Ornamental Horticulture
ISSN 2447-536X | WWW.ORNAMENTALHORTICULTURE.COM.BR

SBFPO Sociedade Brasileira de Floricultura e Plantas Ornamentais

ARTICLE

Feasibility analysis of floating floriculture system for aesthetic and economical use of polluted wetlands in urban areas of Bangladesh

Análise de viabilidade de sistema flutuante de floricultura para uso estético e econômico de áreas úmidas poluídas em áreas urbanas de Bangladesh

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Abstract: Rapid urbanization possesses detrimental impacts on the environment especially on water bodies. Polluted water from industrial and residential sources ends up in water bodies and make them unattainable and unsightly. An indigenous cultivation practice, floating agriculture allows the fallow wetlands for agricultural production. Cultivation of economically important flower like marigold (*Tagetes erecta* L.) on wetlands through floating agriculture technique make the water bodies productive and aesthetically valuable. Considering this, an experiment was carried out to evaluate the performance of marigold on floating bed. To perform the experiment, two different samples (based on flower color) of marigold seedlings were cultivated on floating and soil bed. Data on different morphological, physiological as well as yield-related parameters were collected and subjected to statistical analysis. Results of the study revealed that, with other favorable growth parameters number of flowers was greater in floating condition. These profound growth responses suggest the sound adaptation of marigold in floating agriculture technique.
Keywords: climate adaptation, floating agriculture, marigold, submergence, urbanization.

Resumo: A rápida urbanização gera impactos prejudiciais ao meio ambiente, especialmente nos corpos d'água. A água poluída de fontes industriais e residenciais acaba em corpos d'água e os torna inacessíveis e desagradáveis. Uma prática de cultivo indígena, a agricultura flutuante permite o uso das zonas húmidas em pousio para a produção agrícola. O cultivo de flores economicamente importantes como o tagetes (*Tagetes erecta* L.) em áreas úmidas por meio da técnica de agricultura flutuante torna os corpos d'água produtivos e esteticamente valiosos. Considerando isso, foi realizado um experimento para avaliar o desempenho do tagetes em leito flutuante. Para realizar o experimento, duas amostras diferentes (com base na cor da flor) de mudas de tagetes foram cultivadas em leito flutuante e em solo seguindo um desenho experimental de parcelas subdivididas. Dados sobre diferentes parâmetros morfológicos, fisiológicos e relacionados ao rendimento foram coletados e submetidos à análise estatística. Os resultados do estudo revelaram que, com outros parâmetros de crescimento favoráveis, o número de flores foi maior na condição flutuante. Estas respostas significativas de crescimento sugerem a boa adaptação do tagetes na técnica de agricultura flutuante.
Palavras-chave: adaptação climática, agricultura flutuante, submersão, tagetes, urbanização.

Introduction

Bangladesh is one of the world's most densely populated countries. It has also faced rapid population growth throughout the last century, although the population growth rate has recently decreased to a moderate level. The country will witness a rapid spread of urbanization over the next decade. Urbanization brings economic and social benefits, but it also poses some serious challenges, especially when it takes place at a pace as rapid as the one in evidence in Bangladesh today. Rapid urbanization, both in terms of population growth and expansion, directly impacts the environment in the form of encroachment and pollution of water bodies. Wetlands in urban areas are often viewed as wastelands. Urban waters take on large amounts of pollution from various sources, including mobile sources and residential waste products. Urban wetlands should be integrated into a city's sustainable future planning and development, not viewed as wastelands. Wetlands are a precious national resource. The economic value of wetlands cannot be calculated; our spirit, mind, body and health are related to wetlands. We need to save our wetlands, ensuring a healthy environment in rural and urban areas.

If we can aesthetically decorate the existing waterbodies, people are expected to restrain themselves from polluting waterbodies, participate in wetland management, preserve, and restore urban wetlands, and reduce water consumption and harmful runoff. One of the best natural ways to give an aesthetic look to the water bodies is to grow flowers in the water body, as flowers symbolize beauty and purity.

People from southern areas of Bangladesh (Barishal, Gopalganj, and Pirojpur) has practiced crop cultivation (including highly waterlogging sensitive crop plants like chili) in low-lying areas using a floating agriculture system for two centuries (Jahan & Khanam, 2020; Hutton et al., 2015; Islam & Atkins, 2007). Floating cultivation can help to reduce the pressure on arable lands by turning flooded and waterlogged areas into productive ones (Irfanullah, 2009). In this system, the local farmers of the southern region of Bangladesh use different types of macrophytes, for instance, Topapana (*Pistia stratiotes* L.), Khudipana (*Lemna minor* L.), Kutipana (*Azolla pinnata* R. Br.), Sonapana (*Spirodela polyrhiza* L.), Asian water moss (*Salvinia mollesta* D. Mitch.), Kariba weed (*Salvinia cucullata* Roxb.) along with the water hyacinth (*Eichhornia crassipes* Mart.) to prepare floating bed (Rahman, 2011). Some of these macrophytes, such as water hyacinth (Lubembe et al., 2023), and *Salvinia* spp. (Sultana et al., 2023), have extremely high reproductive rates, and they can become invasive. Therefore, this traditional cultivation technique is an environment-friendly means to utilize the natural resources of wetlands to grow vegetables and other crops almost year-round (Irfanullah et al., 2011).

If it is possible to cultivate flower in water bodies through this method, it will help to reduce the pollutants in water bodies and pave the way for profitable use of water bodies. It may be possible to cultivate flowers in polluted waterbodies using this technology. In this way, reducing of pollutants in the water body is possible and economically beneficial. Nowadays, flowers have become an essential part of the country's economy. Over the years, the demand for flowers as an agricultural product has been rising in Bangladesh, making floriculture a potential sector.

Corresponding Author: mrsubroto@yahoo.com | https://doi.org/10.1590/2447-536X.v31.e312824 | Editor: Raissa Rachel Salustriano da Silva-Matos, Universidade Federal do Maranhão, Brasil | Received: Oct 10, 2024 | Accepted: Mar 10, 2025 | Available online: Apr 16, 2025 | Licensed by CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/)

Available research indicates that marigolds (*Tagetes erecta* L.) can absorb heavy metal from the contaminated soil like other macrophytes and ornamental plants (Huqail et. al., 2023; Khilji et. Al., 2024). marigold is an aesthetically significant and economically important flower from the family Asteraceae. It is one of the most important commercially grown loose flower crops in Bangladesh due to its extensively used in religious and social functions, in controlling plant parasitic nematodes (Mehmood et al., 2020), in pharmaceuticals for having antioxidant properties (Huang et al., 2022), and in garments industry to dye fabrics commercially. Commercial floriculture in Bangladesh is a new dimension in farming culture. Economic evaluations of marigold cultivation have found that it can be a profitable enterprise for farmers, and that it can generate employment and income opportunities. Considering the market value some farmers in association with entrepreneurs have started marigold cultivation in their cultivated land. It is noted that, Marigold cultivation can be profitable, with higher net returns than other crops. For example, in Bangladesh, marigold cultivation had a net return that was 81% higher than lentil and 85% higher than mustard. But in recent years, the production of marigolds has been decreasing day by day. There is no clear recommendation based on existing technology to increase yield potential. In 2019-2020, the production was 2997.62 t which decreased by 1812.64 t in 2020-2021 and 1777.54 t in 2021-2022. The production area is also decreasing daily (BBS, 2023). One of the major constraints is the unavailability of land due to waterlogging. The marigold plant is very much sensitive to waterlogging. In this situation, if it is possible to incorporate the fallen waterbodies into marigold cultivation, then it will be helpful to meet the annual demand for marigolds in different sectors in Bangladesh.

Materials and Methods

Plant materials and Experimental design

African marigold (*Tagetes erecta*) having two different colors of flower were used for the experiment. Flower color orange was denoted as Sample 1 (S_1) and flower color yellow as Sample 2 (S_2). The experiment was laid out in a split-plot design where growing conditions (floating and soil conditions) were employed in the main plot and samples (orange and yellow flower) in the sub-plot. Each treatment was replicated three times.

Preparation of experimental plot

To prepare floating bed first a floating frame of 3.0 m × 1.35 m was made by joining PVC pipe with suitable fittings. The joints are closed tightly with plastic glue. A platform on the frame was made by binding net with bamboo sticks. Then the bed materials i.e water hyacinth (*Eicchornia crassipes*, locally known as *kochuripana*) and water fern (*Salvinia cucullata*, locally known as *topapana*) were placed sequentially on the floating platform. The water hyacinth was placed in a manner that the root part remains at the outer side and leaf part at the inner side of the bed. This process was continued until the bed reached the desired height (1.0 m). Finally, a four to five-inch layer of water fern was made on the bed, which acts as mulch on hyacinth (Fig. 1).

For soil bed preparation, all the existing vegetation was removed from the land area. Then the soil of the area was plowed by a spade neatly as the soil particle become fine and nearly uniform. Well-decomposed cow dung was mixed thoroughly with the soil. Then the beds of 3.0 m × 1.35 m with about 6-inch height were prepared by outlining the area. An irrigation channel of about 12 inches was made around the bed. Three soil beds were prepared in the same manner. All the beds acted as the main plot, which was divided into two equal-sized sub plots. So, the unit plot size was 1.5 m × 1.35 m.

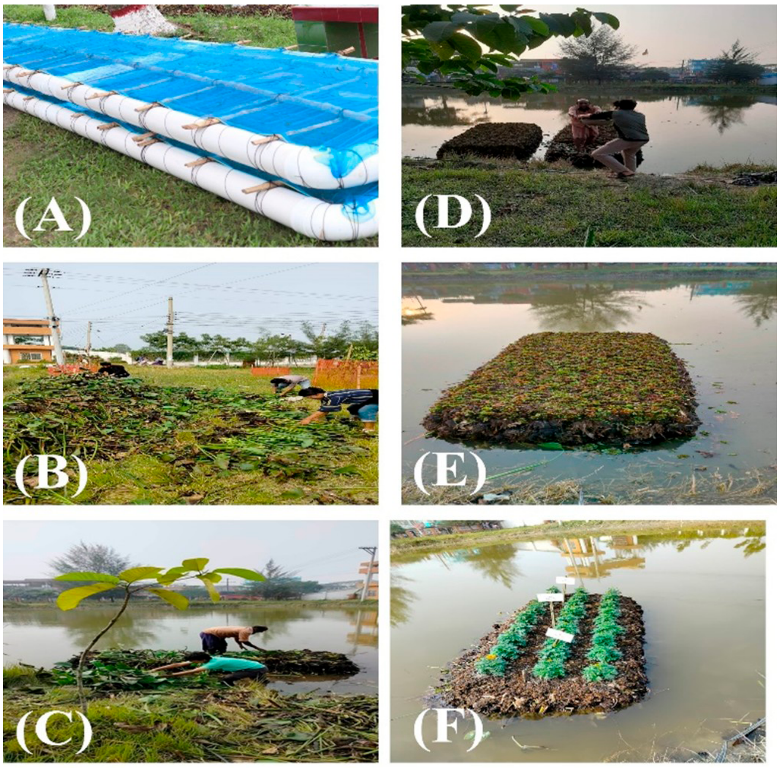

Fig. 1. Preparation of floating bed (A) a floating platform, (B) arranging water hyacinth, (C) gathering water hyacinth on the platform, (D) addition of mulch on the bed, (E) A prepared bed, (F) A bed with marigold flower.

Transplantation of seedlings and maintenance

Seedlings of one-month age were collected from the nursery and transplanted in the experimental plots. Number of seedlings in each plot was 12. Plant-to-plant spacing was nearly uniform. Uniformity in transplantation pattern, number of seedlings, and spacing was maintained in all the floating and soil beds. No additional chemical fertilizers were used for the experiment. The plots were maintained in weed-free condition and all other conditions were fulfilled to keep the plants healthy.

Flowers were harvested when matured. Harvesting was done several times during the crop season. Proper care was taken to avoid injury of flowers during harvesting. Number of flowers per plant was counted.

Data collection

Morphological attributes

Shoot morphology was observed as plant height (cm), Stem diameter (mm), number of leaves, Number of branches and leaf area (cm^2). All the parameters were measured at the time of transplantation, 15 DAT (Days After Transplantation), 30 DAT, and 45 DAT. Plant height was recorded as the distance from the point of plant emergence to the top by a measuring tape. The number of leaves and branches were counted visually. The leaf area of each genotype under different growing conditions were measured by a leaf area meter (LI 3100C Area Meter, USA). Diameter of stem of each treatment was measured at the time of harvest by digital slide calipers (Digimatic Caliper, Mitiutoyo, Japan). Diameter was measured at the base of plant.

Root morphology was recorded as root length and volume. Root length was recorded with a measuring tape after uprooting of plant at the end point of the experiment. Root volume was measured by a root scanner (Regent WinRhizo-2019, USA).

All the parameters were recorded as mean value of five randomly selected plants from each treatment.

K^+ content

K^+ content was determined from stem root and leaf sample at 120 DAT according to Begum, 1993. The mean value of K^+ content was recorded from three replicates. Samples were taken in test tubes separately and soaked in 6 mL of distilled water for 30 minutes after recording dry weight. The test tubes were then boiled in a water bath for 10 minutes. Then, the extract was collected in another test tube. Again, 4 ml of distilled water was added to the residue and boiled for another 5 minutes. The extract was collected as before. The combined extract was made up to a final volume of 10 mL with distilled water. K^+ contents were measured using a flame photometer (Labtronics LT-671, India). The concentration of K^+ was calculated using standard curves and expressed as m. equiv. g^{-1} dry tissue.

Yield attributes

Yield was measured as the number and size of flowers. The effective number of flowers produced by a single plant was counted and recorded. The diameter of full-bloom flower was measured by digital slide calipers (Digimatic Caliper, Mitiutoyo, Japan). The mean value of the number of fruits and diameter was recorded from five randomly selected plants in each plot.

Benefit cost ratio

The benefit cost ratio (BCR) is a relative measure which is used to determine benefit per unit cost. Benefit cost ratio is the proportion of the net return to the total cost of production.

BCR = Net return/Total cost

Data analysis

Recorded data were subjected to analyzed statistically to find out the statistical significance of the experimental results. The means for all the treatments were calculated and the analyses of variance for all the characters were performed by LSD test. The analyses were done following the software STATISTIX 10. The significance of the difference among the means was evaluated by the Least Significant Difference Test (LSD) at $p \leq 0.05$ (Gomez and Gomez, 1984).

Results

Plant height

Significant differences were observed between the samples at different growing conditions (Table 1). At the time of transplantation, the maximum plant height (22.067 cm) was recorded from S_1 at soil condition. At 15 DAT, 30 DAT, and 45 DAT the tallest plant was found in S_1 in floating bed which were 28.913 cm, 31.887 cm, and 35.845cm respectively. So, Overall superiority was observed in floating condition in terms of plant height.

Table 1. Plant height of marigold in response to growing conditions.

Treatments	Plant height (cm)			
	At transplantation	15 DAT	30 DAT	45 DAT
FC S_1	21.155 ab	28.913 a	31.887 a	33.845 a
FC S_2	19.656 b	23.777 b	31.053 a	34.689 a
SC S_1	22.067 a	28.887 a	28.966 a	35.567 a
SC S_2	17.888 c	25.553 ab	26.689 a	34.522 a
Mean	20.191	26.783	26.646	34.656
CV (%)	3.54	8.13	12.17	3.01
F value	10.54	0.48	0.55	2.46
SEM	0.5836	1.7783	2.9447	0.8509
LSD $_{(0.05)}$	1.6203	4.9374	8.1758	2.3626
Significance	*	NS	NS	NS

(*, ** and NS indicate significant at $p \leq 0.05$, significant at $p \leq 0.01$ and non-significant respectively. Means were calculated from three replicates for each treatment. Values with different letters are significantly different at $p \leq 0.05$ applying the LSD test).

Number of leaves

From Table 2, growing conditions had impacts on marigold's leaf number resulting in variation among the treatments. Maximum number of leaves (55.223) was found in the sample S_1 grown in soil bed at transplantation. Highest number of leaves (105.45 and 487.78) was recorded from S_1 in floating condition at 15 DAT and 30 DAT consequently. At 45 DAT, S_2 in floating bed showed the maximum number of leaves i.e., 474.78.

Table 2. Number of leaves of marigold samples at different growth times under different growing conditions.

Treatments	Number of leaves			
	At transplantation	15 DAT	30 DAT	45 DAT
FC S_1	44.910 a	105.45 a	487.78 a	406.89 a
FC S_2	38.00 a	85.22 a	442.22 a	474.78 a
SC S_1	55.223 a	71.00 a	155.33 a	260.89 a
SC S_2	51.223 a	69.11 ab	149.89 a	229.34 a
Mean	47.339	82.696	308.81	342.97
CV (%)	19.91	15.25	15.11	15.85
F value	0.07	1.59	0.55	2.51
SEM	7.6965	10.298	38.105	44.376
LSD $_{(0.05)}$	21.369	28.592	105.80	123.21
Significance	NS	*	NS	*

(* and NS indicate significant at $p \leq 0.05$, and non-significant, respectively. Means were calculated from three replicates for each treatment. Values with different letters are significantly different at $p \leq 0.05$ applying the LSD test).

Number of branches

Table 3 represents the superiority of the floating condition over the soil condition in terms of number of branches. Between samples, S_1 had maximum branches at 15 DAT i.e., 18.778 at floating condition. At 30 DAT and 45 DAT, S_2 exhibited the highest number of branches which was 21.11 and 29 respectively under floating condition.

Table 3. Number of branches in response of growing conditions to marigold samples at several growth time.

Treatments	Number of branches		
	15 DAT	30 DAT	45 DAT
FC S_1	18.778 a	20.667 a	25.667 a
FC S_2	14.444 a	21.110 a	29.00 a
SC S_1	17.113 a	20.000 a	22.777 a
SC S_2	17.966 a	20.000 a	23.110 a
Mean	17.076	20.444	25.138
CV (%)	11.40	5.95	8.99
F value	5.33	0.10	1.32
SEM	1.5889	0.9927	1.8449
LSD $_{(0.05)}$	4.4114	2.7563	5.1223
Significance	*	*	NS

(* and NS indicate significant at $p \leq 0.05$, and non-significant respectively. Means were calculated from three replicates for each treatment. Values with different letters are significantly different at $p \leq 0.05$ applying the LSD test.)

Leaf area

A significant difference was observed in leaf area of marigold grown under floating and plain land system. Plants of S_1 and S_2 on floating bed showed maximum leaf area i.e., 1581.2 cm^2 and 915.5 cm^2 consequently. On the other hand, leaf area of 861 cm^2 and 830.6 cm^2 were found in S_1 and S_2 respectively in soil condition (Table 4).

Stem diameter

In Table 4, the variation observed in the stem diameter of marigold. Floating condition showed greater stem diameter in case of both samples. The thickest plant stem (16.18 mm) was recorded from sample S_1 in floating bed whereas in soil bed maximum stem diameter was 12.317 mm in S_1.

Root length

Significant difference was found between growing conditions in both the conditions in terms of root length. In Fig. 2 and 3, Floating condition reflects higher results of root length than soil conditions. In the case of sample, S_1 had the longest root in both the floating and soil conditions.

Table 4. Changes in leaf area and root length of marigold in response to growing condition.

Treatments	Leaf area (cm²)	Stem diameter (mm)
FC S_1	1581.2 a	16.180 a
FC S_2	915.5 b	14.207 ab
SC S_1	861.0 b	12.317 b
SC S_2	830.6 b	12.147 b
Mean	1047.1	13.713
CV (%)	9.84	8.49
F value	6.27	1.80
SEM	179.39	0.9506
LSD $_{(0.05)}$	498.07	2.6392
Significance	**	NS

(** and NS indicate significant at $p \leq 0.01$ and non-significant respectively. Means were calculated from three replicates for each treatment. Values with different letters are significantly different at $p \leq 0.05$ applying the LSD test).

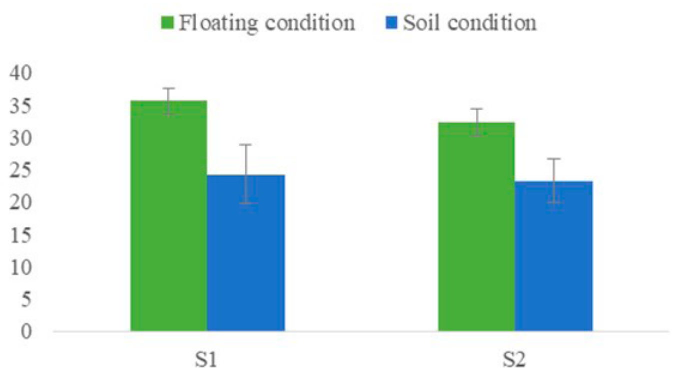

Fig. 2. Root length of marigold in relation to growing condition

Fig. 3. Root length of different marigold varieties (A) Orange sample in floating condition, (B) Yellow sample in floating condition, (C) Orange sample in soil condition, (D) Yellow sample in soil condition

Root analysis

Table 5 represents the root analysis data of marigold samples grown under floating and soil condition. Floating condition was superior in terms of root analysis. In case of sample, greater values of Len, SA, PA, and Vol (788.95 cm, 245.75 cm², 78.226 cm², 6.6747 cm³ respectively) were recorded from S_1 in the floating bed. In soil bed, S_1 had the value of 658.05 cm, 230.62 cm², 73.407 cm² and 5.6703 cm³ of Len, SA, PA and Vol consequently.

Table 5. Root analysis of different marigold samples under different growing conditions.

Treatments	Len (cm)	SA (cm^2)	PA (cm^2)	Vol (cm^3)
FC S_1	788.95	245.75 a	78.226 a	6.6747 a
FC S_2	542.77	152.89 bc	48.666 bc	3. 4780 bc
SC S_1	658.05	230.62 ab	73.407 ab	5.6703 ab
SC S_2	544.40	149.16 c	47.478 c	3.3020 c
Mean	658.54	194.60	61.944	4.7813
CV (%)	10.89	10.88	18.89	13.59
F value	0.15	0.22	0.22	1.22
SEM	58.55	17.282	5.5011	0.5304
LSD $_{(0.05)}$	162.56	47.983	15.274	1.4726
Significance	*	*	NS	**

(*, ** and NS indicate significant at $p \leq 0.05$, significant at $p \leq 0.01$ and non-significant respectively. Means were calculated from three replicates for each treatment. Values with different letters are significantly different at $p \leq 0.05$ applying the LSD test).

K^+ content

Fig. 4 reflects the discrepancy in potassium ion concentration among the treatments. The maximum K^+ in stem tissues (0.1347 m. equiv. g^{-1} dry tissue) was observed in S_2 under the floating agriculture system. In leaf tissue, the highest K^+ (0.1511 m. equiv. g^{-1} dry tissue) was found in S_1 in soil condition. The highest amount of K^+ (0.1323 m. equiv. g^{-1} dry tissue) in root tissue was observed in S_1 grown on the floating bed.

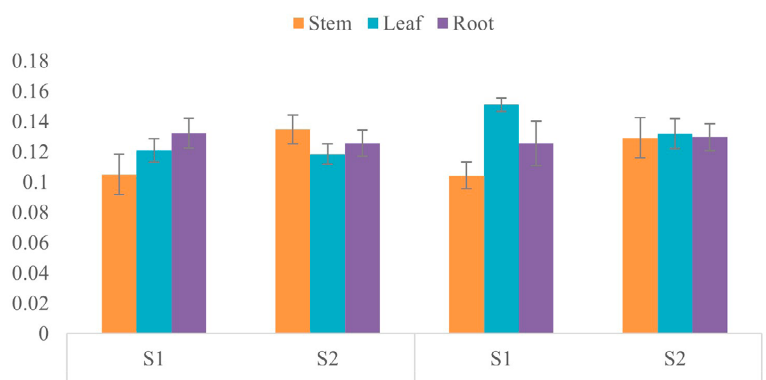

Fig. 4. Potassium ion concentration in stem, leaf and root tissues of marigold grown under floating agriculture and soil-based system

Number of flowers per plant

Significant difference was observed in number of flowers in marigold samples in relation to growing conditions (Fig. 5). In case of both the samples, floating condition reflects greater number of flowers than soil condition. The highest number of flowers (8.0333) was found in V_1 on the floating bed whereas in soil bed the maximum number of flowers (6.5133) was recorded from V_2.

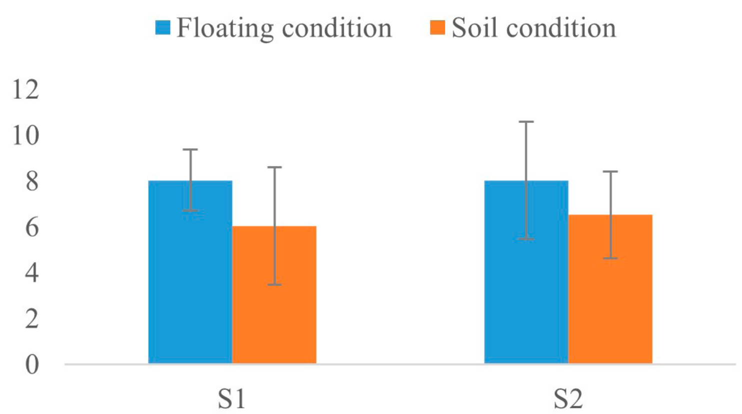

Fig. 5. Number of flowers per plant in marigold plants grown under floating and soil bed

Size of flower

The size of flower is expressed as diameter in mm. Figure 6 and 7 present the variation in flower diameter among the treatments. The greatest flower diameter (49.444 mm and 47.417) was found in V_1 in floating condition and soil condition respectively. Flower size of V_2 was higher in soil condition i.e., 48.528 mm.

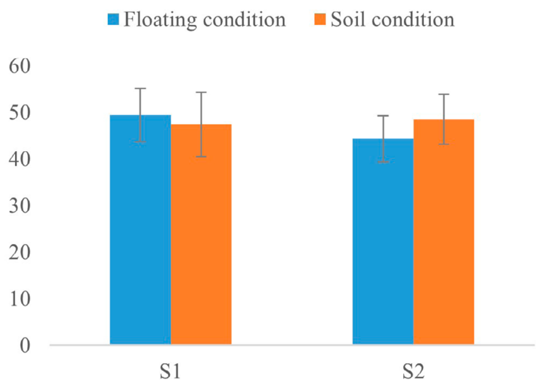

Fig. 6. Size of marigold flower grown under floating and soil bed

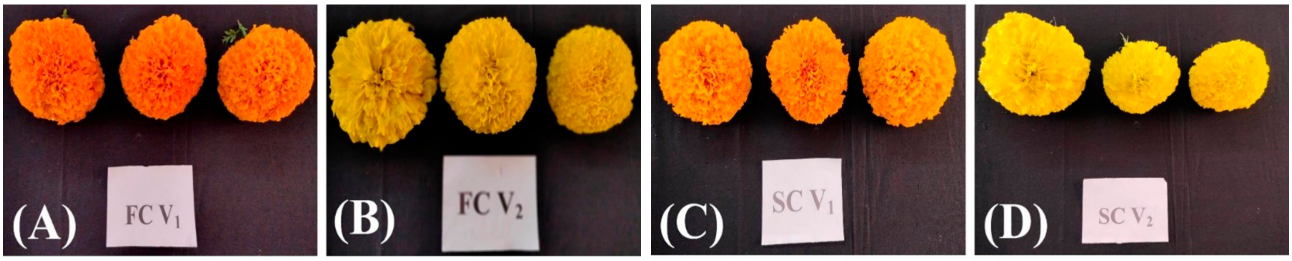

Fig. 7. Mature marigold flower (A) Orange sample in floating condition, (B) Yellow sample in floating condition, (C) Orange sample in soil condition, (D) Yellow sample in soil condition

Benefit-cost ratio (BCR)

Table 6 represents the benefit-cost ratio of flower production. On the basis of floating materials, it is expected that the floating platform could be used at least 6 times. For this, one-sixth of the total cost of floating frame preparation have been considered as the cost of floating frame preparation cost. Since the aquatic macrophytes used in the present investigation as bed materials spread in waterbodies of Bangladesh as invasive plants thus it has been harvested free of cost. Hence, the total cost of production for one floating bed reaches 1393 BDT. Net return from a bed 1450 produces a BCR of 1.041. For the soil bed, production cost was 1068 BDT whereas the outcome of 1170 BDT makes a BCR of 1.09.

Table 6. The benefit-cost ratio of flower production through floating bed technique.

Condition	Cost (BDT/bed)		Gross input (BDT/bed)	Return (BDT/bed)	BCR
	Elements	Price (BDT)			
Floating condition	Floating frame	505	1393	1450	1.041
	Seedlings	288			
	Labor	600			
Soil condition	Labor	600	1068	1170	1.09
	Fertilizers	180			
	Seedlings	288			

Discussion

Present experiment was launched with the aim of testing the suitability of floating agriculture system for marigold cultivation in wetlands. Locally available macrophytes water hyacinth and water fern were used to construct the floating bed. Several previous studies reported that farmers use water hyacinth as a base material for floating bed preparation for its availability and aggressive growth (Al-Maruf, 2020). A number of other macrophytes like *Salvinia cucullata*, *Salvinia molesta, Lemna perpusilla*, *Pistia stratiotes*, *Imparata cylindrica*, *Potamogeton alpinus*, *Hygroryza aristata*, *Hamerthria protens*have have also been used as mulching materials or to prepare seed balls (Hira, 2019). These macrophytes are locally available (Islam et al., 2017).We used water fern as mulching material. Karmaker et al. (2023) reported water fern as the best-performing mulching material for crop cultivation on floating beds.

The experiment found a profound growth of marigold on floating bed. This may be a result of nutrient elements present in floating bed materials. Floating macrophytes accumulate substantial amount of N and P (Kalengo et al., 2021). Water hyacinth collects great amount of nutrients from the environment and thus contains a greater amount of nutrients (Wang et al., 2012). Water fern is also reported as nutrient accumulating macrophyte (Xu et al., 2020). Present investigation finds greater value of yield attributes like plant height, number of leaves, leaf area, stem diameter, number of flower and flower size in floating bed. These findings supported by (Priyadarshini et al., 2018), they found better marigold growth by applying nitrogen. Floating bed serves as a nutrient source for marigold which enhances the growth and productivity. Previous literature suggests influence of different nutrient elements on the growth of African marigold (Priyadarshini et al., 2018). Floating bed represents marigold an integrated nutrient management resource. Integrated nutrient management greatly influence marigold growth positively (Upadhya et al., 2022). Water hyacinth is reported as a potential source of organic matter. Upon degradation of water hyacinth organic carbon has been added to the soil and growing medium (Begum et al., 2022; Madikizela, 2021). Organic matter emphatically affects the growth and production of marigolds (Buthe et al., 2022; Halder et al., 2023). Besides profound morphological growth, we observed explicit impacts of potassium on growth and flower formation. Floating bed supplies more potassium to marigold plant. Al-Imran et al. (2024) found immense supply of potassium from floating bed to chili plant.

Accompanying nutrient source mulch has several other benefits. Organic mulches improve water retention capacity and maintain optimum temperature (Kader et al., 2019). Application of organic mulches promote marigold cultivation in different ways by limiting irrigation, reducing weed infestation and improving soil characteristics (Sikarwar et al., 2021; Wagan et al., 2022).

Finally, we find floating agriculture as a climate smart alternative for marigold cultivation. Cultivation of marigold on floating bed in wetlands not only uses the fallen area but also improves the aesthetic value of the area.

Conclusions

In compendium, our study finds floating agriculture as an effective way of floriculture in wetlands especially in urban polluted water bodies. We found a notable improvement in growth and flower production of marigold under floating agriculture system. These findings can guide urban policymakers to create water bodies as recreational places. Besides, it can also be an income generating cultivation practice. Further research is important for wide adaptation of the technique.

Acknowledgements

The authors are grateful to the University of Barishal for providing institutional support to carry out the research and to the Ministry of Science & Technology (MOST) of Bangladesh for financial support through Special allocation (Funding no. SRG231318, 2023-24).

Author Contribution

MAI.: Conceptualization, Formal Analysis, Data Curation, Writing – Original Draft, Writing – Review & Editing. **DD:** Conceptualization, Formal Analysis, Methodology, Writing – Review & Editing. **MAM:** Conceptualization, Formal Analysis, Methodology, Writing – Review & Editing. **SA:** Conceptualization, Writing – Review & Editing. **SM:** Conceptualization, Funding Acquisition, Writing – Review & Editing. **SKD:** Conceptualization, Funding Acquisition, Project Administration, Supervision, Writing – Original Draft, Writing – Review & Editing.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

Data will be made available upon request to the authors.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declared no AI was used in the writing or editing in this manuscript.

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