high" category will remain stable. Hence, an effective water management is crucial to address the anticipated shortages and ensure sustainable resource use.

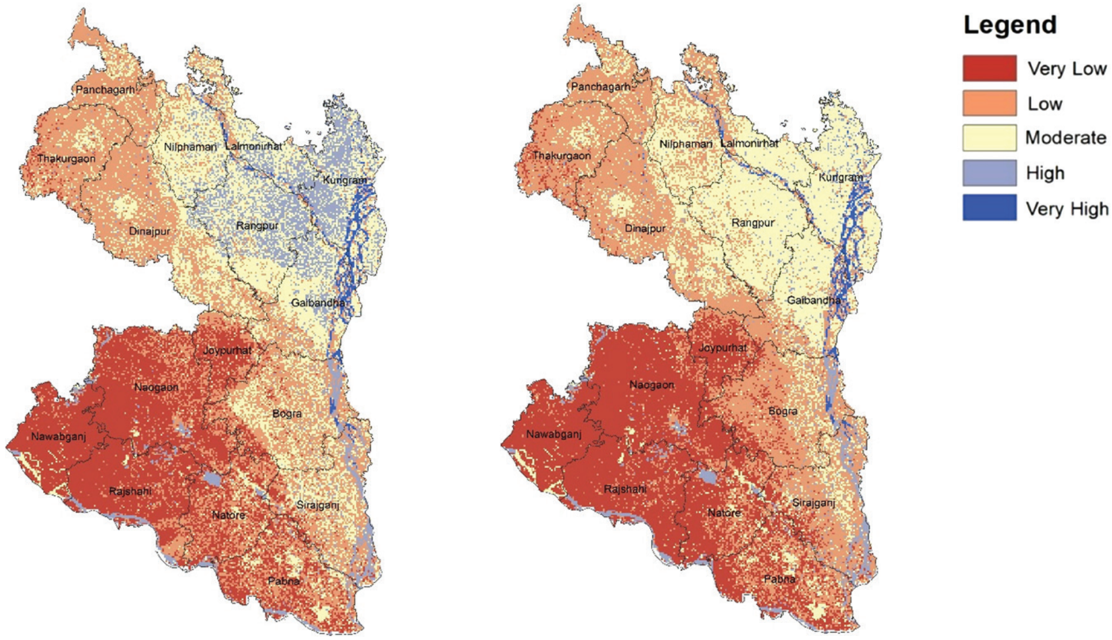
In 2031, several districts are projected to face "very low" water security, indicating severe water scarcity. Naogaon (mean pixel value 1.19), Nawabganj (1.22), Rajshahi (1.27), Joypurhat (1.35), Natore (1.53), and Pabna (1.75) are the most affected, underscoring critical water availability challenges. The areal predictions highlight that by 2026, approximately 8,771.38 square kilometers might fall into this category, covering 25.65% of the region. This area is expected to expand significantly to 10,402.53 square kilometers by 2031, representing 30.42% of the total region (Table 3 and Figure 4). The "low" water security category also shows concerning trends. Districts such as Thakurgaon (mean pixel value 2.03), Bogra (2.11), Panchagarh (2.21), Dinajpur (2.30), Sirajganj (2.34), Nilphamari (2.66), Lalmonirhat (2.79), Gaibandha (2.86), and Rangpur (2.92) are experiencing challenges in maintaining a sustainable water supply. The areal expansion for this category is forecasted to cover 12,115.75 square kilometers in 2026, which constitutes 35.43% of the region. By 2031, this area is expected to increase to 12,557.70 square kilometers, making up 36.72% of the region. However, only one district, Kurigram (mean pixel value is 3.21), was projected to fall into the "moderate" water security category in 2031. This indicates relatively better water availability compared to other districts. The areal prediction for this category shows a coverage of 8,886.09 square kilometers in 2026 (i.e. 25.98% of the region), which is expected to increase slightly to 9,220.64 square kilometers by 2031, representing 26.96% of the region. While this reflects a more balanced water situation, continuous monitoring and management are crucial to maintain these conditions. The "high" water security category is projected to see a significant reduction. In 2026, this category might be anticipated to cover 3,935.31 square kilometers, accounting for 11.51% of the region. By 2031, it is expected to contract to just 1,527.69 square kilometers, or 4.47% of the region. However, the "very high" water security category remains stable. It is expected to cover 489.17 square kilometres in both 2026 and 2031, representing 1.43% of the region.

Discussion

The validation of the results identified an accuracy rate of about 99 percent for each year. During this validation process, the findings were found to be an alignment with the field perceptions of the respective organizations and the local stakeholders. However, Very Low water security conditions in the Barind area of Bangladesh has shown a concerning upward trend from 1988 to 2021. In 1988, Very Low water security was almost negligible, affecting only 0.02% of the region. However, by 1997, this situation had changed significantly, with Very Low water security affecting 11.09% of the region, reflecting a marked decline in water availability. This worsening trend persisted, with Very Low water security covering 8.80% of the region in 2006 and expanding further to 14.42% by 2016. By 2021, Very Low water security had deteriorated alarmingly, affecting 17.08% of the region

Table 3. Areal expansion of water security predicted for the year 2026 and 2031 in the Barind area

Predicted water security condition	2026		2031	
	Area (km^2)	%	Area (km^2)	%
Very low	8771.38	25.65	10402.53	30.42
Low	12115.75	35.43	12557.7	36.72
Moderate	8886.087	25.98	9220.64	26.96
High	3935.31	11.51	1527.69	4.47
Very High	489.17	1.43	489.17	1.43



2026 2031

Figure 4. **Areal expansion of water security predictions for the years 2026 and 2031.**

(Table 2 and Figure 3). This significant increase highlights the growing severity of water scarcity, driven by factors such as climate change, urbanization, and environmental degradation, which have led to critical challenges in water management and availability across the Barind area.

Low water security condition in the Barind area of Bangladesh has demonstrated an upward trend from 1988 to 2021, reflects an increasing water stress. In 1988, Low water security affected 12.22% of the region, covering 4,180.7 sq. km, indicating that a moderate portion of the area faced some degree of water scarcity. By 1997, the situation worsened significantly, with Low water security areas expanding to 18.12%, encompassing 6,195.44 sq. km. The trend continued into 2006, with Low water security areas rising to 19.07% (6,520.05 sq. km). In 2016, Low water security further increased to 22.61% (7,730.91 sq. km), reflecting a continued decline in water availability and quality across a larger portion of the region. By 2021, the extent of Low water security had expanded to 27.39% (9,364.68 sq. km), marking a significant rise in areas experiencing substantial water stress. This persistent increase underscores the growing challenges in managing water resources, likely exacerbated by urban expansion, climate change, and environmental degradation. The trend reflects a critical need for improved water management strategies to address the expanding regions facing low water security.

Moderate water security conditions in the Barind area of Bangladesh has undergone notable changes from 1988 to 2021. In 1988, a substantial portion of the region, 43.17% (14,774.63 sq. km), enjoyed moderate water security, indicating that a large area had a reasonably stable water supply. However, by 1997, this proportion increased to 47.44% (16,220.95 sq. km), suggesting a slight shift in water security conditions, with more areas falling into the moderate category as high water security areas declined. The trend continued into 2006, with moderate water security encompassing 42.81% (14,638.07 sq. km) of the region. This slight decrease from 1997 indicates a gradual shift away from high security but still reflects a considerable portion of the region maintaining a stable water supply. By 2016, moderate water security further declined to 33.56% (11,474.53 sq. km), reflecting a more pronounced reduction as areas with lower water security increased. In 2021, moderate water security accounted for 41.06% (14,040.9 sq. km) of the region, showing a partial recovery from previous lows but still indicating a general trend of declining water security. These changes highlight ongoing challenges in maintaining stable water resources amidst growing pressures from urbanization, climate change, and environmental changes.

High water security condition in the Barind area of Bangladesh has seen a significant decline from 1988 to 2021. In 1988, a significant percentage (i.e. 44.06%) of the region, covering 15,080.2 sq. km, was classified as having high water security, indicating that a large area enjoyed optimal water conditions. However, by 1997, this proportion had dropped sharply to 21.90% (7,488.88 sq. km), revealing a considerable decrease in areas with robust water security as pressures on water resources began to intensify. The decline continued into 2006, with high water security areas further shrinking to 27.20% (9,300.78 sq. km). By 2016, only 27.55% (9,419.22 sq. km) of the region maintained high water security, indicating that while there was a slight recovery, the overall trend remained downward. By 2021, the situation had worsened significantly, with high water security covering just 12.29% (4,204.1 sq. km) of the region. This stark reduction underscores a severe decline in regions with optimal water availability, reflecting the increasing impact of urbanization, climate change, and environmental degradation on water resources. The significant loss of high water security areas highlights the growing challenges in ensuring adequate water resources and managing water security effectively in the Barind area.

Very High water security conditions in the Barind area of Bangladesh has remained limited throughout the period from 1988 to 2021, reflecting a generally stable but small proportion of the region with optimal water conditions. In 1988, Very High water security covered 0.53% (182.19 sq. km) of the area, indicating that only a small fraction of the region had exceptional water availability. By 1997, the extent of Very High water security increased to 1.45% (496.58 sq. km), suggesting a modest improvement in certain areas but still representing a minor portion of the region. This trend continued into 2006, with Very High water security covering 2.12% (726.05 sq. km), reflecting a slight expansion but still indicating limited coverage. In 2016, Very High water security covered 1.87% (639.9 sq. km), showing a decrease from the previous period, which may reflect worsening conditions elsewhere or changes in measurement criteria. By 2021, Very High water security accounted for 2.18% (743.99 sq. km) of the region, indicating a marginal increase from 2016. Overall, the extent of Very High water security has been relatively small throughout the years, with only a small proportion of the region experiencing optimal water conditions. The limited coverage highlights that, despite some fluctuations, the number of areas with exceptionally high water security has remained consistently low, emphasizing the challenges in achieving and maintaining such ideal water conditions in the Barind area.

The aerial expansion of very low water security condition in future emphasizes the urgent need for effective water management strategies to mitigate the severe water scarcity (Table 3 and Figure 4). Similarly, the low water security category in future highlight the increasing difficulties in managing water resources across these districts. The noticeable decrease of high water security condition in future underscores the pressing need to preserve and enhance water security in areas currently enjoying higher levels of water availability. The static rate of very high category indicates that while some areas maintain optimal water conditions, the overall trend in water security is concerning, highlighting the need for continued efforts to manage and improve water resources across all categories. However, the local communities in water-stresses Barind area adopt to the shortage of water in a number of techniques. Among them, ‘Da Jhoro’ and ‘Mulching’ are two most efficient indigenous practices to retain moisture in their agricultural fields. Moreover, local government (e.g. DPHE) took several initiatives such as Deep Tube Well, Shallow Tube Well and Managed Aquifer Recharge to manage surface and ground water in the Barind area.

Conclusions

Over the past 40 years, the Barind area has witnessed significant variability in temperature and rainfall. Average temperatures have hovered around 34.75°C, with fluctuations of 1.23°C. Some districts, like Pabna and Bogra, have experienced rising temperatures, while others, such as Nilphamari, have seen cooling trends. Rainfall has varied widely, from a high of 25,722.63 mm to a low of 12,017.2 mm, averaging 18,765.04 mm. This variability has resulted in increasing rainfall in districts such as Panchagarh and Nilphamari, contrasted by decreasing trends in Naogaon and Rajshahi, with Pabna showing the most significant decrease. Looking ahead, water security is expected to worsen significantly by 2026 and 2031. The "very low" category has been projected to cover 25.65% of the region by 2026 and 30.42% by 2031, with severe shortages anticipated in districts like Naogaon and Rajshahi. The "low" category would also be expanded, reaching 35.43% in 2026 and 36.72% by 2031. These trends emphasize the urgent need for improved water management strategies to address the expanding areas of scarcity and to sustain current water conditions. The increasing decline of water resources indicates the pressing needs for improved water management strategies such as surface water conservation, sustainable irrigation practices, managed aquifer recharge and afforestation to mitigate increasing water scarcity and ensure sustainable resource use in the Barind area.

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Taxonomic account of a new genus of jumping spider from Jhenaidah, Bangladesh

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Abstract

Taxonomic account of a new genus of jumping spider *Harmochiroides* n. gen. is proposed with its newly identified type-species *H. shikerpurensis* n. sp. from Jhenaidah, Bangladesh. Generic diagnosis and distribution together with illustrated description of the species is provided herewith.

Keywords: Araneae, Harmochirinae, *Harmochiroides,* Taxonomy, Genus, Species, Salticidae

Introduction

Jumping spider of family Salticidae is the largest, cosmopolitan and widely distributed throughout the world. At present, the family contains a total of 6,804 valid species belonging to 689 genera distributed throughout the world (World Spider Catalog 2025). In Bangladesh, records of these spiders are scarce and composed of only 72 species under 21 genera (Chowdhury and Nagari 1981, Chowdhury and Pal 1984, Okuma *et al.* 1993, Biswas 2009, 2019, 2024a, b, Biswas and Raychaudhuri 2021). But a good number of species are recorded and described in other Asian countries like – India (Tikader 1977a, b, Caleb and Mathai 2015), China (Song *et al.* 1999, Xiao and Wang 2005, Peng 2020), The Philippines (Barrion and Litsinger 1995), Viet-Nam (Zabka 1985, Proszynski 1992), Singapore (Koh 1989), Japan (Yaginuma 1986, Ikeda 1993, Ono and Ogata 2018), Korea (Paik 1986, 87, Kim and Lee 2014) etc.

However, the present study is the addition of a new genus *Harmochiroides* n. gen. with its type-species *H. shikerpurensis* n. sp. to the fauna of the family Salticidae of Bangladesh. It contains detail illustrated description of the new species together with diagnosis of the new genus and its distribution. Remarks are also given comparing to the present species with the world fauna of nearly related species.

Materials and methods

Collection and preservation: Specimens were collected from the garden of village South Shikerpur, district Jhenaidah, by jarking the branches of shrubs on an inverted umbrella placed underneath the plants. Collected specimens were paralyzed with chloroform filled in a large glass jar. Then carried to the laboratory and transferred this to a petri-dish filled with 70% ethyl alcohol for sorting. After sorting, each specimen was preserved in separate vial with 70% alcohol.

Identification and study: The specimens thus preserved were identified following the books and journals of home and abroad, these are Berland and Millot (1941), Tikader (1977, 87), Davies and Zabka (1989), Barrion and Litsinger (1995), Peng (2020), Song *et al.* (1999), Koh (1989), Zabka (1985, 97), Proszynski (1992), Chen and Zhang (1991), Yaginuma(1986), Fuhn and Gherasim (1995), Biswas (2009, 24) and Kim (2014).

After identification, the necessary body-parts of the specimens were dissected out under the Stereozoom Binocular Microscope on a petri-dish with 70% alcohol. Male palps after dissection, were boiled in 10% KOH for 3-5 minutes (Levi 1965, Tikader 1987). Thus, the palpal organs are expanded and studied under the same condition. After study, the palps are preserved along with the parent spider in Audemans' Preservatives.

Illustrations: The adult spider and its necessary body-parts were illustrated by Camera Lucida fitted with a Stereozoom Binocular Microscope. Leg measurements were done in the following sequences: femur, patella, tibia, metatarsus, tarsus and total length and was taken in millimeters (mm).

Type-deposition : After illustration, the specimens were placed to the collection of the Department of Zoology, Khulna Government Womens' College, Khulna and will deposited to the Museum of the Department of Zoology, University of Dhaka, in due course of time.

Results and discussion

Systematics

Class: Arachnida Lamarck 1801
Order: Araneae Clerck 1757
Family: Salticidae Blackwall 1841
Subfamily: Harmochirinae Proszynski 2013
Genus : *Harmochiroides* n. gen.
Type-species : *H. shikerpurensis* n. sp.

Diagnosis: Spiders of the genus *Harmochiroides* n. gen. are small to nearly medium in size. Body brown to blackish-brown and robust. Cephalothorax broad, elongately oval with nearly straight on anterior margin. Eyes dissimilar, arranged in 3 rows, with anteromedians are largest ; each eye with black basal band. Chelicerae brown, strong, with few teeth on inner margin, fang strong, pointed marginally. Sternum is nearly hear-shaped. Maxillae and labium are brown, scopulate anteriorly. Leg -I largest with broad, expanded tibia, leg -III is usually smallest. Palpal organs are varies species to species. Female is unknown.

Abdomen broad, oval, brown, narrowing anteriorly with a small constriction. Spinnerets small and dissimilar in size. Dorsum of abdomen covered with small spines and hairs.

Biological note: Spiders of this genus are small to medium, very strong and active. They usually live on the leaves of plants at the gardens. They cannot build any web but can make typical nests in winter in which they hibernate and maintain the offspring within this. These are good predators of small insects and can jump during preying. Like other Salticids, they are one of the important biological control agents of insect pests in the garden crops.

Remarks: Jumping spider genus *Harmochiroides* n. gen. does not show any close similarity to its congeners of neighbour countries and also with its world relatives. However, a little similarity is found of its general appearance with the genus *Harmochirus* Simon but stands distinct as a new genus in the following characters:

1. Cephalothorax broad and elongate.
2. Arrangement of eyes on the cephalothorax much different.
3. Specialized structure of leg -I and abdomen.
4. Male palpal characters are different with that of all Harmochirus species.

Etymology: The genus is named with the similarity to genus *Harmochirus* in general appearance.

Distribution: Village South Shikerpur, district Jhenaidah, Bangladesh**.**

Description of new species

Harmochiroides shikerpurensis n. sp.

(Figs. 1a – 1g)

Material examined:1 male (holotype), 18. VII. 2021, village South Shikerpur, district Jhenaidah,Coll. V. Biswas ; 1 male (Paratype), from same area, 07. V. 2022, Coll. V. Biswas.

General: Body small, dark brown, clothed with small hairs and spines. Cephalothorax dark brown and abdomen light brown, both covered with small spines and hairs. Legs brown, strong, 1st leg largest. With brown, sharp spines. Total body length is 5.00 mm. Carapace 2.00 mm long, 1.82 mm wide; abdomen 3.00 mm long and 1.98 mm wide.

Cephalothorax: Broad, elongately oval with anterior and lateral margins nearly straight. Eyes dissimilar, arranged in 3 rows, each encircled with black basal band ; anterior row of eyes a little recurved with the anteromedians largest ; median eyes small and but the median and posterior row straight ; ocular quad posteriorly wide (Fig. 1a). Chelicerae brown, strong, little elongate each of inner and outer margins with 2 teeth (Fig. 1b). Maxillae brown, elongate, anteriorly light and scopulate (Fig. 1c). Labium brown, small, vase-shaped, anteriorly light and scopulate (Fig. 1c). Sternum light brown, nearly heart-shaped, with anterior margin little concave, posteriorly pointed (Fig. 1d). Legs brown, strong, dissimilar, clothed with few strong spines; leg-I largest with tibial segment broad, expanded and with few strong spines, tarsi with 2 claws (Fig. 1e); leg - III smallest, covered with small spines; leg formula 1423 and the measurements (in mm) of leg segments are shown in Table 1.

Table 1. Measurements (mm) of leg segments of *H. shikerpurensis* n. sp.

Leg	Femur	Patella and Tibia	Metatarsus	Tarsus	Total
I	1.50/1.50	1.84/1.84	1.20/1.20	1.00/1.00	5.54/5.54
II	1.00/1.00	1.10/1.10	0.80/0.80	0.52/0.52	3.42/3.42
III	0.80/0.80	0.72/0.72	0.50/0.50	0.38/0.38	2.40/2.40
IV	1.20/1.20	1.12/1.12	0.72/0.72	0.50/0.50	3.54/3.54

Male palp typical, with apophysis pointed and tegulum curved and terminal end pointed anteriorly, each clothed with sharp spines (Figs. 1f and 1g).

Abdomen: Brown, broad, oval, narrowing anteriorly with a small lateral constriction, clothed with numerous small spines. Spinnerets small, unequal.

Female: (Allotype) Unknown and will be described separately after collection.

Type-specimen: Holotype: male in spirit, **Paratype:** one male in spirit.

Type-locality: Village South Shikerpur, district Jhenaidah, Bangladesh (Southwest part).

Etymology: The species is named according to the name of the type-locality.

Remarks: The species *H. shikerpurensis* n. sp. does not show any similarity to its Indian congeners.

However, it shows some special characters (those are shown in the following) for which it stands distinct as species new to science. The characters are –

1. Structure of cephalothorax and abdomen much different with others.
2. Presence of two teeth on inner and outer margins.
3. Leg - I and Sternum structurally much different with *Harmochirus* species.
4. Structure of male palp much different with others.

Therefore, the species is described as new to science.

Conclusion

The taxonomic history of salticids of Bangladesh is very short (Chowdhury and Pal 1984, Okuma *et al.* 1993, Biswas 1996, ‘2009, 2016, ’19, ’21, Biswas and Raychaudhuri 2019) and it is clearly observed that none of the salticids of Bangladesh or its neighbouring congeners show any close similarity with the present species *H. shikerpurensis* n. sp. But the biology and behaviouris nearly similar with *Harmochirus* species viz. – predatory, jumping habits etc. The species of both these genus make typical nests during breeding season specially in winter and lay eggs there and the female stay there up to the maturity of newly born spiderlings.

Species of the genus *Harmochiroides* n. gen. are good predators of insect pests in the gardens. It catches prey insects by jumping from plant to plant foliages. They are one of the important biological control agents of garden

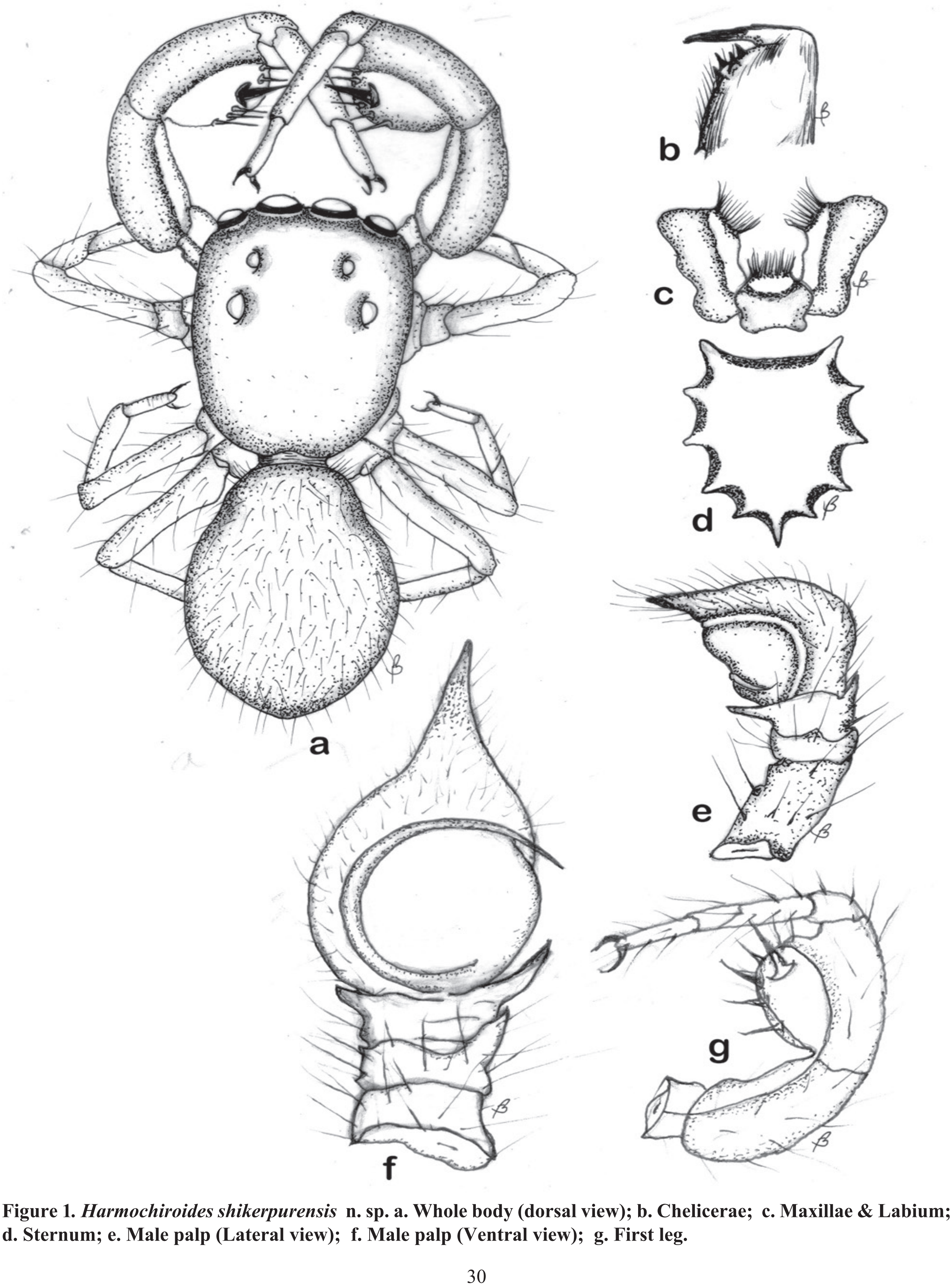

Figure 1. ***Harmochiroides shikerpurensis*** **n. sp. a. Whole body (dorsal view); b. Chelicerae; c. Maxillae & Labium; d. Sternum; e. Male palp (Lateral view); f. Male palp (Ventral view); g. First leg.**

insect pests. Therefore, a detail revisional study of these spiders is needed to identify the species composition and ecological role as a predator of crop-pests of Bangladesh.

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Genetic diversity evaluation of brinjal germplasms for varietal improvement

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Abstract

A field experiment was conducted with 72 brinjal (*Solanum melongena* L.) germplasms at the Plant Genetic Resources Centre (PGRC) of BARI, Joydebpur, Gazipur, to assess the variability among the germplasms. A wide variation in genetic diversity was observed in both qualitative and quantitative characters studied. Qualitatively all the germplasms showed distinct variation except leaf hairs, corolla colour, fruit cross section and fruit position. The maximum variation observed in overall leaf prickles, fruit calyx prickles, fruit colour at ripening and fruit flesh density. The variability was maximum in leaf prickles. Five categories of leaf prickles were found such as very few (4.17%), few (51.39%), intermediate (26.39%), many (8.33%) and very many (9.72%) in the studied germplasms. Quantitatively the highest variation was observed in 100 seed weight (CV- 67.91%) which was followed by yield per plant (CV-62.40) and number of fruits per plant (CV-59.93%). Based on yield and yield-contributing parameters, the germplasms K 21 (1116.67 g), K 24 (1221.67 g), and RAI 230 (1680.83 g) were identified as the top performers in terms of yield.

Keywords: *Solanum melangena*, characterization, germplasms, improvement

Introduction

Brinjal (*Solanum melongena* L.) is one of the most common, popular and principal vegetable crops grown in Bangladesh as well as other parts of the world. It is highly productive and usually referred as the poor man's crop. Brinjal is usually self-pollinated crop but the extent of cross pollination has been reported as high as 29% due to heterostyle condition and hence it is classified as 'often' cross pollinated crop or facultative cross-pollinated crop (Yadav *et al.* 2018). Bangladesh, being the Indian sub-continent, and the primary centre of origin has accumulated wide range of variation of this crop (Shingh *et al.* 2006, Choudhary *et al.* 2009). Bringal has a great genetic variation with regard to colour, maturity, fruit shape, and other morphological characters (Islam *et al*. 2009). The success of breeding programme for better yield and quality depends on the nature and magnitude of variation available in the genotype (Roychowdhury *et al.* 2011).

All germplasms does not respond similarly in all agroclimatic regions. The consumer preference varies from region to region (Tirfessa *et al.* 2020). The regional preferences differ greatly with shape, colour and even presence of prickles on calyx. However, yield of any crop plant is the result of interaction of several genetic factors and environmental factors. These are actually qualitative and quantitative characters which is associated with component characters. These component characters including yield are influenced by environmental fluctuations. Thus, the improvement in yield is possible only through selection of the desired component characters.

The knowledge of association between yield and its component characters as well as their direct and indirect contribution towards yield is essential for crop improvement in brinjal (Roychowdhury *et al.* 2011). Hence the characterization needs to be done with reference to the morphological characterization and evaluation in both qualitatively and quantitatively. Morphological characterization and evaluation help the breeder to select an appropriate genotype for crop improvement based on the knowledge of genetics of various characters (Baswana *et al.* 2002). The germplasms performing well can be released as a variety or it can be put to further use in the breeding programme as breeding line by the breeder. Keeping in view the above aspects an investigation was carried out to evaluate indigenous brinjal germplasms through qualitative and quantitative characters to identify the promising germplasms and provide genetic diversity for the crop improvement program.

Materials and methods

The experiment was conducted in the field of Plant Genetic Resources Centre (PGRC) of Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur October 2023 to march 2024. Seventy-two germplasms (Table 1) were used in this experiment as treatments**.** The experiment was laid out in augmented design with standard check variety. Direct seeding was done in the well-prepared seed beds. Thirty-five days aged seedlings were transplanted in the prepared pits of main experimental field. The plot size was 3 x 2.1 m^2. Seedlings of each germplasms was planted in a plot of three rows having four pits. Row to row and plant to plant distance was 70 × 60 cm. Cowdung, urea, TSP, MoP and borax were applied at the 10 t/ha, 210 kg/ha, 33 kg/ ha, 200 kg /ha and 5 kg/ ha, respectively (Mondal *et al*. 2011). The full doses of cowdung, TSP and borax were applied during land preparation before one week of transplanting. Urea and MP were applied in the three equal splits at 15, 35 and 50 days after transplanting. Weeding and mulching were done four times at 20 days' interval starting from mid-December. Individual net was used per plot to avoid the cross pollination. Sevin 75 WP @ 0.1 g/pit, Sumithion 60 EC @ 2.5 ml/L and Vertimac 18 EC @ 1.2 ml/L were sprayed for controlling insect and mite, respectively. The data was recorded as per the descriptor developed by IBPGR (1990).

Soil and Climate: The soil type of the experimental field belongs to the shallow light brown terrace type under Joydebpur series of Madhupur Tract of Agro Ecological zone (AEZ) 28 which is characterized by silty clay with pH value of 6.5.The experimental site is under the sub-tropical climatic zone .In the experiment period it was characterized by less rainfall, almost clear sun shine and low temperature at earlier part and moderate to high temperature in later part. The heavy rainfall occurred during the month of May to July.

Passport information and data recording: collector's number: Original number assigned by collector of the sample normally composed of the name or initials of the collector(s) followed by a number. This item is essential for identifying duplicates in different collections.

Data recording: Qualitative data were recorded at respective stage of plant on growth habit, leaf blade lobing, leaf blade tip angle, leaf prickles, leaf hairs, corolla colour, fruit calyx prickles, fruit colour distribution, fruit curvature, fruit apex shape, fruit cross section, fruit colour at ripening, fruit flesh density, fruit position, seed colour, and seed size. Quantitative data were also recorded at mature stage of plant growth on leaf blade length (cm), eaf blade width (cm), Fruit length (cm), Fruit width (cm), 100 seed weight, Plant height (cm), Days to 50% flowering, Average number of fruits per plant and Yeild per plant (g)

Statistical analysis: Data were collected, coded, analyzed, and tabulated using the Statistix 10 and Microsoft Excel 2019 program.

Results and discussion

Qualitative characters: A total of 16 qualitative characters were evaluated to know the variability of the studied germplasms (Table 2). All the characters showed distinct variation among the germplasms except leaf hairs, corolla colour, fruit cross section and fruit position. The maximum variation observed in overall leaf prickles, fruit calyx prickles, fruit colour at ripening and fruit flesh density.

Variability in growth and foliage: All the characters studied related to plant growth habit and foliage showed distinct variation among the germplasms except leaf hairs and corolla colour (Table 2). Plant growth habit were observed in upright (5.56%), intermediate (93.06%) and prostrate only (1.39%). Leaf prickles and hairiness in brinjal germplasms are more pronounced in wild types and indicated pest resistance and medicinal value

Table 1. Lists of germplasms used in this experiment

Sl no.	Germplasms	Collected area	Sl no.	Germplasms	Collected area
1.	K-10	Pabna	37.	RAI-219	Chattogram
2.	K-11	Pabna	38.	RAI-230	Sherpur
3.	K-12	Pabna	39.	AMA-294	Sherpur
4.	K-13	Pabna	40.	AMA-302	Sherpur
5.	K-15	Pabna	41.	AMA-312	Sherpur
6.	K-16	Pabna	42.	AMA-368	Jamalpur
7.	K-17	Pabna	43.	AMA-410	Sherpur
8.	K-18	Pabna	44.	AHI-101	Jashore
9.	K20-	Pabna	45.	AHI-102	Jashore
10.	K-21	Pabna	46.	AHI-124	Jhenaidah
11.	K-22	Pabna	47.	AR-216	Dinajpur
12.	K-23	Pabna	48.	IAH-39	Dhaka
13.	K-24	Pabna	49.	ART-12	Kishoregonj
14.	K-25	Natore	50.	AH-41	Gazipur
15.	K-26	Pabna	51.	AC-47	Dhaka
16.	K-27	Pabna	52.	AC-172	Narshingdi
17.	K-28	Pabna	53.	AC-212	Manikgonj
18.	K-29	Pabna	54.	AC-222	Manikgonj
19.	K-30	Pabna	55.	AC-240	Manikgonj
20.	K-32	Pabna	56.	AC-285	Dhaka
21.	K-33	Pabna	57.	AC-396	Dhaka
22.	K-34	Pabna	58.	AC-434	Narsingdi
23.	K-35	Pabna	59.	TT-27	Mymensingh
24.	K-36	Natore	60.	TT-56	Mymensingh
25.	K-37	Natore	61.	TT-58	Mymensingh
26.	K-38	Chuadanga	62.	TT-64	Mymensingh
27.	K-39	Pabna	63.	TT-78	Mymensingh
28.	K-40	Pabna	64.	TT-102	Netrokona
29.	K-41	Chapainawabgonj	65.	TT-103	Netrokona
30.	K-42	Chapainawabgonj	66.	TT-105	Netrokona
31.	K-44	Chapainawabgonj	67.	TT-136	Mymensingh
32.	K-45	Chapainawabgonj	68.	TT-169	Mymensingh
33.	RAI-81	Chattogram	69.	TT-176	Mymensingh
34.	RAI-99	Chattogram	70.	TT-200	Mymensingh
35.	RAI-216	Chattogram	71.	TRMR-102	Cumilla
36.	RAI-150	Chattogram	72.	B-13	Patuakhali

(Naujeer, 2009).

Leaf prickles (Fig. 1) were found in maximum variation such as very few (4.17%), few (51.39%), intermediate (26.39%), many (8.33%) and very many (9.72%) in studied germplasms. The Leaf blade tip angle were also exhibited as four categories such as very acute (4.17%), acute (27.78%), intermediate (48.61%) and obtuse (19.44%). Leaf hairs and corolla colour showed no variation. All leaf hairs were observed as 'very many' type and corolla colour as 'light violate'.

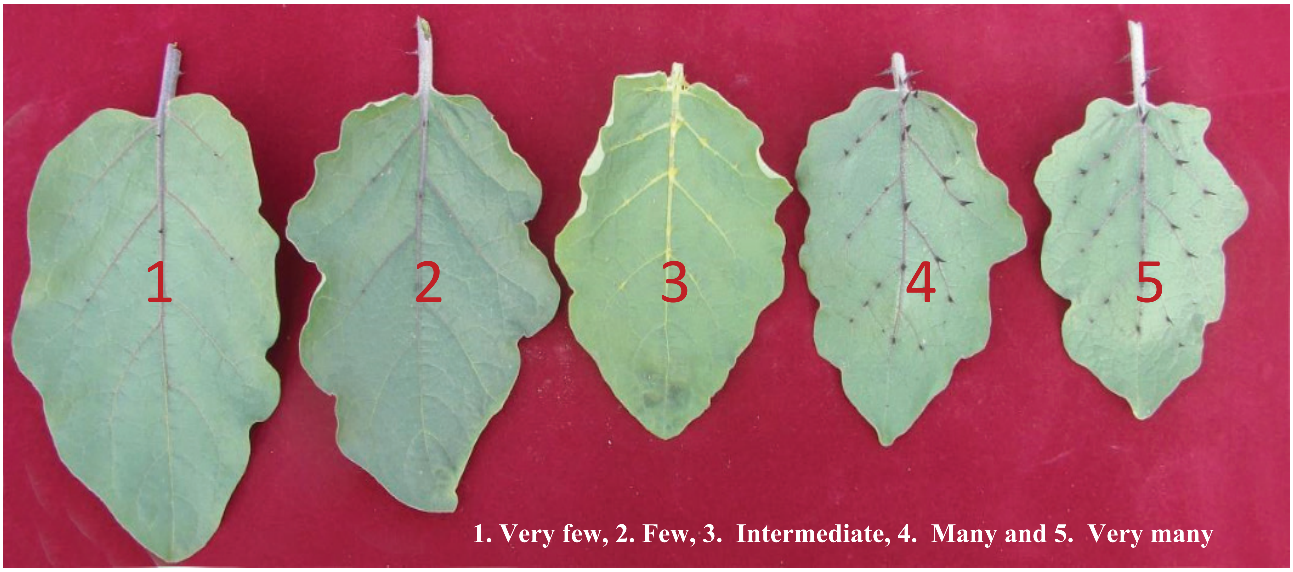

Figure 1. Different types of leaf prickles found in the studied germplasms.

Four categories of leaf blade lobing (Table 2, Fig. 2) were found such as weak (33.33%), intermediate (50.00%), strong (15.28 %) and very strong (1.39 %).

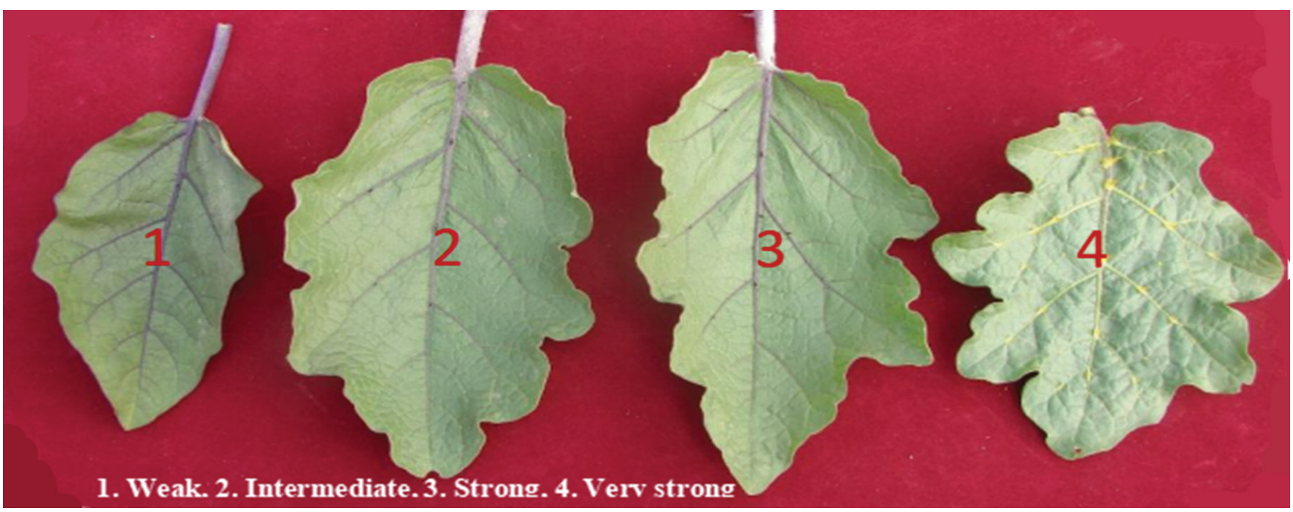

Figure 2. Different kinds of leaf lobing found in the studied germplasms.

Leaf blade lobbing is an important trait to choose a brinjal genotypes for future breeding programme. Leaf blade lobbing can help to a breeder to know the information on photosynthesis rate. Strong leaves can have a greater opportunity to get maximum sunlight than the weaker leaves (Akther, 2015).

Variability in fruit characters: All the characters studied related to fruit of brinjal showed distinct variation among the germplasms except fruit cross section and fruit position (Table 3). The maximum variation was found in 'fruit colour at ripening stage'. Six categories fruit colour at ripening such as milky white (1.39%), lilac grey (4.17%), purple (22.22%), green with mottled at the distal end (25.00%), and green with yellowish stripe (34.72%) and purple with light green at the distal end (12.50%) were observed (Table 3 and Fig. 3.). Fruit color is one of the important traits for consumer preference in brinjal marketing. This variation offered a good scope for breeding consumer preference attributes (Akther, 2015). The next higher variation was found in 'fruit flesh density'. Very loose (spongy), loose (crumbly), average density, dense and very dense type of fruit flesh density was found. Brinjal fruit flesh density is a good storage indicator for culinary purpose as a vegetable (Jha & Matsuoka, 2002). Brinjal germplasms with density type flesh are long lasting germplasms in kitchen storage. However, the majority of the studied germplasms exhibited as average density type (40.28%).

Table 2. Variability in growth and foliage characters in brinjal germplasms

Name of descriptor	Descriptor state	No. of germplasms	% of germplasms
Plant growth habit	Upright	4	5.56
	Intermediate	67	93.06
	Prostrate	1	1.39
Leaf blade lobing	Weak	24	33.33
	Intermediate	36	50.00
	Strong	11	15.28
	Very strong	1	1.39
Leaf blade tip angle	Very acute	3	4.17
	Acute	20	27.78
	Intermediate	35	48.61
	Obtuse	14	19.44
Leaf prickles	Very few	3	4.17
	Few	37	51.39
	Intermediate	19	26.39
	Many	6	8.33
	Very many	7	9.72
Leaf hairs	Very many	72	100.00
Corolla colour	Light violate	72	100.00

[1. Milky white, 2. Lailac grey, 3. Purple, 4. Green with mottled at the distal end, 5. Green with yellowish striped, 6. Purple with light green at the distal end]

Figure 3. Different fruit color at ripening stage of bringal.

On the other hand, fruit calyx prickles were found as very few (1.39%), few (2.78%), intermediate (22.22%), many (41.67%) and very many (31.94%). Fruit colour distribution (Table 3, Fig. 4.) was exhibited as Uniform (23.61%), molttled (16.67%), netted (13.89%) and striped (45.83%). No fruits were found curved in 80.56% of the germplasms. Only 8.33 % germplasms showed curved and 11.11%

Figure 4. Different fruit colour distribution in brinjal germplasms.

showed slightly curved. Fruit apex were exhibited as two categories such as rounded (40.28%) and depressed (59.72%).

Variability in seed characters : Only seed colour and seed size were studied (Table 4). Both parameters varied in three categories. Fifty percent of the germplasms exhibited brown seed colour and rest were grey yellow (8.33%) and brownish yellow (41.67%) (Fig. 5.). Seed size exhibited as small (38.89%), intermediate (54.17%) and large 6.94%).

Quantitative-characters: Range, mean, standard deviation and CV% of the quantitative data of brinjal is presented in Table 4 and Table 5. The highest quantitative variation was observed in 100 seed weight (CV- 67.91%) which was followed by yield per plant (CV-62.40) and number of fruits per plant (CV-59.93%). Leaf blade length ranged from 13.62 cm to 46.50 cm with an average of 19.90 cm. leaf blade width ranged from 8.94 cm to 15.08 cm with an average of 14.20 cm. The fruit length was measured from 6.73cm to 29.40 cm with an average of 15.08 cm and Fruit width from 1.00 to 12.00 cm with an average of 7.03 cm. The longer fruit was observed in TRMR-102 (29.40 cm), TT-105 (24.83 cm), and AH-41 (23.63 cm). The 100-seed weight was ranged from 0.07 g to 4.00 g with an average of 0.82 g. Plant height was measured from 25.20 cm to 115.57 cm with an average of 81.90 cm. The taller plant exhibited in the germplasms of AH-41 (112.50 cm), TT-105 (113.33 cm) and K-13 (115.57 cm). This plant height of studied brinjal germplasms was more or less consistent with the findings of Kishorbhai, 2021 in India.

Based on 50% flowering data, it was evident that the early flowering germplasms were RAI-216 (67.0 days), RAI-219 (68.0 days), AR 216 (77.0 days) and TT 56 (77.0 days). The average time required from transplanting to flowering (98.78 days). Yield of fruits showed highly significant and positive association with number of fruits per plant and individual fruit weight, which indicate the importance of these characters during selection for high yielding genotypes in brinjal (Islam & Uddin 2009). The maximum fruiting was observed in the germplasms of RAI-230 (8.25) which was followed by RAI-216 (4.17) and RAI-150 (4.25). The highest yield per plant found in the germplasms of RAI 230 (1.68 Kg) and it was followed by K 24 (1.32K g) and K-21 (1.12 k g). In India, Kumar *et al.* (2016) found highest brinjal fruit yield per plant was produced by MR/04-26 (1.30 kg) followed by PSR-11883(1.08 kg).

Table 3. Variability in fruit characters in brinjal germplasms

Name of descriptor	Descriptor state	No. of germplasms	% of germplasms
Fruit calyx prickles	Very few	1	1.39
	Few	2	2.78
	Intermediate	16	22.22
	Many	30	41.67
	Very many	23	31.94
Fruit colour distribution	Uniform	17	23.61
	Mottled	12	16.67
	Netted	10	13.89
	Striped	33	45.83
Fruit curvature	None (fruit straight)	58	80.56
	Slightly curved	8	11.11
	Curved	6	8.33
Fruit apex shape	Rounded	29	40.28
	Depressed	43	59.72
Fruit cross section	Circular (no groovs)	72	100.00
Fruit colour at ripening	Milky white	1	1.39
	Lilac grey	3	4.17
	Purple	16	22.22
	Green with mottled at the distal end	18	25.00
	Green with yellowish stripe	25	34.72
	Purple with light green at the distal end	9	12.50
Fruit flesh density	Very loose (spongy)	57	79.17
	Loose (Crumbly)	25	34.72
	Average density	29	40.28
	Dense	14	19.44
	Very dense	3	4.17
Fruit position	Pendant	72	100.00

Brown seeds Yellow seeds Brownish yellow seeds

Figure 5. Different seed colour of brinjal germplasms.

Table 4. Variability in seed characters in brinjal germplasms

Name of descriptor	Descriptor state	No. of germplasms	% of germplasms
	Grey yellow	6	8.33
Seed colour	Brownish yellow	30	41.67
	Brown	36	50.00
	Small	28	38.89
Seed size	Intermediate	39	54.17
	Large	5	6.94

Table 5: Quantitative variation of different characters in brinjal

Parameters	Min	Max	Mean	Std	CV (%)
Leaf blade length (cm)	13.62	46.50	19.90	4.00	20.12
Leaf blade width (cm)	8.94	19.58	14.20	1.94	13.66
Fruit length (cm)	6.73	29.40	15.08	4.27	28.30
Fruit width (cm)	1.00	12.00	7.03	2.18	31.02
100 seed wt. (g)	0.07	4.00	0.82	0.56	67.91
Plant height (cm)	25.20	115.57	81.90	18.90	23.08
Days to 50% flowering	67.00	109.00	98.78	9.17	9.29
Number of fruits per plant	0.83	8.25	1.92	1.15	59.93
Yield per plant (g)	94.33	1680.83	509.62	317.98	62.40

Conclusion

A wide variation was observed in the collected brinjal germplasms. Most of the qualitative characters showed distinct variation among the germplasms. Qualitatively the maximum variation was observed in leaf prickles, fruit calyx prickles, fruit colour at ripening and fruit flesh density. Quantitatively highest variation was observed in fruit length which was followed by 100 seed weight and yield per plant. The germplasms K 21 (1.22kg), K 24 (1.32 kg) and RAI 230 (1.68 kg) could be considered as the best yielder among the studied germplasms as per individual fruit yield per plant. The present findings have a great genetic variability of the studied germplasms. Therefore, the promising germplasms identified in the present study might be used in future breeding programs for crop improvement program.

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Research article

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Analyzing temperature fluctuations in Khulna: A long-term assessment

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Abstract

The study investigates the temperature fluctuations in Khulna from 2005 to 2024. From the study, it has been found that the maximum temperature in Khulna has risen by 0.306°C over the past 20 years, according to the yearly average maximum temperature changes at the rate of 0.015°C. A notable increase of 0.072°C over the past 20 years was indicated by a 0.0036°C per year increase in annual average minimum temperatures. The annual average minimum temperature ranged from 21.73°C to 22.74°C; remarkably, the highest recorded annual average minimum temperature was 22.74°C in 2016. According to a monthly temperature analysis, January has the lowest mean monthly maximum temperature (25.06°C), and April has the highest (35.31°C). Mean monthly temperature showed both increasing and decreasing trends over the years. These findings highlight the gradual warming trend in Khulna, which could have significant implications for agriculture, water resources, and public health. The rise in temperature may contribute to increased heat stress, changes in crop productivity, and shifts in local ecosystems.

Keywords: Annual, meteorology, Bangladesh, mean, temperature

Introduction

Climate change and variability has emerged as a key concern for environmentally vulnerable countries (FAO 2011). Bangladesh is widely recognized as one of the most climate vulnerable countries in the world (Hossain 2024).Natural disasters strike it frequently, resulting in fatalities, destruction of infrastructure and financial resources, and negative effects on people's lives and means of livelihood, particularly for the poor who reside in isolated or environmentally vulnerable areas of the nation, such as river islands and coastal belts vulnerable to cyclones (MOEF 2008).

One of the world's largest deltas, Khulna is particularly sensitive to climate change because of its extreme weather occurrences, which include storms, cyclones, droughts, floods, and cold spells (Murtaza 2001). Bangladesh's low-lying, flat terrain, high population density, high poverty, dependence on climate-sensitive industries, especially agriculture and fisheries, and ineffective institutional features make it one of the most susceptible nations to damage from climate change (Rahaman and Bari 2024). Sea level rise, increased temperatures, increased monsoon precipitation, and intensified cyclones are some of the predicted negative effects of climate change that will worsen the stresses that already impede Bangladesh's development, especially by lowering food and water security and destroying vital infrastructure. The economy, ecology, national development, and people of Bangladesh may all suffer greatly from these effects (Shahid 2010).

By the final ten years of the twenty-first century, the Intergovernmental Panel on Climate Change (IPCC) predicts that sea levels will have risen by 0.18 to 0.79 meters due to global warming. Despite the fact that polders protect the majority of the region, this could lead to a rise in coastal flooding and salt intrusion into aquifers and rivers along a broad belt in the south of the country (IPCC 2007). The semi-active delta makes up the southwestern portion, sometimes referred to as the Ganges tidal plain, which is crisscrossed by countless streams and canals. Because of its extremely flat and low terrain, this area is highly susceptible.

Temperature, humidity, sunlight hours, rainfall, and other climate characteristics can change across time and space.

Research shows that there are important variations in a number of climatic factors in different parts of the world. The key contributor of global warming is the growth in greenhouse gases in the atmosphere, such as carbon dioxide, methane, and nitrous oxide. These gases function as a blanket to store solar energy's infrared radiation. Heat radiation from stored energy warms the ground surface and the cooler regions of the atmosphere. In their fourth assessment report, the Intergovernmental Panel on Climate Change (IPCC) said that during the 100 years ending in 2005, the global surface temperature rose by 0.74 ± 0.18 °C (IPCC 2007, Zaman *et al.* 2013).

There has been an increased tendency in both summer and winter temperatures (Islam *et al.* 2010). Bangladesh's mean annual maximum temperature is expected to increase by 0.4°C by 2050 and 0.73°C by 2100 (Karmakar *et al.* 2000). The average monthly temperature in Khulna city ranges from 11.4 °C (52.5 °F) to 34.6 °C (94.3 °F) in April, with a yearly average of 26.3 °C (79.3 °F) (Rajib *et al*. 2010).

This study aims to analyze how one of the key climatic variable 'Temperature' fluctuates at the local level in the Khulna district of Bangladesh during (2005-2024). Khulna region is particularly vulnerable to climatic changes, and the effects of climate change are becoming more obvious there. Increasing temperatures in this region is associated with more fluctuating precipitation, more severe weather, and higher humidity, all of which intensify climate-related problems. Significant sea level rise is a result of these climatic changes, which is particularly concerning because it has broad regional implications.

Methodology

This study primarily relies on quantitative data, specifically secondary data obtained from the Bangladesh Meteorological Department (BMD), encompassing temperature records from all meteorological stations in the Khulna from 2005 to 2024. Daily temperature records were processed by calculating monthly average values, which were then aggregated to compute annual mean values. Missing data were addressed by using the mean of surrounding available data, and any detected outliers were removed to maintain data integrity. The temperature trend was analyzed using the Simple Linear Regression (SLR) method, as it provides a straightforward and interpretable approach to identifying long-term trends. The processed data was then visualized on a monthly and annual basis to examine shifting temperature patterns, with Microsoft Excel. The choice of SLR was made due to its simplicity, efficiency, and suitability for detecting linear trends in climate data, whereas more complex models like polynomial regression or machine learning approaches were not used due to the limited scope of this study and the need for interpretability. Additionally, alternative statistical models, such as ARIMA or exponential smoothing, were deemed unnecessary given the focus on long-term trend estimation rather than short-term forecasting. Despite its advantages, this methodology has limitations, including the assumption of a linear trend, potential biases in missing data estimation, and the exclusion of external factors influencing temperature variations. However, these constraints were acknowledged, and the chosen approach remains robust for understanding temperature trends in the Khulna division over the given period.

Results and discussion

Using data collected from Bangladesh Meteorological Department (BMD), Annual Average maximum temperature, minimum temperature and Trend analysis of monthly temperature of Khulna are discussed in the following subsections.

Temporal shifts in mean annual temperatures: The variation in Khulna's mean annual maximum, minimum, and average temperatures between 2005 and 2024 has been analyzed in this segment. The average temperature was 31.54°C, with the mean maximum temperature ranging from 30.86°C to 32.08°C. During 2016 it had the highest recorded maximum temperature (32.08°C), closely followed by 31.94°C during 2009, 31.89°C during 2010 and 31.80°C during 2014. In 2007, the lowest recorded maximum temperature was 30.86°C. However, 2006 (31.68°C), 2009 (31.94°C), 2010 (31.89°C), 2012

(31.64°C), 2014 (31.80°C), 2015 (31.57°C), 2016 (32.08°C), 2017 (31.57°C), 2018 (31.62°C), 2019 (31.61°C), and 2021 (31.76°C) were the years with above-average maximum temperatures. With an average of 22.23°C, the annual average lowest temperature varied between 21.73°C and 22.74°C. During 2016 it had the minimum temperature (22.74°C), closely followed by 22.67°C during_2010 and 22.56°C during_2022. In 2018 minimum temperature was the lowest (21.73°C). The minimum temperatures was observed in 2007 (21.97°C), 2008 (22.21°C), 2011 (21.85°C), and 2012 (22.21°C) were below average. Alternatively, 2005 (22.44°C), 2006 (22.39°C), 2009 (22.41°C), 2010 (22.67°C), 2015 (22.28°C), and 2016 (22.76°C) had below-average minimum temperatures.

Temporal dynamics of maximum, minimum, and average temperatures: Figure 1 shows the correlations between various years and the annual mean maximum, minimum, and average temperatures. Although this increase was not statistically significant, the data show an increased trend in the yearly mean maximum, minimum, and average temperatures. The average annual maximum temperature increased by 0.0153°C, indicating that during the last 20 years, Khulna's maximum temperature has increased by 0.306°C. According to a group study between 1960 and 2015, Khulna's annual maximum temperature rose by 0.008°C per annum (Mondal *et at.* 2017) Similarly, the annual temperature of Bangladesh increased by 0.02°C between 1981 and 2019 (Bosu *et al.* 2020). additionaly, from 1988 to 2017, Sarkar and Chakraborty (2022) found that the mean maximum annual temperature in South 24 Parganas District, West Bengal, India, increased. The mean annual minimum temperature rose by 0.0036°C annually in a similar pattern (Figure 1), meaning that Khulna's minimum temperature rose by 0.072°C during the previous 20 years. The finding is consistent with a study that found that between 1960 and 20015, the mean annul minimum temperature in Khulna

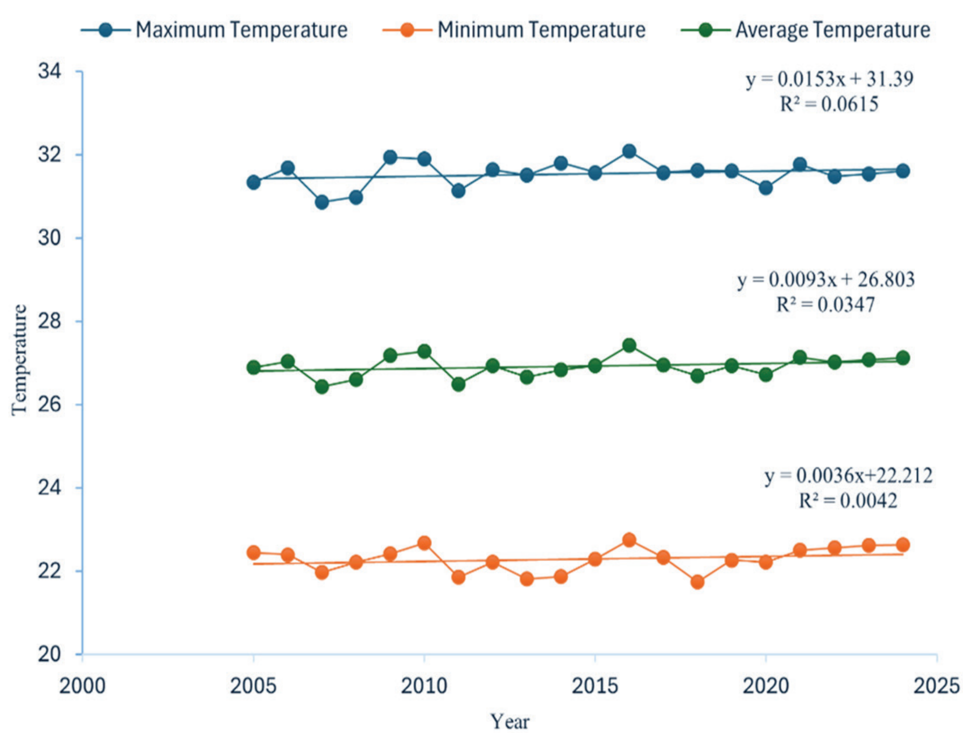

Figure 1. Comparison among maximum, minimum and average temperatures over the period (2005-2024) in Khulna.

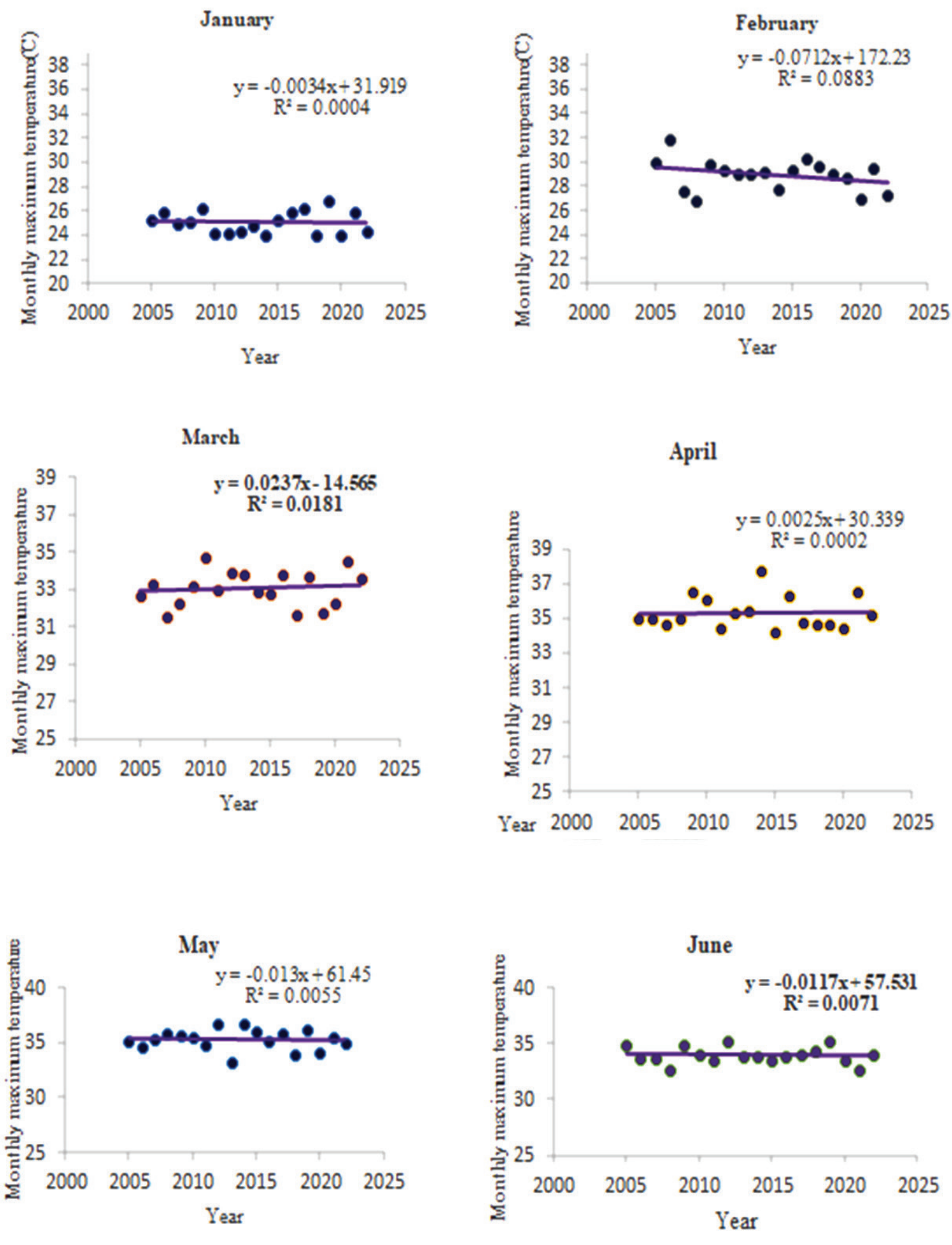

Figure 2(a). Trend analyses of monthly maximum temperatures (January to June) in Khulna.

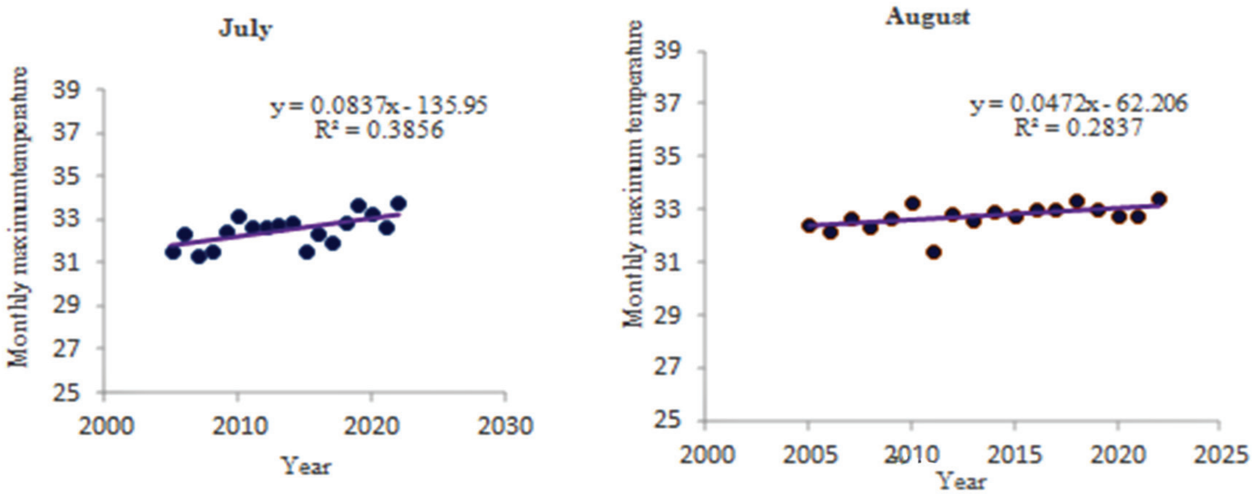

Figure 2(b). Trend analyses of monthly maximum temperatures (July, August) in Khulna.

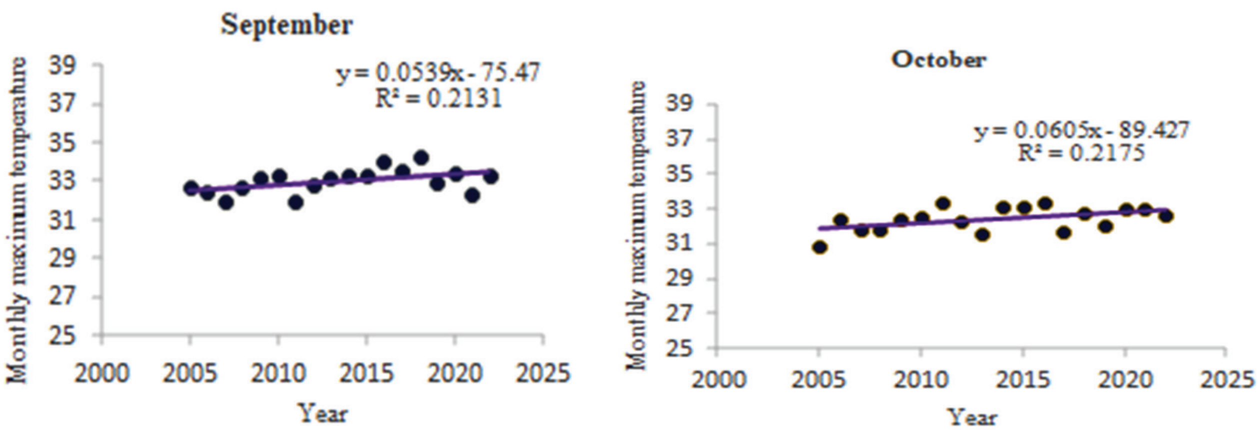

Figure 2(c). analyses of monthly maximum temperature (September, October) in Khulna.

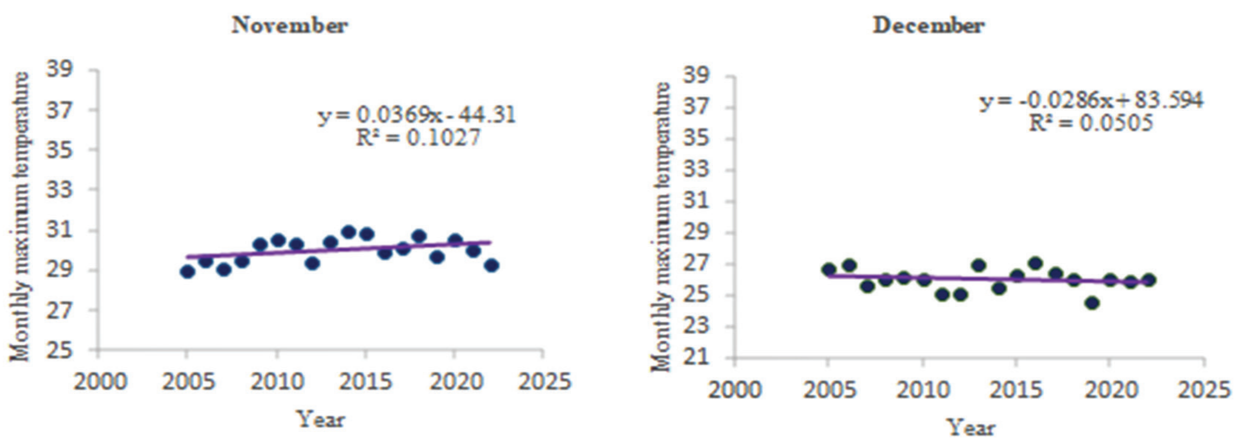

Figure 2(d). Trend analyses of monthly maximum temperatures (November, December) in Khulna.

district increased by 0.002°C per year (Mondal *et al.* 2017).

Temperature trends and variability: Trend analysis of monthly temperature of Khulna are discussed in the following subsections.

Fluctuations in monthly maximum temperatures: Insights into Khulna's temperature distribution have been gained over time through an analysis of monthly maximum temperature data shows that at 35.31°C, April has the greatest mean monthly maximum temperature, while January has the lowest (25.06°C). According to Singh *et al.* (2018), these results are in good agreement with those who reported that May is the warmest month in India's Haryana state, with an average monthly maximum temperature of over 40°C, while January is the coolest month, with an average monthly maximum temperature of about 20°C. Furthermore, the peak temperatures in May (35.29°C) are strikingly similar. Furthermore, a team of researchers documented comparable monthly high temperatures in Bangladesh in December (26.04°C) and February (28.94°C) (Bosu *et al*. 2020). In Khulna district, the mean monthly maximum temperature standard deviation (SD) was highest in February (1.28°C) and lowest in August (0.47°C), suggesting that February saw more unpredictability in temperature and August had more consistency

Fluctuations in monthly minimum temperatures: It is observed that January had the lowest mean minimum temperature (13.11°C), while June had the highest (26.81°C). These results are in line with research showing that January has the lowest average temperature, at around 13°C, and July has the highest average minimum temperature, at about 27°C (Jahan MS *et al*., 2024). Additionally, the data indicates that the mean lowest temperatures in June (26.81°C), July (26.63°C), August (26.65°C), and September (26.34°C) were closely clustered. Conversely, January (13.11°C), February (16.36°C), and December (14.96°C) saw cooler temperatures. These results align with those that documented comparable monthly minimum temperature trends in Bangladesh (Bosu *et al*. 2020). There was more variability in February and more stability in August, as evidenced by the SD for Khulna's mean monthly minimum temperature, which peaked in February at 1.22°C and fell to 0.29°C in August .

Trend analysis of mean monthly temperature: Simple linear regression has been used to look into trends in monthly mean maximum temperatures across time. From January through December, Figures 2(a), 2(b), 2(c), 2(d) display the regression equations and coefficients of determination for each month. These results show that there was no obvious trend in the monthly mean maximum temperatures throughout time, with both fluctuating tendencies noted. With the exception of January, February, May, June, and December, when a decrease was observed, the mean monthly maximum temperature rose in every month. The data also shows that different years accounted for almost 38% of the variation in the mean monthly maximum temperature for July. The progression of the years, however, was shown to account for about 28% of the fluctuation in the mean monthly maximum temperature for August. These results align with those of (Mondal *et al*. 2017), who likewise found no changes in the Khulna district's average maximum temperatures over time.

Conclusion

The study attempted to depict the current trend in temperature of Khulna region for the period of 2005-2024. The region has experienced an annual average maximum temperature of 0.306°C and an annual average minimum temperature of 0.072°C hike during the last 20 years. The month of April has the highest mean monthly maximum temperature of 35.31°C while January has been observed as the lowest. The implications of this study are significant for understanding climate trends and informing policy decisions. By analyzing temperature data over nearly two decades, the study provides insights into long-term temperature variations in the Khulna region, which can help in assessing climate change impacts in the region. The findings can aid policymakers, environmental researchers, and urban planners in developing climate adaptation strategies, mitigating potential risks related to rising temperatures, and enhancing resilience in agriculture, public health, and infrastructure planning. Additionally, the methodology used can serve as a framework for similar studies in other regions, contributing to a broader understanding of temperature trends and their potential consequences. However, given the limitations in data handling and model assumptions, further studies incorporating more advanced statistical models and additional climate variables are recommended to enhance accuracy and depth of analysis.

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In vitro regeneration and dry matter assessment of pyrethrin-rich *Tanacetum cinerariifolium* genotypes

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Abstract

Pyrethrins, a group of six closely related insecticidal esters derived from *Tanacetum cinerariifolium* (pyrethrum), are considered the safest natural pesticides for the environment. This study focused on the in vitro propagation of six naturally pyrethrin-producing genotypes of *T. cinerariifolium* through direct shoot regeneration using apical shoot explants. Highly pyrethrins reproducing genotypes were identified by regeneration technique using apical shoot. Significant variation was observed among genotypes in terms of plant height and number of leaves. The Chlorophyll A content of leaves at 60 days old varied significantly among pyrethrum genotypes. Data analysis showed that percent dry matter content was significantly difference between genotypes. The maximum percent dry matter content was observed in genotype LW 8-9 (9.03%) which was followed by genotype LW 9-10(8.75%) of *T. cinerariifolium*. These findings suggest that direct shoot regeneration is an effective method for selecting and propagating high pyrethrin-producing genotypes of *T. cinerariifolium* for potential use in sustainable pest management programs.

Keywords: *Insecticide, repellent, tanacetum cinerariifolium, root, shoot*

Introduction.

Natural pyrethrins producing plant, *Tanacetum cinerariifolium* belonging to the family Asteraceae commonly known as pyrethrum. The pyrethrins are produced all over the plant parts (Figure 1) but highly concentrated in the glandular trichomes of flower achenes (ssultana *et al.* 2015). The ability of natural pyrethrins to quick knock-down effect on a wide range of insect species and paralysis within a few minutes with minimal or no adverse ecological impact (Casida and Quistad 1995). It acts as contact poison and affects the central nervous system of insects by blocking their nervous functions (Grdisa *et al.* 2009). The term pyrethrins referred to the six insecticide active ingredients: pyrethrin I, cinerin I, jasmolin I, pyrethrin II, cinerin II and jasmolin II (Figure 2). Pyrethrins is about 0.1-0.2% (dry weight) in leaves and 1-2% (dry weight) in flowers (Baldwin *et al.* 1993). The inadequate supply of natural pyrethrins has led to comparatively high prices and an inability to meet the fast-growing demand. It is therefore essential to reduce cost by increasing the production of pyrethrins.

It is widely known that plants from a natural resource or plants propagated by conventional means generally produce small quantities of secondary metabolites which makes their price very high; hence the studies on plant tissues and plant micropropagation offer various advantages for obtaining massive amounts of plant material. The plant micropropagation is an efficient method for propagating disease-free and genetically uniform plants. The vegetative propagation of this plant is generally achieved by either splits or shoot cuttings. These propagation methods result in a low multiplication rate (Hitmi *et al.* 1998).

An additional problem is the high susceptibility of *T. cinerariaefolium* to attack by rootknot nematodes; the splitting of infected stock plants results in a contaminated clone (Wambugu and Rangan 1981). Besides offering increased rates of propagation and pathogen-free plants, in vitro clonal multiplication facilitates asexual multiplication of species that have desirable characteristics. Due to the higher cost compared to many other insecticides, the applications of natural pyrethrins are still restricted. There have been very few attempts to develop regeneration techniques for *T. cinerariifolium* (Zito *et al.* 1994). This study was carried out with the objective of enhancing pyrethrins production in different genotypes by direct shoot organogenesis.

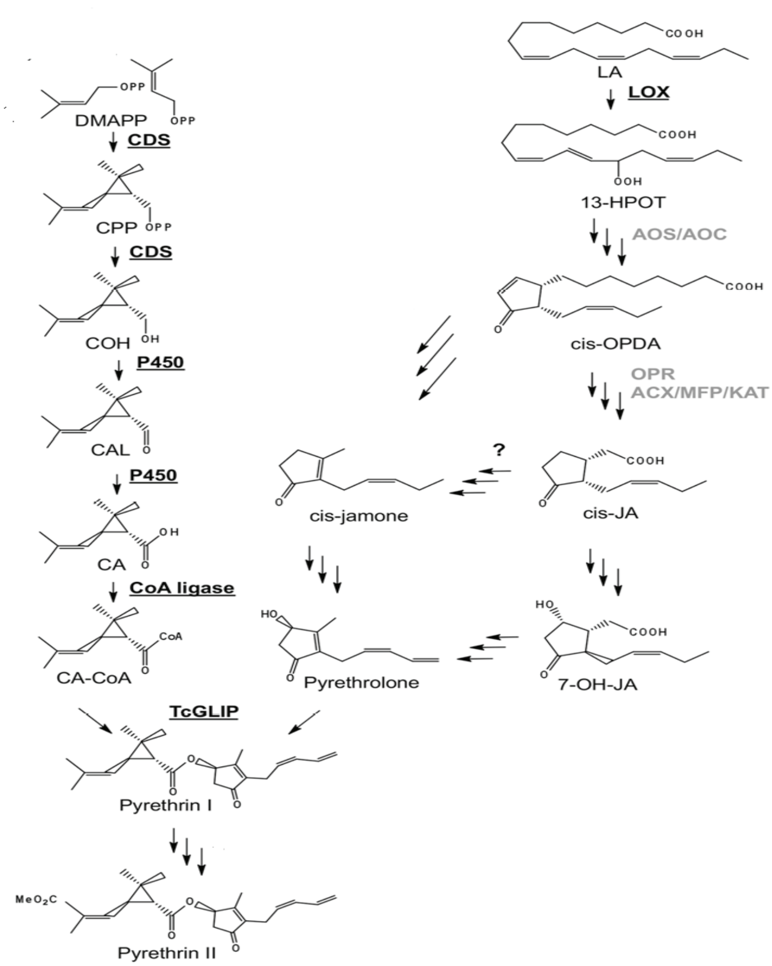

Figure 1. Biosynthesis pathway of pyrethrins (Sultana *et al.* 2015)

Materials and methods

Plant material and explant preparation: Seeds were collected from Honghe Senju Biology Co., Ltd. Luxi County, Yunnan Province, China and sown in plastic pot containing peat soil and transfer to culture chamber. The culture chamber environment is 12 hours light, 8 hours dark, and 2 hours semi-dark condition. One week later seedlings were transfer in a pot and placed in green house. Thirty plants were allowed to grow for two months. Two months old fresh leaves of six genotypes were excised and thoroughly washed with running tap water for about half an hour, treated with commercial detergent (2.0% Teepol) for 4-5 min and were rinsed well with distilled water. Fresh, young apical shoots of six genotypes LW1-1, LW2-3, LW4-5, LW7-8, LW8-9, and LW9-10 were selected for in vitro regeneration methods. The explants were thoroughly washed with running tap water for about half an hour, treated with commercial detergent (2.0% Teepol) for 4-5 min and were rinsed well with distilled water. Subsequently, these nodes were surface sterilized with 0.1% $HgCl_2$ for 3-5 min and thoroughly washed in sterile distilled water for 4-5 times.

Shoot induction: The explants were sub cultured on shoot induction medium supplemented with 2.0 mg/L 6-BA, 0.2 mg/L, IBA 1.0 mg/L at pH 5.8 under a photoperiod of 14 hours light (3000 lx) and 10 hours darkness (Sultana *et al.* 20155). The induced shoots were then sub-cultured on fresh shoot induction media at weekly intervals for 4 weeks. Shoots were then sub-cultured on shoot elongation medium for 4 weeks.

Figure 2. Pyrethrum flower and mosquito repellant from natural pyrethrins

Root induction and transfer to soil: Well-developed shoots were then transferred on rooting medium supplement with MS salts, vitamins, NAA (at suitable concentration), 3% (w/v) sucrose, and 0.8% (w/v) agar adjusted to pH 5.8. All cultures were maintained under the same environment conditions as described above.

Regenerated healthy plants from different genotypes were carefully removed from the culture bottles and agar was gently washed off the roots. Plants were then transferred to small pots containing a 1:1 (v/v) mixture of vermiculite and compost for acclimatization. They were maintained for further growth under 16 hours light/8 hours darkness at 22°c in a culture chamber before being moved to green house. This experiment was conducted following a complete randomized design (CRD) with three replications.

Phenotypic data analysis: For the direct regeneration of pyrethrum apical shoot, data were recorded for different parameters including average number of shoots per explant, average number of leaves per shoot and average number root per shoot. Six genotypes were grown in a greenhouse. Phenotypic data, including plant height and number of leaves per plant, were recorded.

Chlorophyll content: For analysis chlorophyll and carotinoid content, 200mg leaves were collected from two-month-old plant. Leaf samples were extracted and kept in the dark for 48 hours. The absorbance was measured at wave lengths of 665 nm and 649 nm using a spectrophotometer ((Lichtenthaler 1987).

Dry matter content: One month old plants were used for dry matter content measurements. Samples were immediately placed in polythene bag at 4°C for 24 hours in darkness and measured as soon as possible. Subsequently, samples were oven-dried in paper bags at 60°C for at least 72 hours, before their dry mass was measured.

Statistical analysis: All the experiments were repeated three times. Statistical significance was determined using Duncan's Multiple Range Test at $p<0.05$.

Results and discussion

It is widely known that production of pyrethrins from natural resource generally yields small quantities, which makes their price is very high. Hence, studies on plant tissues and plant micropropagation offer various advantages. To obtain massive amounts of plant materials within very short time many efforts have focused on enhancing the production of pyrethrins. Plant micropropagation provides an efficient method for propagating disease-free and genetically uniform plants.

Pyrethrum is naturally self-incompatible and highly heterozygous resulting in each seedling producing a different genotype. Thus, the development of an alternative system and the selection of suitable genotypes for the rapid production of pyrethrum through tissue culture methods are crucial. The production of pyrethrum using tissue culture methods from leaf, flower and node were studied (Hitmi *et al.* 2000, Ikahu and Ngugi 1993). Shoot regeneration from calluses through organogenesis has been reported (Paul *et al.* 1988, Smith 1997). Artemisinin production in shoot cultures of such species as *A. pontica*, *A. judaica*, *A. vulgaris, A. annua,* and *A. scoparia* were investigated by a group of researchers (Gulati *et al.* 1996, Liu *et al.* 2004, Mannan *et al.* 2010, Mathur and Kumar 1996, Singh and Sarin 2010, Sujatha *et al.* 2007).

Selection of high pyrethrin-producing genotypes through regeneration techniques using apical shoots as explants was studied. After two weeks of explants cultured in all the genotype showed shoot bud initiation (Fig. 2). The maximum number of regenerated shoots were found from genotype LW7-8 (7.5) whereas minimum from genotype LW1-1 (5.5) (Table 1).

These results are supported by the observations of Bhattacharya *et al.* (1990), who also reported maximum (2.15) shoots per explant in chrysanthemum shoot tips when MS medium was supplemented with 0.1 mg/L IAA.

Maximum number of leaves per shoot and regenerated root were observed significantly different among genotypes. For root induction and its development in pyrethrum micro-shoots, half strength MS media supplemented with different concentrations of IBA and NAA were used. Karim *et al.* (2002) who reported that 0.2 mg/l IBA had produced maximum results regarding the rooting of chrysanthemum micro-shoots.

All phenotypic data, including plant height and number of leaves, showed significant differences among genotypes (Table 2). Sixty days old plants among pyrethrum genotypes varied significantly Chlorophyll A content of leaves (Table 2). The genotype LW8-9 showed maximum chlorophyll A content (1.01 mg/g fresh weight**)**, while the lowest was obtained from genotype LW2-3 (0.54 mg/g fresh weight**)** (Table 2). Similarly, high chlorophyll

Table 1. Performance of six genotypes on average number of shoot/ explants, number of regenerated leaf/ shoot, number of regenerated root/ explants on culture medium at 28 days after culture.

Genotype	Average no of regenerated shoot/explant	No of regenerated leaf/shoot	No of regenerated root/shoot
LW1-1	5.5c	43.56b	8.67c
LW2-3	6.0b	45.34b	10.24b
LW4-5	5.6c	39.65c	10.12b
LW7-8	8.5a	46.32a	6.87d
LW8-9	6.6b	48.24a	9.45c
LW9-10	6.2b	45.69b	12.05a

Same letters on columns denote non-significant differences ($p \leq 0.05$)

Table 2. Comparisons of growth parameters among six genotypes (60 days old plant in green house).

Genotype	No. of leaves	Plant height	Chlorophyll A content (mg g^{-1} FW)	Chlorophyll B content (mg g^{-1} FW)
LW1-1	14.78	13.03b	0.78b	0.42c
LW2-3	14.63	15.30a	0.54c	0.38d
LW4-5	15.03	13.36b	0.98a	0.35b
LW7-8	15.56	13.56a	0.97a	0.52b
LW8-9	15.23	13.95a	1.01a	0.64a
LW9-10	14.87	13.63	0.79b	0.58d

Same letters on columns denote non-significant differences ($p \leq 0.05$)

Figure 3. Regeneration of plantlets from shoot tip of *Tanacetum cinerarrifolium*. A) Explants on shoot induction medium; B.C). Calli-derived shoot formation; D) Shoot elongation medium E) ; Plantlet on regeneration medium ; F) Plantlets transferred into rooting medium; H) Plant transferring to soil; G) Plants in pot; H) Well developed plants in green house.

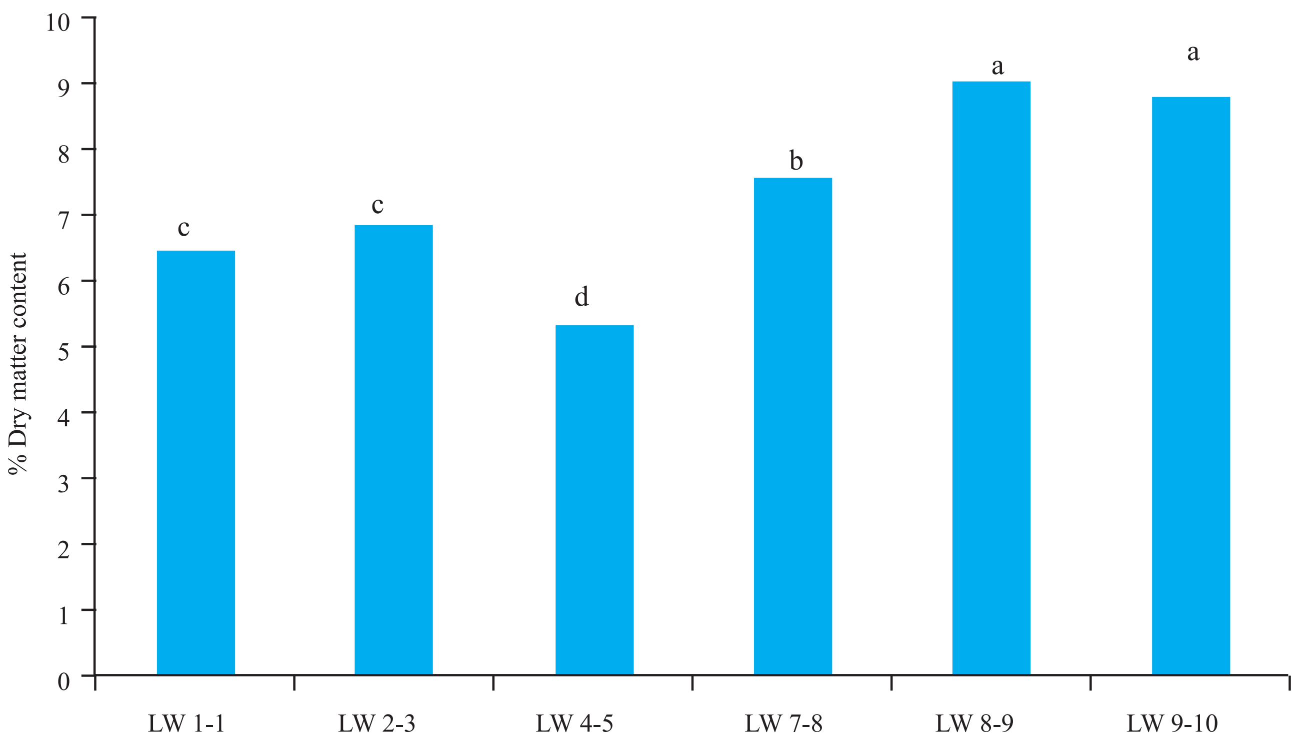

Figure 4. Percent dry matter content of *Tanacetum cinerariifolium* genotypes (LW1-1, LW2-3, LW4-5, LW7-8, LW8-9, and LW9-10)

B content was obtained in genotype LW 8-9 (0.64 mg/g fresh weight) and the lowest chlorophyll B were found in genotype LW 4-5 (0.35 mg/g fresh weight). Thomas and Lekharani, (2008) reported in orchid that chlorophyll content variation in might be due to the varietal characteristics. Increased chlorophyll content in leaves enhances photosynthetic activity, leading to higher carbohydrate production. In this study, percent dry matter content was also observed in six genotypes Significant variations were found in different genotype (Figure 3). Genotype LW8-9 showed the highest dry matter content (9.03%) followed by genotype LW9-10 (8.79 %). The lowest dry matter content was found in genotype LW4-5 which was 5.33%.

Conclusion

In the present study, shoots were regenerated from excised shoot tips. High yielding and disease-free plants produced apical shoots represent a better practice to increase pyrethrins production. In conclusion, based on the present investigation genotypes LW8-9 and LW9-10 appear promising for use as stock material for pyrethrins production.

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Research article

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Toxicity of insecticides to red pumpkin beetle on sweet gourd leaf

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Abstract

Red pumpkin beetle *Aulacophora foveicollis* Lucas (Coleoptera: Chrysomelidae) is a major devastating insect pest of sweet gourd. The larva and adult stages of this beetle are injurious to sweet gourd plants. Several groups of insecticides are applied by the farmers in Bangladesh to control this insect pest. However, the efficacy of these insecticides in field and laboratory conditions have not been assessed in Bangladesh. In this study, the efficacy of the frequently used insecticides namely, Cyren 20 EC, Marshal 20 EC, Ripcord 10 EC and Orogard 55 EC were evaluated to control adult red pumpkin beetles. The mortality rates of the beetles at 24, 48 and 72 hours after application of the insecticides ranged from 14.4 to 46.7%, 33.3 to 73.3% and 52.4 to 86.7%, respectively, and the results differed significantly. Among the tested insecticides, only Orogard 55 EC with recommended dose revealed statistically higher mortality rate (86.7%) of the beetle at 72 hours after treatment, and the computed toxicity data (LC_{50} and LC_{95}) were 7260 ppm and 8323.4 ppm, respectively. Cyren 20 EC, Marshal 20 EC and Ripcord 10 EC with recommended doses revealed very lower rates of mortality and showed toxicity at very high concentrations, indicating that the beetle has developed resistance to these insecticides.

Keywords: *Aulacophora foveicollis*, sweet gourd, insecticide, mortality, toxicity

Introduction

Sweet gourd, a vegetable crop of Cucurbitaceae is used as a component in the preparation of bread, flour, soup, pies, and other dishes (Guiné *et al*. 2012). The fleshy shell, seeds, leaves, and even the flowers are eaten. In Bangladesh, cucurbits make up roughly 66% of the vegetable fields but only produce 11% of the overall vegetable crop (Nasiruddin *et al*. 2004). Sweet gourd is cultivated year-round in Bangladesh, and the area and total production during the year 2021-22 were 30.1 thousand ha and 145.2 thousand Mt, respectively (BBS 2022). The soil and climate of Bangladesh are ideal for growing this vegetable; however, the main production challenge is the infestation of insect pests. The red pumpkin beetle *Aulacophora foveicollis* (Coleoptera: Chrysomelidae) is one of the major insects that hamper cucurbit production in Bangladesh (Nancy *et al*. 2018).

The red pumpkin beetle is a frequent and serious pest of a variety of cucurbits, including sweet gourd, bottle gourd, bitter gourd, white gourd, water melon, and musk melon. The adult and grubs of the beetle feed on the leaves of cucurbits and they cause 30 to 100% yield loss in *Cucurbita pepo* (Aslam *et al*. 2017). Afroz *et al*. (2022) reported 8.5 to 34.6% leaf infestation of red pumpkin beetle among twelve genotypes of sweet gourd. Occurrence and damage severity of red pumpkin beetle in sweet gourd cultivation stand in need of tactics for controlling. In order to control this insect, farmers of Bangladesh apply chemical insecticides numerous times.

The synthetic insecticides prevent, destroy and repel insect pests or mitigate their damage potential very quickly, and are considered as one of the most effective strategies of pest control. But frequent applications and overuse of synthetic insecticides lead to gene mutation in insect resulting in insecticide resistance (Yuan *et al*. 2017). So, efficacy evaluation should be an integral part to assess the toxicity effect and determining the dose of an insecticide for successful pest management in order to combat pests and boost agricultural productivity. Hence, the objective of this study is to evaluate the laboratory efficacy of some commonly used synthetic insecticides on red pumpkin beetle of sweet gourd.

Material and methods

The study was conducted from July 2022 to September 2023 in the laboratory facilities of the Department of Entomology, Gazipur Agricultural University (GAU), Gazipur, Bangladesh. In this study four synthetic insecticides from four different chemical groups (active ingredient) were selected to evaluate their efficacy on adult red pumpkin beetle. Trade name, active ingredient, mode of action, recommended doses and tested doses of the insecticides are noted in Table 1. The five different concentrations of each synthetic insecticide were generated prior to bioassay using repeated dilutions with distilled water.

Application of insecticide treatments and observation of mortality of the beetles: A leaf dip approach was used to assess the toxicity of insecticides to red pumpkin beetle. Fresh sweet gourd leaves were collected from the field laboratory of the Department of Entomology, GAU and dipped into the prepared insecticide doses for few seconds. Then the leaves were air dried on filter paper, afterwards transferred to a Petri dish contained five adult beetles and covered with a ventilated wrap. Only fresh leaves were offered in the untreated control. The number of dead insects in each petri dish was counted at 24, 48 and 72 hours after treatment, and the % mortality was calculated. Three repetitions for each dose of the insecticides were performed and the means were used in the probit analysis.

Statistical analysis: For data analysis, IBM SPSS 20.0 statistical software was utilized. A one-way analysis of variance (ANOVA) was conducted to determine variation in the mortality rate of the insecticides. The dose-dependent mortality response was analyzed at a 95% fiducial confidence interval using probit analysis to estimate the LC_{50} and LC_{95} values.

Results and discussion

The mortality effect of Cyren 20 EC, Marshal 20 EC, Ripcord 10 EC and Oroguard 55 EC with different doses on the adult red pumpkin beetle at 24, 48 and 72 hours after treatment (HAT) are presented in Table 2. From the table, it is seen that the doses of Cyren 20 EC ($F_{4,45} = 6.4$, $p < 0.01$) and hours after treatment ($F_{2,45} = 43.4$, $p < 0.001$) showed significant differences but the interaction effect of the doses and hours after treatment ($F_{8,45} = 0.2$, $p = 0.97$) did not show significant difference. The mortality rate of adult red pumpkin beetles treated with Cyren 20 EC at 24, 48 and 72 HAT varied from 14.4±0.0 to 41.7±14.4%, 33.3±8.2 to 58.3±14.3% and 52.4±8.2 to 75.0±0.0%, respectively. The highest mortality rate of the beetle was observed at 72 HAT with 1200 ppm. It was found that the doses of Marshal 20 EC ($F_{4,45} = 2.8$, $p < 0.05$), hours after treatment ($F_{2,45} = 82.4$, $p < 0.001$) and the interaction effect of the dose and hours after treatment ($F_{8,45} = 0.9$, $p < 0.5$) showed significant differences. The mortality effect of Marshal 20 EC at 24, 48 and 72 HAT ranged from 19.1±8.2 to 28.6±14.3%, 47.6±8.2 to 52.4±8.2% and 52.4±8.2 to 81.9±8.3%, respectively. The highest mortality (81.9±8.3%) of the beetle was recorded at 72 HAT with a dose of 3400 ppm.

Table 1. Details of the insecticides used in the experiment

Trade name	Active ingredient	Mode of action	Recommended dose (ppm)	Company
Cyren 20 EC	Chlorpyrifos	Contact and stomach	1000	Shetu Agro Industries Limited
Marshal 20 EC	Carbosulfan	Contact and stomach	3000	FMC Chemical International AG
Ripcord 10 EC	Cypermethrin	Contact and stomach	1000	BASF Bangladesh Limited
Oroguard 55 EC	Chlorpyrifos + Cypermethrin	Contact and stomach	8000	Oroni International Ltd

Table 2. Effect of different insecticides on the mortality rates (%) of red pumpkin beetle adult at different hours after treatment (HAT)

Insecticide	Dose (ppm)	Mortality (%)		
		24 HAT	48 HAT	72 HAT
Cyren 20 EC	1200	41.7±11.5	58.3±11.5	75.0±11.5
	1100	33.3±11.5	53.3±11.5	73.3±11.5
	1000	33.3±14.4	50.0±0.0	66.7±11.5
	900	26.7±11.5	46.7±11.5	66.7±11.5
	800	14.4±0.0	33.3±8.2	52.4±8.2
Marshal 20 EC	3400	28.6±14.3	52.4±8.2	81.9±8.3
	3200	23.8±8.2	47.6±8.2	80.9±8.2
	3000	19.1±8.2	47.6±8.2	76.2±8.2
	2800	19.1±8.2	47.6±16.5	71.4±11.3
	2600	19.1±8.2	47.6±8.2	52.4±8.2
Ripcord 10 EC	1200	46.7±11.5	73.3±11.5	86.7±11.5
	1100	43.7±11.5	60.0±0.0	73.3±11.5
	1000	33.3±11.5	53.3±11.5	73.3±11.5
	900	26.7±11.5	53.3±11.5	66.7±11.5
	800	20.0±0.0	46.7±11.5	53.3±11.5
Oroguard 55 EC	8300	46.7±11.5	73.3±11.5	86.7±11.5
	8000	46.7±11.5	66.7±11.5	86.7±11.5
	7700	43.3±5.8	53.3±11.5	80.0±20.0
	7400	33.3±11.5	53.3±11.5	73.7±11.5
	7100	33.3±11.5	53.3±11.5	60.0±0.0

From the Table 2, it is seen that the doses of Ripcord 10 EC ($F_{4,45}$ = 9.2, $p < 0.01$) and hours after treatment ($F_{2,45}$ = 43.0, $p < 0.01$) showed significant differences but the interaction effect of the doses and hours after treatment ($F_{8,45}$ = 0.5, p = 0.85) did not show significant variation. The mortality rate of red pumpkin beetle of Ripcord 10 EC at 24, 48 and 72 HAT ranged from 20.0±0.0 to 46.7±11.5%, 53.3±11.5 to 73.3±11.5% and 53.3±11.5 to 86.7±11.5%, respectively. The highest mortality (86.7±11.5%) of the beetle was observed at 72 HAT with 1200 ppm. The doses of Oroguard 55 EC ($F_{4,45}$ = 4.3, $p < 0.01$) and hours after treatment ($F_{2,45}$ = 37.2, $p < 0.001$) showed significant differences but the interaction effect of the dose and hours after treatment ($F_{8,45}$ = 0.71, p = 0.67) show significant difference. The mortality effect of the beetle treated with Oroguard 55 EC at 24, 48 and 72 HAT varied from 33.3±11.5 to 46.7±11.5%, 53.3±11.5 to 73.3±11.5% and 60.0±0.0 to 86.7±11.5%, respectively. The highest mortality (86.7±11.5%) of the beetle was observed at 72 HAT with 8300 ppm.

The study revealed that Oroguard 55 EC and Ripcord 10 EC achieved 86.7% mortality at 72 HAT, which closely aligns with Thomas and Jacob's (1994) findings of an 84.3% reduction in red pumpkin beetle populations using carbofuran over 80 days. In contrast, the considerably lower mortality rates observed for Cyren 20 EC and Marshal 20 EC may indicate the development of resistance. Osman *et al*. (2013) reported that Larvin 75 WP and Diazinon 60 EC achieved significant reductions in beetle populations, with mortality rates of 81.9% and 75.0% at 72 hours after treatment (HAT), respectively. In comparison, the current study found that Cyren 20 EC and Marshal 20 EC were less effective, showing maximum mortality rates of 75.0% and 81.9% only at higher concentrations.

Toxicity effect of the insecticides at 24 hours after treatment is presented in Table 3. Toxicity data revealed that LC_{50} and LC_{95} values ranged from 1139.5 to 8067.9 and 2160 to 9437.5 ppm, respectively. Ripcord 10 EC and Cyren 20 EC showed maximum TR_{50} and TR_{95} (7.0 and 4.4, respectively). The TR_{50} and TR_{95} of Marshal 20 EC were 2.5 and 2.0. Oroguard 55 EC showed the lowest toxicity on red pumpkin beetle. The concentration response curves had the steepest slopes and thus small variations in the concentrations induced greater responses in mortality.

Toxicity data of the insecticides at 48 HAT revealed that LC_{50} and LC_{95} values ranged from 989.9 to 7426.4 and 2160.1 to 9437.5 ppm, respectively (Table 4). Ripcord 10 EC showed maximum TR_{50} and TR_{95} 7.5 and 3.4, respectively. The TR_{50} and TR_{95} of Cyren 20 EC were 6.9 and 3.2. And the TR_{50} and TR_{95} of Marshal 20 EC were 2.4 and 1.7. Oroguard 55 EC showed the lowest toxicity on red pumpkin beetle. The concentration response curves had the steepest slopes and thus small variations in the concentrations induced greater responses in mortality.

Toxicity data at 72 HAT revealed that LC_{50} and LC_{95} values ranged from 662.8 to 7260.0 and 2005.3 to 8323.4 ppm, respectively (Table 5). Ripcord 10 EC showed maximum TR_{50} and TR_{95} 10.9 and 4.2, respectively. The TR_{50} and TR_{95} of Cyren 20 EC were 7.7 and 4.0. And the TR_{50} and TR_{95} of Marshal 20 EC were 3.0 and 2.0. Oroguard 55 EC showed the lowest toxicity on red pumpkin beetle. The concentration response curves had the steepest slopes and thus small variations in the concentrations induced greater responses in mortality.

Table 3. Toxicity effect of the studied insecticides on red pumpkin beetle at 24 hours after treatment

Insecticides	Slope (±SE)	LC_{50} (95% fl)	TR_{50}	LC_{95} (95% fl)	TR_{95}	χ^2 (df)	P
Cyren 20 EC	2.5±0.9	1139.5	7.0	2160.1	4.4	5.6 (3)	0.132
Marshal 20 EC	4.5±1.5	3268.5	2.5	5642.2	2.0	8.0 (3)	0.045
Ripcord10 EC	6.3±0.9	1139.5	7.0	2970.3	4.4	5.6 (3)	0.132
Oroguard 55 EC	29.9±3.9	8067.9	-	9437.5	-	6.5 (3)	0.086

Each datum represents the mean of three replicates, each set up with available insects. Concentrations are expressed as ppm. fl stands for fiducial limits.

Table 4. Toxicity effect of the studied insecticides on red pumpkin beetle at 48 hours after treatment

Insecticides	Slope (±SE)	LC_{50} (95% fl)	TR_{50}	LC_{95} (95% fl)	TR_{95}	χ^2 (df)	P
Cyren 20 EC	5.4±0.9	1083.3	6.9	2116.8	3.2	3.2 (3)	0.351
Marshal 20 EC	6.3±1.4	3110.1	2.4	4537.6	1.7	2.3 (3)	0.497
Ripcord10 EC	3.4±0.9	989.9	7.5	2074.7	3.4	1.6 (3)	0.64
Oroguard 55 EC	15.8±2.3	7426.4	-	9154.0	-	5.0 (3)	0.169

Each datum represents the mean of three replicates, each set up with available insects. Concentrations are expressed as ppm. fl stands for fiducial limits.

Table 5. Toxicity effect of the studied insecticides on red pumpkin beetle at 72 hours after treatment

Insecticides	Slope (±SE)	LC_{50} (95% fl)	TR_{50}	LC_{95} (95% fl)	TR_{95}	χ^2 (df)	P
Cyren 20 EC	4.7±0.9	940.2	7.7	2074.7	4.0	3.4 (3)	0.986
Marshal 20 EC	7.8±1.5	2442.5	3.0	3956.3	2.0	2.7 (3)	0.804
Ripcord10 EC	3.4±0.9	662.8	10.9	2005.3	4.2	1.2 (3)	0.743
Oroguard 55 EC	26.1±2.7	7260.0	_	8323.4	_	13.3 (3)	0.789

Each datum represents the mean of three replicates, each set up with available insects. Concentrations are expressed as ppm. fl stands for fiducial limits.

The toxicity data revealed that Ripcord 10 EC consistently exhibited the highest TR_{50} and TR_{95} values, highlighting its strong efficacy against red pumpkin beetles. These findings are consistent with the observations of Khorsheduzzaman *et al*. (2010), who emphasized the effectiveness of integrated pest management strategies, such as combining soil applications with neem-based treatments, to enhance control measures.

The tested insecticides demonstrated limited effectiveness against the red pumpkin beetle, as indicated by the LC_{50} and LC_{95} values, suggesting that the beetle exhibits resistance to these chemicals. Among the tested insecticides, Ripcord 10 EC showed the highest toxicity; however, its recommended dose did not result in substantial efficacy based on mean insect mortality. In contrast, Oroguard 55 EC, which exhibited the lowest toxicity, achieved a significantly higher mortality rate with its recommended dose compared to the other three insecticides.

Khan and Khattak (1992) evaluated five synthetic insecticides—Cropgard (Pyrethroid), Cypergard (Cypermethrin), Sunmerin (Cypermethrin), Stinger (Pyrethroid), and Mavrik (Pyrethroid)—against the red pumpkin beetle and reported resistance to these treatments. Similarly, Bharathi and John (2013) explored control methods for the red pumpkin beetle, using carbaryl, kerosene-mixed ash, and Parthenium hysterophorus extract. Babu *et al*. (2002) found that carbaryl was the most effective insecticide, followed by chlorpyriphos. Later studies by Rathod *et al*. (2009) and Ratnakar *et al*. (2016) also highlighted carbaryl and cypermethrin as effective options for beetle management.

Conclusion

The results revealed that the insecticides did not show any efficacy to control the beetle at their recommended dosages, probably due to the development of resistance to these insecticides. Mortality data showed that the Oroguard 55 EC depicted comparatively higher efficacy in controlling the red pumpkin beetle. Therefore, new chemical groups should be used to replace these insecticides.

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Review article

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Climate change creates threats to pest management in Bangladesh: way forward

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Abstract

Bangladesh, with its large population and heavy reliance on agriculture, is particularly vulnerable to the impacts of climate change. These changes complicate traditional pest management strategies, as pests that were once seasonal or localized may now thrive year-round or spread to new areas. Unpredictable weather conditions can affect pest control practices, including the effectiveness of chemical treatments and the timing of pest monitoring. This article explores the impact of climate change on pest management in Bangladesh, focusing on the vulnerabilities of the agricultural sector and the need for adaptive strategies. It discusses how climate-induced changes in temperature, rainfall, and humidity can facilitate the spread of pests, the introduction of invasive species, and the outbreak of pest populations. These changes also enhance the reproduction of pests like rice stem borers, aphids, and fruit flies, which are already damaging key crops. As pests become difficult to control with conventional methods, leading to greater reliance on chemical pesticides, which carry long-term environmental and health risks. Agricultural production and food security in Bangladesh are at serious risk due to the spread of these arthropod pests and diseases. Global warming, irregular rainfall, and extreme weather events are disrupting current pest management methods, such as cultural, biological, and chemical approaches. Therefore, promoting sustainable agricultural practices like integrated pest management, climate-smart agriculture, and biotechnological approaches is essential for mitigating the impacts of climate change on pest outbreaks. Priority should be given to the development of resistant varieties, conservation of natural enemies and development of effective forecasting models.

Keywords: Climate change, food security, global warming, pest outbreak, resistant variety

Introduction

Climate change is rapidly transforming environmental conditions across the globe, and Bangladesh, with its vast agricultural sector and high population density, faces significant threats to food security and agricultural sustainability. The country's agriculture is particularly vulnerable to climate-induced changes, especially in relation to pest management, as rising temperatures, erratic rainfall, and extreme weather events create favorable conditions for pests to thrive. One of the major biotic stressors in agriculture is pests, whose populations and behavior are directly influenced by climate change and weather disruptions. Rising temperatures accelerate pest reproduction, survival, and spread while also altering interactions between pests, their environment, and natural predators (Prakash *et al*. 2014). Conventional strategies, which primarily rely on chemical pesticides, are not only becoming less effective due to evolving pest resistance but also pose environmental and health hazards, making sustainable alternatives essential. Global warming, which has reached record-breaking levels as evidenced by unprecedented increases in atmospheric temperature and sea levels, further intensifies these challenges (Field *et al*. 2014). Climate change creates new ecological niches that allow insect pests to establish themselves in previously uninhabitable regions, leading to geographic shifts and unpredictable outbreaks (FAO 2020).

The increasing levels of CO_2, fluctuating precipitation, and the migration of non-native insect species further complicate pest-plant interactions, making Integrated Pest Management (IPM) strategies harder to predict and implement effectively (Trumble and Butler 2009). Changes in agro-ecosystems may also lead to new challenges, such as greenhouse pests becoming more problematic in open fields and pastures. According to Morris (2008), the population growth and longevity of short-lived pest species may increase under warming conditions, while reduced cold constraints could enable pests to expand into new regions and extend their active seasons in existing areas (Diffenbaugh *et al*. 2008). A longer growing season may further exacerbate pest infestations, requiring adaptive management strategies to minimize agricultural losses. To mitigate these risks, farmers must adopt climate-resilient pest management approaches that reduce reliance on chemical pesticides while ensuring long-term agricultural sustainability (Ziska 2014; Rosenblatt and Schmitz 2014). The objective of this review article is to analyze the impact of climate change on pest dynamics in Bangladesh and assess the challenges faced in existing pest management strategies. It aims to explore sustainable, climate-resilient pest control methods, including Integrated Pest Management (IPM) and eco-friendly alternatives. Additionally, the article seeks to provide policy recommendations and practical solutions to enhance pest management while ensuring environmental sustainability and food security. Lastly, it emphasizes the importance of farmer education and capacity-building initiatives to help agricultural communities adapt to evolving pest threats in a changing climate.

Climate change effects on agricultural insect pests

Effect of temperature increase: Climate change directly impacts pest reproduction, development, survival, and dispersal while also influencing interactions within and between insect species and their environment. Temperature fluctuations significantly affect insect physiology, doubling metabolic rates for every 10 °C increase (Dukes *et al*. 2009). Higher temperatures enhance feeding, performance, and dispersal, altering population dynamics (Shrestha 2019). Global warming boosts insect populations, leading to earlier infestations and crop damage. Increased overwinter survival of pests like the corn earworm and cotton bollworm has expanded their range, complicating pest control (Nayak *et al*. 2020). Additionally, warmer conditions shorten developmental times, increasing generations per season and shifting pest-host relationships. Lehmann *et al*. (2020) observed varied responses of insect pests to climate warming, with the majority of case studies showing increased pest impact. Figure 1, present, the impact of increased temperature on insect pests.

Here in Table 1, the dynamic impact of increased atmospheric temperature on crop pest dynamics is shown.

Effect of elevated CO_2 concentration: As CO_2 levels rise, leaves produce more carbohydrates but have lower nitrogen levels. This reduces the plant's defense hormone, jasmonic acid (JA), while increasing salicylic acid (SA) (Delucia *et al*. 2012). Elevated CO_2 (ECC) can affect insect pests by changing their food intake, growth, fertility, and population size (Table 2). For example, ECC increases aphid numbers but does not impact their parasitism rate.

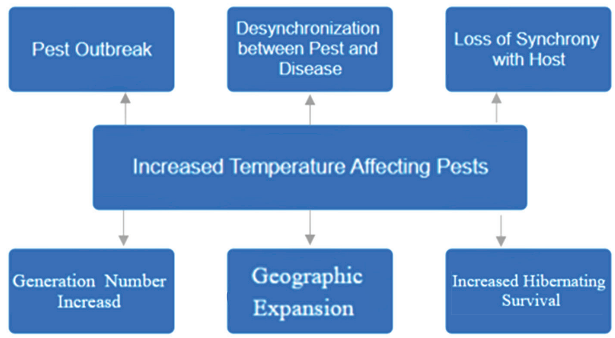

Figure 1. Impact of increased temperature on insect pests.

Table 1. Effect of enhanced atmospheric temperature on crop pest dynamics

Increasing effect	Decreasing effect
Insect extinctions	Effectiveness of insect biocontrol by fungi
Insect developmental rates and oviposition	Reliability of economic threshold levels
Potential for insect outbreaks	Insect diversity in ecosystems
Invasive species introductions	Parasitism

These changes may require adjusting crop management, such as altering planting and harvest times, to avoid peak pest activity.

Effect of changeable precipitation pattern: The survival and reproduction of many insect pests depends on rainfall, which affects their population levels. There is clear evidence of amplification of the global hydrological cycle, which is strongly influenced by changes in temperature (Figure 2). Heavy rain can help by washing away small pests like aphids, mites, jassids, and whiteflies. However, dry soil weakens plants, making them more vulnerable to diseases and pests (Zayan 2019). Additionally, sap-feeding insects tend to thrive on trees that experience occasional water stress rather than constant.

Table 2. Effect of increasing atmospheric carbon dioxide on plant insect interaction

Increasing effect	Decreasing effect
Food consumption by caterpillars	Insect development rates
Reproduction of aphids	Response to alarm pheromones by aphids
Predation by lady beetle	Parasitism
Carbon based plant defenses	Effect of transgenic *Bacillus thuringiensis*
Effect of foliar application and *Bacillus thuringiensis*	Nitrogen-based plant defense

Effects on introduction of invasive alien species: Invasive alien species are organisms introduced outside their native range, either intentionally or accidentally. Studies suggest that climate change may expand their range, increase population density, and shorten generation time, harming agriculture (Ratnayake 2014). Climate change also influences their spread by affecting traits like adaptability to daylight shifts. As ectotherms, insects may adapt through behavioral changes that regulate energy metabolism (Gonzalez *et al.* 2020). The increase in temperature and the shifting of agro-ecosystems create favorable conditions for pests that were once limited by colder climates, such as the *fall armyworm*, which has spread to rice and maize fields in Bangladesh in recent years.

Effects on efficacy of bio-pesticides and synthetic insecticides: Temperature, humidity, and UV radiation are key environmental factors affecting the survival, spread, and virulence of entomopathogenic fungi. High temperatures drastically reduce conidial viability, while high humidity promotes conidial germination. *Beauveria bassiana* strains germinated faster at 95.5% RH (20 h) than at 90% RH (72 h) at 25 °C. Extreme winter (10-15°C) and summer (35-40 °C) temperatures slowed their germination and growth (Sen *et al*. 2009). Additionally, elevated CO_2 significantly reduced the germination and growth rate of *B. bassiana*. The high temperatures, particularly for long periods, decrease the viability of *Bacillus thuringiensis*, and the larvicidal activity was either undetectable or very low within 3 to 10 days after application. Higher temperatures can accelerate the

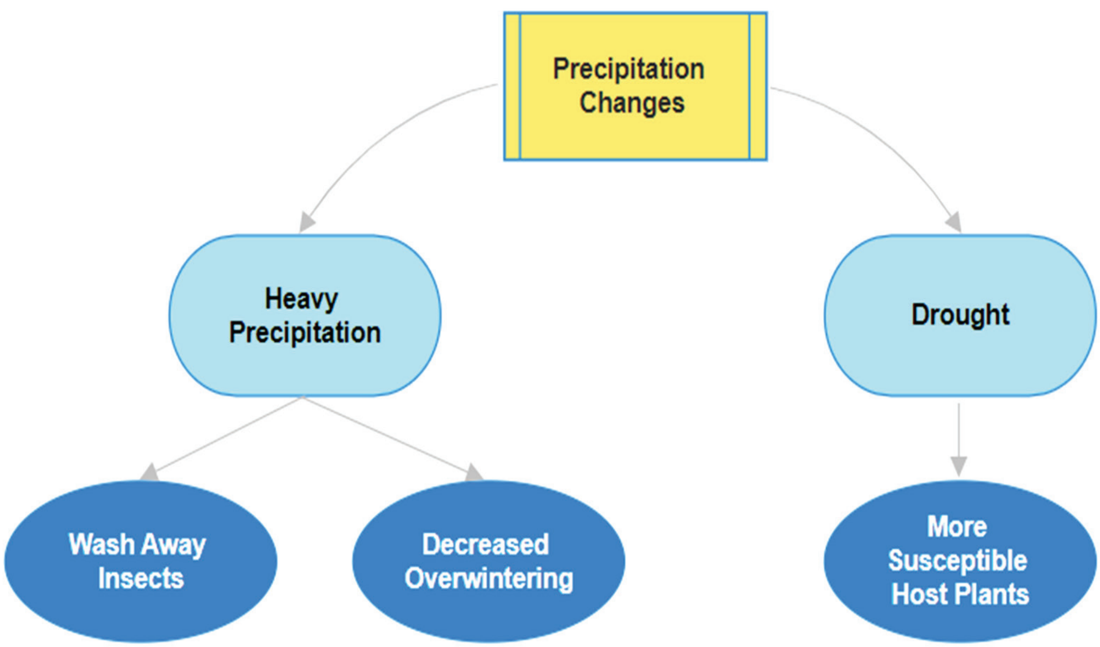

Figure 2. Impact of the changes in precipitation on insect pests.

chemical breakdown of pesticides, reducing their residual effectiveness and shortening the time they remain active in the environment. Additionally, extreme weather events like heavy rainfall can wash away pesticides before they have a chance to work, while dry conditions may limit their spread or effectiveness.

Yield loss of some major crops by insect pests: A study on rice diseases revealed that bacterial leaf blight and nematode are a great threat to rice production throughout the country, and about 4–14% of rice yield is also lost by bug pests annually (Mondal 2010). Moreover, several other crop yields are also undermined by pests and diseases because of climate change (Table 3).

Table 3. Estimated yield loss from insect pests for major crops

Crops	Yield Loss (%)
Rice	16.0
Maize	20.0
Wheat	11.0
Pulses	25
Sugarcane	20.0
Jute	15.0

Challenges in existing pest management strategies: Climate change poses significant challenges to existing pest management strategies, including chemical pesticides, biological control methods, and Integrated Pest Management (IPM).

Chemical pesticides: As the temperature rises, pesticide efficacy decreases due to increased volatilization, a process in which the pesticides turn into gas after application. This results in a higher risk of inhalation, reduced effectiveness, and contamination as the pesticides drift away from the intended area.

Biological control: Variations in CO_2 levels, temperature, and water availability are expected to impact different species within a biocontrol system in unique ways. Milder winters may fail to limit insect reproduction, allowing pests like aphids and thrips to multiply, while predators struggle to control their numbers. Warmer temperatures can lead to various effects, including changes in invertebrate feeding habits, altered pathogenicity of fungi, and often increased survival rates of parasitized hosts. Extreme weather events often lead to pest population surges due to the loss of natural predators. Parasitoids, being more sensitive than their hosts, typically recover more slowly, further reducing their effectiveness in controlling pest populations.

Integrated pest management: While IPM integrates various pest control methods, the unpredictability of climate-induced changes in pest behavior makes it harder to implement effectively. Climate induced changes, such as rising temperatures, can accelerate pest reproduction and resistance to control methods, including biological and chemical components of IPM, reducing their effectiveness. Climate change alters the dynamics between pests, crops, and natural enemies, making it harder to maintain the balance that IPM relies on.

Monitoring and forecasting: Shifting weather patterns, unpredictable temperature fluctuations, and extreme weather events disrupt pest behavior, making it more difficult to predict when and where pest outbreaks will occur. Additionally, climate change may alter the migration patterns and life cycles of pests, leading to unexpected pest invasions in new region. This unpredictability hampers the ability to track pest populations accurately and plan interventions in advance. As a result, existing monitoring systems and forecasting tools may no longer be reliable, undermining the effectiveness of pest management strategies such as Integrated Pest Management (IPM). Enhanced, climate-resilient monitoring technologies and better forecasting models are needed to keep pace with the evolving challenges posed by climate change.

Potential pest management strategies to overcome climate change effects: Managing insect pests under climate change requires a multi-faceted approach (Figure 3) that considers the evolving environmental conditions and the need for sustainable and resilient agricultural practices. These following strategies can be followed in the context of changing climate for better pest management:

Pest-resistant crop varieties: Developing and planting pest-resistant crop varieties one of the most effective long-term solutions to climate-induced pest pressures.

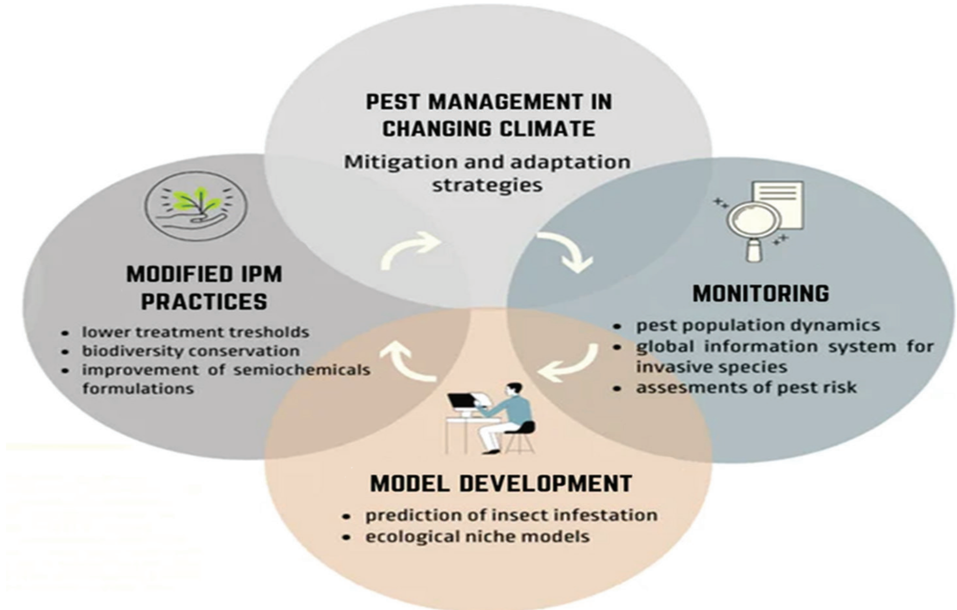

Figure 3. Potential pest management strategies for mitigation and adaptation.

These crops are bred to naturally resist or tolerate specific pests, reducing the need for chemical interventions. With changing climate conditions, pest-resistant varieties can help reduce crop losses and increase resilience against unpredictable pest outbreaks. Breeding for pest resistance can be an effective long-term strategy, especially in changing climates (Kumari *et al*. 2022). Research into climate-resilient varieties, such as drought-tolerant and pest-resistant crops, is critical for adapting to new pest challenges.

Biological control agents: Biological control involves using natural predators, parasites, or pathogens to manage pest populations. These agents, such as beneficial insects (e.g., ladybugs, parasitoid wasps) or biocontrol microorganisms, can effectively reduce pest numbers without harming the environment. Climate change may alter the effectiveness of biological control, but adapting bio-control agents to new climate conditions can offer a sustainable alternative to chemical pesticides. In some cases, introducing or strengthening native predators can help control pest populations more naturally and effectively. *Trichogramma* and *Telenomus* are the most active biological control agents, which parasitized the Fall armyworm eggs and other key pests (Zang *et al*. 2021).

Eco-friendly pest management strategies: Eco-friendly pest management involves a combination of cultural, physical, and mechanical practices that reduce the reliance on chemical pesticides. Techniques such as crop rotation, intercropping, mulching, and using pest-repellant plants can disrupt pest life cycles and reduce pest habitats. Additionally, using physical barriers like nets or traps, and promoting soil health through organic farming, can help prevent pest infestations. These strategies, when integrated with IPM, create a holistic approach that promotes long-term agricultural sustainability and reduces environmental impact.

Modified integrated pest management practices: Modified IPM practices adapt to climate change by incorporating climate-sensitive monitoring, crop diversification, and enhanced biological control methods. These practices focus on using climate data for better pest forecasting, reducing chemical pesticide reliance, and promoting sustainable farming techniques like crop rotation and pest-resistant varieties. By training farmers in climate-smart pest management, these practices aim to balance effective pest control with environmental sustainability, ensuring resilience to climate induced pest challenges.

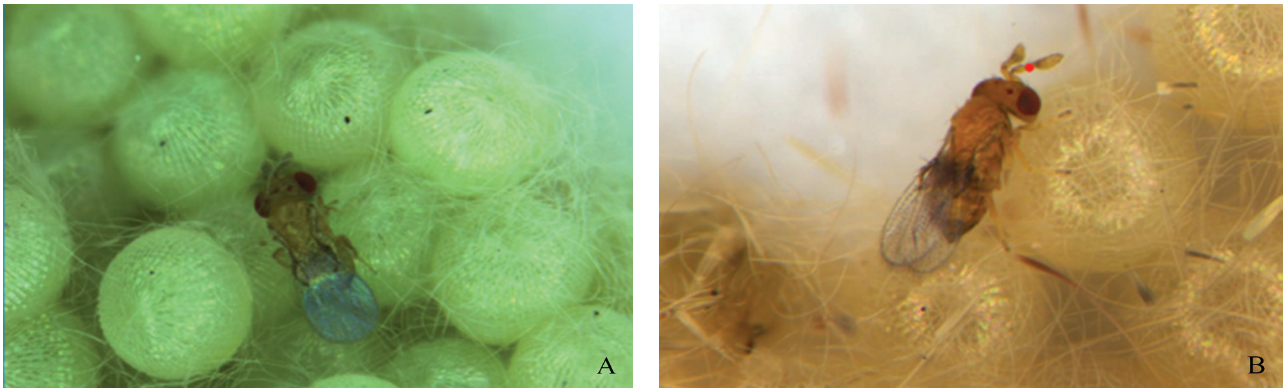

Figure 4. *Trichogramma* species parasitizing the egg mass of fall armyworm, *Spodoptera frugiperda.* (A) *Trichogramma pretiosum*, (B) *Trichogramma chilonis*.

Climate-responsive pest management and climate-smart agriculture in pest control: To address the challenges of climate change on agriculture, Bangladesh needs to combine climate-responsive pest management with climate-smart agriculture. This involves improving early warning systems, enacting climate-responsive policies, and engaging local stakeholders like governments, CBOs, and NGOs (Bodrud-Doza 2022). Figure 5 indicates Climate-smart agriculture enhances productivity and resilience, helping farmers adapt to shifting pest patterns by promoting sustainable practices that reduce pest risks. By integrating these strategies, Bangladesh can better manage pest outbreaks, minimize environmental impact, and ensure long-term agricultural sustainability.

Climate forecasting and model development: An effective early warning system (Figure 6) plays a crucial role in mitigating the impacts of weather extremes by providing timely and accurate information to communities, governments, and organizations. Climate forecasting and model development are essential for predicting how pests will respond to climate change. By using climate data and projections, these models help anticipate pest

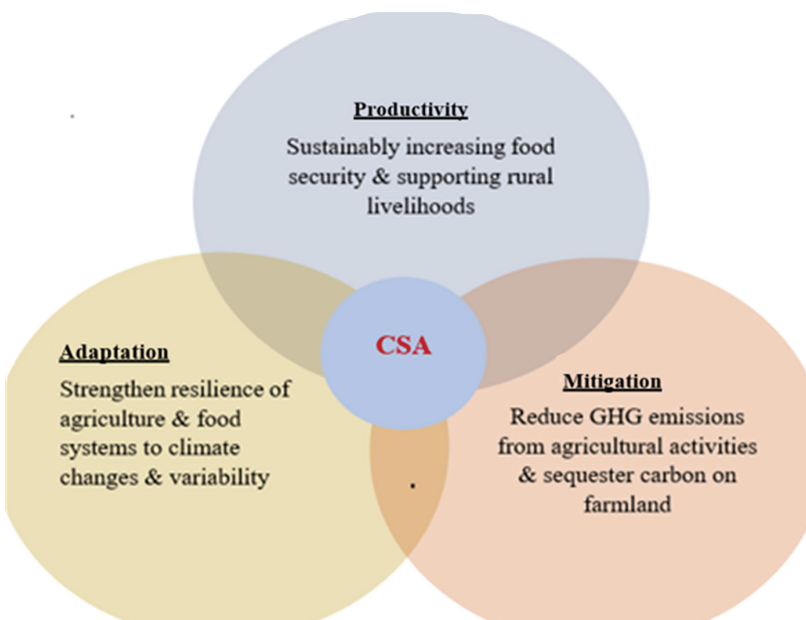

Figure 5. Pillars of climate smart agriculture.

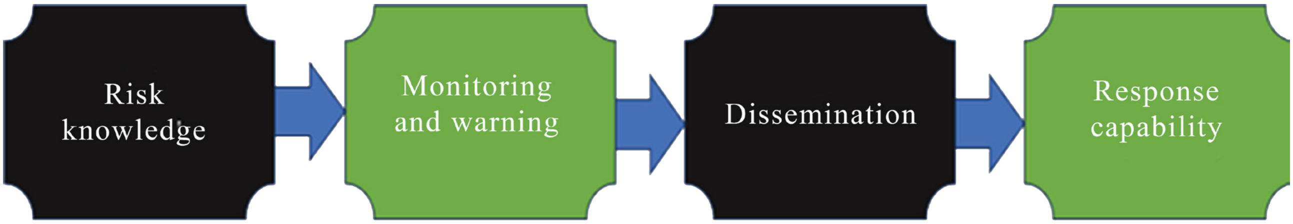

Figure 6. Early warning systems.

outbreaks and identify vulnerable areas. They also enable the development of climate-resilient pest management strategies, allowing farmers and policymakers to better prepare for climate induced pest risks. Modelling the pest risk together with the responses of its plant hosts to climate change can therefore increase the ability to predict the outcome of an insect infestation (Raza *et al*. 2015).

Monitoring abundance and distribution: Without essential baseline data, it becomes challenging to accurately assess changes in pest populations due to climate change and predict future dynamics. Long-term monitoring of pest populations and behavior, especially in climate sensitive regions, is crucial as it can offer valuable insights into how pests biologically respond to shifting climate patterns. (Heeb *et al*. 2019).

Agroecological practices: Agroecological practices, such as polyculture, agroforestry, and conservation tillage, create more diverse and resilient farming systems that naturally control pests. These methods increase biodiversity and strengthen ecosystems, making crops more resistant to pest outbreaks. Agricultural practices, including water management, soil conservation, and carbon sequestration, can also help farmers adapt to changing climatic conditions while managing pest threats in a sustainable manner.

Disaster risk management: The disaster risk management cycle (Figure 7) in pest management includes prevention, preparedness, response and recovery. It involves proactive measures like pest-resistant crops and early warning systems, preparing farmers through training and monitoring, responding quickly with control measures during outbreaks, and recovering by restoring agriculture and refining strategies for future resilience. This cycle helps reduce pest impacts and strengthen food security.

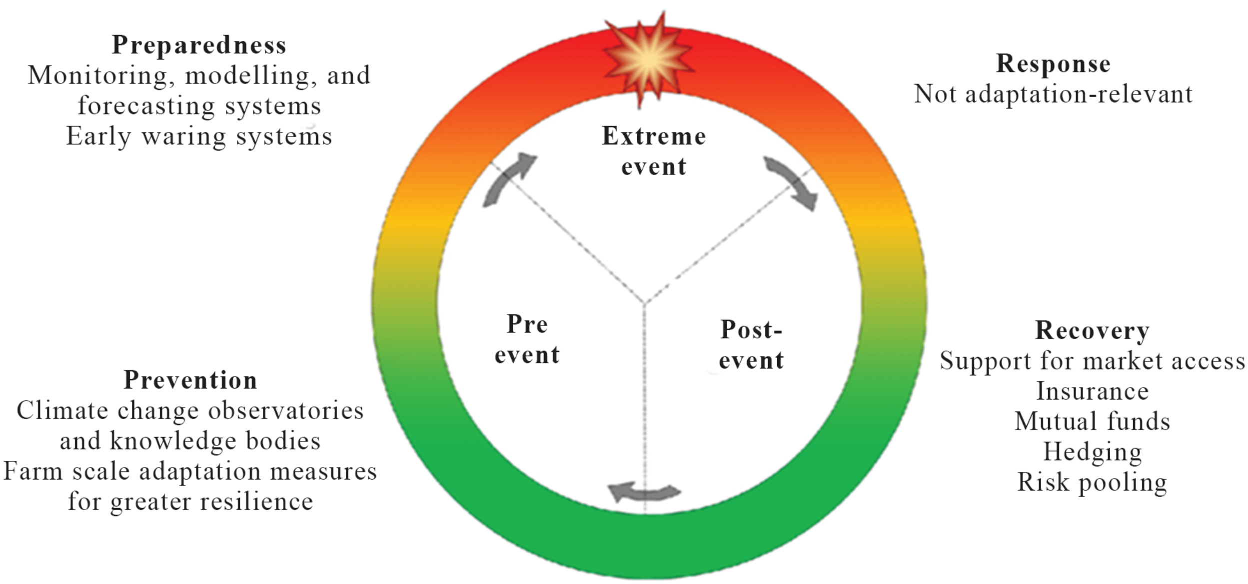

Figure 7. Disaster risk management cycle.

Policy recommendations for improved pest management in Bangladesh: To address the growing challenges posed by climate change on pest management, a coordinated effort involving government agencies, agricultural institutions, and farmers is essential. Below are actionable policy recommendations aimed at improving pest management strategies in Bangladesh while ensuring environmental sustainability and food security:

Promote research and development of climate-resilient pest control solutions: The government should invest in research to develop pest-resistant crop varieties and climate-adapted biological control agents. Agricultural institutions should focus on breeding pest-resistant and climate tolerant crops, as well as identifying native biocontrol agents that can thrive under changing environmental conditions.

Strengthen integrated pest management framework: The government should establish policies that encourage the adoption of IPM, includes providing training and extension services to farmers on IPM techniques, including pest monitoring, biological control, and eco-friendly alternatives to chemical pesticides. Policymakers should also create incentives, such as subsidies or tax breaks, for farmers who adopt sustainable pest management practices and reduce pesticide usage.

Support sustainable agricultural practices: The government should promote agroecological and climate-smart farming practices through financial support, technical guidance, and public awareness campaigns.

Enhance climate-smart extension services and farmer education: Agricultural extension services should be strengthened to educate farmers about climate change impacts on pest dynamics and teach them adaptive pest management strategies. Training programs should include practical workshops on pest forecasting, biological control methods, and the use of climate-resilient crop varieties.

Implement early warning systems for pest outbreaks: The government should invest in the development of digital platforms that provide real-time pest monitoring and forecasts. This would allow farmers to take timely action, such as applying targeted biological controls or adjusting planting schedules, to minimize pest-related crop damage.

Promote public-private partnerships (PPP): Collaboration between the public and private sectors can help accelerate the development and dissemination of innovative pest management technologies. Public-private partnerships could also improve access to financing for smallholder farmers to adopt climate-resilient pest management practices.

Enforce stronger regulations on pesticide use: The government should enforce laws that limit the use of harmful pesticides and promote the safe handling, storage, and disposal of chemicals. Most farmers overuse insecticides indiscriminately, often applying excessive doses, yet still struggle with pest issues (Amin and Islam 2020). So strict regulations should be implemented to prevent the misuse of pesticides that contribute to pest resistance and environmental degradation.

Strengthen data collection and monitoring systems: To improve pest management strategies, the government should invest in data collection and monitoring systems that track pest populations, weather patterns, and the effectiveness of control measures.

Conclusion

Climate change poses significant challenges to pest management in Bangladesh, threatening agricultural productivity and food security. Rising temperatures, unpredictable rainfall, and extreme weather events disrupt pest life cycles and create favorable conditions for pest outbreaks, making traditional control methods less effective. To address these challenges, Bangladesh must adopt climate-resilient pest management strategies that integrate climate-smart agriculture and modified Integrated Pest Management (IPM) practices. These strategies should include climate-sensitive monitoring, enhanced biological control, and reduced reliance on chemical pesticides. Strengthening early warning systems and providing farmer education on adaptive pest management are also essential. Additionally, collaboration between local governments, NGOs, and agricultural stakeholders is crucial for creating effective policies and ensuring community engagement. By embracing these adaptive measures, Bangladesh can improve agricultural sustainability, reduce pest risks, and secure food production in the face of climate change.

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Aesthetic horticulture for conservation of nature and natural resources in the context of climate change: A perspective view

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Abstract

Aesthetic horticulture, the art and science of cultivating plants for beauty and functionality, has emerged as a vital tool in addressing climate change and conserving natural resources. This paper explores the role of aesthetic horticulture in promoting biodiversity, enhancing ecosystem services, and mitigating the adverse effects of climate change. Through a review of existing literatures and analysis of secondary data, the study highlights how integrating aesthetic horticulture into urban and rural landscapes can improve carbon sequestration, reduce urban heat islands, and conserve water resources. Findings reveal that aesthetic horticulture makes significant contributions to biodiversity conservation, water efficiency, urban greening, and climate resilience. The paper recommends policy interventions, community engagement, awareness programs, and sustainable landscaping practices to maximize environmental benefits and achieve ecological sustainability.

Keywords: Aesthetic horticulture, climate change, carbon sequestration

Introduction

Aesthetic horticulture is a comprehensive field that integrates ornamental plant science, landscape architecture, and ecological awareness (Sumalatha *et al.* 2024), is progressively acknowledged as a viable and sustainable methodology for tackling environmental issues amidst the rapid progression of climate change (Pandey and Ghosh 2023). This discipline involves the cultivation and organization of flora not solely for aesthetic appeal but also for extensive ecological benefits, including atmospheric purification, microclimate management, enhancement of biodiversity, and the promotion of psychological health (Naimuzzaman *et al*. 2024, Priya and Senthil 2024). In light of the ongoing and significant impact of climate change on natural ecosystems, exemplified by increasing temperatures, irregular precipitation patterns, and habitat depletion, there is an urgent necessity for innovative methodologies aimed at environmental conservation (Change 2007).

Within this framework, aesthetic horticulture emerges as a powerful tool that integrates ecological restoration with cultural and aesthetic values (Adeyela *et al*. 2016). Unlike traditional horticulture, which focuses on productivity or ornamental features, aesthetic horticulture integrates building natural systems and providing landscaping to plants serving ecosystems to strengthen them against climatic stresses (Mahesh *et al*. 2025). Such species, including indigenous and adaptive plants, help reduce the need for irrigation, soil erosion, and the active insects, enhancing the green cover of the area, which increases the sustainability of freshwater resources in urban and peri-urban environments (Dagar *et al*. 2023).

More importantly, conservation of natural resources in terms of water, soil, and biodiversity may be significantly enhanced through climate-responsive horticultural practices, e. g. xeriscaping, rain gardens, and vertical greening systems (Ryan and Browning 2020). Plants such as xeriscaping, rain gardens, and vertical greening strategies maximize the use of natural resources to reduce urban heat island effects and enhance carbon sink capacities (Hefnawy 2024). Such efforts go beyond developing measures for climate adaptation and serve as an example of environmental ethics and stewardship by promoting a more humane, human-natural relationship

(Wolf *et al*. 2013).

Moreover, in urbanized and densely populated settings, the integration of aesthetic horticulture into public infrastructures such as parks, rooftops, highways, and urban districts offers multifunctional landscapes that enhance environmental resilience and human health (Ogwu *et al*. 2025). Empirical evidence has indicated that close interaction with well-designed green spaces promotes physiological (e.g., cognitive) functioning as well as overall life quality, leading to the conclusion that there is a connection between horticultural aesthetics, ecosystem services, and social well-being (Selanon and Chuangchai 2023).

As such, aesthetic horticulture has the potential, when well aligned with conservation biology and climate change action initiatives, to transform landscapes into regenerative, carbon-neutral ecosystems. This study contends for the unique contribution aesthetic horticulture has made to conservation biology and natural resource management, and also offers insights into how aesthetic management practices can serve as tools to mitigate climate change's various consequences for biodiversity, while also providing opportunities for positive environmental and human impacts.

Role on biodiversity conservation

Human activity promotes the growth of species. To support the existence of pollinators, flora, and fauna, biodiversity is essential. By supporting the health of pollinators, flora, and fauna, we create a harmonious ecosystem on our planet; a healthy ecosystem is necessary for the health of our planet. As with an appealing diversity in a garden, a heterogeneous ecosystem is more resistant to loss and change in the environment.

Habitat creation and the building of complex ecosystems are thus necessary to increase biodiversity in addition to plant yield. Pollinators are a large group of diverse insects that contribute to the reproduction of over 80% of flowering plants, leading to their importance in biodiversity conservation and food security (Kaur and Kaleka 2022). As habitat loss and the application of pesticides have adverse impacts on pollinators, solutions such as the restoration of habitats and plant feeding are needed to manage this population effectively (Jarpla *et al*. 2023). On the basis of evidence synthesized during field studies, diverse plant species should increase the abundance of pollinators as well as improve plant yield in cases exemplifying flower strips that boost the population of bumblebees and plant seed production by more than 200% when planted near floral margins. To this end, planting diverse habitats increases pollinator health and promotes plant resilience against environmental fluctuations (Jarpla *et al*. 2023).

Role on carbon sequestration

Trees and shrubs absorb carbon and reduce atmospheric levels of carbon. Trees and shrubs are important for taking in carbon from the atmosphere and helping to offset the effects of climate change. Carbon sequestration occurs when trees and shrubs absorb carbon from the atmosphere. Carbon sequestration is important in preventing global warming and improving air quality. By learning about and getting involved in carbon sequestration, people can help work toward preserving the planet.

Trees and shrubs have a major role in climate change mitigation by absorbing CO_2 and, thus, reducing atmospheric carbon levels. Urban trees can store large amounts of carbon. A study in Tehran showed that the urban trees' storage capacity in each year is 60, 102 tons. This shows the importance of building urban green infrastructure (Rasoolzadeh *et al*. 2024). Diverse ecosystem communities, including forests, wetlands, and marine environments, offer greater carbon storage capacity than monocultures. Host habitat restoration has greater carbon capture capacity (such as mangroves were restored to exfoliate and remold on site, while carbon accumulation was carried out over 40 years) (Bourgeois *et al*. 2024). Biodiversity as well as carbon storage should be considered interrelated because heterogeneous ecosystems are more resilient to natural change. Therefore, the benefits of different organisms in an ecosystem are matched and balanced and balanced to all individuals (Parida *et al*. 2024). To promote biodiversity and climate change mitigation, by restoration of habitats and developing sustainable forestry practices, ecosystems have to be adapted and conserved (Kasim and Ghassan 2023).

Role on water conservation: Xeriscaping, this strategy reduces the amount of water we're actually using for irrigation by encouraging drought-tolerant landscaping that conserves water. Other approaches to water efficiency include rainwater harvesting and drip irrigation, collecting rainwater where it falls naturally and directly directing it to plants without waste, which makes for pleasing gardens while conserving water.

In addition, modern methods such as precision farming and smart irrigation strategies apply data and real-time monitoring to achieve the best water efficiency (Sankari *et al*. 2024). Innovative practices such as hydrogel application (better soil moisture retention) and graywater recycling further promote the sustainable water use (Abdelhak 2024). Hence, not only do these approaches contribute to fighting water scarcity, but they also increase environmental responsibility and contribute to the sustainability of agriculture. (Eyvaz *et al*. 2022).

Role on urban cooling: Vegetation is important in cooling urban areas; urban climates are more livable, and it reduces the urban heat island effect. Planting trees and greenery not only improves microclimates but also improves public health and environmental quality.

Recently several research papers have demonstrated that blue-green infrastructure (BGI) such as trees and plants directly affect urban climate by influencing the surface energy balance and that it has resulted in average cooling effects (0. 20 K) in cities over the past 20 years, and even city centers have experienced as much as 1. 01 K reductions (Xu *et al*. 2024). The structural and layering of plant communities in cities, especially the presence of tree canopies, increases the efficiency of this cooling (Yu *et al*. 2024). In addition, the cooling performance of urban tree canopies follows a power-law distribution, so this allows for scalable temperature predictions that can be used in urban design. Incorporating diverse types of vegetation and strategically placing them across urban space can maximize the cooling benefits, thus contributing to the comfort and well-being of city dwellers (Xu *et al*. 2024).

Role on soil conservation: Protecting soil is crucial to keep it healthy and stop erosion. This matters for farm success and a healthy environment. Methods like conservation tillage, cover cropping, and using organic nutrients help make soil more fertile. They do this by improving its structure, organic content, and biodiversity (Omer *et al*. 2024). Seaweed extracts are part of the broader classification of agricultural bio stimulants, which possess the ability to effectively augment farming systems encompassing diverse soil (Rahman *et al*. 2024). Humic acid increases nutrient availability, promotes root growth, and improves soil structure (Rahman *et al*. 2024). These sustainable methods don't just cut down on erosion. They also make farm ecosystems stronger, which supports long-term food security without hurting the environment.

On top of that, new solutions like nanomaterials and advanced irrigation tech help conserve soil and water even more. This shows how new ideas play a part in managing land in a sustainable way (Abdelhak 2024). Just like we take care of ourselves, we need to make soil health a priority. This is key to keep producing food and maintain balance in nature for future generations (Singh *et al*. 2024)

Role on community engagement: Getting the public involved in gardening projects has a big impact on raising environmental awareness and making people feel responsible for nature. Studies show that when people take part in urban green spaces (UGSs), it not only makes these areas easier to access but also helps fix social and environmental inequalities by giving communities a sense of ownership and responsibility (Bressane *et al*. 2024).

Projects like the Sungai Jernih Geo Park show how more community involvement can lead to successful conservation. This proves how powerful it is when people work together to protect fragile ecosystems (Kassim *et al*. 2024). When local communities have a say in decisions made by non-profit organizations like the Kenya Wildlife Conservancies Association, it improves how resources are used, increases accountability, and makes things more sustainable in the long run (Awuor 2024).

In places such as Cikelat Village, environmental projects led by the community have resulted in people adopting more eco-friendly practices. This shows how involvement at the local level can promote sustainable development (Sidik *et al*. 2024). All these examples highlight how public participation is crucial to foster care for the environment and to support lasting positive changes.

Recent works on aesthetic agriculture

The idea grew out of the need to blend farming with eye-catching design and city living. New studies have shed light on "productive aesthetics," where farm areas are designed to be both useful and pretty, matching green and long-term goals (Liu *et al*. 2020). These landscapes often have strips of flowers, gardens with fruit trees, food-producing forests, rows of bushes, gardens that grow up walls, and art made from farm stuff (Thacker 1985).

Urban and suburban farming projects have incorporated these visual elements to improve community health, build stronger social connections, and even raise property values (Lovell 2010, Table 1). Community gardens across the U.S., Europe, and Asia, where they use bright flower displays, straight planting rows, and designs that reflect local culture.

New tech like drones, AI landscape planning software, and high-precision farming systems now help to create farm settings that look good and work well for nature. This "smart farm design" mixes seasonal plant colors, bloom timing, and eco-friendly buildings with regular farm output.

Harnessing aesthetic horticulture for nature conservation and sustainable resource management in the era of climate change

Gardening with style takes a big part in fighting and getting used to climate change. Features like green spots in cities, gardens on walls and roofs, and large plant parks help cool down the extremely hot areas in cities, absorb carbon, and make the air cleaner (Gill *et al*. 2007, Table 2). Placing local plants that can withstand the weather in beautiful gardens is beneficial for pollinators and promotes a greater variety of living organisms, while also conserving water and labor (Majewska and Altizer 2020). Garden with plants that don't need much water, ground that lets rain through, and little gardens made just to catch rainwater, it can manage stormwater better and help water get back into the ground. This does a lot of good for nature and still looks amazing (Steiner and Domm 2012).

Aesthetic gardening pushes for resource saving by doing stuff like piling up organic mulch turning yard junk into compost, and cutting down on chemicals. These moves make dirt healthier, keep water in the soil, and cut down on nasty pollution and gases heating up the planet (Rossi *et al*. 2024). But it's not just about what it does for Mother Nature. Aesthetic gardening also gets folks to care more about the planet. Places like botanical gardens and city parks turn into spots where people learn and want to do better by nature, helping to grow communities that think about the earth first (Westwood *et al*. 2021).

Table 1. Recent developments and benefits of aesthetic agriculture

Innovation/Focus	Outcomes
Aesthetic preferences in urban agriculture	Enhanced citizen engagement, biodiversity, and urban green value
Continuous Productive Urban Landscapes (CPULs)	Integration of beauty, food, and ecology in urban planning
Human health and green space exposure	Aesthetic farms are linked to reduced stress and improved mental health
Flower strips in agricultural landscapes	Increased pollination, pest control, and landscape beauty
Agro-art and cultural expression through farming design	Strengthened rural tourism and heritage preservation

In our fast-moving climate change times, making gardens pretty is more than just about looks now. It's a smart, do-it-all approach for dealing with weather woes, protecting all kinds of living things, and helping to use stuff without wasting it. If city folks put this kind of gardening into the mix when they plan and make rules, they can make their cities tougher against Mother Nature's mood swings, push forward with goals for keeping the planet healthy, and just make life better for the people living there.

Key factors influencing the impact of climate change on horticultural practices and biodiversity: Climate alteration brings real problems to gardens and wildlife. It does so with higher heat uneven rain extra big storms, and more CO_2 in the air. These elements mess up how much food we grow and play tricks on nature's harmony and efforts to save species. Here's what shapes how much this climate shifting touches our plant growing and creature variety.

Extreme temperatures and shifting agro climatic zones: Global warming has caused the average temperature to rise by about 1.1°C since the pre-industrial era (Change 2007), which has shifted climate zones and has an impact on crop suitability (Fig. 1). Temperature changes affect many fruit and vegetable crops. Heat stress can result in poor pollination, fewer fruits, and shorter growing times. (Hatfield and Prueger 2015). To give an example, farmers now grow apples and cherries at higher latitudes or elevations because these crops need less cold exposure. (Atkinson *et al*. 2013).

Rainfall variability and water scarcity: Shifts in rainfall patterns have an impact on water supply and irrigation techniques. More unpredictable weather leads to both dry spells and floods, harming crops with shallow root systems (Lesk *et al*. 2016). In places such as South Asia and Sub-Saharan Africa, erratic monsoon behavior is already lowering vegetable yields (Jagtap and Chan 2000).

Rising CO_2 levels: Now that CO_2 levels have gone beyond 420 ppm, it has an impact on plant growth in tricky ways (Soeder 2022). C_3 plants might at first do better with more CO_2 because of faster photosynthesis, but this often results in less nutrient-rich plants when it comes to proteins, iron, and zinc (Singh *et al*. 2024). This "nutrient thinning" puts food quality and people's health at risk.

Increased pest and disease pressure: Climate changes have an impact on how pests and diseases spread making them more widespread. When it gets warmer, pests from tropical areas can move into cooler regions, which brings new challenges to pest control (Deutsch *et al*. 2018). Pests like *Tuta absoluta* have expanded their reach, and this has a big effect on tomato growing in places that didn't have this problem before (Maharjan 2024).

Pollinator loss and ecosystem disruptions: Bees that pollinate plants are at great risk due to changes in climate. Rising temperatures and habitat fragmentation have an impact on flower blooming times and pollination periods.

Table 2. Key contributions of aesthetic horticulture in the climate change era

Aspect	Contribution	Outcome
Urban Greening	Reduces urban heat islands, captures carbon	Lower ambient temperatures, improved air quality
Native Plant Landscaping	Supports local flora/fauna, requires less water	Biodiversity conservation, reduced maintenance
Rain Gardens & Green Roofs	Manages storm water, reduces runoff	Prevents urban flooding and groundwater recharge
Organic Mulching & Composing	Enhances soil fertility and water retention	Sustainable soil management
Educational Horticulture	Public awareness of sustainability	Increased community engagement in conservation

This causes a disconnect between plant flowering and pollinator activity.

Habitat degradation and biodiversity erosion: Changes in land use due to climate and extreme events play a part in destroying habitats, which has an impact on the natural reserves of wild crop relatives. These wild relatives are key genetic resources to breed varieties that can withstand climate changes (Benlioğlu and Adak 2019, Jordanovska *et al*. 2020). When we lose biodiversity, it weakens how stable ecosystems are and makes it harder for them to adapt.

Socioeconomic challenges and adaptive limitations

The ability of farmers to deal with climate risks depends on their access to resources, technology, and support systems. Small-scale fruit and vegetable growers in developing areas face extra challenges. They often lack basic infrastructure, better crop types, and money services (Morton 2007). This makes it harder for them to handle climate-related problems. Model presented in Figure 1 reflects the socioeconomic challenges and adaptive limitations in aesthetic agriculture (Manzoor *et al*. 2024).

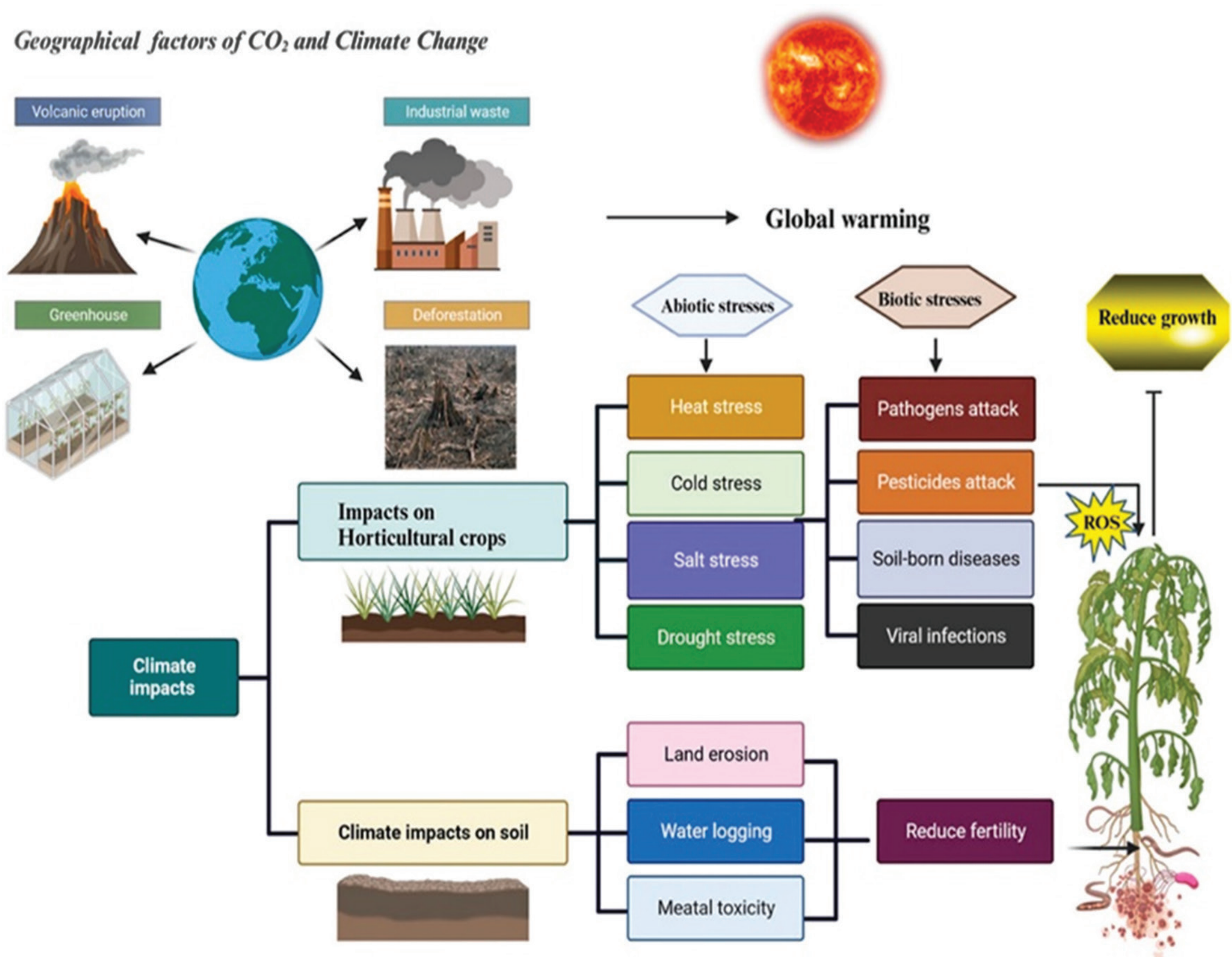

Figure 1. **Geographical factors of CO_2 and climate change that influence the adaptation of aesthetic agriculture (Manzoor *et al*. 2024).**

Salt stress is a common environmental challenge that has a big impact on how well crops grow and produce. This issue affects farming all over the world. Scientists looked at using nitrobenzene treatments to help plants deal with salt stress. They found that certain amounts of nitrobenzene seemed to help plants grow better at first. These treatments also appeared to reduce the harmful effects of salt stress. This suggested that nitrobenzene could be useful in managing crops under salty conditions (Haque *et al*. 2024). Increasing the toxicity of HMs to ecosystems, soils, and plants. HMs' toxicity significantly reduces plant development and modifies several physiological and molecular alterations in several plant species (Roy *et al*. 2023). Through symbiotic relationships, plant growth-promoting fungi (PGPF) provide a promising way to improve plant growth, nutrient uptake, and stress tolerance (Naimuzzaman *et al*. 2024).

Climate change has a big impact on how we grow plants and on the variety of living things around us. It causes many problems, from less food and lower food quality to unstable ecosystems and money worries. To tackle these issues, we need to use several methods together. These include growing plants that can handle changing weather using water, helping bees and other pollinators, and keeping different types of plant genes safe. By doing all this, we can help protect our plants and the world around us from the harm caused by our changing climate.

The role of horticultural therapy in promoting environmental awareness and conservation amid climate change

Horticultural therapy has an influence on raising environmental awareness and has an impact on advancing conservation as we face climate change. These programs build a stronger link between people and nature when schools like universities put them into action. They boost mental and physical health while encouraging eco-friendly habits (Li *et al*. 2024). Horticultural therapy projects can also teach people, showing them climate-tough gardening methods. These include ways to save water when watering plants and managing pests without harming the environment, key strategies to adapt gardening to our changing climate (Devrani and Tiwari 2024).

Also, botanical gardens have an important role in climate research and public outreach. They offer insights on how plants react to climate stressors and get communities involved in conservation work (Primack *et al*. 2021). In places like India that are vulnerable to climate change, methods based on horticultural therapy can be helpful. They give small farmers adaptive knowledge and practices to better handle environmental pressures (HR *et al*. 2024). In the end, horticultural therapy not only boosts individual well-being but also fosters a shared commitment to sustainability and caring for the environment.

Future outlook of aesthetic horticulture

The future of aesthetic horticulture has an impact on how we blend it with sustainable growth, city toughness, and people's well-being. As cities grow bigger, aesthetic horticulture is ready to make a big difference. It will help to put green structures into city plans. These include gardens on roofs, plants growing up walls, green spaces to heal, and paths that help wildlife. (Gaston *et al*. 2013).

Breakthroughs in plant science and ecological design will help create ornamental plants that look good and suit the climate. These plants will clean the air, cool down cities, and boost people's mood (Wootton-Beard *et al*. 2016). More people now like biophilic design, showing a change in culture. This design uses pretty plants to reconnect with nature encourage care for the environment, and keep cultural landscapes intact (Beatley and Newman 2013). As taking care of the environment becomes crucial aesthetic horticulture will change. It will stop being just for decoration and become a complex field that brings together knowledge of ecology, cultural identity, and the ability to handle climate change.

Aesthetic horticulture practices in south and southeast Asia

In Southeast Asia, artistic design, care for nature, and cultural heritage come together in garden-making to create lively, meaningful green areas (Holden 2003). The region, rich in plant and animal life and with deep spiritual roots, shows how gardening goes beyond just making landscapes look nice (Hutterer 1983). Gardening for beauty in this area has deep ties to religious meanings, smart planning for the climate, and work to make cities greener (Austin 2014). People often see gardens as more than just pretty spaces. They view them as holy and shared havens that boost mental health and cultural identity (Elior 2014). The choice of plants often has symbolic value (Rival 2021). For example, many people grow lotus *(Nelumbo nucifera)* in Vietnam and Thailand (Zhou *et al*. 2022). In Buddhist traditions, this flower stands for purity and spiritual growth (La-Ongsri *et al*. 2009).

Singapore shows how good-looking gardening can teach people about nature and help cities deal with climate change (Sharath and Peter 2019). Big projects like the Super Tree Grove and Gardens by the Bay don't just attract tourists. They also cool down the city and boost plant and animal life (Kaprielian 2025). At the same time, the Philippines and Malaysia have started using gardens on walls and roofs (Tang *et al*. 2023). This helps them handle their crowded cities and limited space (Sheweka and Magdy 2011, Table 3) presents an overview of aesthetic horticultural traditions across Southeast Asian countries, highlighting their botanical richness, cultural symbolism, and regional diversity.

Suggestions to strengthen aesthetic horticulture Bangladesh

To get the most out of aesthetic horticulture's environmental perks and tackle climate change and resource conservation issues, here's what we suggest:

Policy interventions and development: Governments need to create and put into action policies that encourage the use of aesthetic horticulture in city planning, farming, and urban growth plans. These policies should push for green landscaping in both public and private areas, making sure horticultural practices are adopted.

Community engagement and public awareness: We

Table 3. Aesthetic horticulture practices in south southeast Asia

Country	Common Practices	Popular Plants	Cultural Significance
Indonesia	Balinese garden design, water gardens, tropical landscaping.	Frangipani (Plumeria), Orchids, Hibiscus.	Gardens reflect harmony with nature and spirituality through the Tri Hita Karana philosophy.
Malaysia	Rooftop gardens, and bonsai cultivation	Bougainvillea, Heliconia, Pitcher Plants.	Incorporate Islamic motifs that emphasize peace and tranquility.
Thailand	Temple gardens	Lotus, Jasmine, Golden Shower Tree.	The lotus symbolizes purity in Buddhism and gardens are an integral part of temple design.
Philippines	Urban vertical gardens, natural landscaping	Sampaguita, Anahaw, Waling-waling Orchid.	Sampaguita, the national flower.
Vietnam	Zen gardens, bonsai	Lotus, Bamboo, Areca Palm.	Lotus denotes enlightenment, bamboo symbolizes resilience.
Singapore	Supertree Grove, vertical gardens, urban green spaces	Orchids *(Vanda Miss Joaquim)* Ferns, Bougainvillea.	Orchids are national symbols, gardens support.
Myanmar	Monastery gardens, tropical gardens, floating garden	Padauk, Orchids	Padauk, the national flower.
India	Mughal gardens, temple gardens, urban terrace gardens.	Marigold, Lotus, Neem, Jasmine.	Gardens reflect spiritual, medicinal, and aesthetic values; marigolds and lotuses are used in religious rituals.
Bangladesh	Courtyard gardens, rooftop gardens, floating gardens.	Water Lily, Mango Tree, Bamboo.	Water lily is the national flower; gardens are tied to agrarian traditions and seasonal festivals.

should get local communities involved in horticulture projects through info campaigns, hands-on workshops, and learning programs. Helping people understand the benefits of aesthetic horticulture can lead to better environmental care and community-led conservation efforts.

Research and innovation: We need more research to come up with new gardening methods. This includes plants that can handle tough weather, ways to water plants using less water, and landscaping that's good for the environment. Putting money into research will help us get the most out of aesthetic horticulture's benefits for the environment. It will also help us tackle challenges specific to different areas.

Education and training: We should start educational programs at different levels to teach professionals, people who make policies, and the general public about the basics and practices of aesthetic horticulture. This will help build skills and make sure we can put horticultural strategies into action.

Collaboration and partnerships: Strong partnerships between horticulturists, environmentalists, policymakers, and urban planners play a crucial role in putting aesthetic horticulture into action. Team efforts can boost knowledge sharing, help allocate resources better, and make sustainable practices more widespread.

Integration into urban development: Urban development plans should include aesthetic horticulture as a key part. This means adding green roofs, vertical gardens, urban forests, and bioswales to city designs. These projects can make cities more resilient, cut down on heat islands, and improve city life overall.

Conclusion

The successful integration of aesthetic horticulture into environmental conservation and climate change mitigation strategies needs a multi-faceted approach. Policymakers, communities, researchers, and environmental agencies must team up to push for sustainable practices, boost awareness, and come up with groundbreaking solutions. By putting these suggestions into action aesthetic horticulture can have a big impact on creating resilient and appealing landscapes helping to build a sustainable future.

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