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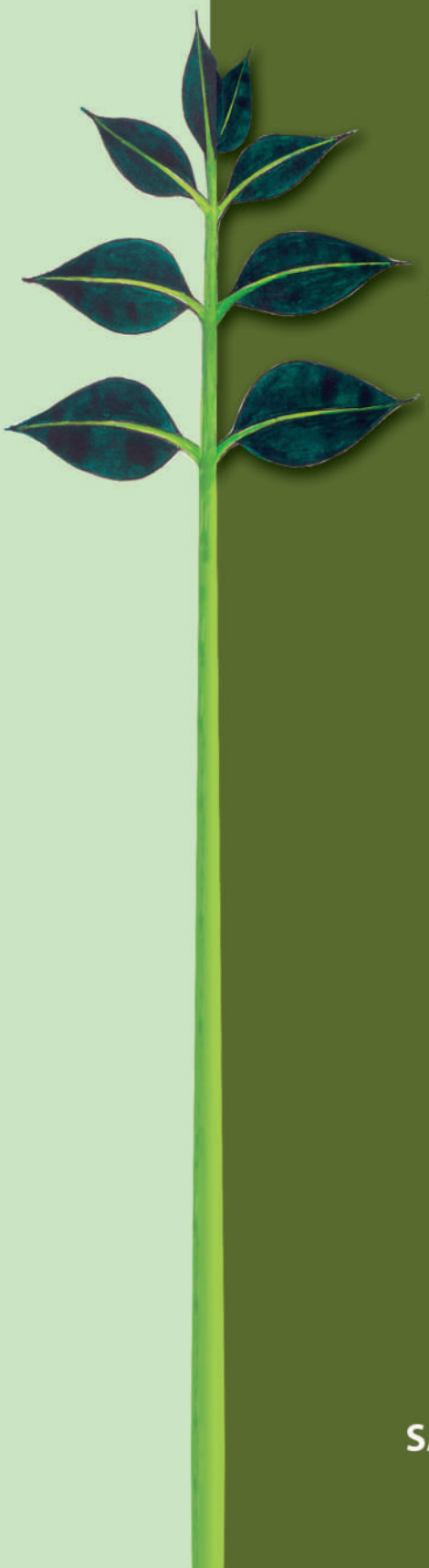

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FRUIT FLIES (DIPTERA: TEPHRITIDAE: DACINAE: DACINI) SPECIES DIVERSITY IN NEPAL: A REVIEW

R. Sapkota[1*], K.C. Dahal[1], G.B. KC[1], A.S.R. Bajracharya[2] and R.B. Thapa[1]

[1]Postgraduate Program, Institute of Agriculture and Animal Science, Tribhuvan University
[2] Nepal Agriculture Research Council, Khumaltar, Lalitpur, Nepal

ABSTRACT

The tribe Dacini, within the sub-family Dacinae of the Tephritidae family, includes major fruit flies within the genera *Zeugodacus*, *Bactrocera*, and *Dacus*. The *Bactrocera* spp., which were previously grouped into sub-genera *Zeugodacus* and *Bactrocera*, have been treated as separate genera in recent years. These dacine flies are widely spread in fruits and vegetables. The first dacine fruit fly, i.e. *D.* (*Callantra) nepalensis* reported in 1964 from Nepal is still a holotype. Altogether, 27 species have been reported in Nepal from three genera–*Dacus* (6), *Zeugodacus* (8), and *Bactrocera* (13), of which 10 species are attracted to cue-lure, 7 species to methyl eugenol, 2 species to zingerone, 1 species to lati-lure and 5 species to more than one lure, while lure for 2 species are unknown. Among them, 7 species are oligophagous pests, 6 species are polyphagous pests, and the pest status of 14 species is unknown. Fruit fly infestation and damage have been recorded in different crops such as; 5 species on cucurbits, 2 species on different fruits, 4 species on different fruits and vegetables, 1 species on citrus fruits, and 1 species on solanaceous vegetables. Three species; *Z. cucurbitae*, *Z. tau,* and *B. minax,* have been recorded from infested fruit cultures of cucurbits and sweet orange too. However, pest status, preferred hosts, and biology of many species remain yet to be explored and reported from Nepal. Further studies are necessary focusing on fruit fly species of economic importance concerning host preference for developing appropriate management strategy. Efforts are needed to identify the fruit fly species that inflict actual damage to the hosts.

Keywords: Cucurbits, damage, distribution, flies, monitoring

INTRODUCTION

Fruit flies (Diptera: Tephritidae) are economically important worldwide except in extreme desert and polar areas. Korneyev (1999) classified that the Tephritidae family

[*] Corresponding author: merekha.sapkota@gmail.com

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into six sub-families (Blepharoneurinae, Dacinae, Phytalmiinae, Tachiniscinae, Tephritinae and Trypetinae) comprises of over 469 genus, 62 sub-genus and over 4700 recognized species worldwide (Han et al., 2017; ITIS, 2023). Of them, nearly 325 species of fruit flies are known to occur in Indian sub-continent in four sub-families; namely Dacinae, Phytaminae, Tephritinae and Trypetinae (Nair et al., 2018). The tribe Dacini is the most species rich clades (reported 932 species worldwide) within the family Tephritidae (Doorenweerd et al., 2018). More than 92 dacine fruit fly species have reported from India (Vasudha et al., 2019) while 26 are reported from Nepal (Leblanc et al., 2019).

Of the recognized dacine fruit flies, around 10% are pests of commercially cultivated fruits and vegetables, with cucurbits being their major hosts. Dacine fruit flies are polyphagous in nature, exhibiting high reproduction potential, wide climatic tolerance, and a high dispersal capacity. Cucurbits represent number of crops within the family Cucurbitaceae (~100 genera and ~1000 species), 50 species are being cultivated for various purposes worldwide (Chomicki et al., 2020). Dacine fruit fly causes enormous devastation to both production and trade of fresh cucurbits. However, the preference for the host is important, and the damage extent may vary with species and host (Prabhakar et al., 2007). In Nepal, *Bactrocera, Zeugodacus* and *Dacus* are most common genera of dacine fruit fly affecting both vegetables and fruits. Among them, *Z. cucurbitae* (Coquillett) and *Z. tau* (Walker) are major pests in cucurbits (Nair et al., 2017; Sawai et al., 2019). The extent of yield-loss due to fruit flies in cucurbits ranges from 30–100%, depending upon host species, locality and the season (Dhillon et al., 2005).

Majority of dacine fruit flies reported in Nepal were collected from fruit and cucurbits growing areas. Studies on population density, yield loss and management measures of dacine fruit flies are typically limited to one season and focus on a specific crop only. Systematic review is needed for better understanding of fruit flies to devise effective management measures. This study aims to document the chronological studies reported on dacine fruit fly diversity in Nepal and identify the research gaps, with special reference to cucurbitaceous vegetables as hosts.

A. The tribe Dacini

Dacine fruit flies are characterized by black to brown scutum with or without yellow vittae and primarily hyaline wing a with well-developed costal band and anal streak (David and Ramani, 2019). Fabricius first reported the genus *Dacus* in 1805, while *Z.* (*Dacus*) *cucurbitae* was first described by Coquillett in 1899. Dacine fruit flies have been variably assigned to species complexes, species groups, and sub-genera; Drew (1989) proposed four groups of Dacini: *Bactrocera, Zeugodacus, Melanodacus* and *Queenslandacus.* Furthermore, Drew et al. (1998) and Drew and Hancock (1999) classified four genera within Dacini: *Dacus*, *Bactrocera*, *Ichneumonopsis* and *Monacrostichus*. Norrbom et al. (1999) reported the tribe Dacini which comprises the subtribes; Ceratitidina, Dacina and Gastrozonina. Korneyev (1999) studied the

morphological framework for the phylogenetic relationships and concluded that the relationships among sub-families and tribes have not yet been satisfactorily defined.

Dacine fruit flies are phenotypically very similar, making them one of the most difficult groups of Tephritidae to identify at species level. *Bactrocera* was considered a sub-genus of *Dacus* until Drew (1989) elevated both taxa to the status of genera, based on distinguished characteristics in abdominal tergites. *Zeugodacus* was also regarded as a sub-genus of *Dacus* but was later considered as a sub-genus under *Bactrocera* (Drew 1989). White (2006) claimed that the sub-genus *Zeugodacus* might be sister group to *Dacus*. Krosch et al. (2012) provided strong phylogenetic evidences supporting the relationship between the *Zeugodacus* group of sub-genus and the genus *Dacus*. Drew and Romig (2013) considered *Ichneumonopsis* to be a member of Dacini, while Freidberg et al. (2017) included this genus in the tribe Gastrozonini.

Diagnostic attributes (e.g. patterns in body color) used to distinguish species have been confounded by intraspecific variation, leading to a long history of unstable classification. However, phylogenetic studies at the molecular level have provided valuable insights, resulting in a general consensus that morphology-based classifications need revision. The majority of species belonging to *Bactrocera* and *Dacus* have been divided into several sub-genera. With over 930 described species within the genus *Bactrocera* including *Zeugodacus* and *Dacus* within the tribe Dacini (Table 1). Based on the recent phylogenetic studies and increased use of molecular data, the large genus *Bactocera* splited into *Zeugodacus* and *Bactorcera* (Krosch et al., 2012; Virgilio et al., 2015). Virgilio et al. (2015) grouped few *Bactrocera* species into a new generic rank *Zeugodacus* Hendel stat. nov. Considering the advancement in species identification, four genera, viz. *Dacus* Fabricius, *Bactrocera* Macquart, *Zeugodacus* Hendel and *Monacrostichus* Bezzi are now recognized within the tribe Dacini (Doorenweerd et al., 2018).

Table 1. Number of described dacine fruit fly species per region (Doorenweerd et al., 2018)

Category	Worldwide	Africa	Asia-pacific
Bactrocera	461	13	451
Dacus	273	193	81
Zeudodacus	196	1	195
Monacrostichus	2	0	2
Dacini	932	207	730

Five species (*D. ciliates, B. oleae, B. dorsalis, B. latifrons* and *Z. cucurbitae*) share both Africa and Asia-pacific regions.

B. Distribution of the tribe Dacini fruit flies

The dacine fruit flies are primarily concentrated in two regions of the world; Afrotropical region and Southeast Asia to Northeastern Australia (Table 2). The Asian-Pacific Dacini; *Bactrocera* and *Zeugodacus* species are predominately found in Southeast Asia and Papua New Guinea (Drew and Romig, 2013). *Dacus* species, on the other hand, are widely distributed throughout the Afrotropical region. Papua New Guinea has the greatest diversity of dacine fruit fly species, with 188 species described, 18 of which are of economic importance and over 50 species awaiting description (Allwood et al., 2001). Similarly, Solomon Island has more than 48 described species of tribe Dacini, including at least four economically important species (Hollingsworth et al., 2003). Vasudha et al. (2019) reported 92 dacine fruit fly species in India, 28 of which are endemic. This includes 51 species of genus *Bactrocera*, 10 species of *Dacus* and 31 species of *Zeugodacus*. Species such as *Zeugodacus caudatus*, *Z. tau*, *Z. diversus*, *Z. scutellaris* and *Dacus longicornis* are widely distributed in Southeast Asia. Five species namely: *D. ciliates*, *B. oleae*, *B. dorsalis*, *B. latifrons* and *Z. cucurbitae* are found in both Africa and Asia-pacific regions (Table 2; Figure 1). In Nepal, out of the total reported dacine fruit fly species, only four are found in Africa region, with the majority belonging to the genus *Bactrocera* (52%) followed by *Zeugodacus* (30%) (Figure 1).

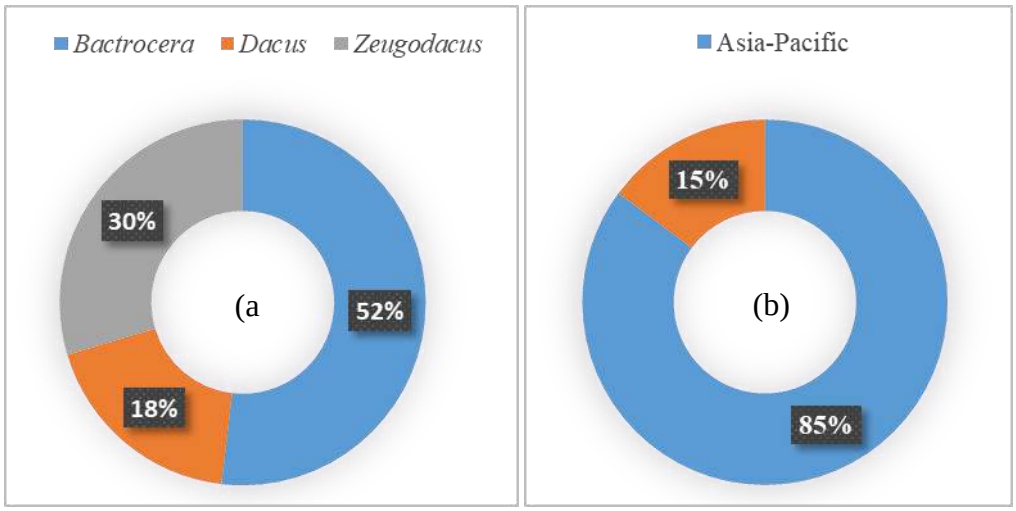

Figure 1. Species identified within three genera (a) and category of species based on their global distribution (b) of 27 dacine fruit flies found in Nepal.

C. Fruit fly species of the tribe Dacini in Nepal

The first information regarding Tephritidae fruit flies (Dacinae: Dacini) in Nepal was reported in 1964 based on the 20 specimens collected from eastern part of Nepal during 1961-62 (Hardy, 1964). This study reported four sub-families (Dacinae, Aciurinae,

Trypetinae and Tephritinae), six tribes, nine genera and eleven species, including tribe Dacini. The first fruit fly species, i.e. *Dacus* (*Callantra) nepalensis* (Hardy, 1964) reported from Nepal within the tribe Dacini is still holotype (NHM, 2023). Kapoor et al. (1979) reported two species, *D. (Zeugodacus) caudatus* Fabricius and *D. (Zeugodacus) scutellaris* Bezzi of fruit flies within the tribe Dacini from specimens collected in the Kathmandu valley. Subsequently, numerous studies have discussed fruit fly species, although taxonomic studies on species diversity and identification have been made by only a few researchers. Leblanc et al. (2019) conducted a comprehensive study on dacine fruit fly species identification, reporting 26 species with new country records of 11 species including *B. tuberculata.* However, Tiwari (2016) had reported the *B. tuberculate* in the earlier study. A chronological order of studies over time regarding dacine fruit flies, conducted either from preserved specimens, fruits or field level monitoring/management studies, is presented in Table 2.

Table 2. Reported fruit fly species within the tribe Dacini, Nepal

SN	Fruit fly within Dacini	Samples	Location	References
1	*Dacus (Callantra) nepalensis* (Hardy 1964)	Collected specimen	East shore of River Arun, Eastern Nepal	Hardy (1964) NHM (2023)
2	**D. dorsalis* Hendel	Collected specimen	Different part of Nepal	Pradhan (1970)
3	**Dacus (Zeugodacus) caudatus* Fabricius, **D. (Z.) scutellaris* Bezzi	Collected specimen	Kirtipur, Kathmandu	Kapoor et al. (1979)
4	*Bactrocera cucurbitae* Coquillett	Monitoring and field management in cucurbits	Western hills	Manjunathan (1997), Jaiswal et al. (1997), Gautam et al. (1998) GC (2001)
5	*Bactrocera (Dacus) dorsalis* complex	Citrus	Western hills	Pandey et al. (1997)
	**D.* sp. Prob. *Tsuneonis* Miyaka; **D. diversus* Coq., *D. cucurbitae, D.* sp. Nr. *Dorsalis, D. scuttellaris*, **D. zonatus* Hend, **D. tau* Walker	Collected specimen in 1964, 1965, 1968 & 1984 AD	Kathmandu and its vicinity	Khatri and Sthapit (1997)
6	*B. cucurbitae, B. diversus* Coq., *B. dorsalis* Hendel, *B.* sp. Nr. *Dorsalis* Hendel, *B. scutellaris* Bezzi, *B. tau, B. tsuneonis (?)* Miyaka, *B. zonatus* Saud.	Collected specimen at NARC	Different parts of the country	Joshi and Manandhar (2001)
7	*B. cucurbitae, B. dorsalis, B. zonatus, B. tau, B. scutellaris and B. yoshimotoi*	Cucurbits and fruits	Kavre and Kathmandu	Shrestha (2006)
8	*B. cucurbitae, B. tau and two unidentified* spp.	Cue-lure in Zucchini	Lamjung	Sapkota (2009)
9	*B. minax (*earlier reported *as B. tsuneonis)*	Citrus Orchard	Dhankuta	NCRP (2006)
10	*D. succaelestis/nepalensis; B. scutellaris B. luteicinctuta/yoshimotoi* Ito sp. Nov.	Field collection	Northeast Nepal	Ito (2011)

SN	Fruit fly within Dacini	Samples	Location	References
11	*B. cucurbitae, B. dorsalis, B. tau, B. scutellaris, B. zonatus, B. yoshimotoi, B. diversus, B. minax, B. caudatus and B. correcta.*	Collected specimen at NARC and Fruit development directorate	Entomology division, NARC Entomology Lab, Kirtipur	Entomology Division NARC cited in Sharma et al. (2015)
12	*B. cucurbitae, B. dorasalis, B. zonata, B. tau and B. scutellaris*	Collected specimen	Sindhuli and Syangja	Sharma et al. (2015)
13	*B. nigrofemoralis, B. latifrons, B. atrifacies, B. tuberculata and D. ciliates*	Collected specimen	Entomology division, NARC	Gautam et al. (2015)
14	*B. cucurbitae, B. scutellaris and B. caudatus*	Cucumber field	Kathmandu	Maharjan et al. (2015)
15	*B. cucurbitae, B. scutellaris, B. tau, B. nigrofemoralis, B. dorsalis, B. zonata, B. minax, B. yoshimotoi, D. longicornis and other D. spp.*	Collected specimen in different lures	Syangja, Sindhuli and Kaski	PPD (2016)
16	*B. dorsalis, B. tuberculata, B. tau, B. scutellaris, B. minax, B. cucurbitae, B. atrifacies, and B. yoshimotoi*	Cue-lure, methyl eugenol and protein bait traps	Eastern hill-Paripatle citrus orchard	Bhandari et al. (2017)
17	*B. minax* Enderlein, *B. cucurbitae, B. dorsalis, B. zonata, B. tau, B. scutellaris, D. longicornis*	Cue-lure and methyl eugenol monitoring, rearing sweet orange	Sindhuli	Adhikari and Joshi (2018)
18	*B. dorsalis, B. zonata, B. tau, B. correcta, B. cucurbitae, B. minax, B. diversus, B. scutellaris, B. caudatus, B. tuberculate, B. latifrons, B. atrifacies, B. yoshimotoi, B. tsuneonis, B. nigrofemoralis, D. longicornis and D. ciliates*	Monitoring, field specially citrus	Different parts of the country	Adhikari et al. (2019)
19	*B. dorsalis, B. zonata, B. correcta, B. minax, B. latifrons, B. nigrofemoralis, Z. cucurbitae, Z. tau, Z. scutellaris, Z. diversus, Z. caudatus, Z. yoshimotoi, D. longicornis, Z. atrifacies, D. ciliatus, B. tuberculata, B. abbreviate, B. aethriobasis, B. digressa, B. nigrifacia, B. rubigina, B. syzygii, Z. duplicatus, D. feijeni, D. maculipterus* and *D. trimacula*	Fruit fly male lures; cue-lure, methyl eugenol, and Zingerone	Different parts of the country	Leblanc et al. (2019)
Total	27 species			

Genus and species with bold text within 2nd column were reported 1st time in Nepal by the respective author(s)/ organization and date. The genus/species name with asterisk (*) was later updated into new genus/species name [e.g. G J Steck, Florida State Collection of Arthropods, USA in 2007 confirmed that *B. minax had been misidentified as *B. tsuneonis* in earlier reports].

D. Distribution and host range of the tribe Dacini fruit flies

In Nepal, identification of the most fruit fly species is based on morphology of specimen monitored using lures such as methyl eugenol, cue-lure, and citronella. The majority of fruit fly species (>80%) are known to infest commercial and/or edible fruits and fleshy vegetables, while 8 species are known to infest cucurbits (Leblanc et al., 2013). Mostly, *Zeugodacus* species are highly polyphagous, and some of them have repeatedly invaded and even established in non-native ranges (Vargas et al., 2015). The pest status of 14 identified dacine fruit flies in Nepal has not been reported (Figure 2). *B. nigrifacia* and *B. rubigina* are considered potential pest (Drew and Romig, 2013). The distributions within the tribe Dacini of known species in Nepal are presented in Table 3.

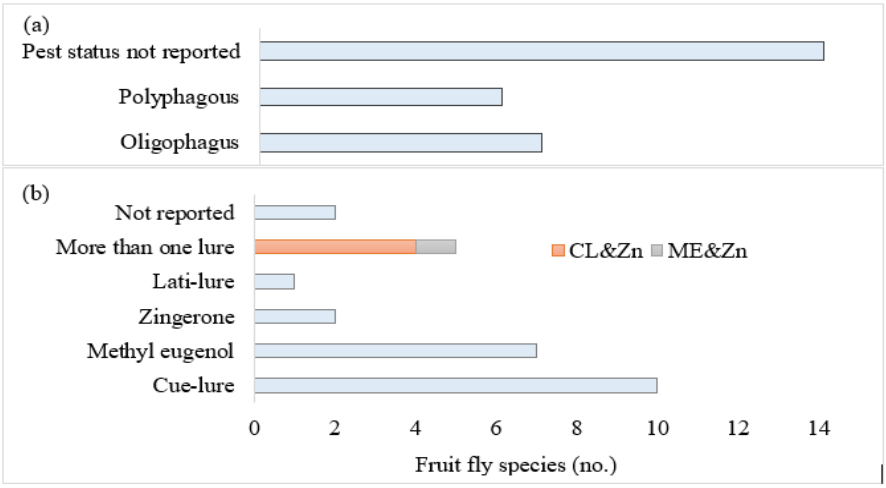

Figure 2. Pest status (a), and lures (b) reported to monitor dacine fruit flies globally and in Nepal as presented in Table 3.

Table 3. Identified fruit fly species in Nepal within the tribe Dacini with their attractant, pest status, distribution and host ranges.

SN	Fruit fly species reported in Nepal	ttractant eported	Pest status	Distribution	Infested fruit cultured, Nepal	Potential host reported globally
1.	*Dacus (Callantra) nepalensis* (Hardy 1964)	NR	NP	Eastern Nepal	Holotype	No specific record. Potentially synonym of *Dacus polistiformis* (Leblanc et al., 2019)
2.	*Zeugodacus cucurbitae* (Coq.1899) CN: Melon fruit fly	CL*; Zn*	PP; mainly cucurbit fruit & flower	Asia-Pacific; Africa and Oceania, USA	Cucumber and Zucchini (Sapkota et al., 2010)	136 hosts of 30 families; different cucurbit crops and *Carica papaya* (Allwood et al., 1999; Drew, 1989; Vargas et al., 2015; Leblanc et al., 2019)

SN	Fruit fly species reported in Nepal	ttractant eported	Pest status	Distribution	Infested fruit cultured, Nepal	Potential host reported globally
3.	*Bactrocera dorsalis* (Hendel 1912). CN: Mango/Oriental fruit fly	ME*; Zn*	PP; mainly fruits	Asia-Pacific; Africa, Oceania Europe	NYR	More than 478 kinds of fruits and vegetables (USDA, 2016); 490 hosts in 81 families (Allwood et al., 1999; Leblanc et al., 2013).
4.	*Z. diversus* (Coq. 1904) CN: Three-striped fruit fly	weak ME[#], ME*	OP; cucurbit flowers	Asia-Pacific	NYR	Bred from flowers of nine species of Cucurbitaceae (Allwood et al., 1999; Vasudha et al., 2019)
5.	*Z. scutellaris* (Bezzi 1913)	CL*	OP; cucurbit flowers	Asia-Pacific	NYR	Bred from flowers of *Cucurbita* sp., *Lagenaria siceraria*, and *Zehneria wallichii* (Allwood et al., 1999; Vasudha et al., 2019)
6.	*Z. tau* (Walker 1849). CN: Pumpkin fruit fly	CL*	PP; mainly cucurbits	Asia-Pacific	Cucumber (Sharma and Tiwari, 2020)	77 hosts of 23 families; major are*: Cucumis* sp., *Cucurbita* sp., *Luffa* sp., *Manilkara* sp., *Momordica* sp., *Psidium* sp. (Allwood et al., 1999; Vasudha et al., 2019)
7.	*B. zonata* (Saunders 1842) CN: Peach fruit fly	ME*	PP; mainly fruits	Asia-Pacific; introduced in USA and Africa	NYR	54 hosts of 23 families; Major are*: Prunus persica, Malus* sp., *Mangifera* sp., *Psidium* sp. (Allwood et al., 1999; Culliney et al., 2017)
8.	*Z. yoshimotoi* (Hardy 1973)	CL*	NP	Asia-Pacific	NYR	No specific record. Potentially synonym of *Z. luteicinctutus* (Doorenweerd et al., 2018)
9.	*B. minax* (Enderlein 1920) CN: Chinese citrus fly	weak ME[¥]	OP; citrus fruits	Asia-Pacific	Sweet Orange (Adhikari and Joshi, 2018)	*Citrus* spp. (Allwood et al., 1999; Jaleel et al., 2021).
10.	*Z. caudatus* (Fabricius 1805)	CL*	OP; cucurbit flowers	Asia-Pacific	NYR	Male flowers of *Cucurbita moschata* (Allwood et al., 1999); cucurbit flower (Vasudha et al., 2019)
11.	*B. correcta* (Bezzi 1916) CN: Guava fruit fly	ME*	PP; fruits	Asia-Pacific	NYR	73 hosts of 35 families; Major are*: Anacardium* sp., *Averrhoa* sp., *Mangifera* sp., *Psidium* sp., *Syzygium* sp., *Ziziphus* sp. (Culliney et al., 2017; Jaleel et al., 2021).
12.	*B. latifrons* (Hendel 1915); CN: Malaysian/Solanum fruit fly	Lati-lure[¥]	OP; fruit vegetables	Asia-Pacific	NYR	*Capsicum* sp., *Solanum* sp. (Allwood et al., 1999)
13.	*Z. atrifacies* (Perkins 1938)	CL*	NP	Asia-Pacific	NYR	No specific record.
14.	*D. ciliatus* Loew 1862 CN: Lesser pumpkin fly	NR	OP; cucurbit fruits	Africa	NYR	Various cucurbit crops (White and Elson-Harris, 1992)
15.	*B. nigrofemoralis* White & Tsuruta 2001	CL*	NP	Asia-Pacific	NYR	*Cucumis sativus* (Devi et al., 2018)

SN	Fruit fly species reported in Nepal	ttractant eported	Pest status	Distribution	Infested fruit cultured, Nepal	Potential host reported globally
16.	*D. longicornis* (Wiedemann 1830)	CL*	OP; cucurbit fruits	Asia-Pacific	NYR	*Luffa* spp., *Trichosanthes* sp., *Trichosanthes* sp. and *Zehneria* sp. (Allwood et al., 1999; Nair et al., 2017)
17.	*B. tuberculata* (Bezzi 1916)	ME*	PP; fruits	Asia-Pacific	NYR	Hosts in 8 families; Major are*: Mangifera* sp., *Carica* sp., *Prunus* sp., *Manilkara* sp.; *Syzygium* sp. (Allwood et al., 1999; Jaleel et al., 2021).
18.	*B. abbreviata* (Hardy 1974)	Zn*	NP	Asia-Pacific	NYR	*Chionanthus* sp. and *Olea* sp. (Allwood et al., 1999)
19.	*B. aethriobasis* (Hardy 1973)	ME*	NP	Asia-Pacific	NYR	*Azadirachta* sp. (Drew and Romig, 2013)
20.	*B. digressa* Radhakrishnan 1999	CL*; Zn*	NP	Asia-Pacific	NYR	*Alangium* sp. (David and Ramani, 2011)
21.	*B. nigrifacia* Zhang, Ji and Chen 2011	CL*	NP	Asia-Pacific	NYR	*Callicarpa* sp., *Capparis* sp., *Zehneria* sp.and *Flueggea* sp. (Drew and Romig, 2013)
22.	*B. rubigina* (Wang and Zhao 1989)	CL*; Zn*	NP	Asia-Pacific	NYR	*Litsea* sp. (Liang et al., 1993)
23.	*B. syzygii* White and Tsuruta 2001	Zn*	NP	Asia-Pacific	NYR	*Syzygium* sp. (Tsuruta and White, 2001)
24.	*Z. duplicatus* (Bezzi 1916)	CL[@]	NP	Asia-Pacific	NYR	No specific record.
25.	*D. feijeni* White 1998	CL*	NP	Asia-Pacific	NYR	No specific record.
26.	*D. maculipterus* Drew and Hancock 1998	ME[@]	NP	Asia-Pacific	NYR	No specific record.
27.	*D. trimacula* Wang 1990	CL*, Zn*	NP	Asia-Pacific	NYR	No specific record.

CN: Common Name; NR: Non-Recorded; NP: Non-pest; ME: Methyl Eugenol; CL: Cue-lure; OP: Oligophagous; PP: Polyphagous; NYR: Not Yet Reported; *Doorenweerd et al. (2018); [#]Drew and Roming (2013); [@]Leblanc et al. (2019); [¥]Vasudha and Agrawal (2019).

In 13 identified pests of dacine fruit flies in Nepal, six are polyphagous and seven are oligophagous, but none of them are strictly monophagous (Figure 2). Most of them prefer fruit, while a few prefer flowers only (Figure 2, Table 2). Doorenweerd et al. (2018) and Vasudha et al. (2019) reported that *B. nigrofemoralis* is considered as non-pest while Devi et al. (2018) was reported as pest of cucumber.

Various lures are being investigated and some species are specific to one lure, while others attracted to more than one lure. More attractive male lures such as (isoeugenol, methyl-isoeugenol, dihydroeugenol, lati-lure and zingerone) are being studied for several non-responsive and weak responsive species to cue-lure and methyl eugenol (Manoukis et al., 2019; Royer et al., 2019). Many fruit fly species which are non-responsive to any lure are reported to be managed by using Zingerone while lati-lure

is now suggested for *B. latifrons* (Vasudha and Agarwal, 2019). *B. minax* has become a dominant pest in citrus orchard, particularly in sweet orange (Acharya and Adhikari, 2019; Adhikari et al., 2022; Sharma et al., 2015) and is not attracted in lures (Doorenweerd et al., 2018). However, Vasudha and Agarwal (2019) reported methyl eugenol is a weak lure for this pest. Prabhakar et al. (2007) reported that *B. scutellaris* is a new threat to cucurbit, with females laying eggs in tender stems, leaf axils and floral axils while Doorenweerd et al. (2018) reported it as a pest of cucurbit flowers only. *B. diversus* appears to have a weak attraction to methyl eugenol (Drew and Roming, 2013, Vasudha and Agarwal, 2019) while Royer et al. (2018) reported that *Z. (B.) diversus* is better attracted in methyl-isoeugenol than in methyl eugenol.

CONCLUSION

The first fruit fly species reported from Nepal, *Dacus* (*Callantra) nepalensis* (Hardy, 1964), is still holotype preserved in the British Museum. Over time, a chronological study of fruit flies in Nepal has revealed 27 species belonging to three genera *Bactrocera*, *Zeugodacus* and *Dacus* within the tribe Dacini reported through collected specimens, monitoring with different lures, and observations of infested fruit culture. Among these, two closely related fruit fly species, *Z.* (*B.) cucurbitae* (Coq.) and *Z. (B.) tau* (Walker) are widely reported in cucurbits across Nepal, spanning from the east to west and from the terai to mid-hill region while *B. minax* has been reported from citrus fruits only. Much of the knowledge regarding these fruit fly species from infested fruit cultures remains limited in Nepal. Therefore, there is a pressing need for studies focused on seasonal distribution, geological distribution and host specific fruit fly species to develop better management practices of fruit flies. Further studies should be directed towards species that inflict actual damages to the host, in order to develop management strategy of dacine fruit flies. Economically important hosts, particularly cucumber, pumpkin, sponge gourd, bitter gourd and citrus fruits need special consideration for the effective management of dacine fruit fly species.

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POTENTIAL USE OF ZEOLITES IN AGRICULTURE: A REVIEW

M.R. Khan*, M.A. Tarafder and M.S. Priti

Soil Science Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh

ABSTRACT

Zeolites are crystalline aluminosilicates that exist naturally, and they are the most common mineral in sedimentary rocks. These minerals are called tectosilicates, and they have an open, three-dimensional structure with the cations required to maintain equilibrium of electrostatic charge between the aluminum framework and silicon tetrahedral units. Most common zeolites are chabazite, clinoptilolite, phillipsite, erionite, stilbite, heulandite, and mordenite. Zeolites are harmless for the environment and living things. Their multipurpose application in agriculture is mainly due to their high porosity, sorption-ion-exchange capability, and well-developed specific surface area. Applying zeolites directly to the soil improves its sorption capacity while simultaneously decreasing acidity and boosting nutrient uptake efficiency. Increased yields and less nutrient dispersion in the environment are achieved through better nitrogen utilization from fertilizers. This contributes to the closed-loop economy, the depletion of environmental resources, and the principles of sustainable development. Thus, zeolites have the potential to directly enhance agricultural environments.

Keywords: Agriculture, Synthetic fertilizer, Water stress, Zeolite

INTRODUCTION

The increasing demand of food for the ever increasing population creates serious pressure on agriculture resulting increasing use of synthetic fertilizer specially nitrogen and phosphorus into ecosystems to levels of about 121 million tons of nitrogen (N) and 9 million tons of phosphorus annually, (Passaglia and Prisa, 2018). The different way of nitrogen loss from the soil are ammonia (NH_3) volatilization source of nitrogen loss in agricultural systems, which leads to low fertilizer nitrogen usage efficiency, harm to human health and the environment, and indirect emissions of nitrous oxide (Pan et al. 2016).

* Corresponding author: binamunna@yahoo.com

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Sustainable agriculture seeks to address these challenges by adopting practices that minimize the negative environmental impacts of farming while simultaneously improving crop yields and soil health (Kremen and Miles, 2012). Crop yields are essential for global food security, and soil health plays a critical role in supporting productive and resilient agricultural systems (Lal, 2016).

According to Chmielewska 2014b and Enamorado-Horrutiner et al. (2016), zeolites are one of the most commonly used naturally occurring inorganic soil conditioners to enhance the physical and chemical characteristics of soil, including water holding capacity, infiltration rate, saturated hydraulic conductivity, and cation exchange capacity.

Zeolites enhance a variety of physical characteristics of soil, the most significant of which are hydraulic conductivity and infiltration (Gholizadeh-Sarabi and Sepaskhah 2013). It is well known that adding zeolitic minerals to soil enhances water retention and keeps water from penetrating deeply, which can reduce water use for farming (Polat et al. 2004; Talebnezhad and Sepaskhah 2013). Cation exchange capacity (CEC) of natural zeolites ranges from 100 to 200 cmol (+) kg^{-1} (Inglezakis et al. 2015). One feature that sets zeolite apart from other silicate minerals is the abundance of large pores and channels in its structure (Chmielewska and Lesný 2012).

Cations like calcium (Ca^{2+}), potassium (K^{+}), and sodium (Na^{+}) are abundant in natural zeolites. They each possess unique, noteworthy qualities. First, they have a high CEC that is higher than that of soils (Inglezakis et al., 2015); second, they have a lot of free water in their structural channels; and third, they have high surface area strong adsorption capabilities. Environmental research has made use of these qualities to improve soil quality and water quality (Cobzaru and Inglezakis 2012).

The following are the most significant applications for zeolites: agriculture (fertilizer efficiency, soil amendment, slow release of herbicides, heavy metal traps, water absorption, gas absorption, antifungal activity, photosynthesis enhancement in crops, heat stress and sunburn of zeolites in crops, aquaculture, animal feed additive); industrial application areas (petroleum refining, synfuel and petrochemical productions) (Li et al., 2017); water and wastewater treatment (Collins et al., 2020); ecology and environmental protection (Szerement et al., 2021); remediation (Cadar et al., 2021). Zeolites are frequently employed in catalytic processes. According to Ennaert et al. (2016), zeolites are also being used in a novel way to catalyze numerous chemical conversions of biomass, where biomass components can serve as an alternate feedstock in place of crude oil.

However, it is believed that the fertilizer sector is a source of natural radionuclides and heavy metals (Savci, 2012). Most heavy metals, including mercury (Hg), cadmium (Cd), arsenic (As), lead (Pb), copper (Cu), nickel (Ni), and natural radionuclides, including uranium (U-238), thorium (Th-232), and polonium (Po-210), are found in synthetic fertilizers. Thus, fertilizer may have an impact on the build-up

of certain heavy metals in soil and plant systems (Adhikari, 2020). The majority of agricultural soils are therefore either naturally low in fertility or have been rendered less fertile by improper or insufficient replenishment as a result of inefficient use of inputs (water and fertilizers) due to nutrient losses through a variety of loss mechanisms, including water deficit, runoff, non-absorption, and volatilization.

The scenario of declining soil resources is combined with the issue of climate change, which has resulted in a variety of ecological reactions in crops (Malhi, 2021). Increased evapo-transpiration results from higher temperatures, which also affects plants' ability to collect and use moisture. As a result, crops are more frequently exposed to extreme temperatures due to global warming, which raise the danger of a water deficit and can harm crop quality and productivity. The application of zeolites in agriculture, water stress, heavy metals, and soil fertility management takes on more importance in this setting (Ramesh, 2011). This research examines the vital characteristics of natural zeolites and highlights their significant applications in agriculture.

ORIGIN OF ZEOLITES

Because of its intriguing surface and structural characteristics, which have been used in a variety of industries, including biotechnology, agriculture, industrial technology, animal husbandry, and cosmetics, the discovery of natural zeolites has opened a significant chapter in the field of mineralogy. First, naturally occurring zeolites were discovered in cavities and vugs in basalt rocks. Later (19th century), they were also found in sedimentary rocks. Natural zeolite was originally recognized as a mineral in 1756 by Swedish mineralogist Alex Fredrik Crönstedt, who took a sample of crystals from a Swedish copper mine. The mineral scientist found that the novel mineral created a lot of water vapor when heated rapidly after absorbing water (Mahesh et al., 2018). He dubbed the material zeolite "boiling stones" (from the Greek words "boil" and "stone") based on this behavior (ability to froth when heated to roughly 200 °C) (Polat, et al., 2004). Following a number of geological investigations, scientists identified the following genetic categories in the development of zeolites:

i) Crystals found from hot-spring or hydrothermal activity (reaction with basaltic lava flows);
ii) Sediments originating from volcanic deposits in saline and alkaline lake systems;
iii) Deposits originating in alkaline soil from volcanic sediments;
iv) Deposits formed from marine sediments’ low-temperature or hydrothermal alteration;
v) Formations resulting from low-grade burial metamorphism.

The years 1954 to 1980 are considered the zeolites' "golden age" of development while many countries started using and producing them commercially in the 1960s.

Numerous research groups have reported on about 50 different forms of natural zeolites so far, including clinoptilolite, chabazite, erionite, phillipsite, mordenite, and analcite. Natural zeolites are rarely found in pure form in sediments; rather, they are frequently tainted with other minerals, quartz, and metals.

STRUCTURE OF ZEOLITES

One of the most significant mineral families in microporosis materials is zeolite. According to Ghasemi et al. (2018), the term "zeolite" refers to a crystalline aluminosilicate or silica polymorph based on multiple corner-sharing TO_4 (tetrahedrals, often silicon and aluminum) forming a three-dimensional four-connected framework with regularly sized pores of molecular dimension. According to Nakhli et al., (2017), zeolites are tectosilicates, which are hydrated crystalline aluminosilicates of alkaline and alkali earth elements (cations).

The structure of the "roca magica" is open, endless, and three-dimensional. In a nutshell, they are solids with an open, three-dimensional crystal structure made of a variety of elements, including oxygen (O), silicon (Si), and aluminum (Al), along with alkaline or alkali metals, like potassium (K), sodium (Na), and magnesium (Mg), and trapped water molecules. The sizes of the pores are around 12 ångström (Å); the pores are connected by channels that have a diameter of about 8 Å; these cages are made up of rings that are roughly 12 linked tetrahedrons (Sangeetha and Baskar, 2016). One of the most significant properties of zeolites is their Si/Al ratio, which really establishes the mineral's ion exchange properties. The Si/Al ratio was used to differentiate zeolite minerals until 1977, with the exception of clinoptilolite ($Si/Al \geq 4.0$) and heulandite ($Si/Al < 4.0$). The following is a classification of zeolite minerals based on the silica/alumina ratio (Ramesh et al., 2010): (i) Zeolites erionite and mordenite—high Si/Al ratio (from 10 to several thousands); (ii) Zeolites Y—intermediate Si/Al ratio (2 to 5) and (iii) Zeolites A - low Si/Al ratio (between 1.0 and 1.5).

Zeolite species nomenclature was proposed following the International Mineralogical Association Commission on New Minerals and Mineral Names report. Dehydration, overhydration, and partial hydration were insufficient conditions for the identification of several zeolites. A new categorization of zeolites was introduced by Jacobs et al., in 2001, based on the pore diameter or size of the pores (Table 1):

Table 1. Categories of Zeolites

Number of rings	Pore size	Free pore diameter
14 member rings	extra-large-pore zeolites	0.8–1.0 nm
12 member rings	large-pore zeolites	0.6–0.8 nm
10 member rings	medium-pore zeolites	0.45–0.6 nm
8 member rings	small-pore zeolites	0.3–0.45 nm

PROPERTIES OF ZEOLITES

A zeolite's empirical formula is Mn_2O Al_2O_3 $xSiO_2$ yH_2O, where n denotes the element's valence charge, M is an alkali or alkaline earth element, and y is a value between 2 and 7. Table 2 and 3 list some of the most popular natural zeolites along with their empirical and unit-cell formulae and physical properties respectively. Exchangeable cations are found in the first set of parenthesis in the formula, whereas structural cations which, along with oxygen, create the tetrahedral framework of the structure are found in the second set of parentheses. Molecular water that is loosely bonded is typically seen in the structures of naturally occurring zeolites.

Table 2. Representative formulae and selected physical properties of important zeolites.

Zeolite	Representative Unit-cell Formula	Void volume	Channel Dimension, A	Thermal Stability	CEC, meq/g
Analcime	$Na_{10}(Al_{16}Si_{32}O_{96})16H_2O$	18	2.6	High	4.54
Chabazite	$(Na_2Ca)_6(Al_{12}Si_{24}O_{72})$ $4H_2O$	47	3.7×4.2	High	3.84
Clinoptilolite	$(Na_3K_3)Al_6Si_{30}O_{72})$ $2H_2O$	34	3.9×5.4	High	2.16
Erionite	$(NaCa_{0.5}K)_9(Al_9Si_{27}O_{72})$ $27H_2O$	35	3.6×5.2	High	3.12
Faujasite	$(Na_{58})(Al_{58}Si_{134}O_{72})$ $240H_2O$	47	7.4	High	3.39
Ferrierite	$(Na_2Mg_2)(Al_6Si_{30}O_{72})$ $18H_2O$	28	4.3×5.5	High	2.33
Heulandite	$(Ca_4)(Al_8Si_{28}O_{72})$ $24H_2O$	39	4.0×5.54.4×7.24.1 ×4.7	Low	2.91
Laumonitte	$(Ca_4)(Al_8Si_{16}O_{48})$ $16H_2O$	34	4.6×6.3	Low	4.25
Mordenite	$(Na_8)(Al_8Si_{40}O_{96})24H_2O$	28	2.9×5.76.7×7.0	High	2.29
Phillipsite	$(NaK)_5(Al_5Si_{11}O_{32})20H_2O$	31	4.2×4.42.8×4.83.3	Medium	3.31
Linde A	$(Na_{12})(Al_{12}Si_{12}O_{48})27H_2O$	47	4.2	High	5.48
Linde X	$(Na_{86})(Al_{86}Si_{106}O_{384})26H_2O$	50	7.4	High	4.73

High water-holding capacity in the free channels in soil and pots, high cation-exchange capacity, and high adsorption capacity are the three major qualities of zeolites that make them attractive for use in agriculture. Zeolite's crystal structure contains vast, open "channels" that allow for cation exchange and adsorption despite the mineral's extremely complicated structure (Morris and Nachtigall, 2017). Zeolites' interior channel surface area makes them incredibly efficient ion exchangers. Additional beneficial characteristics are its high cation-exchange capacity of 150–250 cmol/kg (CEC), low density (2.1–2.2 g/cm3), high void volume (50%) and cation selectivity, particularly for cations like potassium, cesium, and ammonium (Bhattacharya, 2015).

Table 2. Some physical properties among the most well-known zeolites are (Polat et al. 2004):

Zeolites	Heat stability	Porosity (%)	Specific gravity (g/cm^3)	Bulk density (g/cm^3)	Ion exchange capacity (meq/g)
Analcite	High	18	2.24–2.29	1.85	4.54
Chabazite	High	47	2.05-2.10	1.45	3.84
Clinoptilolite	High	34	2.15-2.25	1.15	2.16
Erionite	High	35	2.02-2.08	1.51	3.12
Heulandite	Low	39	2.18-2.20	1.69	2.91
Mordenite	High	28	2.12-2.15	1.70	4.29
Phillipsite	Moderate	31	2.15-2.20	1.58	3.31

To summarize, zeolites' properties that are structure-related are; (i) behavior of 'zeolitic' water: high potency of hydration and dehydration, (ii) extensive void volume and low density when dehydrated, (iii) molecular sieve property, (iv) stability of the crystal structure of many dehydrated zeolites when 50% volumes of the dehydrated crystals are void, (v) dehydrated crystals, homogenous molecular-sized channels, (vi) cation exchange features and the removal of heavy metals, (vii) electrical conductivity, (viii) gases and vapors adsorption and (ix) catalytic properties.

APPLICATION OF ZEOLITES IN AGRICULTURE

The various ways that zeolite is used in agriculture highlight how important the current environmental situation. Clinoptilolite, a type of zeolite that belongs to the heulandite group naturally occurring in soils and sediments, is the most prevalent type of zeolite utilized in agricultural practices (e.g., as a soil amendment and to help retain nitrogen in soils) (He et al., 2002). Zeolites are excellent carriers of mineral nutrients and have the ability to regulate their delayed release following application. They can also enhance crop yield and improve water retention in sandy soils and increase porosity in clay soils (Bhattarai et al., 2015).

Zeolite and water holding capacity of soil

Zeolite can retain upto 60% of their weight in water molecules because of the greater porosity of their crystalline structure. Compared to untreated soil, treated soil with natural zeolite increased water holding capacity by 0.4 to 1.8% in drought and 5 to 15% in general condition by and, respectively (Chmielewska, 2010). Zeolite have the ability to raise soil water content by increasing bulk density and total porosity, because of their incredibly porous nature, zeolites increase soil water-holding capacity (Nakhli, 2017).

Zeolites on soil hydraulic conductivity and infiltration

The chemical, physical, and biological characteristics of a soil are changed by the addition of synthetic or natural zeolites. Zeolites have the ability to alter the structure and texture of soil, which can have an immediate effect on the hydrological parameters of the soil because of their intricate internal structure (Comegna et al., 2023).

According to Gholizadeh-Sarabi and Sepaskhah (2013), zeolites can generally alter the total porosity, pore size distribution, pore channel connectivity, and tortuosity of soils. The effects of these modifications can vary depending on a number of factors, including the nature of the zeolites, the water's properties, soil texture and structure. Zeolites' effects on soil infiltration rate (Szerement et al., 2014), saturated hydraulic conductivity (Jakkula and Wani, 2018), soil water content and water retention capacity (Ravali et al., 2020), and their function in preventing pesticides and fertilizers (such as ammonium NH^{+}, phosphate PO_4^{3-}, potassium K^{+}, and sulphate SO_4^{2-}) from leaching into soils (Ramesh et al., 2015, Nakhli et al., 2017) have all been covered in a number of studies .

Zeolite addition typically results in increased soil water retention and water holding capacity in light-textured soils, such as sandy and loamy soils, and decreased hydraulic conductivity at saturation (Ks) and infiltration rate (Colombani et al., 2015). Zeolites may have radically different impacts in heavy-textured soils (such as clay soils and silty-clay soils) (Jarosz et al., 2022). It is difficult to draw broad conclusions about the relationships between soils and zeolites and their anticipated effects on the physical and hydraulic properties of soils because some aspects of the literature that is currently available still seem contradictory and unclear.

Zeolites may benefit plant development and productivity from an agronomic standpoint (Jarosz et al., 2022). Zeolites have been found to be particularly useful in mitigating the issues associated with intensive agriculture, which have a significant impact on soil and soil-water quality, particularly in arid and semiarid regions (Belviso et al., 2022). Such studies should specifically look into how zeolites affect the whole range of water retention curves (i.e., from saturated to dry zone), with an emphasis on the water domain that is available to plants (Nakhli et al., 2017). Zeolite application significantly reduced soil bulk density and boosted water-holding capacity by up to 48.54%, according to Ravali et al. (2020). Additionally, zeolite significantly affects the pH, EC, and CEC of soil (Ravali et al., 2020).

Zeolites and soil nutrient availability to plants

Zeolites have a high porosity and CEC, which allows them to raise the CEC of soil and improve the soil's capacity to keep and absorb nutrients like potassium (K^{+}) and ammonium (NH_4^{+}) and naturally occurring zeolites have extremely high CECs, ranging from 100 to 200 cmolc /kg. Since only a small portion of chemical fertilizers are actually absorbed by the soil, their widespread usage poses major environmental

risks. The excess fertilizer is washed off, and as a result, surface water bodies experience eutrophication high amounts of potassium, nitrogen, and phosphorus or groundwater nitrates. By enhancing the delayed release of these elements for crop uptake, zeolites improve the soils' ability to retain nutrients (Li, 2003). The zeolite-A surface was positively changed to enhance its ability to hold anion phosphate (PO_4^{3-}). In a greenhouse test, zeolite treated with potassium and ammonium (NH_4^+) increased the yield of spinach and the plants' ability to absorb nutrients (Li et al., 2013). The results showed that the zeolite and fertilizer combination had a considerable positive impact.

Furthermore, the addition of zeolite obviously altered the nutrient concentrations found in the tissues of maize (Zea mays L.); the use of inorganic fertilizers combined with zeolites significantly boosted the uptake of N, P, and K as well as the efficiency with which they were used in the roots, leaves, and stem (Ahmed et al., 2010). In comparison to an ammonium sulfate control, it was discovered that radish tops' nitrogen adsorption increased following zeolite treatment.

Soil health and environmental pollutant management

Zeolites is also able to absorb and retain some environments pollutants. By absorbing and retaining pollutants in their porous structure, zeolites can lower the hazards of contamination to water bodies. It is frequently employed as soil conditioners to improve the physio-chemical properties of soils. According to Doni et al. (2020), zeolite enhanced the cation-exchange capacity of vineyard soils, which in turn affected nutrient availability and induced changes in soil organic matter and microbial metabolic activity stimulation (an increase in dehydrogenase activity). According to de Campos et al., (2013), applying Brazilian zeolitic sedimentary rocks as a soil conditioner greatly boosts the yields of rice, lettuce, tomatoes, and Andropogon grass. Utilizing 6 tonnes ha^{-1}, clinoptilolite (15 tonnes ha^{-1}) increased the yields of sugar cane, potatoes, barley, and clover in sandy soils in Ukraine.

Amend Heavy Metal

One of the most important problems facing modern agriculture is soil pollution from heavy metals like lead, cadmium, zinc, nickel, manganese, chrome, copper, and iron; the misuse of fertilizers and the growth of industry both contribute significantly to this problem. Low pH is the primary determinant of heavy metal solubility in soil and is linked to the possibility of their trophic chain inclusion (Zwolak et al., 2019). Zeolites are frequently employed for the sequestration of cationic pollutants, including heavy metals like Cd, Pb, Cr, Zn, Cu, etc. This is because zeolites generally have a high cation-exchange capacity and they attract positive-charged ions (Kumar et al. 2007). Several writers have shown how naturally occurring zeolites have a strong affinity for heavy metals (Tashauoei et al., 2010); for example, 1% additional zeolite could retain 3.6 mmol Pb kg^{-1} or 750 mg kg^{-1} of soil. Particles sized 3.3-4.0 mm in sewage sludge compost can be treated with clinoptilolite to extract heavy metals.

Reduce gas emissions

In order to collect gases or control odors, zeolites, both natural and synthetic, can absorb a wide range of gases, including methanol (CH_3OH), formaldehyde (HCHO), sulfur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2), hydrogen sulfide (H_2S), water (H_2O), ammonia (NH_3), molecular hydrogen (H_2), argon (Ar), oxygen (O_2), nitrogen (N_2), xenon (Xe), helium (He), krypton (Kr), and many more. The zeolites' abilities to adsorb ammonium varied, ranging from 8.149 mg N g^{-1} to 15.169 mg N g^{-1}. At pH 4 - 7, the estimated clinoptilolite ammonium-adsorption capacity increased linearly and it was 9.660 to 13.830 mg N kg^{-1}. Moreover, zeolite can be widely employed in conjunction with other additives to lower gas emissions, salinity, and nutrient loss throughout the composting process (Awasthi et al., 2016). According to Wang et al., (2018), the use of wood vinegar in combination with zeolite and biochar to compost pig manure reduced emissions of methane (50.39–61.15%), carbon dioxide (33.90–46.98%) and nitrous oxide (79.51–81.10%) respectively, and decreased ammonia loss by 64.45–74.32%.

Antifungal properties

Several writers looked into using zeolites to keep dangerous insects at bay (Floros et al., 2018). These include the rice weevil, *Sitophilus oryzae* L., the confused flour beetle, Tribolium confusum Jacquelin du Val (Coleoptera: Tenebrionidae), the maize weevil, Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae), the red flour beetle, Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae), and the lesser grain borer, *Rhyzopertha dominica* F. (Coleoptera: Bostrychidae) (Eroglu et al., 2019).

Increase photosynthesis

Carbon dioxide molecules can be absorbed by zeolites, which then progressively release them into the environment (Montanari and Busca, 2008). Zeolites sprayed on plant leaves have the potential to increase carbon dioxide levels close to the stomata. For C_3 plants, which include vines, tomato plants, apple trees, and orange trees, this occurrence may result in a higher rate of photosynthesis, a decrease in carbon dioxide loss by the photo-respiratory system, and an improvement in the efficiency of net carbon CO_2 (velocity of carboxylation) uptake. This leads to increased growth, an increase in the pace at which the leaf surface is formed, and a decrease in the rate of transpiration.

Reduce heat Stress

Rubisco, the enzyme in plants that fixes carbon dioxide, has a decreasing affinity for CO_2 and becomes less soluble in O_2 as the temperature rises. As temperature rises, the carboxylation to oxygenation ratio decreases (Ainsworth and Rogers, 2007). Numerous investigations revealed that apple trees and vines have a lower canopy temperature and a faster rate of leaf carbon uptake. a drop in temperature of about 4 °C brought on by the reflecting material for the leaves of kidney bean plants

(*Phaseolus vulgaris* L.), dwarf orange trees (*Citrus sinensis* L. cv. Valencia), and rubber plants (*Ficus elastica* L.).

Challenges and prospects of zeolite use in agriculture

The major challenge with zeolite application in alkaline soils could be potential increases in soil pH. Some studies have reported increases soil pH although others reported a decrease, so we have to check its effects on soil pH in test plots before applying to a larger area. Applications to compost or manure are less likely to cause unacceptable soil pH changes. Removing zeolite from the soil after application is not practical, so it's very important to initially test for effectiveness in very small areas of land. Input cost could be another problem, especially for large-scale operations. However, a plan for yearly applications of small quantities could build up zeolites economically over time.

Numerous research findings demonstrate that zeolites can improve plant growth, yet occasionally they don't operate as intended. Sangeetha and Baskar (2016) found that using zeolites that are high in sodium can have a detrimental effect on plant growth and yield. These authors emphasized the critical significance that zeolites' chemical and mineralogical analyses play in determining the best course for their deployment. Rather than the huge applicability of zeolites in agriculture, it should be considered that the zeolites are not without disadvantages.

The fine-grained synthetic zeolites are highly dispersive in nature which creates worrisome problems during their use. After mining the usable form of natural zeolites is obtained via isolation procedures like crushing and pellet generation while the application of the synthetic form of zeolites are limited into hard, wear—resistant granular forms. The practical use of granular zeolites is not yet discovered (Król, 2020). The distribution of the zeolites sources is very limited such asthezeolitic soil is confined to only 1% of the total geographic area of India and more than 50% of natural zeolites are produced in China among all over the world (Bhattacharyya, et al., 2015) that may increase the price and the gap between demand and supply. Therefore, the uninterrupted availability of zeolites for farming purposes in worldwide is another major constraint.

CONCLUSION

The use of zeolites as fertilizers demonstrates the positive effects on both agricultural productivity and the soil environment. Zeolite has a number of possible applications in agriculture, especially in nutrient utilization efficiency. Zeolites as nutrient transporter, help farmers maintain water content, lower canopy temperature and guarantee productivity in light of climate change and rising temperatures. Zeolites can also be a vital instrument for lowering harmful emissions, eliminating heavy metals from plant stems. Zeolites' application as soil amendment however, requires more investigation to confirm and comprehend the effects of these compounds on soil.

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AGROECOLOGICAL INTERVENTIONS FOR THE SUSTAINABLE MANAGEMENT OF FALL ARMYWORM, *Spodopera Frugiperda* (J.E SMITH) FOR SMALLHOLDER FARMERS

S. Tiwari*

Department of Entomology, Agriculture and Forestry University, Rampur, Chitwan, Nepal

ABSTRACT

The fall armyworm, *Spodoptera frugiperda* J.E Smith, is a worldwide invasive pest of maize, but also damages sweet corn, rice, and sorghum. This pest originates from the Americas and spread to Africa, Asia, and Australia, with more than 80 countries. Pesticidal management practices always get a priority for the immediate intervention of this pest. These practices are against the environment, biodiversity, and human health. Hence efforts are interestingly growing to develop agroecological strategies for fall armyworm management. This review is focused on diagnosing the various agroecological practices that apply to the sustainable management of fall armyworms. The most common pest management practices that are popular among smallholder farmers are intercropping, push-pull systems, crop rotations, mulching, cultural practices, use local pesticidal plants, habitat diversification, soil nutrient management, and many more.

Intercropping including push-pull farming systems with leguminous crops reduces the number of fall armyworm eggs by increasing the biological control (BC) activities and inhibits the movement of pest larvae. Mulching on the soil ameliorates soil microclimate and improves plant health. Habitat diversification improves the quality of farms and improve BC activities by providing shelter, nectar, alternative food, and pollen to the pest's natural enemies. Similarly, local pesticide plants could be a sustainable alternative to synthetic pesticides. Hence, agroecological practices for pest management improve a balanced environment, regulate natural pests, reduce inputs, diversify the agroecosystem, improve biologically mediated soil fertility, increase yields, and finally improve ecosystem services. These practices must be promoted to replace agricultural intensification with sustainable intensification in maize fields.

Keywords: Fall armyworm, invasive, agroecological practices, sustainable intensification

* Corresponding author: stiwari@afu.edu.np

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INTRODUCTION

Fall armyworm (FAW) (*Spodoptera frugiperda* JE Smith, Lepidoptera: Noctuidae) is a generalist and voracious insect pest of many cultivated crops, and is native to America. This pest was first recorded with its invasive status in the mainland of West Africa in 2016 and has rapidly spread across Sub-Saharan Africa from 2017 to late 2018 (FAO, 2018). By 2019 November, this species had been confirmed in Middle East, followed by other Asian countries. By May 2020, it was confirmed in Australia, Mauritania, with more than 80 countries (Kalleshwaraswamy et al., 2018; Sisay et al., 2018). Its rapid spread along with its potential yield losses in corn causes a threat to the food and nutritional security of millions of smallholding farmers (Day et al., 2017).

Montezano et al. (2018) reported more than 353 host plant species of FAW belonging to 76 plant families with major plant families of Poaceae, Asteraceae, and Fabaceae. *Zea mays* L. is the major host of fall armyworm and is considered as a major pest of maize worldwide. Other host crops are paddy, *Oryza sativa* L., sorghum, *Sorghum bicolor* (L.) Moench, wheat, *Triticum aestivum* L., millet, *Eleusine coracana* Gaertn, barley, *Hordeum vulgare* L., etc. (Montenzano et al. 2018).

Spodoptera frugiperda is a sporadic pest with a long-distance migratory habit that can fly more than 100 km per night (Johnson, 1987). This is a noctuid moth with complete metamorphosis. It has six larval stages; the first three instars (i.e. I. II and III) are relatively less voracious and late instars (IV, Vand VI) are more voracious (Sharma et al., 2022). Fall armyworm larvae in maize plants feed young leaves, whorl, ear and tassel, and maize cob.

Pesticide recommendation always got a priority in most of the invasion countries, which was not effective, environmentally friendly, and economical (Kumar and Kumar, 2019; Yang et al., 2021; Kumar et al., 2022). Large farmers can effectively manage this pest with machine spray of synthetic insecticides and adopting precautionary measurements during pesticide spray, but small farmers don't have access to such chemicals as well as protective equipment during pesticide spray and are considered a vulnerable group. Hence, in such countries, environmentally friendly and cost-effective agroecological strategies are demanded by smallholder farmers.

Agroecological approaches support sustainable pest management in three different ways: First, it acts on soil health improvement, and thereby improve crop health and pest resistance; second, diversified habitat in agroecological strategies support to improve biological control by increasing the abundance and diversity of pest natural enemies; and third, specific management activity that acts directly on reducing pest outbreak and pest infestations (Harrison et al., 2019).

This review paper tries to address the potential and popular FAW management practices for smallholder poor farmers with emphasis on the locally available, cost-effective, environmentally friendly, and relevant to small farmers. Agroecological

approaches always offer culturally appropriate low-cost pest control strategies and can be integrated into the core component of integrated pest management (IPM).

REVIEW OF LITERATURE

The definition of each agroecological method and its significance with supporting examples are presented and discussed. There are more than fifteen such potential agroecological practices in this review paper that are directly or indirectly linked to FAW management.

Intercropping

Intercrops are grown between the main crops. There are four major mechanisms for the reduction of the FAW population and infestation in intercropping maize fields. First, intercropping practices improve soil health and promote plant health, thereby increasing the resistance to FAW damage. Second, intercrops interrupt the movement of FAW larvae in maize fields. Third, disrupts the egg-laying capacity of female moths by visual and chemical cues and finally, provides suitable environmental conditions for the fall armyworm biocontrol agents (Khan et al., 2010). Kumar et al. (2022) reported that intercropping maize with leguminous crops resulted a considerable reduction of the fall armyworm population, notably during the early growth stages of the maize to tasseling compared to monocrop maize (Kumar et al., 2022). Another study conducted by Keerthi et al. (2023) reported that the maize crop intercropped with lady's finger, *Abelmoschus esculentus* (L.) Moench significantly reduced the pest infestation and increased the yield (6.17 q/ha) compared to other intercropping systems such as french bean, *Phaseolus vulgaris* L., lablab, *Lablab purpureus* (L.) Sweet, cowpea, *Vigna unguiculata* (L.) Walp., coriander, *Coriandrum sativum* L. and spinach, *Spinacia olearacea* L.

The study conducted by Wu, Jiang, Zhou, and Yang, (2022) in southwest China reported that compared to sole maize cropping, intercropping maize fields significantly reduced the infestation by 80% compared to maize monocrop. These results were also supported by the study conducted by Altieri, (1980) and Khan et al. (2010) who reported that bean intercropping maize fields reduced FAW infestation by 20-23 %. The study conducted by Udayakumar, Shivalingaswamy, and Bakthavastasalam, (2021) in Banglore, India reported that maize and Desmodium intercropping maize fields had the lowest plant damage with a reduced number of FAW larvae compared to monocrop of maize. The authors also added that such intercropping maize fields increased the parasitism rate of *Trichogramma* spp compared to monocrop. Similarly, the abundance of Coccinellid predators and Geocorid bugs was significantly higher in maize intercropped with groundnut compared to the sole maize.

Push-pull farming system

A push-pull farming system is a kind of intercropping system in which trap plants, act as 'pull' that attracts the pests and 'push' crops drive away the pests from the main crops (Cook et al., 2007). In this farming system Napier (*Pennisetum purpureum* (Schumach.) Morrone was used as a 'pull' crop and Desmodium was used as a 'push' crop to manage the maize stem borer (*Chilo partellus* Swinhoe) in Africa (Khan et al., 2018). Midega et al. (2018) in their study in East Africa reported that FAW population and plant damage were significantly lower in the push-pull farming system in the desmodium intercropping maize field and planting *Brachiaria* as a border crop compared to maize monocrop plots. In such fields, maize yield was 2.7 times greater compared to monocrop plots.

Cover cropping

Cover crops are used to cover the soil in the main field which is grown either before or after the main crop is harvested. Leguminous cover crops are normally grown inside the main crop to increase the soil nutrients, suppress the weed populations, increase moisture conservation as well as provide shelter for pests' natural enemies (Adetunji et al., 2020). For FAW management, an experiment conducted in Florida, USA suggested that sunn hemp, *Crotalaria juncea* (L.), and cowpea cover crops in corn fields reduced the FAW larvae populations by 70-96% compared to sorghum-sudan grass cover crops (Meagher et al., 2022). Similarly, a greenhouse study conducted in the USA suggested that *Triticale* cover crops could strengthen maize resistance to FAW compared to *Pisum sativum* L., *Raphanus sativus* L., and no-cover crops (Davidson-Lowe, 2021).

Crop rotation

Crop rotation is a traditional method of managing pest damage in agriculture by rotating host and non-host crops in alternate years. Crop rotation directly does not affect the FAW population. However, crop rotation improves soil fertility, provides adequate plant nutrition, supports healthy plant growth, and increases pest resistance (Bullock, 1992). These practices also increase the diversity of farm and increase natural enemy abundance and diversity (Meagher et al., 2016). Similarly, according to Dotasara and Choudhary, (2023), crop rotation is a kind of agroecological pest management strategy that disrupts FAW breeding cycles in maize farms.

Mulching practices

Mulching is the practice of spreading dead or living materials on the soil surface. Living mulches increase the plant biomass in the soil, increase the nutrient and moisture content, reduce weed growth that helps to grow healthy plants, and reduce pest damage (Barche, Nair, and Jain, 2015). There are very little evidences of the direct impact of mulching on lowering the fall armyworm population including improving yield but reduced fall armyworm damage on maize leaves by mulching practices was reported by Medega et al. (2018). Similarly, neem leaf residue on soil

increases the grain yield by 410-600% which was likely a combined effect of the control of fall armyworm and improved soil fertility (Ewansiha et al., 2023).

Soil residue and nutrient management

Healthy soil provides adequate nutrients to the plant to produce healthy plants. Soil health can be improved by adding organic manure, FYM, green manuring, legume intercropping, cover cropping, mix cropping as well as exogenous application of balanced nutrients. Healthy plants are likely less damaged by insect pests and diseases.

The study conducted in southwest Ethiopia in 2018/2019 reported that maize plots with retained crop residue had a significant reduction in FAW infestation compared with plots without maize residue (control). Furthermore, cattle manure-fertilized maize plots had a lower percentage of FAW infestation when compared with maize plots. Researchers in their study focused on conventional tillage with 100% maize residue with cattle manure showed a significant reduction of FAW compared to the control maize field (Bayissa et al., 2023). Another study conducted by Baudron et al. (2019) reported that applying the optimum dose of cattle manure in maize fields reduces FAW infestation in maize crops.

The study conducted by Singh, Waltz, and Joseph, (2021) at the University of Georgia in 2018/2019 suggested that the growth and development of FAW larvae were favored by the Nitrogen (N) but discouraged by the Potassium (K) on bermudagrass. Similarly, K plays a significant role in various physiological processes such as photosynthesis, respiration, carbohydrate metabolism, translocation, and protein synthesis (Pettigrew, 2008), and directly influences the insect pests and disease resistance on crops (Altieri and Nicholls, 2003).

Another study by Reddy, Sugeetha, Asha, and Mahadevu, (2024) highlighted that nutrient components like nitrogen, phosphorous, magnesium, and sulfur may influence the attack of FAW with greater damage, whereas, potassium, calcium, zinc, and manganese reduce the infestation by FAW.

Another important element, silicon (SiO2) significantly influences the growth and development of *S. frugiperda* larvae, particularly on colonization and damage in maize by reducing the fecundity and increasing the mortality of newly emerging FAW larvae (Haq et al. 2022). To support these findings, Zimba et al. (2022) suggested that silicon element (Si) accumulation in plants acts as a mechanical barrier to insect herbivory but creates a suitable chemical environment to increase the attraction of nymphs of *Euthyrhynchus floridanus* L., a generalist predator of FAW. Hence, using silicon sources of organic manure or compounds on maize crops reduces the fall armyworm damage which can be integrated into integrated pest management (IPM) or organic pest management (OPM) (Pavani, Kalleshwaraswamy, and Onkarapp, 2023).

Whorl application of soils and sand

Smallholders and poor farmers around the world have been using various local and traditional practices for vegetable pest management including FAW management in corn fields. Soil materials when touching the skin of FAW can damage the protective wax layer of the larval skin may increase abrasiveness, absorption, and desiccation on the larval bodies, and finally increase larval mortality (Hruska, 2019). Similarly, soil contains entomopathogenic communities such as *Bacillus thuringiensis* Berliner, *Beauveria bassiana* (Bals.-Criv.) Vuill. and virus (sfMNPV) also induce fall armyworm larval mortality (Williams, 2023).

The use of diatomaceous earth which is found in sediments of rivers, streams, and lakes are rich in silica, which increases FAW larval mortality by 47%. Similarly, Bentonite, a natural soft, fine, and highly absorbent clay may cause FAW larval mortality by 93% in laboratory conditions (Silva et al., 2016).

Chawanda et al. (2023) reported that soil types as well as methods of application influence their effectiveness on the FAW larval population and damage level. According to them, dry soil applied after watering was the most effective to reduce larval population. However, the application of wet soil before watering can also significantly reduce the number of FAW larvae and reduce leaf damage percentage (Chawanda et al., 2023).

Whorl application of wood ash

Wood ashes from various types of wood fires are a common practice of fall armyworm management by smallholder farmers in Africa and Asia. When wood ashes touch the larva they induce suffocation, abrasion, and desiccation on the larval body. A study conducted from 2020 to 2021 in Malawi by Chawanda et al. (2023) suggested that wood ash (3 g/plat) on maize whorl significantly reduced the FAW larval population and maize leaf damage by 50% and increased the grain yield by 24-36% as compared to the untreated control. A similar study conducted by Jalali et al. (2024) in Pakistan reported that ash-treated plots reduce the FAW larval population and reduce the damage on maize leaves.

Whorl application of animal urine

Urine spray or whorl application is also a general practice of pest management in some parts of the world (Hruska, 2019). Cow urine, buffalo urine, or rabbit urine are the common animal urine used to manage this invasive pest. Farmers of South Asia use animal urine alone or mixed with other ingredients such as plant extracts as an alternative to insecticides. Research in Gujarat, India in 2019-2020 reported that cow urine or buffalo urine sprayed on maize farms reduced the incidence of FAW (Patel et al., 2020).

Spray of fish soup

Use of fish soup alone and fish soup with sugar spray are common FAW management practices in Sub-Saharan Africa. It is reported that fish soup and sugar solutions attracted a wide range of insects, including potential natural enemies (predators and parasitoids) of FAW (Njuguna et al., 2021), and potentially improved BC activity in sprayed plots. Chemical analysis demonstrated that fish soups are rich in N, P, and Ca with 76 volatile organic compounds, out of which 16 compounds are insect attractants (Niassy et al., 2024).

Insecticidal plant materials

In many parts of the world, insecticidal plants are recommended as safe biopesticides which are considered as a substitute for synthetic insecticides. Various studies are conducted to evaluate the efficiency of such insecticidal plant materials in reducing FAW populations and their damage to maize crops. Commonly used such repellent plant materials are *Azadirachta indica* Juss, *Melia azedarach* L., *Nicotiana tabacum* L., *Ageratum conyzoides* L., and many more. Plant families under Asteraceae, Euphorbiaceae, Meliaceae, Sapindaceae, Verbanaceae are insecticidal plant families and are mostly tested to the FAW larvae (Rioba and Stevenson, 2020). The larval mortality of such plant extract ranges from 20-80% and largely such mortality depends on the type of plant species, plant parts used, bioassay environment, bioassay type, concentration of extracts as well as FAW larval stages (Phambala et al., 2020; Ribo and Stevenson, 2020).

Habitat diversification at farm and landscape scales

Diversification of crop or non-crop habitats in or off- the field increases the abundance of natural enemies (Tiwari, Sharma, and Wratten, 2020) and improves the BC activity according to the natural enemy's hypothesis reported by Russell, (1989). Such diversified habitats provide shelter, nectar, alternative food, and pollen to the pest's natural enemies and increase the fitness of biological control agents (Gurr et al., 2017). Crop diversity and landscape complexity provide the resources for alternative prey of generalist predators and regulate the natural population of fall armyworms in the maize cropping system (Dassou et al., 2023). On the other side, diversification increases the partitioning of resources and reduces pest infestations (Root, 1973). Suitable examples of habitat diversification in maize farms are intercropping, mix cropping, cover cropping, trap cropping, planting insectary plants, bund management, creating beetle banks, weed management, agroforestry, etc. (González-Chang et al., 2019; Collins et al., 2002).

The study conducted in Ghana in 2019 reported that FAW damage on corn increased significantly with distance from the semi-natural habitat (field edges) this is because of the increasing richness and diversity of Hymenoptera with a decrease in the distance from the semi-natural habitat (Jordon et al., 2022). Legume-based field diversification in corn fields increases the number of *Trichogramma*, Coccinellid

predators, and Geocorid bugs and reduces the infestation of fall armyworms (Udayakumar, Shivalingaswamy, and Bakthavatsalam, 2021). Maize field diversification with some cover crops such as sun hemp and cowpea increase the larval parasitoids of FAW, *Chelonus insularis* Cresspon (Hymenoptera: Braconidae) and potentially reduces the FAW larval population by increasing parasitism (Meagher et al., 2022).

Weed management practices at the farm level

Plants in general become unwanted if they grow in an unwanted place, overlay abundance and time. They are considered as a weed and pest of the main crop because they compete to the main crop for nutrients, irrigation, space, and sunlight (Ekwealor et al., 2019). But leaving a small patch or strips in fallow land is useful for pests' natural enemies. In some circumstances, if such weeds are flowering plants and grow in field bunds, margins, or between the main crops, are considered ‘beetle bank’ that increases the abundance of natural enemies and often reduces the fall armyworm infestation by improving biological control of pest (Harrison et al., 2019). But sometimes, weeds provide shelter to the FAW increase the abundance of the fall armyworm population and may create an ecosystem disservice (González-Chang et al., 2019)

Crushing egg masses and hand-picking fall armyworm larvae

Regular visits to the maize field, observation of various life stages of the pest, and manual destruction can significantly reduce the FAW populations (Makale et al., 2022). These methods do not require any extra investment and time.

CONCLUSION

Agroecological pest management practices include biodiversity conservation, sustainable farming, promoting multiple ecosystem services, and creating a healthy ecosystem. Such practices focus on utilizing local resources that are economical, socially acceptable, and environment friendly. None of the countries in the world are successful in getting rid from invasive species such as fall armyworm, tomato leaf miners, and many other transboundary pests. In early years, farmers were forced to use synthetic insecticides to manage such invasive threats. Now, such practices are considered non-economical, and highly hazardous. Hence, agroecological pest management has gained prominence. For fall armyworm management, agroecological practices became more popular where multiple ecosystem services such as improving predation, parasitism, and mineralization, soil water conservation, reducing the input cost, increasing soil microbial activity and improving soil health and finally increasing grain yield by promoting sustainable agriculture.

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SSR-MARKER BASED GENETIC DIVERSITY IN SRI LANKAN TRADITIONAL MAIZE (*ZEA MAYS* L.) ACCESSIONS

M.N.F. Nashath, A.N.M. Mubarak[*] and A.D.N.T. Kumara

Department of Biosystems Technology, South Eastern University of Sri Lanka

ABSTRACT

The beneficial alleles possessed by maize landraces are valuable resources for improving novel climate resilient maize varieties *via* crop breeding initiatives. Therefore, this study investigated the genetic diversity of 20 traditional maize accessions of Sri Lanka using five SSR markers (*umc1545, bnlg1627, umc1342, bnlg105* and *bnlg1564*). A total of 35 alleles were identified by all the SSR markers, with observed allele numbers ranging from 4 (*umc1545*) to 10 (*bnlg1627*). The higher values of effective number of alleles, observed heterozygosity, and expected heterozygosity for markers *bnlg1627* and *bnlg1564* suggest their potential as key contributors in identifying the genetic variability within the maize accessions. The Polymorphism Information Content (PIC) values ranged from 0.670 to 0.827 with a mean value of 0.735, further highlighting the informativeness of the markers. Considering the genetic diversity among the accessions, *SEU6, SEU20*, and *SEU23* consistently displayed higher levels in their genetic diversity values while the genetic dissimilarity values ranged from 0.1 to 1.0 with the mean value of 0.81. The accessions *SEU3* and *SEU4* were closely linked among the pairwise combinations. Further, the cluster analysis identified five clusters of Sri Lankan maize accessions. Based on the results of this study, *SEU6* and *SEU20* can be the potential candidates for conservation and beneficial for the adaptability of maize to changing environments. These results can pave the way for targeted maize breeding strategies and highlight the need for continued efforts in improving food, feed and forage industries, with implications for enhancing crop resilience and sustainable agricultural development.

Keywords: Crop breeding, Genetic diversity, SSR markers, Traditional maize accessions

[*] Corresponding author: anmubarak@seu.ac.lk.

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INTRODUCTION

Maize (*Zea mays* L.), a member of the Poaceae family, is a widely cultivated grass of substantial agricultural importance (Yadesa, 2021). It is a crop with a long history dating back thousands of years. Maize has risen to global prominence, becoming one of the most extensively produced crops across continents. It is grown from North and South America through Africa, Europe, and Asia, adapting to different climates and soils (Cairns et al., 2012). In many nations, maize is a staple crop, supplying necessary nutrients through its grains, which can be consumed fresh, dried, or processed into a variety of items (Ranum et al., 2014). Maize has various purposes beyond food production, such as animal feed in the form of grains and forage, an ingredient in biofuels and other industrial products (Tanumihardjo et al., 2020). Because of its adaptability and versatility, maize is an essential part of the world's agricultural landscape.

Maize farming confronts a number of significant concerns around the world (Shahzad et al., 2021). Changing weather patterns, rising temperatures, more frequent extreme weather events, and insect and disease attacks have all caused immense problems on maize productivity (Tripathi et al., 2016). Addressing these concerns requires an integrated strategy that utilizes the exploration of genetic diversity and identify the candidate genotypes with greater potentials for improved photosynthetic, biomass with rapid forage and grain yield production. In this light, maize landraces are regarded as the living heritage of agricultural diversity, embodying ancestral wisdom and local adaptation of maize farming. These traditional maize varieties, shaped by generations of farmers, have developed to survive in specific conditions, displaying incredible resistance and unique features (Nashath et al., 2023). Various landraces have had a significant impact on the world's maize genetic resources. Preserving these maize landraces by investigating their genetic diversity holds potential for improving agricultural sustainability (Mufeeth et al., 2023).

The molecular-based characterization is a revolutionary method of studying the genetic diversity of plant populations' intricate complexity (Wambugu and Henry, 2022). This accurate and effective technology enables the identification and analysis of specific genetic markers linked with desirable features, allowing for the selective breeding of plants with superior characteristics (Barcaccia, 2010). Traditional observational approaches are limited by molecular techniques, which provide a full perspective of genetic diversity at the molecular level (Wang et al., 2020). When comparing with other markers including AFLPs and RAPDs, Simple Sequence Repeat (SSR) markers, commonly known as microsatellites, offer several distinct advantages in plant genetic studies. Some of the important advantages include their high degree of polymorphism, co-dominant nature, and relative abundance throughout plant genomes, making them widely relevant and transferrable between species (Silva et al., 2012; Wang et al., 2010). Furthermore, several studies have demonstrated the utilization of SSR markers by researchers all around the world to

describe the genetic makeup of maize landraces (Mathiang et al., 2022; Vathana et al., 2019; Adeyemo and Omidiji, 2019; Belalia et al., 2019). The genetic diversity of Sri Lankan maize landraces has been explored using SSR markers related to photosynthetic, canopy architectural and grain yield traits (Nashath et al., 2024) and insect resistant traits (Nashath et al., 2023) in recent studies. The study's objectives were to determine genetic variation among 20 Sri Lankan maize accessions using 5 SSR markers, to examine the polymorphism of the chosen SSR marker set, and lastly to estimate the genetic diversity characteristics of the investigated maize accessions.

MATERIALS AND METHODS

Plant material

Twenty maize accessions (Nineteen Sri Lankan traditional maize landraces and one high-performing commercial cultivar *Bhadra*) were used for the study, among which 12 were collected from Badulla, six were from Ampara and one was from Trincomalee, major maize growing districts in Sri Lanka (Table 1) (Mubarak et al., 2023). The collected seeds were multiplied and stored in airtight containers at 1 ^{o}C for future usages. These collections were grown inside a net house of the Department of Biosystems Technology, Faculty of Technology, South Eastern University of Sri Lanka (7^{o} 18′00” N and 81^{o} 51’ 41” E, 16 m above sea level) for DNA extraction.

Table 1. List of maize accessions and their collection site.

S.N	Accessions	Collected area	District	Latitude	Longitude	Name of the farmer	Quantity collected
1	*SEU1*	Ridimaliyadda	Badulla	7^{o} 14’ N	81^{o} 6’ E	AI Praneeth	200 g
2	*SEU2*	Ridimaliyadda	Badulla	7^{o} 14’ N	81^{o} 6’ E	AI Praneeth	250 g
3	*SEU3*	Kirawana, Padiyathalawa	Ampara	7^{o} 4’ N	81^{o} 22’ E	YM Shayama	1 kg
4	*SEU4*	Udakumbure Gedara, Kandaketiya	Badulla	7^{o} 21’ N	81^{o} 01’ E	MN Dharmawardana	200 g
S.N	ccessions	Collected area	District	Latitude	Longitude	Name of the farmer	Quantity collected
5	*SEU5*	Dehigama, Kandakatiya	Badulla	7^{o} 29’ N	80^{o} 56’ E	S Bandara	250 g
6	*SEU6*	Padiyathalawa	Ampara	7^{o} 36’ N	81^{o} 20’ E	WM Karunapala	2 kg
7	*SEU7*	Padiyathalawa	Ampara	7^{o} 36’ N	81^{o} 20’ E	WM Karunapala	2 kg
8	*SEU8*	Padiyathalawa	Ampara	7^{o} 36’ N	81^{o} 20’ E	H.M. Darmawardena	1 kg
9	*SEU9*	Kandepoththawa, Baduluoya, Kandekatiya	Badulla	7^{o} 12’ N	80^{o} 59’ E	YM Yasapala	250 g

S.N	Accessions	Collected area	District	Latitude	Longitude	Name of the farmer	Quantity collected
10	*SEU10*	Kirawana, Padiyathalawa	Ampara	7° 4' N	81° 22' E	YM Shayama	3kg
11	*SEU11*	Kirawana, Padiyathalawa	Ampara	7° 4' N	81° 22' E	YM Shayama	1kg
12	*SEU14*	Udakumbure Gedara, Kandaketiya	Badulla	7° 21' N	81° 01' E	MN Dharmawardana	200 g
13	*SEU15*	Kandepoththawa,Baduluoya, Kandekatiya	Badulla	7° 12' N	80° 59' E	MN Dharmawardana	500 g
14	*SEU16*	Kandepoththawa,Baduluoya, Kandekatiya	Badulla	7° 12' N	80° 59' E	MN Dharmawardana	250 g
15	*SEU17*	Udakumbure Gedara, Kandaketiya	Badulla	7° 21' N	81° 01' E	MN Dharmawardana	200 g
16	*SEU18*	Baduluoya	Badulla	7° 12' N	80° 59' E	NK	1kg
17	*SEU20*	Nagadeepaya	Badulla	7° 26' N	81° 12' E	NK	1kg
18	*SEU21*	Kinniya	Trincomalee	8° 5' N	81° 18' E	NK	1kg
19	*SEU23*	Dehigama, Kandakatiya	Badulla	7° 29' N	80° 56' E	S Bandara	500 g
20	*Bhadra*	DoA	-	-	-	-	-

NK – Not Known

Maize DNA extraction

Using the DNeasy plant Mini Kit (Qiagen, Milan, Italy), genomic DNA was extracted from young, three-weeks-old maize seedlings (three seedlings per accession) in accordance with the manufacturer's instructions. A UV spectrophotometer (Genesys 10S UV-Vis, Thermo Scientific Inc.) was used to verify the DNA's purity and calculate its concentration. Purified water was used to dilute the DNA samples to 50 ng/l, and they were then kept in the freezer at -20 °C for subsequent usage.

SSR analysis

In this study, five SSR primer pairs from Singode and Prasanna, (2010), Vathana et al. (2019) and Chen et al. (2008) were chosen based on their high performance in maize genetic diversity studies (Table 2). A total of 15 µl of materials were used for the PCR, including 2 µl of DNA template, 7.5 µl of Taq ReadyMix (2X FastGene®), 1 µl of forward and reverse primers, and 3.5 µl of distilled water. PCR reaction was performed in a PCR machine (Prima-96, HiMedia, LA949, China) and the DNA amplifications were carried out in 35 cycles of 30 seconds at 94 °C, 30 seconds at 52 - 55 °C, 30 seconds at 72 °C, and a 10 minute final extension period at 72 °C. The

PCR products were dissolved on a 3% Agarose gel (FastGene®, Nippon Genetics Europe) and separated using a horizontal gel electrophoresis apparatus (Enduro, Labnet, USA) at 90 volts. Then staining was done for 15 minutes with ethidium bromide (1 g/ml), and then de-staining for 10 minutes using distilled water. A gel documentation system (Axygen, GD1000, USA) was used to examine the gels under ultraviolet light and photographs were taken for later examination (Nashath et al., 2023).

Table 2. SSR primer details used in this study

Locus	Primer sequences	Motif	T_A (^oC)
umc1545	F – GAAAACTGCATCAACAACAAGCTG R - ATTGGTTGGTTCTTGCTTCCATTA	$(AAGA)_4$	54
umc1342	F – TCTAATCCAATCGACATCGACAGA R - TCGCCCTCTTTTCTTTTCTTTTCT	$(AG)_8$	52
bnlg105	F – GACCGCCCGGGACTGTAAGT R - AGGAAAGAAGGTGACGCGCTTTTC	N/A	55
bnlg1627	F – CGGACGGGGGTTATTAAAAT R - TGTGTTCGCAGAATCTCTCG	$(AG)_{19}$	54
bnlg1564	F – ACGGGAGAACAAAAGGAAGG R - CTCTCCCTCACATCCGCC	$(AG)_{24}$	54

Data analysis

The bands that the primers produced were graded individually based on 100 bp DNA ladder and the data were scored as binary data (0 for absence and 1 for presence) in an Excel sheet separately for SSR markers and maize landraces for data analysis. The observable number alleles (N_a), effective number of alleles (N_e), expected (H_e) and observed (H_o) heterozygosity, Shannon diversity index (*I*), and Fixation index (*F*) among maize accessions and SSR markers were all determined by GenAlex (6.51b2) software (Smouse and Peakall, 2012). The Polymorphic Information Content (PIC) values were calculated according to Sharma et al. (Sharma et al., 2009). The genetic distances were estimated for the 20 maize germplasm sets using DARwin 6 software. The binary data matrix was converted into a dissimilarity matrix based on the Jaccard coefficient. A UPGMA-based dendrogram and a principal coordinate analysis (PCoA) were then constructed using the matrix (Khan et al., 2022).

RESULTS AND DISCUSSION

SSR Polymorphism

Table 3 provides a summary of the genetic characteristics of the SSR markers examined in this investigation. These variables offer important information about the

genetic diversity of the studied samples. There were a total of 35 alleles produced by all the SSR markers. The observed allele number (N_a) ranged from 4 (*umc1545*) to 10 (*bnlg1627*), with an average of 7. The markers effective allele numbers (N_e), varied from 3.505 for *umc1342* to 6.446 for *bnlg1627*, indicating variations in the allele distribution and frequencies. The observed heterozygosity (H_o) values in this study ranged from 0.000 (*bnlg105* and *umc1342*) to 0.368 (*bnlg1627*). Moreover, the H_e values ranged from 0.715 (*umc1342*) to 0.845 (*bnlg1627*), with higher H_e values for markers *bnlg1627* and *bnlg1564*, indicating their importance in maintaining genetic diversity. The PIC values varied from 0.670 (*umc1342*) to 0.827 (*bnlg1627*). Further, the fixation index (*F*) values ranged between 0.564 (*bnlg1627*) and 1.000 (*bnlg105*).

The marker *bnlg1627* showed the greatest N_a value, indicating a locus with a comparatively higher level of allelic diversity. Notably, the absence of any observable heterozygosity was completely evident for the possible genetic fixation or inbreeding within the population. Based on allele frequencies, expected heterozygosity (H_e) depicts the genetic diversity within a population. The PIC value of a marker is a measure of how informative it is in identifying alleles and provide insights into the marker's utility for genetic studies (Kim et al., 2021). The PIC values of all the markers used in this study were higher than 0.5 expressing the potential of those in classifying the given maize accessions sets (Varshney et al., 2007). Markers with higher PIC values, such as *bnlg1627* and *bnlg1564*, offer greater discriminatory power in distinguishing alleles, making them valuable tools for genetic analyses and selection strategies. The higher values of N_a, Ne, H_o, and H_e for markers *bnlg1627* and *bnlg1564* suggest their potential as key contributors to maintaining genetic variability within the population. According to Guo et al. (2018), marker *bnlg1564* is linked with ear length and *bnlg1627* (Figure 1) is linked with shoot dry weight traits of maize plants. Markers *umc1342* and *bnlg105* exhibited lower levels of genetic diversity, as indicated by their absence of observed heterozygosity and lower expected heterozygosity and due to the fixation of certain alleles within these loci.

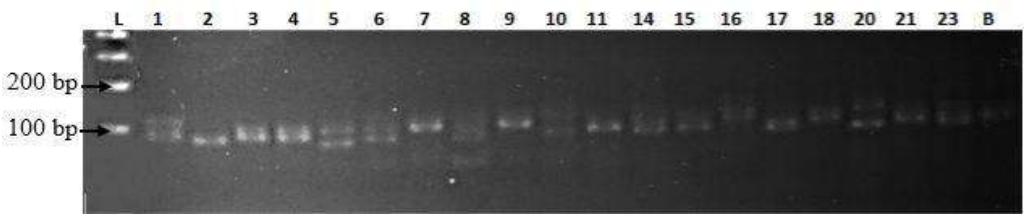

Figure 1. PCR amplification profile of 20 Sri Lankan maize accessions with the SSR marker bnlg1627. L: 100 bp ladder, the numbers in the gel correspond to the identification of maize accessions as indicated in table 1.

Table 3. Summary statistics of genetic parameters of the SSR markers

SSR marker	No of observed alleles (N_a)	No of effective alleles (N_e)	Observed Heterozygosity (H_o)	Expected Heterozygosity/ Genetic diversity (H_e)	Polymorphic Information Content (PIC)	Fixation Index (*F*)
bnlg1627	10	6.446	0.368	0.845	0.827	0.564
bnlg1564	8	4.819	0.200	0.793	0.770	0.748
umc1342	5	3.505	0.000	0.715	0.670	1.000
bnlg105	8	4.255	0.000	0.765	0.733	1.000
umc1545	4	3.636	0.100	0.725	0.675	0.862
Average	7	4.532	0.133	0.768	0.735	0.835
Maximum	10	6.446	0.368	0.845	0.827	1.000
Minimum	4	3.505	0.000	0.715	0.67	0.564

Similar to previous research, the SSR markers in this study exhibited polymorphism, generating a substantial number of alleles, showcasing the diversity within the population. Joshi et al. (2020) analyzed 23 maize landraces cultivated in Nepal with 5 SSR markers and determined the average allele number as 2 per locus, H_o as 0.687, H_e as 0.445 and the PIC value as 0.345. A sum of 65 alleles were identified in the 40 maize populations studied by Vivodik et al. (2017) using 10 SSR markers. The number of these alleles fluctuated between 4 and 8 (mean value of 6.5), while the PIC value varied from 0.734 to 0.848 (mean PIC of 0.810). In another investigation, nine SSR markers with 0.297 PIC and 0.373 gene diversity values were used to identify a total of 19 polymorphic alleles in eight maize genotypes (Kumari et al., 2018). According to PIC values (0.367), the *phi064* and *phi053* were shown to be the best markers for genotype detection. Using 12 SSR markers, a total of 40 alleles were found in 38 maize hybrids, with an average of 3.33 alleles per locus (Shiri, 2011). The 12 SSR loci in that study had a mean PIC of 0.53 and a PIC ranging from 0.23 (*Phi080*) to 0.79 (*UMC2359*).

Maize diversity

A detailed analysis of the genetic diversity parameters found in a group of Sri Lankan traditional maize accessions is provided in Table 4. These variables offer insightful information on the genetic diversity present in the examined maize germplasm. The observed alleles (N_a) detected ranged from 2 (*SEU4*) to 6 (*SEU6, SEU20*, and *SEU23*), which reflects different levels of allelic diversity. The highest N_a values were found in three accessions suggests a comparatively higher level of allele diversity within these accessions. Effective alleles (N_e), with a mean value of 3.834, ranged from 1.515 (*SEU1*) to 5.556 (*SEU6* and *SEU20*). The observed heterozygosity (H_o) values ranged from 0.000 to 0.400. Significantly, the accessions *SEU3, SEU20*, and *SEU23* showed higher observed heterozygosity values, indicating greater genetic diversity within these accessions. Expected heterozygosity (H_e) and

PIC values were highest in *SEU1* (0.820 and 0.794, respectively), and lowest in *SEU6* and *SEU20* (0.314 and 0.340, respectively). The fixation index (*F*) values which measures the inbreeding level among the population ranged from 0.259 to 1.000.

The observed variations in N_a, N_e, H_o, H_e, PIC, and *F* provide a comprehensive view of the genetic makeup of the tested maize accessions. Accessions with higher N_a and N_e values (*SEU6* and *SEU20*) exhibit greater genetic diversity. These accessions are potential candidates for conservation and breeding due to their diverse allele repertoire. Higher observed and expected heterozygosity suggests a higher level of genetic variation within the population. This is beneficial for the adaptability and resilience of maize to changing environments. Moreover, the degree of H_o was discovered to be lower than H_e, probably due to inbreeding (Vahdati et al., 2015) since landraces are restricted to particular ecological niches with limited geographic ranges, which causes significant fixation of alleles (Yousuf et al., 2021). This is also proven by the higher *F* values in most of the maize landraces analyzed in this study. Additionally, the farmers grow landraces from their own preserved seed, frequently from little seed samples that could have led to random drift and thus increased homozygosity. The accessions *SEU6*, *SEU20*, and *SEU23* consistently displayed higher levels of genetic diversity, as indicated by their higher genetic diversity values. These accessions stand out as potential reservoirs of genetic diversity, making them valuable resources for future breeding programs.

Table 4. Genetic information of Sri Lankan traditional maize accessions

Accessions	Number of observed alleles (N_a)	Number of effective alleles (N_e)	Observed Heterozygosity (H_o)	Expected Heterozygosity/ Genetic diversity (H_e)	Polymorphic Information Content (PIC)	Fixation Index (*F*)
SEU1	3.000	1.515	0.200	0.340	0.314	0.412
SEU2	3.000	2.462	0.250	0.594	0.511	0.579
SEU3	3.000	2.174	0.400	0.540	0.466	0.259
SEU4	2.000	1.724	0.200	0.420	0.332	0.524
SEU5	4.000	3.333	0.200	0.700	0.645	0.714
SEU6	6.000	5.556	0.200	0.820	0.794	0.756
SEU7	5.000	5.000	0.000	0.800	0.768	1.000
SEU8	4.000	4.000	0.000	0.750	0.703	1.000
SEU9	5.000	5.000	0.000	0.800	0.768	1.000
SEU10	5.000	4.545	0.200	0.780	0.745	0.744
SEU11	4.000	3.571	0.000	0.720	0.672	1.000
SEU14	3.000	2.778	0.000	0.640	0.563	1.000

Accessions	Number of observed alleles (N_a)	Number of effective alleles (N_e)	Observed Heterozygosity (H_o)	Expected Heterozygosity/ Genetic diversity (H_e)	Polymorphic Information Content (PIC)	Fixation Index (*F*)
SEU15	5.000	4.545	0.200	0.780	0.745	0.744
SEU16	5.000	5.000	0.000	0.800	0.768	1.000
SEU17	4.000	3.571	0.000	0.720	0.672	1.000
SEU18	4.000	3.571	0.000	0.720	0.672	1.000
SEU20	6.000	5.556	0.400	0.820	0.794	0.512
SEU21	3.000	2.778	0.000	0.640	0.563	1.000
SEU23	6.000	5.000	0.400	0.800	0.768	0.500
Bhadra	5.000	5.000	0.000	0.800	0.768	1.000
Mean	4.250	3.834	0.133	0.699	0.652	0.787
Maximum	6.000	5.556	0.400	0.820	0.794	1.000
Minimum	2.000	1.515	0.000	0.340	0.314	0.259

Cluster analysis and genetic relationship

The genetic dissimilarity values based on the SSR markers and 20 maize accessions varied from 0.1 to 1.0 with the average value of 0.81. Of the pair wise combinations, *SEU3* and *SEU4* were closely related accessions. The dendrogram discriminated and clustered the Sri Lankan maize accessions into five clusters. Cluster I comprised 3 landraces (*SEU14, SEU1*8 and *SEU21*), cluster II had 3 landraces (*SEU10, SEU11* and *SEU15*) and *Bhadra,* cluster III consisted of 5 landraces (*SEU5, SEU6, SEU8, SEU17* and *SEU20*), cluster IV and V had of 2 (*SEU9* and *SEU16*) and 6 (*SEU1, SEU2, SEU3, SEU4, SEU7* and *SEU23*) landraces respectively (Figure 2). Further, principal coordinate analysis was constructed to examine the genetic clustering using genetic distances. The clustering of maize accessions was further demonstrated by two primary coordinates. The percentage of variance for the first two principal coordinates were 23.86 % and 18.41 % (Figure 3).

The close resemblance of accessions *SEU3* and *SEU4* in the pair-wise combinations stands out, indicating possible genetic relatedness or common ancestry between these two kinds. The grouping of the maize populations into five different clusters was made easier by the dendrogram construction, exhibiting patterns of genetic relatedness and differentiation. The distinct combinations of landraces shown in Clusters I, II, III, IV, and V highlighted the variety of genetic ancestries and linkages found in the Sri Lankan maize germplasm. In a previous study, Mufeeth et al. (2020) classified 17 Sri Lankan landraces into three groups based on morphological and physiological characters. In their study, *SEU4* and *SEU7* expressed close relationship followed by *SEU8* and *SEU9*.

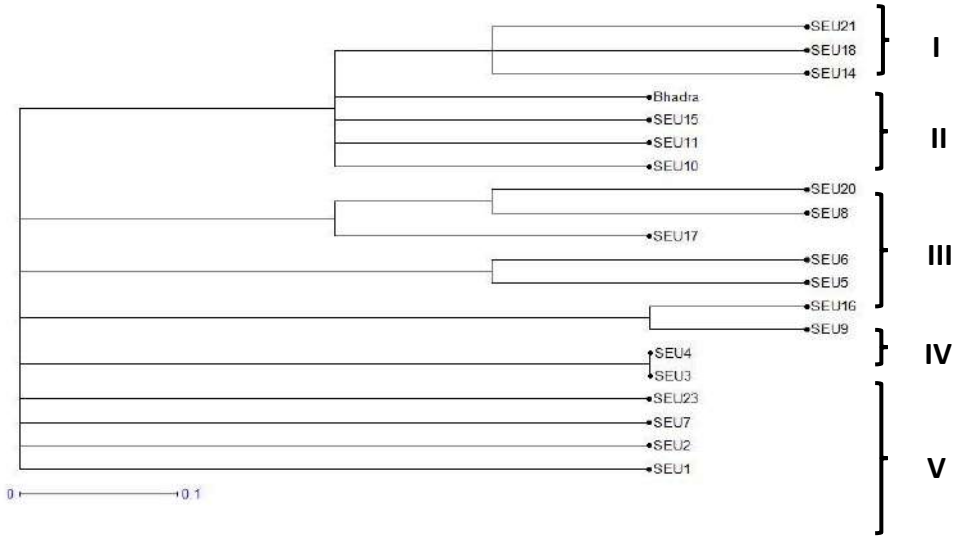

Figure 2. Distribution of Sri Lankan traditional maize accessions shown by cluster analysis

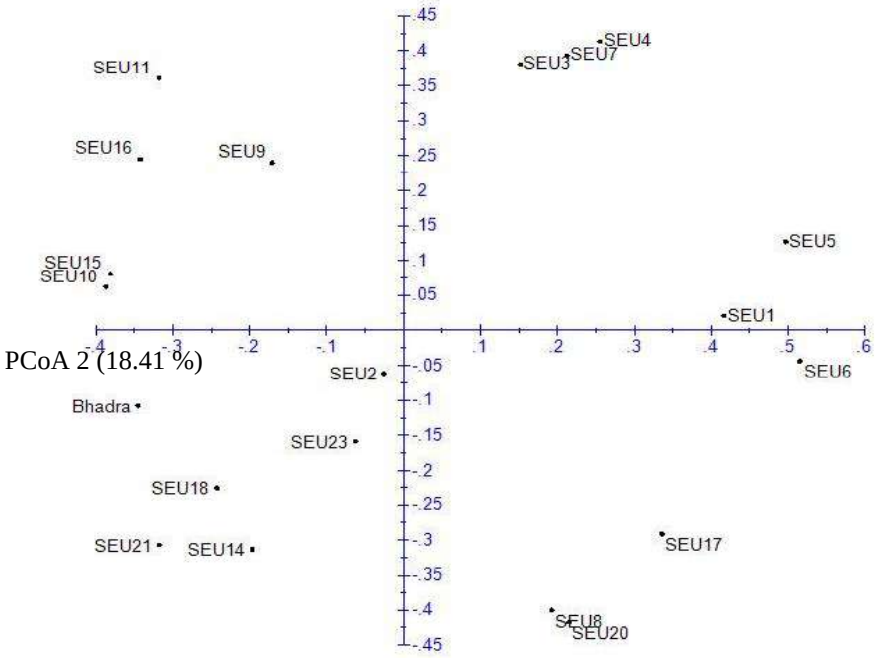

Figure 3. Principal Coordinate Analysis

CONCLUSION

Using five SSR markers, the study sought to evaluate the genetic diversity of 20 Sri Lankan maize accessions. There were found to be 35 alleles in total, with the markers *bnlg1627* and *bnlg1564* being particularly notable for their contribution to genetic variability. The informativeness of the markers was demonstrated by their PIC scores. Notably, *SEU3* and *SEU4* were closely related, although *SEU6* and *SEU20* showed significant genetic diversity. Among the accessions, the study found five clusters. Two landraces that are considered as viable options for conservation and environment adaptation were *SEU6* and *SEU20*. These results lay the foundation for future research into conservation, breeding, and genetic improvement techniques for Sri Lankan maize accessions.

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MORPHOLOGICAL CHARACTERIZATION AND GENETIC DIVERSITY ANALYSIS OF YIELD AND YIELD CONTRIBUTING PARAMETERS IN BRINJAL (*SOLANUM MELONGENA* L.) GENOTYPES

M.A. Zabbar[1], S. Parveen[1], M.A. Rahim[1], K.M.K. Huda[1], M.A.I. Arif[1], M.R. Sharif[3], I. Jahan[1] and M. Harun-Ur-Rashid[1*]

[1]Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka
[3]BS student, Department of Biotechnology and Genetics Engineering, Jahangirnagar University, Savar, Dhaka

ABSTRACT

A field experiment was carried out at Sher-e-Bangla Agricultural University in Dhaka from November 2021 to June 2022 using a Randomized Complete Block Design (RCBD) with three replications to assess the significance of variance, heritability, genetic advance, correlation, path coefficient and genetic diversity for different yield contributing parameters in twenty brinjal genotypes. High heritability associated with high genetic advance and high genetic advance in percentage of mean was found in plant height, individual fruit weight and percent of brinjal shoot and fruit borer infestation, which indicated selection based on phenotype would be effective. Assessments of character association indicated that fruit yield plant^{-1} had highest significant positive correlation with days of last harvesting (r_g= 0.495, r_p= 0.454), number of secondary branches plant-1 (r_g=0.356, r_p=0.315), leaf blade length (r_g = 0.714, r_p = 0.462), leaf blade width (r_g = 0.674, r_p = 0.498) and number of fruits plant-1 (r_g= 0.798, r_p= 0.787) in both genotypic and phenotypic level. Path analysis revealed that the number of flowers plant^{-1} (1.421) had the maximum positive and direct effect on yield plant^{-1}. According to PCA, D^2 and Cluster analysis, twenty brinjal genotypes were grouped into five different clusters- I, II, III, IV and V with three, three, four, six and four genotypes respectively. Considering magnitude of cluster mean performance and genetic parameters genotypes G10 (Choto Katali), G20 (BARI Bt Begun 2), G11 (BARI Hybrid Begun 2), G8 (BARI Begun 6), G5 (BARI Hybrid Begun 4), G18 (Local Black Long) might be used in future breeding program.

Keywords: Brinjal, Characterization, Correlation, Diversity

[*] Corresponding author: sumonsau@sau.edu.bd

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INTRODUCTION

Brinjal (*Solanum melongena* L.) is a warm season crop mostly cultivated in tropical and subtropical regions of the world. It is one of the most common, popular and principal vegetable crops of Bangladesh grown throughout the country except at higher altitudes. Brinjal is the most popular vegetable with high nutritional value and lots of health benefits. It is highly beneficial for the regulation of blood sugar levels which helps to control the absorption of glucose (Saha *et al.*, 2019). Fiber contents help in digestion by removing toxins and harmful materials from our stomach thus by reducing stomach and colon cancer (Fraikue, 2016). The extracts of brinjal root and leaves can cure problems such as skin diseases, cough, toothache, piles, inflammation, throat problems, and stomach problems (Barik *et al.*, 2020).

More than 70 different types of insect species attack the brinjal (Subbarathnam, 1982). However, more than 80% yield loss occurs due to Brinjal Shoot and Fruit Borer attack (Mishra, 2008). It feeds internally on the fruit and excretes inside the fruit making worthless for human consumption (Baral *et al*., 2006).

Therefore, brinjal improvement programs need to focus on developing higher yield potential varieties, better fruit quality, good shelf-life, resistance to major insect, pest, and diseases with greater adaptation to different stress conditions. This research aimed to characterize as well as to assess the genetic diversity among different existing genotypes, and to identify the best genotypes for the varietal improvement of brinjal in Bangladesh.

MATERIALS AND METHODS

The brinjal genotypes were distributed randomly in each block. Five plants were planted for each genotype in every single row. From every block, three plants were chosen randomly for each genotype and tagged properly for data collection. At different growth stages, data were recorded on different morphological parameters. The analysis of variance, the mean values of all characters and the significant difference among the treatment means were calculated by using R package (variability, agricolae). The generalized distance method of Mahalanobis (1936) was used to determine genetic diversity (D^2) using GENSTAT software.

RESULTS AND DISCUSSION

Variability, heritability and genetic advance

The results of ANOVA showed that the brinjal genotypes varied significantly for all the studied characters (Table 1). The significant differences among the genotypes indicated the presence of genetic variability in the material used and provided a good opportunity for improvement. For all the studied attributes, the existence of genetic variability was investigated using heritability, genetic advance, genetic advance in percentage of mean, genotypic, and phenotypic co-efficient of variation (Table 2).

Table 1. Analysis of variance of fifteen characters of twenty genotypes of brinjal

Source of Variation	df	Mean sum of square													
		DFF	DFPF	DFH	DLH	PH	NPBP	NSBP	LBL	LBW	FW	FL	FD	NFPP	BSFBI	YPP
Replication	2	71.47	32.85	3.35	5.60	220.37	1.07	56.11	12.40	2.04	41.92	0.02	0.12	6.22	101.68	0.02
Genotype	19	327**	243.93**	207.42**	539.87**	575.93**	5.14**	49.28*	13.76**	14.08**	1363.24**	51.86**	7.73**	70.77**	1232.14**	0.19**
Error	38	12.26	12.38	11.82	23.06	55.00	1.71	25.72	3.65	2.68	51.20	1.28	0.12	3.84	121.90	0.01

df = Degrees of freedom, ** = 1% level of significance, * = 5% level of significance

Table 2. Estimation of genotypic and phenotypic variation, genotypic and phenotypic co-efficient of variations, heritability, genetic advance and genetic advance percentage over mean for fifteen characters of brinjal

Characters	σ^2_g	σ^2_p	GCV	PCV	h^2b	GA	GAPM
DFF	104.92	117.17	9.66	10.21	90	19.97	18.82
DFPF	77.19	89.56	7.81	8.42	86	16.80	14.94
DFH	65.20	77.02	6.14	6.67	85	15.30	11.64
DLH	172.27	195.33	6.63	7.06	88	25.39	12.82
PH	173.64	228.64	17.51	20.09	76	23.66	31.43
NPBP	1.15	2.85	12.76	20.13	40	1.40	16.65
NSBP	7.86	33.57	17.37	35.92	23	2.79	17.31
LBL	3.37	7.03	10.08	14.55	48	2.62	14.38
LBW	3.80	6.48	15.34	20.03	59	3.08	24.20
FW	437.35	488.54	31.49	33.28	90	40.76	61.37
FL	16.86	18.14	29.79	30.90	93	8.16	59.16
FD	2.54	2.65	37.69	38.54	96	3.21	75.94
NFPP	22.31	26.15	46.36	50.19	85	8.99	88.20
BFSBI	370.08	491.98	59.50	68.60	75	34.37	106.30
YPP	0.06	0.07	48.38	53.67	81	0.46	89.85

(σ^2_g - Genotypic variation, σ^2_p - Phenotypic variation, GCV- Genotypic co-efficient of variation, PCV- Phenotypic co-efficient of variation, h^2b- Heritability percentage in broad sense, GA- Genetic advance, GAPM- Genetic advance percentage over mean), DFPF- Days to first flowering, DFPF- Days to 50% flowering, DFH- Days to first harvesting, DLH- Days to last harvesting, PH- Plant height (cm), NPBP- No. of primary branches plant^{-1}, NSBP- No. of secondary branches plant^{-1}, LBL- Leaf blade length (cm), LBW- Leaf blade width (cm), FL- Fruit length (cm), FD- Fruit diameter (cm), FW- Individual fruit weight (g), NFPP- No. of fruits plant^{-1}, BSFB- Percent of BSFB infestation, YPP- Yield

For all studied characters, the phenotypic variance was higher than the corresponding genotypic variance, indicating a greater influence of the environment on these characters' expression. Characters like individual fruit weight, fruit length, fruit diameter, number of fruits plant^{-1}, percent of BSFB infestation and yield plant^{-1} exhibited high genotypic and phenotypic co-efficient of variation. Plant height, number of primary branches plant^{-1} and number of secondary branches plant^{-1} exhibited high phenotypic co-efficient of variation. The phenotypic co-efficient of variation was higher than the genotypic co-efficient of variation for all the characters. The maximum difference between phenotypic and genotypic coefficient of variation were 35.92 and 17.37, respectively which indicated that the number of secondary branches plant^{-1} was mostly depended on the environmental condition. Highest phenotypic co-efficient of variation (68.60) was found in percent of BSFB infestation and genotypic co-efficient of variation (59.50) was found in percent of BSFB infestation. High heritability associated with high genetic advance and high genetic advance in percentage of mean was found in plant height, individual fruit weight and percent of BSFB infestation which indicated that additive gene expression on this character and selection methods can be accomplished for the improvement of these traits. Fruit length, fruit diameter, number of fruits plant^{-1} and yield plant^{-1} showed high heritability with low genetic advance and high genetic advance in percentage of mean that might be presence of additive and non-additive gene expression. High heritability with high genetic advance and low genetic advance in percentage of mean were found in days to last harvesting**.**

Table 3. Mean performance, range, standard error and coefficient of variation in respect of fifteen characters of twenty brinjal genotypes

Genotypes	DFF	DFPF	DFH	DLH	PH	NPBP	NSBP	LBL	LBW	FW	FL	FD	NFPP	BFSBI	YPP
G1	105.34fg	111ef	128ef	176.33fg	71.23d-f	8.55a-d	12.77c-e	16.9c-e	10ef	50.44ij	14.07de	3.2e	10.22d-g	10.26e-h	0.29f-h
G2	109.67d-f	113de	130d-f	183f	68.46ef	9a-c	17.1a-d	18.56bc	13.37a-c	61.22g-i	14.49d	3.85d	8.88e-g	43.83bc	0.34e-g
G3	109.67d-f	113.67de	129ef	196de	61.25fg	7.44b-d	15.88a-e	18.67a-c	14.03a-c	61.45g-i	14.06de	3.82d	12.78cd	12.31d-h	0.65c
G4	96.34h	106.67f	126f	197cde	71.81d-f	9.11ab	9.88de	18.63a-c	12.1c-e	70.03e-g	9.45g	6.07bc	8.55fg	49.19b	0.43d-g
G5	106.33e-g	111.33ef	128ef	207.67ab	85.68b	9.abc	24.22a	20.76ab	15.27ab	75.58de	10.07g	5.95bc	22.33a	29.06cd	1.10a
G6	106e-g	117.33b-d	128ef	204bc	62.58fg	9.22ab	13.21c-e	16.93c-e	10.17d-f	79.67de	9.62g	6.92a	7.33gh	22.6def	0.44d-g
G7	103.34g	114.67de	129.33d-f	204bc	78.68b-e	8.55a-d	15.49b-e	18.7a-c	13.23a-c	63.07f-h	12.7d-f	3.92d	13.05b-d	20.49d-g	0.53c-e
G8	117.33ab	121.33ab	140b	203b-d	70.15d-f	9.a-c	19.61a-c	17.63b-d	13.7a-c	117.3a	10.57g	6.78a	2.39j	29.96cd	0.38e-g
G9	119a	120.67bc	139b	196de	81.21b-d	6.94cd	12.33c-e	18.43bc	13.57a-c	93.11bc	10.5g	6.07bc	3.83ij	28.33c-e	0.32fg
G10	70.67i	82h	105g	168.33h	39.76h	7.55b-d	17a-d	14.06ef	8.73f	29.42l	9.35g	3.08e	11.33c-f	7.48f-h	0.42d-g
G11	113b-d	115c-e	146a	204bc	99.75a	9.a-c	23.5ab	20.2ab	14.57a-c	101.33b	12.6ef	3.92d	4.78h-j	45.23bc	0.43d-g
G12	108.33d-g	114de	132c-e	204.33bc	84.7bc	9.a-c	19.66a-c	21.73a	14.83ab	74.1d-f	11.09fg	5.52c	13.88bc	48.69b	0.87b
G13	108.67d-g	113.67de	139b	210.33ab	78.75b-e	8.5a-d	15.88a-e	20.53ab	13.9a-c	55.92h-j	19.12bc	2.78e	8.16fg	61.46ab	0.40d-g
G14	105.67e-g	112d-f	128ef	206.67ab	72.90c-f	8.33a-d	15.88a-e	19.6a-c	14.2a-c	84.67cd	10.58g	6.38ab	14.11bc	28.92cd	1.06ab
G15	106e-g	111.67d-f	135b-d	207.67ab	87.05b	9.77a	19.66a-c	19.13a-c	15.67a	53.8h-j	18.52bc	2.78e	16.05b	52.93b	0.66c
G16	111.33c-e	115.67b-e	139b	209ab	80.4b-e	8.78a-d	16.33a-e	18.3bc	13.06a-c	56.11h-j	20.01ab	2.08f	7g-i	72.92a	0.26gh
G17	106.33e-g	114.67de	132cde	213a	87.65ab	9.22ab	15.1c-e	17.96bc	12.8b-d	61.31g-i	19.93ab	2.75e	11.9c-e	50.85b	0.59cd
G18	109.66d-f	114de	132.33c-e	207.67ab	89ab	9.89a	18.1a-d	19.3a-c	13a-c	56.39h-j	17.27c	2.87e	11.11c-f	28.97cd	0.47c-f
G19	92.34h	99.67g	127ef	193e	52.49g	4.11e	12.88c-e	14.8d-f	9.47ef	46.11jk	21.72a	2.88e	13.11b-d	3.2gh	0.39e-g
G20	116.33a-c	127a	137.33bc	170gh	81.7b-d	6.83d	8.11e	13.56f	8.53f	37.33kl	9.98g	2.93e	3j	0h	0.12h

Genotypes	DFF	DFPF	DFH	DLH	PH	NPBP	NSBP	LBL	LBW	FW	FL	FD	NFPP	BFSBI	YPP
MAX	119.00	127.00	146	213	99.75	9.89	24.22	21.73	15.67	117.3	21.72	6.92	22.33	72.92	1.10
MIN	70.67	82.00	105	168.33	39.76	4.11	8.11	13.567	8.53	29.42	9.35	2.08	2.39	0.00	0.12
MEAN	108.48	112.45	131.50	198.05	75.26	8.39	16.13	18.22	12.71	66.42	13.78	4.23	10.19	32.33	0.51
CV%	3.30	3.06	2.67	2.42	9.85	15.54	31.43	10.48	12.88	10.77	8.18	7.84	19.23	34.15	19.70
SE	2.86	2.87	2.81	3.92	6.06	1.07	4.14	1.56	1.34	5.84	0.92	0.28	1.60	9.01	0.10
LSD	5.79	5.81	5.68	7.94	12.26	2.16	8.38	3.16	2.71	11.83	1.87	0.56	3.24	18.25	0.20

SE- Standard error, CV- Co-efficient of variation, LSD- Least Significant Differences, DFPF- Days to first flowering, DFPF- Days to 50% flowering, DFH- Days to first harvesting, DLH- Days to last harvesting, PH- Plant height (cm), NPBP- No. of primary branches plant^{-1}, NSBP- No. of secondary branches plant^{-1}, LBL- Leaf blade length (cm), LBW- Leaf blade width (cm), FL- Fruit length (cm), FD- Fruit diameter (cm), FW- Individual fruit weight (g), NFPP- No. of fruits plant^{-1}, BSFB- Percent of BSFB infestation, YPP- Yield plant^{-1} (kg)

According to the mean performance, G10 (70.67 DAS) had the shortest length needed for first flowering, whereas G9 (119 DAS) had the longest. The maximum time was observed in G20 (127 DAS) and the shortest duration needed for 50% flowering was identified in G10 (82 DAS). G10 had the minimum 105 DAS period needed for first fruit harvesting while G11 had the 146 DAS maximum length. The longest period needed for the last fruit harvesting has been found in G17 (213 DAS), and the shortest period was reported in G10 with 168.33 DAS. The G11 plant measured 99.75 cm in height at its maximum, whereas the G10 plant measured 39.76 cm at its shortest. The genotype G18 scored the most primary branches (9.89), while the genotype G19 recorded the fewest (4.11). G5 was found to have the most secondary branches (24.22), whereas the genotype G20 had the fewest (8.11). The largest fruit weight in G8 was 117.3 g, and the smallest fruit weight in G10 was 29.42 g. The genotype G19 had the longest fruit length at 21.72 cm, while genotype G10 had the shortest fruit length (9.35 cm). The genotype G6 had the largest fruit diameter (6.92 cm), whereas G16 had the smallest (2.08 cm). Genotype G5 produced the most fruits plant-1 (22.33) and the genotype G8 produced the fewest (2.39). G16 had the highest brinjal shoot and fruit borer infestation (72.92%), whereas the genotype G20 had the lowest infestation (0%). The largest fruit yield plant^{-1} 1.10 kg emerged in G5, and the lowest 0.12 kg was found in G20.

Correlation co-efficient

Assessments of character association (Table 4) indicating that fruit yield plant^{-1} had highest significant positive correlation with days of last harvesting (r_g = 0.495, r_p = 0.454), number of secondary branches plant^{-1} (r_g=0.356, r_p=0.315), leaf blade length (r_g = 0.714, r_p = 0.462), leaf blade width (r_g = 0.674, r_p = 0.498) and number of fruits plant^{-1} (r_g= 0.798, r_p= 0. $^{-1}$787) in both genotypic and phenotypic level indicating the importance of these trait in selection for increasing yield and were identified as yield attributing characters. Thus, selection can be effective upon these characters for the genetic improvement of brinjal yield.

Path co-efficient analysis

Table 6 shows the partitioning of genotypic correlations into direct and indirect effects of significant features of brinjal. Path analysis showed that the highest positive direct effect was number of fruits plant^{-1} (1.421) and the lowest positive direct effect was fruit length (0.083). Days to 50% flowering, days to first harvesting, no. of primary branches plant^{-1}, no. of secondary branches plant^{-1}, leaf blade width, individual fruit weight, fruit length, fruit diameter, no of fruits plant^{-1} and percent of BSFB infestation showed positive direct effect on fruit yield plant^{-1} indicating that direct selection based on these traits may be effective in evolving high yielding varieties. The residual effect of path co-efficient analysis was 0.1033 which reported that the traits under study contributed 89.67% of the fruit yield plant^{-1}. It can be said that there were some other traits that contributed 10.33% to the yield plant^{-1} that were not included in the present study.

Table 4. Genotypic and Phenotypic correlation co-efficient among different pairs of yield and yield contributing characters for 20 genotypes of brinjal

Traits	Symbol	DFF	DFPF	DFH	DLH	PH	NPBP	NSBP	LBL	LBW	FW	FL	FD	NFPP	BFSBI
DFPF	rg	0.984**													
	rp	0.913**													
DFH	rg	0.907**	0.868**												
	rp	0.854**	0.748**												
DLH	rg	0.389^{NS}	0.354^{NS}	0.505*											
	rp	0.345**	0.288*	0.413**											
PH	rg	0.736**	0.712**	0.800**	0.580**										
	rp	0.611**	0.555**	0.683**	0.496**										
NPBP	rg	0.296^{NS}	0.328^{NS}	0.236^{NS}	0.536*	0.673**									
	rp	0.210^{NS}	0.172^{NS}	0.128^{NS}	0.359**	0.358**									
NSBP	rg	0.093^{NS}	-0.175^{NS}	0.237^{NS}	0.651**	0.480*	0.654**								
	rp	0.060^{NS}	-0.023^{NS}	0.091^{NS}	0.312*	0.267*	0.328*								
LBL	rg	0.509*	0.375^{NS}	0.492*	0.877**	0.721**	0.832**	0.884**							
	rp	0.285*	0.176^{NS}	0.309*	0.565**	0.504**	0.376**	0.434**							
LBW	rg	0.561*	0.399^{NS}	0.566**	0.845**	0.694**	0.656**	0.974**	0.956**						
	rp	0.344**	0.227^{NS}	0.353**	0.571**	0.496**	0.395**	0.490**	0.853**						
FW	rg	0.572**	0.478*	0.555*	0.518*	0.385^{NS}	0.349^{NS}	0.533*	0.593**	0.607**					
	rp	0.489**	0.447**	0.462**	0.444**	0.312*	0.243^{NS}	0.288*	0.389**	0.462**					
FL	rg	0.031^{NS}	-0.053^{NS}	0.260^{NS}	0.354^{NS}	0.139^{NS}	-0.164^{NS}	0.061^{NS}	0.041^{NS}	0.096^{NS}	-0.388^{NS}				
	rp	0.03^{NS}	-0.041^{NS}	0.216^{NS}	0.319*	0.130^{NS}	-0.077^{NS}	0.017^{NS}	0.041^{NS}	0.097^{NS}	-0.325*				
FD	rg	0.189^{NS}	0.220^{NS}	-0.003^{NS}	0.197^{NS}	-0.054^{NS}	0.203^{NS}	0.046^{NS}	0.329^{NS}	0.246^{NS}	0.751**	-0.748**			
	rp	0.179^{NS}	0.204^{NS}	-0.002^{NS}	0.180^{NS}	-0.042^{NS}	0.116^{NS}	0.107^{NS}	0.205^{NS}	0.194^{NS}	0.720**	-0.696**			
NFPP	rg	-0.370^{NS}	-0.407^{NS}	-0.458*	0.262^{NS}	-0.046^{NS}	0.143^{NS}	0.637**	0.384^{NS}	0.349^{NS}	-0.290^{NS}	0.155^{NS}	-0.044^{NS}		
		-0.373**	-0.377**	-0.421**	0.242^{NS}	0.017^{NS}	0.041^{NS}	0.240^{NS}	0.283*	0.283*	-0.240^{NS}	0.135^{NS}	-0.042^{NS}		

Traits	Symbol	DFF	DFPF	DFH	DLH	PH	NPBP	NSBP	LBL	LBW	FW	FL	FD	NFPP	BFSBI
BFSBI	rg	0.278^{NS}	0.204^{NS}	0.483*	0.709**	0.590**	0.777**	0.514*	0.829**	0.746**	0.280^{NS}	0.378^{NS}	-0.068^{NS}	-0.010^{NS}	
	rp	0.288*	0.196^{NS}	0.403**	0.553**	0.436**	0.404**	0.227^{NS}	0.462**	0.485**	0.194^{NS}	0.322*	-0.088^{NS}	-0.039^{NS}	
YPP	rg	-0.048^{NS}	-0.103^{NS}	-0.182^{NS}	0.495*	0.170^{NS}	0.366^{NS}	0.885**	0.714**	0.674**	0.249^{NS}	-0.182^{NS}	0.416^{NS}	0.798**	0.147^{NS}
	rp	-0.121^{NS}	-0.135^{NS}	-0.205^{NS}	0.454**	0.163^{NS}	0.134^{NS}	0.291*	0.462**	0.479**	0.238^{NS}	-0.166^{NS}	0.370**	0.787**	0.058^{NS}

*(5% level of significance), ** (1% level of significance), NS (Non- significant), rg - Genotypic correlation, rp- Phenotypic correlation DFPF- Days to first flowering, DFPF- Days to 50% flowering, DFH- Days to first harvesting, DLH- Days to last harvesting, PH- Plant height (cm), NPBP- No. of primary branches plant^{-1}, NSBP- No. of secondary branches plant^{-1}, LBL- Leaf blade length (cm), LBW- Leaf blade width (cm), FL- Fruit length (cm), FD- Fruit diameter (cm), FW- Individual fruit weight (g), NFPP- No. of fruits plant^{-1}, BSFB- Percent of BSFB infestation, YPP- Yield plant^{-1} (kg)

Table 5. Path coefficient analysis showing direct and indirect effects of different characters on yield plant^{-1} of brinjal

Characters	DFF	DFPF	DFH	DLH	PH	NPBP	NSBP	LBL	LBW	FW	FL	FD	NFPP	BFSBI	r
DFF	-1.209	0.900	0.952	-0.160	-0.375	0.165	0.010	-0.469	0.321	0.237	0.003	0.069	-0.526	0.035	-0.048^{NS}
DFPF	-1.190	0.915	0.910	-0.145	-0.362	0.183	-0.018	-0.345	0.228	0.198	-0.004	0.081	-0.578	0.026	-0.103^{NS}
DFH	-1.097	0.794	1.049	-0.207	-0.407	0.131	0.024	-0.453	0.323	0.230	0.022	-0.001	-0.651	0.061	-0.182^{NS}
DLH	-0.471	0.324	0.529	-0.411	-0.295	0.299	0.066	-0.808	0.483	0.215	0.030	0.072	0.372	0.090	0.495*
PH	-0.890	0.651	0.839	-0.238	-0.509	0.375	0.049	-0.664	0.397	0.160	0.012	-0.020	-0.066	0.075	0.170^{NS}
NPBP	-0.358	0.300	0.247	-0.220	-0.343	0.557	0.067	-0.766	0.375	0.145	-0.014	0.074	0.203	0.098	0.366^{NS}
NSBP	-0.113	-0.160	0.248	-0.267	-0.244	0.364	0.102	-0.814	0.557	0.221	0.005	0.017	0.906	0.065	0.885**
LBL	-0.615	0.343	0.516	-0.360	-0.367	0.463	0.090	-0.921	0.546	0.246	0.003	0.121	0.546	0.105	0.714**
LBW	-0.679	0.365	0.594	-0.347	-0.353	0.365	0.100	-0.881	0.571	0.252	0.008	0.090	0.495	0.094	0.674**
FW	-0.692	0.437	0.582	-0.213	-0.196	0.194	0.054	-0.547	0.347	0.414	-0.032	0.276	-0.412	0.035	0.249^{NS}
FL	-0.038	-0.048	0.273	-0.146	-0.071	-0.091	0.006	-0.038	0.055	-0.161	0.083	-0.275	0.220	0.048	-0.182^{NS}
FD	-0.229	0.202	-0.003	-0.081	0.028	0.113	0.005	-0.303	0.141	0.311	-0.062	0.367	-0.063	-0.009	0.416^{NS}
NFPP	0.448	-0.372	-0.480	-0.108	0.024	0.080	0.065	-0.354	0.199	-0.120	0.013	-0.016	1.421	-0.001	0.798**
BFSBI	-0.336	0.186	0.507	-0.291	-0.301	0.433	0.053	-0.764	0.426	0.116	0.031	-0.025	-0.014	0.127	0.147^{NS}

Residual: 0.1033, r indicates genotypic correlation coefficient with NS (Non- significant), 5% (*) and 1% (**) level of significance

DFPF- Days to first flowering, DFPF- Days to 50% flowering, DFH- Days to first harvesting, DLH- Days to last harvesting, PH- Plant height (cm), NPBP- No. of primary branches plant^{-1}, NSBP- No. of secondary branches plant^{-1}, LBL- Leaf blade length (cm), LBW- Leaf blade width (cm), FL- Fruit length (cm), FD- Fruit diameter (cm), FW- Individual fruit weight (g), NFPP- No. of fruits plant^{-1}, BSFB- Percent of BSFB infestation, YPP- Yield plant^{-1} (kg)

Genetic diversity of twenty brinjal genotypes

A two-dimensional scatter diagram utilizing component score 1 as the X-axis and component score 2 as the Y-axis was constructed based on the values of principal component scores 2 and 1 obtained from the principal component analysis. This

diagram is shown in Figure 1. There was clearly a five-group distribution of genotypes positions in the scatter diagram, indicating that there was a high degree of genotypic diversity.

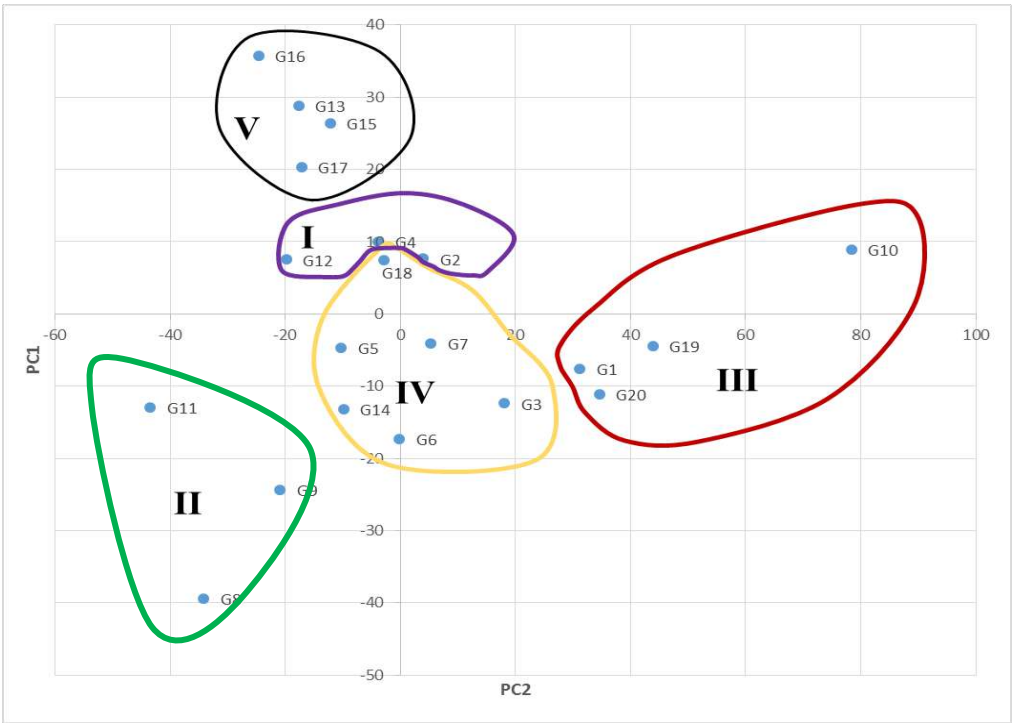

Figure 1. Scattered distribution of twenty brinjal genotypes on principal component score superimposed with clustering

According to PCA, D^2 and Cluster analysis, the genotypes were grouped into five different clusters. Cluster I, II, III, IV and V composed of three, three, four, six and four genotypes respectively (Table 6).

Table 6. Distribution of twenty brinjal genotypes in five different clusters

Clusters	No. of genotypes	Name of genotypes
I	3	G2, G4, G12
II	3	G8, G9, G11
III	4	G1, G10, G19, G20
IV	6	G3, G5, G6, G7, G14, G18
V	4	G13, G15, G16, G17

Plate 1. Leaves from twenty genotypes of brinjal

Plate 2. Flowers from twenty genotypes of brinjal

Plate 3. Fruits shapes of twenty brinjal genoty

Plate 4. BSFB infected fruits from sixteen genotypes of brinjal

Table 7. Cluster mean for fifteen characters of twenty genotypes of brinjal

Characters	Clusters				
	I	II	III	IV	V
Days to first flowering	104.78	116.44	96.16	106.77	108.08
Days to 50% flowering	111.22	119.00	104.91	113.83	113.91
Days to first harvesting	129.33	141.67	124.33	129.28	136.25
Days to last harvesting	194.78	201.00	176.92	204.33	210.00
Plant height (cm)	74.99	83.71	61.30	75.02	83.46
No. of primary branches plant^{-1}	9.03	8.31	6.76	8.74	9.07
No. of secondary branches plant^{-1}	15.55	18.48	12.69	17.13	16.75
Leaf blade length (cm)	19.64	18.76	14.83	18.99	18.98
Leaf blade width (cm)	13.43	13.94	9.18	13.32	13.86
Individual fruit weight (g)	68.45	103.91	40.82	70.13	56.78
Fruit length (cm)	11.68	11.22	13.78	12.38	19.40
Fruit diameter (cm)	5.15	5.59	3.02	4.97	2.60
Number of fruits plant^{-1}	10.44	3.67	9.41	13.45	10.78
Percent of BSFB infestation	47.23	34.50	5.23	23.72	59.54
Yield plant-1 (kg)	0.55	0.38	0.30	0.71	0.48

From the clustering mean values, it was observed that cluster I produced the highest mean values for leaf blade length (19.64 cm) in comparison with other five clusters (Table 9). On the other hand, cluster II produced the highest mean values for days to first flowering (116.44 days), days to 50% flowering (119 days), days to first harvesting (141.67 days), plant height (83.71 cm), no. of secondary branches plant-1 (18.48), leaf blade width (13.94 cm), individual fruit weight (103.91 g) and fruit diameter (5.59 cm) (Table 9). Cluster III produced the second highest mean value for fruit length (13.78 cm). Cluster IV had the highest mean values for number of fruits plant-1 (13.45) and yield plant-1 (0.71 kg). Cluster V had the highest mean values for the number of primary branches plant-1 (9.07), fruit length (19.4 cm), and percentage of BSFB infestation (59.54) (Table 7).

Table 8. Average intra (bold) and inter cluster distances (D^2) for twenty brinjal genotypes

Cluster	I	II	III	IV	V
I	0.819				
II	71.42	0.855			
III	14.44	72.24	1.918		
IV	7.95	64.79	11.94	0.957	
V	24.37	95.69	30.1	31.72	0.604

Results showed the maximum inter cluster distance was recorded between cluster II and V (95.69), followed by between II and III (72.24), and II and I (71.42). So, genotypes from these clusters if involved in hybridization might produce a wide range of segregating populations, as genetic variation was very distinct among these groups. The lowest inter cluster distance was found between the cluster I and IV (7.95) followed by III and IV (11.94), I and IV (14.44) representing a close relationship among these clusters. The intra cluster divergence varied from 1.918 from cluster III which comprised of four cultivars of diverse origin to 0.604 from cluster V which comprised four genotypes. Higher inter cluster distances indicated greater genetic variation among the genotypes of different clusters (Table 8).

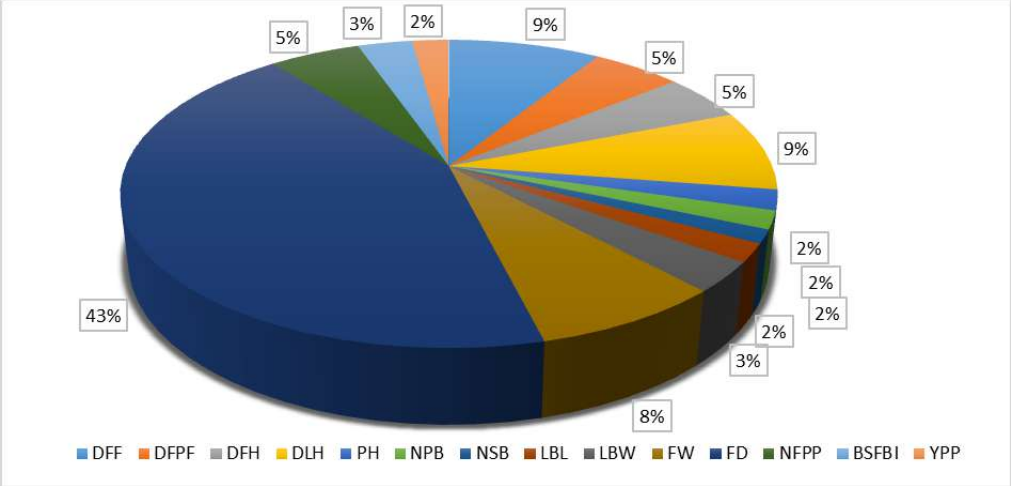

Figure 2. Relative contribution of fifteen characters of twenty brinjal genotypes towards divergence

The relative contribution of fifteen quantitative traits to genetic divergence among the twenty germplasms of brinjal is presented in Figure 2. Among the all characters, the maximum contribution towards divergence was made by fruit diameter (36.4%) followed by fruit length (16%) (Figure 2).

CONCLUSION

Among all the genotypes, maximum (1.10 kg) yield plant^{-1} was found in G5 due to better performances in important yield contributing characters such as number of secondary branches and number of fruits plant^{-1}. The phenotypic co-efficient of variation was higher than the genotypic co-efficient of variation for all characters. High heritability associated with high genetic advance and high genetic advance in percentage of mean was found in plant height, individual fruit weight and percent of BSFB infestation which indicated that additive gene expression on this character,

suggesting the high possibility of selecting the genotypes for this trait. Considering cluster distances, genetic parameters and based on the objectives, the genotypes G10 (Choto Katali) and G20 (BARI Bt Begun 2) from cluster III, G11 (BARI Hybrid Begun 2) and G8 (BARI Begun 6) from cluster II, G5 (BARI Hybrid Begun 4) along with G18 (Local Black Long) from cluster IV might be used in future breeding program.

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YIELD EVALUATION OF CULTIVATED DROUGHT TOLERANT RICE VARIETIES IN BANGLADESH

M.A. Hossain*

Department of Biotechnology and Genetic Engineering, Noakhali Science and Technology University, Noakhali-3814, Bangladesh.

ABSTRACT

An experiment was conducted with seven drought tolerant rice varieties i.e., Binadhan-17, Binadhan-19, BRRI dhan56, BRRI dhan57, BRRI dhan66, BRRI dhan71 and BRRI dhan83 were used as plant materialism. Boro season during December 2022-May 2023 to evaluate the yield performance at the reproductive stage as well as disclose the inherent variability of the varieties for yield and yield attributing traits following a randomized complete block design with three replications. Significant variation ($p<0.01$) was observed for genotype, treatment and G (genotype) × T (treatment) interactions *viz.*, days to maturity, plant height, effective tillers/plant, filled grains/plant, unfilled grains/plant, 100-seed weight, grain yield/plant and H_2O_2. Drought stress lead to a significant decrease in grain yield/plant in all of the varieties; highest decrease was found in BRRI dhan56 (48.65%) followed by BRRI dhan57, BRRI dhan66, Binadhan-17, Binadhan-19, BRRI dhan83, and BRRI dhan71 (42.08, 39.01, 37.58, 34.54, 32.28 and 31.92%, respectively) related to control. Interestingly, the highest yield was recorded in Binadhan-17. Principle component analysis revealed that the first two components explained 76.1% of the total variations of the studied varieties, indicating total tillers/plant, effective tillers/plant, filled grains/plant, 100-seed weight and grain yield/plant are the most important characters contributing to yield. Grain yield/plant showed significant positive correlation with total tillers/plant, effective tillers/plant, filled grains/plant, 100 seed weight. From stress tolerance indices Binadhan-17 was categorized as tolerant genotype with superior yield performance and this genotype was selected for further study under different drought prone areas of Bangladesh as well as for genetic improvement against drought stress.

Keywords: Rice, Drought, Stress Tolerant Index, Yield Performance

* Corresponding author: anwar.bge@nstu.edu.bd

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INTRODUCTION

Rice (*Oryza sativa* L.) is the most extensively consumed staple food for a significant percentage of the world's population, particularly in Asia (Hossain et al., 2023). Climate change poses a significant threat to agriculture, particularly in underdeveloped countries. This danger to food security, as well as the resulting economic losses, has heightened the need for the creation of abiotic stress robust rice cultivars with higher yield potential (Hoque et al., 2020). Drought is the most pressing and significant abiotic factor limiting rice output in rainfed habitats (Pandey & Shukla, 2015). Rice productivity and sustainability in Bangladesh are constantly threatened by abiotic factors such as drought, salinity, and heat or cold stress. Drought linked with high temperatures has a significant detrimental influence on agricultural productivity. Rice yield loss due to minor drought ranges from 10-30% and can reach 70-90% in severe drought (Hossain et al., 2023).

To keep up with population growth, rice production should increase by nearly 50% to 950 million tons by 2025 (Laborte et al., 2012). Drought causes about 1% of land loss in Bangladesh each year. Rice is significant in Bangladesh's agro-economy and national health. Over the previous three decades, Bangladesh has achieved significant success in maintaining a decent growth in rice output. Droughts are common in Bangladesh due to its geophysical location, fluctuating rainfall patterns, and high temperatures (Rahman, 2011). The degree and duration of drought stress during the reproductive stage in rainfed lowland rice requires the development of drought tolerant rice cultivars (Kamoshita et al., 2008), which must survive under water deficit stress during the reproductive stage, quickly recover, and grow rapidly when soil moisture is restored (De Datta et al., 1988). Drought has a negative impact on growth, yield, membrane integrity, pigment content, osmotic adjustment, water relation, and photosynthetic activities (Praba et al., 2009).

Fundamental research has offered considerable insights into the physiological, biochemical, and molecular responses of plants to drought stress, yet there is still a significant yield difference between normal and drought stress conditions. Bangladesh has created some drought-tolerant rice varieties, but yield varies among the drought-tolerant rice cultivars grown in Bangladesh. So, the experiment was carried out to determine the variety with the highest yield potential when cultivated in drought condition.

MATERIALS AND METHOD

Soil and climate

The soil used for the experiment was silt loam, silt clay-loam and its belongs to the high Ganges river floodplain under the agro-ecological zone (AEZ 11, 14) which is predominantly highland and medium highland in nature. The climate here is warmly equated with warmth. Annual average temperature is 22°.24' Celsius and annual rainfall is 152.190 cm.

Location and experimental design

The experiment was conducted at the drought prone area, Jhenaidah (latitude 23.63°, and longitude 89.07°) of farmer's field during Boro season during December 2022 to May 2023. The experiment was laid out in RCBD with 3 replications.

Plant Materials

Seven drought tolerant rice varieties i.e., Binadhan-17, Binadhan-19, BRRI dhan56, BRRI dhan57, BRRI dhan66, BRRI dhan71 and BRRI dhan83 were used as plant materials. The seeds were collected from Bangladesh Rice Research Institute (BRRI) and Bangladesh Institute of Nuclear agriculture (BINA).

Seedlings growth and drought stress treatment

Thirty-eight days old seedlings were transplanted in the main field keeping 15 cm plant to plant and 20 cm row to row distance. The unit plot size was 2×2 m^2. There was no replicate for control set where regular watering was followed when necessary and which was set far beside the drought treated plots. All the plants were grown with sufficient watering until the drought stress treatment was initiated. At the end of rice growth stage-4 one group of rice plants were subjected to drought stress and continued up to ripening stage.

Fertilizer application

Recommended doses of fertilizer (Urea, TSP and MP) were applied to the soil during soil preparation. Urea was applied in three times; first dose was applied after thirty days of transplanting, second dose was applied at active tillering stage, and third dose was applied at panicle initiation stage.

Intercultural operation

Intercultural operations were also done whenever necessary. The following operations also made during experimental time.

Weeding

Weed control is an important step to prevent losses in yield and to preserve good grain quality. The experimental plots were affected by some common weeds and those were removed carefully from the soil by uprooting them without bringing any injury of rice plants.

General observation of the experimental plots

Close observation was prerequisite for any kind of successful experiment. Observation was done regularly. All the stages of plants and responses of plants as per respective treatments were regularly observed.

Harvesting

Harvesting was done based upon the maturity of different genotypes. Maturity of crop was determined when about 80-90% grains of the plant became golden yellow

color. The different varieties were harvested when they attained their maturity and phenotypic changes also observed.

Sampling, threshing and processing

The harvested plants for each plot were collected separately with proper tagging. The sample was sun dried and threshing was done carefully by hand.

Data on morphological traits at the reproductive stage

Observations were recorded on days to maturity, plant height (cm), total tillers/plant, effective tillers/plant, panicle length (cm), filled grains/plant, unfilled grains/plant, 100-seed weight (g), grain yield/plant (g) and hydrogen peroxide (H_2O_2).

Estimation of hydrogen peroxide (H_2O_2)

$H_2O_2$from leaf tissues at the reproductive stage and from flag leaf tissues at the reproductive stage was measured following the method of Velikova et al. (2000) and calculated by utilizing 0.28 $\mu M^{-1}cm^{-1}$ extinction coefficient.

Statistical analysis

Different parameters were compiled and tabulated in proper form for statistical analysis which was carried out in Minitab17 statistical software package. Various statistical tests were performed to assess the varietal performance of the studied varieties.

Calculation of percent yield reduction

For comparing stressed plants with control plants, the reduction percentages for grain yield was calculated by the following formula:

$$(\%)\ \text{Reduction} = \frac{(\textbf{seed yield of stressed plants}) - (\textbf{seed yield of control plants})}{\textbf{seed yield of control plants}} \times 100$$

Estimation of drought stress tolerance indices

Drought stress tolerant indices were calculated using the following formulas:

1. Stress susceptibility index (SSI) = $\frac{1-Y_s/Y_p}{1-\bar{Y}_s/\bar{Y}_p}$ (Fischer & Maurer, 1978)
2. Stress tolerance (TOL) = $Y_p - Y_s$ (Rosielle and Hamblin, 1981)
3. Mean productivity (MP) = $\left(Y_s + Y_p\right)/2$ (Rosielle and Hamblin, 1981)
4. Stress tolerance index (STI) = $\frac{(Y_s)(Y_p)}{({Y_p}^2)}$ (Fernandez, 1992)
5. Geometric mean productivity (GMP) = $\sqrt{Y_p \times Y_s}$ (Fernandez, 1992)
6. Yield index (YI) =$\frac{Y_s}{\bar{Y}_s}$ (Gavuzzi et al., 1997)

RESULTS AND DISCUSSION

Mean performance and effect of drought stress on different yield and yield related traits of rice varieties

Days to maturity

Significant variation was observed among the varieties for days to maturity in response to drought stress. The highest days to maturity under control condition was found in BRRI dhan66 (149.78 days) whereas the lowest was in Binadhan-19 (139.78 days). Under drought condition, days to maturity was highest in BRRI dhan66 (155.15) and the lowest in Binadhan-19 (145.00) (Table 1). Drought stress lead to a significant increase in days to maturity among the varieties studied. The highest induction was observed in BRRI dhan57 (5.29%) whereas the lowest reduction was found in BRRI dhan56 (2.00%) (Table 2).

Table 1. Combined effect of varieties and treatment interaction on yield and yield related traits of rice

Varieties × Treatment		DM	PH	TT/P	ET/P	PL	FG/P	UG/P	100SW	GY/P	H_2O_2
G1	C	143.56def	92.83efg	13.00a	11.72a	22.35abc	1240.00a	666.67bc	2.07abc	25.62a	21.33gh
	D	150.82a-d	85.61hi	11.10abc	9.94abc	21.56bc	794.28e	891.44a	2.01cd	16.00e	23.40efg
G2	C	139.78f	91.83fgh	12.10ab	11.56a	23.56ab	1086.57b	251.94f	2.08ab	22.63bc	23.00fg
	D	145.00def	84.67i	10.70abc	9.72abc	22.46abc	725.33e	357.78ef	2.04bcd	14.80e	25.50e
G3	C	147.93a-e	95.22d-g	7.70cd	6.00de	23.00abc	974.78cd	436.48de	2.10ab	20.46cd	33.43c
	D	150.83a-d	89.56ghi	6.10d	5.04e	22.14abc	514.37g	755.00b	2.04bcd	10.51g	36.04b
G4	C	147.15c-f	100.05bcd	11.30abc	9.48abc	23.22abc	1026.89bcd	503.56d	2.12a	21.77bcd	31.42c
	D	154.93ab	97.00c-f	9.10a-d	7.77cd	22.48abc	615.11fg	940.11a	2.05bc	12.61fg	39.64a
G5	C	149.78a-d	105.67ab	13.00a	10.31ab	23.67a	950.11d	385.00e	2.09ab	19.89d	28.33d
	D	155.15a	101.33a-d	10.00a-d	8.89bc	22.90abc	614.00fg	641.67bc	1.98d	12.14g	36.71b
G6	C	141.33ef	107.00a	11.50abc	9.83a	22.17abc	1072.55bc	418.67de	2.12a	22.78b	21.17gh
	D	147.67b-e	101.67abc	10.00a-d	8.43ab	21.33c	773.67e	621.67c	2.00cd	15.51e	23.80ef
G7	C	147.37cde	98.89cde	10.00a-d	10.00abc	23.11abc	1001.74bcd	698.93bc	2.12a	21.24bcd	20.17h
	D	152.48abc	95.00d-g	8.30bcd	6.78bc	22.19abc	694.81ef	935.89a	2.07abc	14.38ef	22.83fg
Max.	C	149.78	107.00	13.00	11.72	23.67	1240.00	698.93	2.13	25.62	34.12
	D	155.15	101.67	11.10	9.94	22.90	794.28	940.11	2.07	16.00	40.12
Min.	C	139.78	91.83	7.67	6.00	22.17	950.11	251.94	2.07	19.89	19.50
	D	145.00	84.67	6.11	5.04	21.33	514.37	357.78	1.98	10.51	22.00
CV (%)		3.34	7.16	9.27	8.71	4.21	14.62	16.3	2.36	15.94	9.57

Note: C indicate control condition and D indicate drought condition.

Here, DM= Days to maturity, PH= Plant height (cm), TT/P= Total tillers/plant, ET/P= Effective tillers/plant, PL= Plant length (cm), FG/P= Filled grains/plant, UG/P= Unfilled grains/plant, 100SW= 100-seed weight (g), GY/P= Grain yield/plant (g). G1=Binadhan-17, G2=Binadhan-19, G3=BRRI dhan56, G4=BRRI dhan57, G5=BRRI dhan66, G6=BRRI dhan71 and G7=BRRI dhan83.

Table 2. Percent induction/reduction in yield and related traits due to the effect of drought stress among seven rice varieties

Varieties	DM	PH	TT/P	ET/P	PL	FG/P	UG/P	100SW	GY/P	H_2O_2
	+++	---	---	---	---	---	+++	---	---	+++
Binadhan-17	5.05	7.78	14.61	15.15	3.55	35.94	33.91	2.54	37.58	9.72
Binadhan-19	3.74	7.80	11.92	15.90	4.67	33.15	41.99	2.08	34.54	10.98
BRRI dhan56	2.00	5.95	19.91	16.25	3.75	47.25	73.00	2.65	48.65	7.88
BRRI dhan57	5.29	3.03	19.39	17.80	3.20	40.10	86.64	3.30	42.08	26.18
BRRI dhan66	3.59	4.09	22.64	13.83	3.25	35.43	67.01	5.57	39.01	29.62
BRRI dhan71	4.51	4.98	13.00	11.80	3.76	27.86	48.65	5.66	31.92	12.62
BRRI dhan83	3.47	3.94	16.38	12.08	3.99	30.64	33.88	2.36	32.28	13.42

Note: +++ indicate induction and --- indicate reduction.

Here, DM= Days to maturity, PH= Plant height, TT/P= Total tillers/plant, ET/P= Effective tillers/plant, PL= Plant length, FG/P= Filled grains/plant, UG/P= Unfilled grains/plant, 100SW= 100-seed weight, GY/P= Grain yield/plant.

Plant height (cm)

The study found a considerable variation in plant height. Plant height was the highest in BRRI dhan71 (107.00 cm) and the lowest in Binadhan-19 (91.83 cm) under control. Besides, the highest plant height was found in BRRI dhan71 (101.67 cm) and the lowest in Binadhan-19 (84.67 cm) under drought (Table 1). Exposure to drought stress resulted in a remarkable decrease in plant height and the highest decrease was observed in binadhan-19 (7.80%) whereas the lowest in BRRI dhan57 (3.03%) (Table 2).

T**otal tillers/plant**

The treatment effect showed significant variation in total tillers/plant among the varieties studied. number of total tillers/plant was noted maximum in BRRI dhan66 (13.00) and minimum in BRRI dhan56 (7.67) under control condition. Under drought, the highest total tillers/plant was exhibited in Binadhan-17 (11.10) and the lowest in BRRI dhan56 (6.11) (Table 1). Drought stress found to a significant decrease in total tillers/plant in all varieties; highest decrease was found in BRRI dhan66 (22.64%) and the lowest in Binadhan-19 (11.92%) (Table 2).

Effective tillers/plant

The treatment recorded significant variation in number of effective tillers/plant among the varieties. The highest effective tillers/plant was noted in Binadhan-17 (11.72) and the lowest was recorded in BRRI dhan56 (6.00) under control. In contrary, the highest effective tillers/plant was recorded in Binadhan-17 (9.94) and the lowest was in BRRI dhan56 (5.04) under stress (Table 1). Drought stress lead to

significant reduction in effective tillers/plant among all of the varieties; the highest reduction was found in BRRI dhan57 (17.80%) and minimum in BRRI dhan71 (11.80%) (Table 2).

Panicle length

The treatment effect showed considerable variation in panicle length. The highest panicle length was found in BRRI dhan66 (23.67 cm) and the lowest in BRRI dhan71 (22.17 cm) under control. Besides, the maximum panicle length was observed in BRRI dhan66 (22.90 cm) and minimum was in BRRI dhan71 (21.33 cm) under drought (Table 1). Drought stress resulted in decrease in panicle length among all varieties; the highest reduction was found in Binadhan-19 (4.67%) and the lowest was in BRRI dhan57 (3.20%) (Table 2).

Filled grains /plant

In this study, the effect of treatment showed a significant variation in filled grains/plant among the varieties. The highest filled grains/plant were noted in Binadhan-17 (1200.00) and the lowest was in BRRI dhan66 (950.11) under control. In contrary, the highest filled grains/plant were recorded in Binadhan-17 (794.28) and the lowest was in BRRI dhan56 (514.37) under stress (Table 1). Drought stress lead to significant reduction in filled grains/plant among the varieties; the highest reduction was found in BRRI dhan56 (47.25%) followed minimum in BRRI dhan71 (27.86%) (Table 2).

Unfilled grains /plant

Drought treatment displayed significant impacts on unfilled grains/plant as compared to their control. The maximum unfilled grains/plant were observed in BRRI dhan83 (698.93) and the minimum in Binadhan-19 (251.94) under control. Under drought, the highest unfilled grains/plant were noted in BRRI dhan57 (940.11) whereas the lowest was in Binadhan-19 (357.18) (Table 1). Drought stress resulted in a significant increase in unfilled grains/plant, maximum decrease was recorded in BRRI dhan57 (86.64%) and minimum in BRRI dhan83 (33.88%) (Table 2).

100-seed weight

100-seed weight showed a remarkable variation in drought treatment. The highest 100-seed weight was recorded in BRRI dhan83 (2.13 g) and the lowest in Binadhan-17 (2.07 g) under control. The maximum 100-seed weight was found in BRRI dhan83 (2.07 g) and the minimum was in BRRI dhan66 (1.98 g) under drought (Table 1). Drought stress exhibited a significant decrease in 100-seed weight among the varieties studied compared to control. The highest reduction was observed in BRRI dhan71 (5.66%) and lowest in Binadhan-19 (2.08%) (Table 2).

Grain yield/plant

The effect of treatment exhibited significant variation in grain yield/plant among the varieties studied. Grain yield/plant was noted maximum in Binadhan-17 (25.62 g)

and minimum in BRRI dhan66 (19.89 g) under control. Under drought, the highest grain yield/plant was exhibited in Binadhan-17 (16.00 g) and the lowest in BRRI dhan56 (10.51 g) (Table 1). Drought stress lead to a significant decrease in grain yield/plant in all varieties; highest decrease was found in BRRI dhan56 (48.65%) and the lowest in BRRI dhan71 (31.92%) (Table 2).

Hydrogen peroxide (H_2O_2)

H_2O_2 found a significant variation under drought. The highest H_2O_2 was recorded in BRRI dhan56 (34.12 nmol/g) and the lowest in BRRI dhan83 (19.50 nmol/g) under control. The maximum H_2O_2 was found in BRRI dhan57 (40.12 nmol/g) and the minimum was in BRRI dhan83 (22.00 nmol/g) under drought stress (Table 1). Drought stress lead to a significant decrease in H_2O_2 among the varieties studied in comparison with control. The highest induction was observed in BRRI dhan66 (29.62%) and minimum in BRRI dhan56 (7.88%) (Table 2).

The study revealed that the imposition of drought stress significantly reduced yield and yield related characters (Table 2). Tiwari et al. (2019) observed significant variation among varieties for days to maturity, effective tillers/plant, panicle length, and grain yield/plant. These results suggest that all the varieties under study had significant variation with each other, which is very much desirable to breeder for identification of high yielding varieties and also in crop improvement program to enhance the grain yield. The reduction in yield and yield contributing parameters due to drought stress was also found by Mau et al. 2019. The results also showed that drought stress increased H_2O_2 content in all the varieties tested, but the accumulations of H_2O_2 was lower in highly drought tolerant variety having high yield (Table 1). The lower accumulation of H_2O_2 in the drought tolerant varieties implies greater protection against Reactive oxygen species (ROS) and thus perform their signaling function perfectly (Shafiq et al., 2014). The yield contributing traits like filled grains/plant, panicle length, plant height, 100-seed weight, and grain yield/plant were significantly reduced by the imposition of drought stress whereas unfilled grains/plant were increased (Table 2). The reduction of yield attributing traits and yield due to drought were also mentioned by Gupta et al. (2020).

Estimation of correlation coefficient

The results indicated that grain yield/plant showed highly significant ($p<0.001$) positive correlation with total tillers/plant, effective tillers/plant, filled grains/plant and 100-seed weight. Besides, grain yield/plant was found strong negative correlated with days to maturity and unfilled grains/plant (Table 3). Days to maturity exhibited significant ($p<0.001$) positive correlation with H_2O_2 and unfilled grains/plant but strong negative correlation ($p<0.001$) with total tillers/plant, effective tillers/plant, filled grains/plant, 100-seed weight and grain yield/plant. Total tillers/plant showed highly positive significant ($p<0.001$) correlation with effective tillers/plant, filled grains/plant and grain yield/plant and showed significantly negative relationship with days to maturity ($p<0.01$) and unfilled grains/plant ($p<0.05$). Besides, filled

grains/plant and grain yield/plant but showed highly negative association with days to maturity and H_2O_2.The results found that total tillers/plant, effective tillers/plant, filled grains/plant and 100-seed weight were the most important positive characters for yield of rice (Table 3). A similar positive correlation with grain yield/plant was reported by Gupta et al. (2017). The increased number of filled grains/plant contributes to higher grain yield. Furthermore, positive correlation of 100-seed weight with grain yield indicates the importance of individual grain weight for increased yields. However, unfilled grains/plant showed a significant positive correlation with H_2O_2, indicating ROS and H_2O_2 levels are the most important biochemical determinants of spikelet sterility (Sohag et al., 2020). Increased level of ROS and H_2O_2 might be responsible for grain fertility. A similar negative correlation with ROS and rice grain yield were reported by Verma et al. (2017).

Table 3. Phenotypic correlation coefficient among different yield and yield related traits of rice varieties

Traits	DM	PH	TT/P	ET/P	PL	FG/P	UG/P	100SW	GY/P
PH	-0.017								
TT/P	-0.419**	0.234							
ET/P	-0.523***	0.241	0.852***						
PL	-0.056	0.194	-0.013	-0.050					
FG/P	-0.707***	0.235	0.599***	0.604***	0.238				
UG/P	0.648***	-0.194	-0.353*	-0.288	-0.420*	-0.509***			
100SW	-0.465**	0.325*	0.150	0.127	0.303*	0.599***	-0.326**		
GY/P	-0.709***	0.257	0.579***	0.583***	0.253	0.997***	-0.512***	0.655***	
H_2O_2	0.601***	0.031	-0.424*	-0.685***	0.124	-0.585***	-0.179	-0.267	-0.573**

Note: *, ** and *** indicates significant at 5%, 1% and 0.1% level of probability, respectively.

Here, DM= Days to maturity, PH= Plant height (cm), TT/P= Total tillers/plant, ET/P= Effective tillers/plant, PL= Plant length (cm), FG/P= Filled grains/plant, UG/P= Unfilled grains/plant, 100SW= 100-seed weight (g), GY/P= Grain yield/plant (g).

Estimation of drought tolerance indices for yields in seven rice varieties obtained from yield/plant in a control and drought stress conditions

Different stress tolerance characteristics of rice varieties that were estimated from yields in normal and drought stress conditions are presented in Table 4. The highest stress susceptibility index (SSI) was recorded for the variety BRRI dhan56 (1.51) and the lowest in BRRI dhan71 (0.99). The highest stress tolerance (TOL) was observed in the variety BRRI dhan56 (9.95) whereas the lowest in BRRI dhan83 (6.85). The highest mean productivity (MP) was recorded in the variety Binadhan-17 (20.81) and the minimum in BRRI dhan56 (15.48). Maximum stress tolerance index (STI) was

obtained in Binadhan-17 (0.91) whereas minimum in BRRI dhan56 (0.48). The geometric mean productivity (GMP) was the highest in Binadhan-17 (20.24) and the lowest in BRRI dhan66 (15.54). The highest yield index (YI) was obtained in Binadhan-17 (1.11) and the minimum in BRRI dhan56 (0.73). STI estimated from grain yield/plant were found to be effective in separating the susceptibility varieties in terms of yield. The results of this study are in good agreement with the earlier findings (Adhikari et al., 2019). From the stress tolerance indices, it is proved that Binadhan-19 and BRRI dhan83 was the superior drought tolerant varieties having high yield potential.

Table 4. Drought tolerance indices in rice varieties, estimated from yields obtained in a control and drought conditions

Varieties	SSI	TOL	MP	STI	GMP	YI
Binadhan-17	1.16	9.63	20.81	0.91	20.24	1.11
Binadhan-19	1.07	7.83	18.71	0.74	18.30	1.03
BRRI dhan56	1.51	9.95	15.48	0.48	14.66	0.73
BRRI dhan57	1.30	9.16	17.19	0.61	16.57	0.88
BRRI dhan66	1.21	7.75	16.01	0.54	15.54	0.84
BRRI dhan71	0.99	7.27	19.14	0.78	18.80	1.08
BRRI dhan83	1.00	6.85	17.81	0.68	17.48	1.00

Here, SSI=Stress Susceptibility Index, TOL= Stress Tolerance, MP=Mean Productivity, STI= Stress Tolerance Index, GMP= Geometric Mean Productivity and YI= Yield Index.

CONCLUSION

Drought in the field of agriculture is a major obstacle which detrimentally affects rice in terms of growth and productivity leading to low yield potential and food insecurity. The main focus of the study was to evaluate the best drought tolerant rice variety having high yield potential. The results revealed that variety Binadhan-17 was found the best performance in terms of yield under control and drought stress (25.62 g/plant, 16.00 g/plant, respectively). The results of stress tolerance indices (STI) stated that Binadhan-17 showed the best performance. Ranking of the studied drought tolerant rice varieties based on yield performance at the reproductive stage under stress were chronology sequenced as from higher to lower Binadhan-17 (16.00 g/plant) > BRRI dhan71 (15.51 g/plant) > Binadhan19 (14.80 g/plant) > BRRI dhan83 (14.38 g/plant) > BRRI dhan57 (12.61 g/plant) > BRRI dhan66 (12.14 g/plant) > BRRI dhan56 (10.51 g/plant) related to yield. In a nutshell, it could be disseminated as the best drought tolerant rice variety among the cultivated drought tolerant rice varieties in Bangladesh in terms of yield. However, further research under different drought prone areas is necessary to confirm these findings and may be

tested in the drought areas of Bangladesh for evaluating their yield performance and getting higher production as well as more profit.

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LONGEVITY AND MORPHOMETRICS OF CHINESE CITRUS FLY, *BACTROCERA MINAX* (ENDERLIN) (TEPHRITIDAE: DIPTERA)

S. Sharma[1,2*], S. Tiwari[2], D. Adhikari[2,3] and B. Gautam[2]

[1] Plant Village Nepal
[2]Department of Entomology, Agriculture and Forestry University, Chitwan, Nepal
[3]Plant Quarantine and Pesticide Management Centre, Nepal

ABSTRACT

Chinese citrus fly, *Bactrocera minax*, (Enderlin) (Tephritidae: Diptera) is univoltine pest causing severe damage in citrus fruits. Longivity in different carbohydrate diets and morphometrics of adult Chinese citrus fly (CCF) was studied in uncontrolled laboratory room in Agriculture and Forestry University, Chitwan, Nepal. The result showed that the emergence of CCF was the highest (88%) for the pupa weighing more than 0.076 g with male and female emergence ratio of 1:2.1 followed by pupal weight of 0.049-0.076 g with emergence of 82.1%. The maximum population emerged at the last week of March, 2021. The adult emergence was recorded 66-90% at the additional moisture content of 15-20% in oven-dried soil with no adult emergence in completely oven dried soil. The adult longivity was 17.90 ± 1.80 days for female adult in 10% sucrose solution and was 15.09 ± 1.49 days for male adult in 10% jaggery solution. Length of Chinese citrus fly pupa was 7.46 ± 0.30 mm while breadth was 0.97 ± 0.004 mm with average weight of 0.078 ± 0.002 g. Similarly, length of female was 16.09 ± 0.27 mm including ovipositor (4.28 ± 0.41 mm) which was 43.8% higher than male fly (11.39 ± 0.16 mm). Wing span of male was 2.50 ± 0.006 cm and of female was 2.72 ± 0.10 cm where female had 8.8% wider wing span compared to male. The study findings are useful in comparing characters of *B. minax* with other fruit fly species to develop the specific management practices of CCF.

Keywords: CCF; Emergence; Longevity; Morphometrics

INTRODUCTION

Among fruits, citrus covers 23.6% of total fruit cultivated area of Nepal with the productivity of 9.47 tons per hectare (t/ha) (MoALD, 2022). Citrus occupies third position in total fruit production and has 3% share out of total fruit export by volume

* Corresponding author: sushmitasharma533@gmail.com

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from Nepal (Dahal et al. 2020). Citrus cultivation is highly profitable and advantageous in comparison to other crops in hilly regions of Nepal (MoAC, 2011). Among citrus, sweet orange is commonly cultivated in 54 districts of Nepal and the leading districts are Sindhuli (15.04 t/ha) and Ramechhap (13.65 t/ha) (MoALD, 2022).

Chinese citrus fly, *Bactrocera minax* (Enderlin) (Tephritidae: Diptera) has been considered as a major pest of citrus in Asia. Sweet orange is the most preferred host crop (Xia*et al.* 2018) and recently it has been reported that the pest infests mandarin orange along with lemons (Adhikari et al., 2022). This is a univoltine species and adult Chinese citrus fly has the ability of long-range flight (CABI, 2019) that was supposed to migrate from China to the mid-hills of Nepal through India (Sharma and Dahal, 2020). It is the most devastating oligophagous and univoltine insect of sweet orange in eastern hill of Nepal (Acharya and Adhikari, 2019; Adhikari et al., 2020). It is one of the largest dipteran citrus fruit fly species and morphologically similar to the Japanese fruit fly (*B. tsuneonis* Miyaka) (Drew and Romig, 2013). Infestation was seen more frequently in the orchards established above 1,100 meter above sea level and maximum damage was observed in Ramechhap and Sindhuli districts of Nepal (Chauhan et al., 2020). Adhikari et al. (2022) reported that the infestation has been seen extended to the 20 mid-hill districts including both eastern and western part of Nepal. Majority of farmers are confused between the Chinese citrus fly (CCF) (*B. minax*) and cucurbit fruit fly, *Bactrocera cucurbitae* (Coquillett, 1849) or oriental fruit fly, *Bactrocera dorsalis* (Hendel, 1912) and use the management strategies which are effective for the cucurbit fruit fly (Gautam et al., 2020). According to Adhikari et al. (2022), *B. minax* is the most problematic in citrus production and farmers are facing difficulties in managing the pest in the field.

The body length of female fly (14.29 mm) is more than male fly (12.52 mm) (Adhikari et al., (2022). Diatery nutrition plays important role in development and reproduction of adult flies. Lee et al. (2008) reported that high diatery carbohydrate to protein ratio increases the longevity of adult fly. Low protein and high carbohydrate diet intake by adult fly maximizes the life span of fly but feed with only protein diet or carbohydrate diet helps in optimal longevity of fly (Bruce et al., 2013). The life span of adult fly was found increased when adult was reared in higher altitude.

It is essential to have detailed information on the morphological characters and biology of the pest to identify the pest and this information will be helpful in determining the specific management strategy for controlling the pest (Adhikariet al., 2022). The result from the study will be beneficial in longevity and emergence study of CCF in lab condition with detailed understanding on the morphological parameters of adult CCFfor differentiating *B. minax* with other species.

MATERIALS AND METHODOS

Determination of adult emergence based on wight of pupa

The pupae were collected from Gulanjor, Sindhuli (27.2800° N, 86.0707° E) and were brought into the Entomology Laboratory of Agriculture and Forestry University in Chitwan. The pupae were kept in 2 plastic containers (200 ml capacity, 10 cm diameter and 20 cm height) with soil (150 g each) while collecting from Gulanjor, Sindhuli. Hundred randomly selected pupae from total collected pupae (250 pupae) were measured individually by using three-digit electronic weighing balance (Phoenix company). The measured pupae were categorized into three groups based on the pupal weight. The weight category was <0.049 g (19 pupa out of 100), 0.049g - 0.076 g (56 pupa out of 100) and >0.076 g (25 pupa out of 100). Pupae based on the weight were kept in 6 plastic containers (2 for each category of group) having the size of 40 ml capacity (7 cm diameter, 10 cm height with 25 g soil in each container). The plastic containers were covered with fine mesh net which was cut into the sizes just to cover the upper diameter of the container to ensure good air flow. Adult emergence percentage was observed from three categories (mentioned above) based on weight of pupa. Adult emergence date was recorded from each group of pupae.

Emergence of adult based on moisture treatment in soil

Effect of moisture was determined in late stage of pupa. Pupae were collected from 14th February to 20th February, 2020 from Gulanjor Rural Municipality-5. Total of 100 pupae were kept in the soil (soil type was clayey loam, collected from field of Gulanjor Rural Municipality, Sindhuli) which was kept in plastic container (40 ml capacity, 7 cm diameter and 10 cm height). Various moisture levels were maintained in oven dried soil (initial weight = 67.9 g after oven dry = 61.2 g) and kept in fluctuating room temperature. Five moisture levels were: 0% (water 0g, soil 61.2g), 5% (water 3.06 g, soil 61.2g), 10% (water 6.12g, soil 61.2g), 15% (water 9.19 g, soil 61.2g) and 20% (water 12.25 g soil 61.2g). Watering was done at 7-day interval. Five treatments were maintained in Completely Randomized Design (CRD) design. Each treatment was replicated 5 times with 4 pupae each and each moisture level contained 20 pupae. Adult emergence (male and female) from different moisture level was recorded to determine the percentage of adult emergence in various moisture level.

Longevity of adult Chinese citrus fly

Newly emerged adults were observed and separated on the basis of sex. Male and female CCF were separated and kept in plastic containers (50 mm length and 20 mm diameter). The lid of the plastic container had 10 holes to ensure good air flow. Five different carbohydrate-based food baits were used as treatment such as control (only water), sugar solution, sucrose solution, honey water solution and jaggary water solution. For feeding Chinese citrus fly, 10% sugar solution, 10% sucrose solution, 10% honey water solution and 10% jaggary solution were used using soaked cotton roll. In each treatment, there were 25 plastic containers (Hou et al., 2020). Each

plastic container contained one adult CCF. Chinese citrus fly was reared until its death to determine the longevity. The experiment was established in CRD design in a laboratory condition. The soaked cotton was changed in every two-day interval in each container. Date of emergence and date of death of both male and female adult was noted to determine the longevity of fruit fly. Lethal Time 50 (LT50) was calculated in terms of days where mortality of 13 adult Chinese citrus fly was considered as LT50.

Morphometric measurement of pupa and adult Chinese citrus fly

Different body parts of male and female Chinese citrus fly were measured with the help of vernier calipers (0-150 cm) and ocular microscope (Unilab India, IS: 4381:1357 microscope with 1 div = 0.1 mm in ocular micrometer and 1 div = 0.01 mm in stage micrometer) with 10X magnification. Overall body length, head, thorax, legs, abdomen and ovipositor in female was measured using digital vernier calipers while antennae and halter were measured by using ocular microscope. Altogether 50 adult flies (25 males and 25 females) were used for measuring morphological parts and the measurement was expressed in mm. Length and breadth of 100 pupae were measured in mm using vernier calipers and weight was taken using 3-digit electronic weighing balance (Phoenix company) and expressed in gm.

Calibration of ocular microscope was done and index was calculated by using the following formula.

Index = unit of stage/ unit of ocular ×10

Measurement in ocular microscope was noted and measured in micrometer and converted to millimeter by using conversion ration; 1 micrometer = 1/1000 millimeter

Wing span of male and female adult was measured by using vernier calipers and expressed in cm.

Statistical analysis

Data obtained from field and laboratory experiments were analyzed using Excel 2016, R studio version 20 (t-test, ANOVA). One way ANOVA was performed to check whether the data are statistically significant from one another. Mean comparison was done using Least Significant Difference (LSD) test at 5% level of significance. Percentage and frequency calculation was done to indicate percentage and numerical value of data. Percentage analysis and line graph was prepared using Microsoft Excel 2016.

RESULTS AND DISCUSSION

Adult emergence based on pupal weight in laboratory condition

Table 1 shows the emergence of pupae based on their weight. The highest emergence with lowest mortality of Chinese citrus fly pupa was recorded from > 0.076 g pupal

weight followed by 0.049 - 0.076 g. The least emergence of CCF adult was seen in < 0.049 g weight CCF pupa with male to female ratio of 1:1.2. Among the total emergence, the highest percentage of female adult (68.18%) was emerged from > 0.076 g pupal group while the highest male adult emergence (45.65%) was found from 0.046 - 0.076 g group. The mortality percentage of pupa was higher in the pupal weight of > 0.049 g. The emergence of male was less compared to female in all the pupal groups. The percentage emergence of adult from pupa was found directly related to the weight of pupa. Percentage of emergence of female was higher than male which supports the result of Thapaliya et al. (2020).

Table 1. Emergence of adult Chinese fruit fly on the basis of weight of pupa in fluctuating room condition

Weight (g) of pupa	No. of pupa	No. of adult fly emerged (%)	Mortality %	Male (%)	Female (%)	Male to female ratio
<0.049	19	11 (57.8)	42.2	5 (45.45)	6 (54.54)	1:1.2
0.049-0.076	56	46 (82.1)	17.9	21(45.65)	25 (54.34)	1:1.2
>0.076	25	22 (88)	12	7 (31.81)	15 (68.18)	1:2.1

Note: Value in parenthesis is percentage

Figure 1 shows the emergence of pupa in laboratory condition at room temperature. The highest emergence of male adult (11) was recorded on the 29 March 2021 while highest female adult emergence (14) was recorded on 30 March 2021. The figure shows that the adult CCF emergence trend was from 19 March, 2021 to 7 April 2021 while the emergence was decreasing from 31 March with zero emergence on 7 April. The number of female adult emergence was greater than the male which was 24% higher than male emergence. This result differs from Chauhan et al. (2019) who reported that the highest emergence in lab condition was recorded at the second week of March (i.e.17^{th}-18^{th} March) at an elevation of 1400-1474 meter above soil level.

Effects of moisture treatment on rearing media on adult emergence

Moisture treatment in soil significantly affected the emergence of adult Chinese citrus fly (P = 0.002) as shown in Figure 2. The CCF adult emergence was higher at the water content of 20% followed by 15%. There was significant decrease in emergence of adult fruit fly at 5% and 20% water content (P = 0.04). Adult emergence was zero when the water content in soil was 0% (Figure 2).

From the study, it was found that the emergence percentage was higher up to 20% of moisture content in oven dried soil. The least percentage of emergence (0%) was from complete oven dried soil which was not treated with additional water. On the contrary to this result, Liet al. (2019) reported higher percentage of emergence at 15% additional water content and emergence decreased at 20% of additional water content.

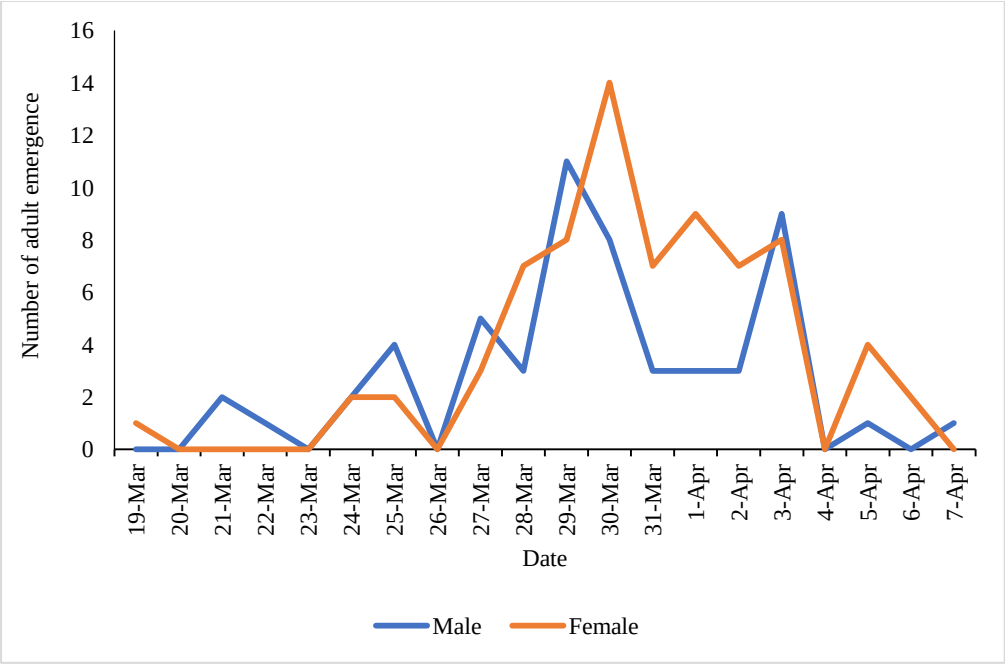

Figure 1. Emergence of adult Chinese citrus fly in the room condition at different dates in 2021

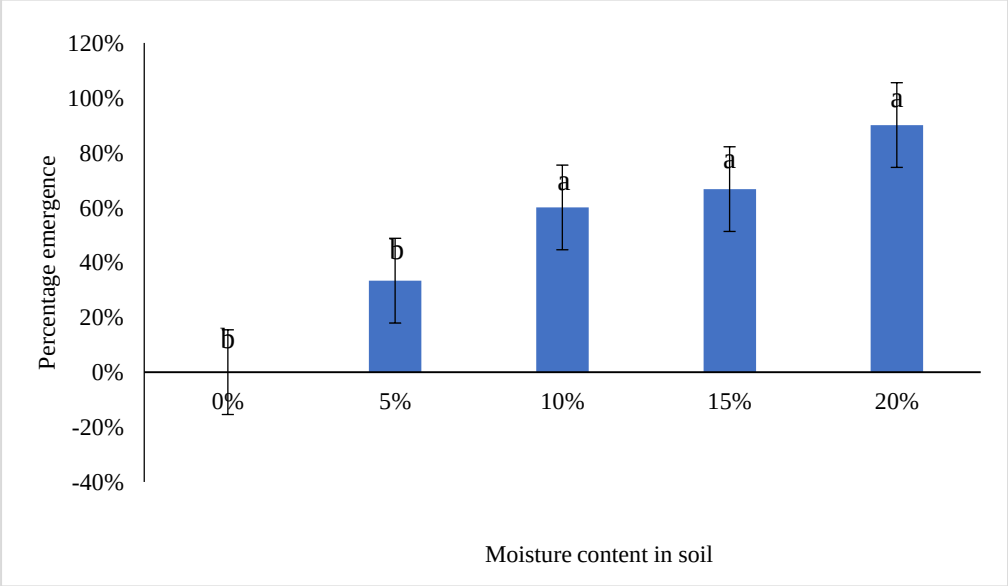

Figure 2. Emergence of adult Chinese citrus fly in different moisture content of soil at room condition

Longevity study of adult Chinese citrus fly

Diet significantly influenced the longevity of male adult ($P < 0.001$) and female ($P = 0.000$) adult Chinese citrus fly (Table 2). In male, the longest life expectancy had been observed when fed with jaggery solution (15.09 ± 1.49 days) which was not significantly different to the sucrose solution (14.72 ± 2.08 days, P=0.40) and sugar solution (14.18 ± 1.96 days, P=0.79) and all of which was significantly different with honey (8.36 ± 1.13 days, P=0.01) and water (6.09 ± 0.7 days, P=0.000).

In female, the longest life expectancy was observed when fed with sucrose solution (17.9 ± 1.8 days) which was significantly similar to the jaggary solution (15.3 ± 1.5 days, P = 0.12). The result was found statistically different when fed with sugar solution (13.2 ± 1.5 days, P = 0.02), honey solution (12.6 ± 1.05 days, P=0.003) and water (9.1 ± 0.8 days, P = 0.000) (Table 2).

The longevity of male and female was tested in different carbohydrate diets in which the longest life expectancy of male was found when fed with 10% jaggery solution while in female the longest life expectancy was seen when fed with 10% sucrose solution. The life expectancy of female from the study was (17.9 ± 1.8 days) which was found slightly different from the results of Wang et al. (2018) where life expectancy in sucrose diet was 19 days. However, life expectancy in water was similar with Wang et al. (2018). There was 100% mortality after 25 days in all the carbohydrate diets which supports the result of Wang et al. (2018). According to the study of 219 inbred lines of *Drosophila*, Arya et al. (2010) reported that about 70% of unmated female had longer life span as compared to unmated males. Similarly, Regan et al. (2016) suggested that difference in the intestinal stem cell activity can be the responsible factor in higher longevity of female fly as compared to male fly.

Table 2. Life expectancy of adult fruit fly in different artificial diet in Lab condition

Diet	Life expectancy (days)	
	Male	Female
Sugar	14.18 ± 1.96^{a}	13.20 ± 1.5^{b}
Honey	8.36 ± 1.13^{b}	12.60 ± 1.05^{b}
Sucrose	14.72 ± 2.08^{a}	17.90 ± 1.8^{a}
Jaggery	15.09 ± 1.49^{a}	15.30 ± 1.5^{ab}
Water	6.09 ± 0.7^{b}	9.10 ± 0.8^{c}
CV%	12.59	9.76
SEM ±	0.29	0.26
LSD	4.045	2.62
F-value	4.91*** (p = 0.000)	6.95*** (p = 0.002)

Note: *** significance at 0.1% level, LSD =Least Significance Difference, CV = Coefficient of variation, SEM = Standard Error of Mean,

Mortality of adult was observed in different carbohydrate diets. The mortality rate was found the highest when fed with water followed by honey (Table 3). Mortality was found 100% in water and honey at 20 days, jaggery, sugar and sucrose at 25 days. The shortest LT50 (Lethal Time 50) was found in the adults fed with water (5.5 days) while longest LT50 value was found in sucrose solution (12.6 days) which was followed by Jaggery (10.25 days), sugar (8.3 days) and honey (6.6 days). Mortality was extended up to 25 days in sucrose, sugar and Jaggery (Table 3).

Table 3. Cumulative adult mortality in different artificial diet in lab condition

Diet	5-day	10-day	20-day	25-day	LT50 (Days)
Water	28%	84%	100%	100%	5.5
Honey	17.8%	57.1%	100%	100%	6.6
Jaggery	0%	26.07%	91.3%	100%	10.25
Sugar	0%	36.8%	76.9%	100%	8.3
Sucrose	0%	35%	65%	100%	12.6

Morphometric measurement of pupa and adult of Chinese citrus fly

Table 4 shows the mean length, diameter and weight of pupa. Average length of Chinese citrus fly pupa was found 7.46 ± 0.3 mm while breadth was 0.97 ± 0.004 mm. The average weight of pupa was found 0.078 ± 0.002 g. The ratio of length and diameter of CCF pupa was found 7:1. As reported by Mir et al. (2014), the length of *B. cucurbitae* pupa was measured 5.72 ± 0.13 mm which was shorter than *B. minax.* The study slightly differs with Zhang (1989) which reported higher length (9-10 mm) and diameter of pupa (4 mm).

Table 4. Measurement of pupa of Chinese citrus fly

Parameters (n=100)	Mean ± SD
Length (mm)	7.460 ± 0.300
Breadth (mm)	0.970 ± 0.004
Weight (g)	0.078 ± 0.002

The overall length of female is higher than male which is about 43.8% (Table 5). Overall body breadth with wingspan of female is higher than male with overall wing span of male (2.5 ± 0.006 cm) and female (2.72 ± 0.10 cm). The length and breadth of head and eye in male and female is similar. Length of foreleg in male and female is same while breadth of foreleg in female is slightly higher than male. Length of meso-thoracic leg is higher in female fruit fly while breadth is found higher in male. Similarly, length of hind leg is higher in female however breadth is similar in both

sexes. Length of wing is nearly similar in both male and female while breadth of wing is higher in female as compared to male. The length and width of antennae and halter is found similar in both sexes (Table 5). In female length breadth ration of ovipositor was 6:1.

The overall length of male was found 11.39 ± 0.16 mm while female was 16.09 ± 0.27 mm with length of ovipositor 4.28 ± 0.41 mm. This result supports the findings of Dorji et al. (2006) who suggested that the length of adult fly was about 10-13 mm without including ovipositor. Besides, Adhikari et al. (2022) reported that the mean body length and average wing length of female fly was higher as compared to male fly. Comparing the overall length of *B. minax* and *Z. cucurbitae*, the length of *Z. curcurbitae* was shorter for male (8.74 ± 0.32 mm) and for female (9.94 ± 0.20 mm) as reported by Miret al (2014). In comparison to the wing length of *B. minax* and *B. dorsalis*, the wing length of adult was shorter in *B. dorsalis* (6 mm) as reported by Drew et al (2008).

The findings revealed that there was no significant difference in wing span according to sex of Chinese citrus fly. However, female had 8.8% wider wing span as compared to male (Table 5). Wing span was found 2.5 cm which differs from Dorji et al. (2006) who reported 10 mm wing span of *B. minax*. This result is similar with the report of Regmi et al. (2023) which showed 16-24 mm range of wing span in adult fly and wing span of female (23.14 mm) was found higher as compared to male (20.71 mm). Comparing the wing span with *B. cucurbitae*, the wing span was shorter in *B. cucurbitae* for male (10.97 ± 0.43 mm) and for female (13.02 ± 1.28 mm) as reported by Akter and Sohel, (2020).

Table 5. Morphometrics of adult Chinese citrus fly (n = 25)

Body parts	Length (mm) Mean ± SD		Breadth (mm) Mean ± SD	
	Male	Female	Male	Female
Overall body	11.39 ± 0.16	16.09 ± 0.27	-	-
Overall body breadth with wingspan	-	-	27.75 ± 0.08	30.18 ± 0.1
Head	2.70 ± 0.16	2.42 ± 0.14	2.83 ± 0.10	2.50 ± 0.16
Eye	1.78 ± 0.11	1.55 ± 0.13	0.96 ± 0.07	0.87 ± 0.08
Fore leg	6.82 ± 0.24	6.81 ± 0.27	0.38 ± 0.03	0.40 ± 0.02
Mesothoracic leg	9.63 ± 0.25	10.13 ± 0.33	0.42 ± 0.01	0.39 ± 0.02
Hind leg	8.61 ± 0.31	9.06 ± 0.37	0.39 ± 0.03	0.39 ± 0.02
Wing	8.44 ± 0.17	8.83 ± 0.17	2.78 ± 0.08	3.92 ± 0.17
Thorax	4.59 ± 0.09	4.34 ± 0.11	3.05 ± 0.12	2.94 ± 0.12
Abdomen	5.87 ± 0.12	5.56 ± 0.18	2.39 ± 0.06	3.52 ± 0.13

Body parts	Length (mm) Mean ± SD		Breadth (mm) Mean ± SD	
	Male	Female	Male	Female
Antennae	1.18 ± 0.02	1.22 ± 0.02	0.52 ± 0.02	0.58 ± 0.02
Arista	1.31 ± 0.02	1.37 ± 0.03	-	-
Halter	0.84 ± 0.02	0.77 ± 0.03	0.42 ± 0.02	0.47 ± 0.03
Ovipositor	-	4.28 ± 0.41	-	0.70 ± 0.11

CONCLUSION

Chinese citrus fly is a major invasive pest in citrus crops. Pest starts emerging in the field after temperature starts increasing and emergence is seen from the month of March. The weight of pupa also affects the emergence percentage where higher weight resulted higher emergence. Moisture content in the soil has direct influence in the emergence whereby there was no emergence at dried soil. Carbohydrate diets are also determining factors for estimating longevity of the adult fly. Life expectancy of female Chinese citrus fly is higher in sucrose solution while male longevity was higher in jaggery solution. The length, diameter and wing span of female adult Chinese citrus fly is greater compared to adult male fly. The present study can be informative in differentiating different species of fruit flies affecting the citrus from *B. minax* and this information can be utilized for the management of Chinese fruit fly in citrus growing orchards.

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OPTIMIZING GROWING CONDITION AND PLANTING DATE FOR GROWTH, YIELD AND QUALITY OF SQUASH IN BANGLADESH

M.A. Hossen[1*], M.N. Islam[1], M.J. Rahman[1], M.M. Uddin[2]
H.M.M.T. Hossain[3] and S. Akther[4]

[1]Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh
[2]Research Division, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh.
[3]Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.
[5]Agronomy Division, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh.

ABSTRACT

An experiment was conducted at the Vegetable Research field of Horticulture Research Centre Division, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh, during October 2018 to March 2019 to find out the effect of growing condition and planting date on yield and yield attributes of squash. The experiment comprised two sets of treatments viz., (a) Growing conditions: (i) Open cultivation (C_1); (ii) Net protected cultivation (C_2) and Cultivation with barrier crop (C_3) and (b) Planting dates: (i) 1 November (D_1); (ii) 15 November(D_2); (iii) 1 December (D_3) and (iv) 15 December (D_4) in a randomized complete block design (RCBD) with three replications. The variety BARI squash-1 was used in this experiment. The results showed that net protected cultivation showed significantly the highest fruit plant^{-1}, fruit length, yield plant^{-1} and yield ha^{-1}. Growing condition did not affect quality parameters of quash. Early planting (1 November) showed significantly higher yield, yield attributes and quality parameters than late planting. Fruit diameter did not showed any significant difference irrespective of planting date. The interaction between growing condition and planting dates was significant for yield and quality parameters. Based on the study results it is concluded that maximum yield (49.33 t ha^{-1}) and quality of BARI squash-1 could be achieved through cultivation under net protected condition with 1 November planting.

Keywords: Squash, Growing condition, Planting dates, Yield and quality.

[*] Corresponding author: afzalhossen@gmail.com

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INTRODUCTION

Bangladesh ranked in third, in terms of the worldwide vegetables production. Considering health issue, vegetables are the cheapest source of vitamins and minerals. Squash (*Cucurbita pepo* L.) is one of the important cucurbit vegetables belongs to the family Cucurbitaceae and is grown throughout the world in both temperate and tropical climatic zones. This crop is relatively new in Bangladesh, but it is gaining popularity day by day as well as growing in economic significance, both in terms of generating cash and providing nutritional value.

Squash has various health benefits to human as well as medicinal potentials (Mohammad *et al.,* 2011). It contains a variety of vitamins, minerals, amino acids, carbohydrates, and minerals, especially potassium, as well as phenolics, flavonoids, β-carotene, vitamin A, vitamin B_2, α-tocopherol, vitamin C, and vitamin E. It has various medicinal effects comprising anti-diabetic, anti-hypertensive, anti-tumor, anti-mutagenic, immune modulating, anti-bacterial, anti-hypercholestero-lemic, intestinal anti-parasitic, antalgic, and anti-inflammation effects, and utilization possibilities of Cucurbitacious crops have been reported (Kostalova *et al*., 2009). It grows well in cool, moist weather conditions than others in the genus. This crop requires 60-70 days as fruits are harvested only few days after bloom. Squash requires 16-27°C temperature for normal growth and development (Lincoln, 1987). It is generally consumed at young immature stage before skin becomes hard. Variation in planting dates affects not only the yield but other characters as well. Squash seeds are germinate above 15°C temperature. Whitakar and Davis (1962) reported that stem elongation was increased with rise in temperature (17-26 °C day and 12-14 °C night).

Through protected cultivation quality and productivity of squash increasing many fold compared than under open field cultivation. Singh *et al.* (2005) conducted a study during 3 season of January-April (2001-2003) under protected and open conditions at New Delhi to study the effect of protected and unprotected condition (open field) on biotic stress, yield and economics of squash (*Cucurbita pepo* L.) variety of "Pusa Alankar". The incidence of biotic stress (insect-pests), plant mortality and use of chemical insecticides are minimum under protected condition. Fruit yield (kg $plant^{-1}$), gross income, net income (Rs $plant^{-1}$), cost: benefit ratio and money saving were higher under protected condition.

Squash cultivation has a great opportunity in Bangladesh as a quick growing vegetable. Keeping in view the present scenario of growing importance of this crop in the Bangladesh, the present studies have been undertaken to workout standardize planting time for optimizing production and also to find out the suitable growing condition for higher yield per unit area.

MATERIALS AND METHODS

Research Location

The research work was conducted at Vegetable Research field of Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh during the period of October 2018 to March 2019. The experimental site is located at 24.0° N latitude and 95.25°E longitude, respectively (UNDP, 1988) at an elevation of 8.4 meters from the sea level (Anon., 1995). Top soil was sandy clay loam in texture having a pH around 6.0. The selected plot was medium high land. Plenty of sunshine and moderately low temperature prevails during experimental period. The weather data during the study period are presented in Table 1.

Table 1. Monthly mean weather data during the crop growing periods at BARI, Gazipur

Year	Month	Temperature (°C)			Relative humidity (%)		Sunshine (hr./day)	Total rainfall (mm)
		Maximum	Minimum	Average	9 am	2 pm		
	October	32.10	23.17	27.64	80.16	64.06	5.89	67.4
2018	November	30.87	18.67	24.77	76.20	54.87	7.38	42
	December	27.08	14.79	20.94	78.61	55.26	6.10	9.2
	January	28.14	13.25	20.70	77.32	46.84	7.23	0
2019	February	29.41	15.39	22.40	78.25	49.36	7.08	93.4
	March	32.00	19.43	25.72	72.39	52.29	7.39	126

Source: Physiology Division, Bangladesh Rice Research Institute, Joydebpur, Gazipur, Bangladesh.

Experimental Design

The experiment consisted of two factors. Factor A: Growing conditions (3) *viz*. (i) Open cultivation (C_1); (ii) Net protected cultivation (C_2) and (iii) Cultivation with barrier crop (C_3) and (b) Planting dates (4): (i) 1 November (D_1); (ii) 15 November (D_2); (iii) 1 December (D_3) and (iv) 15 December (D_4) (Plate 1). The experiment was conducted in a randomized complete block design (RCBD) with three replications. The variety BARI squash-1 was used in this experiment. The layout of the experiment was prepared for distributing the combination of growing conditions and different planting dates. The 12 treatment combinations of the trail were assigned at arbitrary into 36 plots. The size of each unit plot 3 m × 2 m (= 6 m^2). The distance between block to block 1.0 m and plots to plot distance was 0.5 m.

Raising of seedlings and crop management

The seeds of BARI Squash-1 were collected from Olericulture Division, Horticulture Research Centre (HRC), BARI, Gazipur. The seeds of BARI Hybrid Maize-16 (as barrier crop) were collected from Plant Breeding Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur. Squash seeds were sown on 13 October 2018, 28 October 2018, 12 November 2018 and 29 November 2018 according to treatments on in poly bags at net house of olericulture division of BARI. Seeds were sown in polybags which were filled with loose friable, dead roots free, sandy loam soil previously mixed with well rotten cowdung. Eighteen days old seedlings were transplanted in the experimental plots. One fourth of cowdung (20 t ha^{-1}) and all of gypsum (100 kg ha^{-1}) zinc (12.5 kg ha^{-1}) and borax (10 kg ha^{-1}), ½ TSP (175 kg ha^{-1}) and 1/3rd MoP (150 kg ha^{-1}) were applied, respectively during final land preparation. Cowdung @ 10 kg, TSP @ 60 g, MoP @ 50 g and Magnesium Oxide @ 8 g were applied in each pit 7-10 days before planting. Urea @ 30 g is to be top dressed each pit at 4 split applications and MoP @ 25g to be applied 10-15 days after planting according to Krishi Projukti Hatboi (BARI, 2015). Healthy and uniform sized 18 days old seedlings were taken from the net house and were transplanted in the main field on 1 November, 15 November, 1 December and 15 December, 2018 according to treatments. 1m × 1m plant spacing was maintained for transplanting. This operation was carried out during late hour of afternoon. The seedlings were watered after transplanting. The insects were controlled successfully by spraying Malathion 57 EC @ 2 ml/L water. The insecticide was sprayed fortnightly from a week after transplanting to a week before first harvesting. Squash fruits were harvested during maturity stage. Harvesting was started from 14 December, 2018 and completed by 6 March, 2019. Harvesting was done in the morning. The harvested squashes of each plot collect separately, tagged and taken to laboratory for data collection.

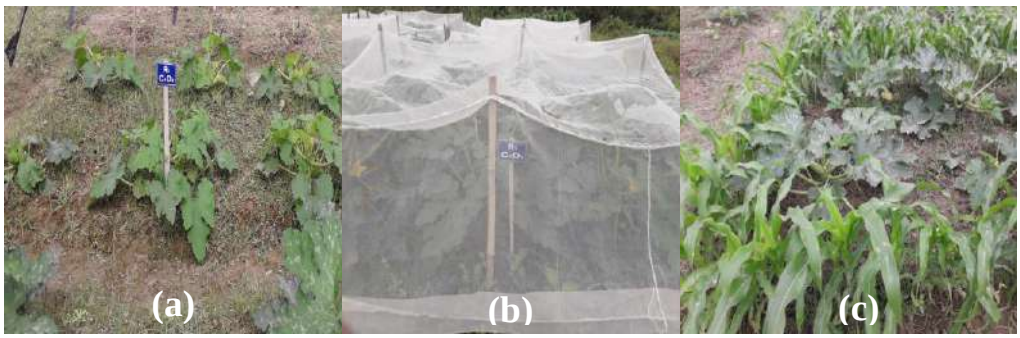

Plate 1. Photograph showing different growing condition (a) Open cultivation (Control) (b) Net protected cultivation (60 mesh) (c) Cultivation with barrier crop

Data collection and analysis method

The following data were collected from the experiment

Fruit length:

The length of the fruit was measured with a meter scale in centimeter from the neck of the fruit to the bottom of the fruit. It was measured from each plot and their average was calculated in centimeter.

Fruit diameter:

The diameter of individual fruit was measured in several directions from five selected fruits with slide calipers and the average of all directions was finally recorded and expressed in centimeter (cm).

Individual fruit weight:

From first harvest to last harvest total fruit number was counted and total fruit weight was measured from each plant of each plot to determine individual fruit weight and expressed in kilogram (kg).

Yield plant^{-1}:

Weight of matured fruits harvested from each picking in the tagged plants in each replication was recorded till final harvest and total yield of fruits per plant computed in kilogram.

Yield ha^{-1}:

After collection of fruit per plot, it was converted to ton per hectare by the following formula:

$$\text{Yield (ton ha}^{-1}) = \frac{\text{Fruit yield plot}^{-1}\text{ (kg)} \times 10000\text{ m}^2}{\text{Plot size (m}^2) \times 1\,000\text{ kg}}$$

TSS:

Total Soluble solids (TSS) content was determined by a refractometer by placing of drop of pulp on its prism. TSS obtained from direct reading of the refractometer.

Vitamin-C content:

The reagent used for the estimation of vitamin C were as follows

a) Metaphoporic acid solution (3%)

b) Standard ascorbic solution

c) Dye solution

For estimation of vitamin C were as follows

Five ml of Standard ascorbic solution was taken in conical flask and 5 ml metaphoporic acid (HPO_3) was added to it and shaken.

A micro burette was filled with dye solution then the mixed solution was titrated with dye using phenolphthalein as indicator solution to a pinked coloured end point, which persisted at least for 15 seconds. Dye factor was calculated using to the following formula-

$$\text{Dye factor} = \frac{0.5}{\text{Titre}}$$

Preparation of sample

10 g of sample was taken and transferred to 250 ml volumetric flask and the volume was made up to the mark with metaphosphoric acid.

Titration

Five ml of metaphosphoric acid extracted sample was taken in an aliquot and titrated with standard dye solution, using phenolphthalein as indicator to a pink coloured end point which persisted at least for 15 seconds.

Vitamin C content was calculated using to the following formula-

$$\text{Vitamin C content (mg/100 g sample)} = \frac{T \times D \times V_1}{V_2 \times W} \times 100$$

Where,

T = Titre

D= Dye factor

V_1= Volume made up

V_2= Volume of extract taken for estimation

W= Weight of sample taken for estimation

Virus incidence (%):

Incidence of virus disease recorded during the cropping period. Virus incidence was calculating by counting number of virus infected plants out of total number of plants assessed on two/three dates at 15 days interval, 30 days, 45 days and 60 days after transplanting. Percent data related to virus disease incidence is further subjected to angular transformation.

$$\text{Virus incidence (\%)} = \frac{\text{Number of virus infected plant}}{\text{Total number of pants assessed}} \times 100$$

Statistical analysis of data:

The recorded quantitative data were analyzed statistically by using MSTAT-C a computer based program to find out the variation among different treatments,

treatment combinations and their interactions. Treatment means were compared by Least Significant Difference (LSD) Test (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Effect of growing conditions

The result presented in Table 2 show that significant effect of growing condition on fruit plant^{-1}, fruit length, yield plant^{-1} and yield ha^{-1}. Growing condition did not play any significant impact on individual fruit weight and fruit diameter. The maximum number of fruits plant^{-1} (3.39) was obtained from net protected cultivation (C_2) while open cultivation condition (C_1) gave minimum number of fruits plant^{-1} (2.24). The longest fruit (43.66 cm) was found from net protected cultivation (C_2) and shortest (33.58 cm) fruit was found from open cultivation condition (C_1). The highest yield plant^{-1} (3.43 kg) and yield ha^{-1} (34.08 t) were also found from net protected cultivation condition (C_2) whereas the lowest yield plant^{-1} (2.18 kg) and yield ha^{-1} (22.04 t) were found from open cultivation condition (C_1). For several crops, including green beans (Gogo *et al*., 2014b), tomatoes (Gogo *et al*., 2014a) and cabbage (Vidogbéna *et al*., 2015); net protected cultivation techniques increased marketable yield.

The result presented in Table 3 show that there was no significant effect of growing condition on total soluble solid (TSS) and vitamin C content.

Table 2. Yield parameters of squash as influenced by different growing conditions

Growing conditions	Yield parameters					
	Fruit plant^{-1} (no.)	Individual fruit weight (kg)	Fruit length (cm)	Fruit diameter (cm)	Yield plant^{-1} (kg)	Yield (t ha^{-1})
C_1	2.24 b	0.92	33.58 b	7.14	2.18 b	22.04 b
C_2	3.39 a	0.97	43.66 a	7.85	3.43 a	34.08 a
C_3	2.29 b	0.93	34.33 b	7.20	2.20 b	22.29 b
$LSD_{0.05}$	0.104	NS	0.7806	NS	0.128	0.969
CV (%)	4.58	12.13	2.48	1.95	5.88	4.38

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

C_1 = Open cultivation (Control), C_2 = Net protected cultivation, C_3 = Cultivation with barrier crop.

Table 3. Quality parameters regarding TSS and vitamin C content of squash as influenced by different growing conditions

Growing conditions	Quality parameters	
	TSS (%)	Vitamin C content (mg/100g)
C_1	5.58	12.79
C_2	5.69	12.96
C_3	5.60	12.93
$LSD_{0.05}$	NS	NS
CV (%)	2.18	1.60

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability

C_1 = Open cultivation (Control), C_2 = Net protected cultivation, C_3 = Cultivation with barrier crop.

Effect of planting date

The result presented in Table 4 show that there were significant effects of planting dates on fruit plant^{-1}, individual fruit weight, fruit length, yield plant^{-1} and yield ha^{-1}. Fruit diameter did not differ significantly due to planting dates. The maximum number of fruits plant^{-1} (3.54), highest individual fruit weight (1.12 kg), longest fruit (44.79 cm), highest yield plant^{-1} (3.98 kg) and yield ha^{-1} (39.56 t) were found from early planting (01 November) (D_1) whereas the minimum number of fruits plant^{-1} (1.53), lowest individual fruit weight (0.68 kg), shortest fruit (26.98 cm), lowest yield plant^{-1} (1.17 kg) and yield ha^{-1} (10.94 t) were found from late planting (15 December)(D_4). Jerry and Hmod (2011), Latifi *et al*. (2012) and Wadas and Mioduszewska, (2011) also reported that early plantation of squash contributed higher fruit number than late plantation. Khanuma *et al*. (2021) and Seong *et al*. (2004); they reported that early plantation of squash gave higher individual fruit weight whereas reduced fruit weight was recorded with delayed plantation. Khanuma *et al*. (2021) also reported that early plantation gave maximum fruit yield ha^{-1} of squash whereas delay plantation showed less yield ha^{-1} which result was also supported by the findings of Shivaprakash *et al*. (2018), Latifi *et al*. (2012) and Jerry and Hmod (2011).

The result presented in Table 5 also showed that there was significant effect of planting date on total soluble solid (TSS) and vitamin C content. The highest total soluble solid (TSS) (5.97%) and maximum vitamin C content (13.59 mg/100g) was recorded from 01 November planting (D_1) and the lowest vitamin C content (12.12 mg/100g) was recorded from 15 December planting (D_4).

Table 4. Yield parameters of squash as influenced by different planting dates

Planting dates	Yield parameters					
	Fruit plant^{-1} (no.)	Individual fruit weight (kg)	Fruit length (cm)	Fruit diameter (cm)	Yield plant^{-1} (kg)	Yield (t ha^{-1})
D_1	3.54 a	1.12 a	44.79 a	7.86	3.98 a	39.56 a
D_2	3.01 b	1.04 a	40.47 b	7.79	3.16 b	31.67 b
D_3	2.48 c	0.90 b	36.53 c	7.38	2.21 c	22.39 c
D_4	1.53 d	0.68 c	26.98 d	6.57	1.07 d	10.94 d
$LSD_{0.05}$	0.120	0.112	0.901	NS	0.148	1.119
CV (%)	4.58	12.13	2.48	1.95	5.88	4.38

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability

D_1 = 1 November, D_2 = 15 November, D_3 = 1 December, D_4 = 15 December

Table 5. Quality parameters regarding TSS and vitamin C content of squash as influenced by different planting dates

Planting dates	Quality parameters	
	TSS (%)	Vitamin C content (mg/100g)
D_1	5.97 a	13.59 a
D_2	5.83 a	13.18 b
D_3	5.44 b	12.69 c
D_4	5.24 c	12.12 d
$LSD_{0.05}$	0.155	0.111
CV (%)	2.18	1.60

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability

D_1 = 1 November, D_2 = 15 November, D_3 = 1 December, D_4 = 15 December

Interaction effect of growing condition and planting date

Interaction effect of growing conditions and planting dates showed significant effect on fruit plant^{-1}, individual fruit weight, fruit length, fruit diameter, yield plant^{-1} and yield ha^{-1} (Table 6). The maximum number of fruits plant^{-1} (4.30), highest individual fruit weight (1.17 kg), longest fruit (49.0 cm), highest fruit diameter (8.23 cm), highest yield plant^{-1} (4.97 kg) and yield ha^{-1} (49.33 t) were found fromnet protected growing condition with 01 November planting (C_2D_1). Nevertheless the minimum number of fruits plant^{-1} (1.20), lowest individual fruit weight (0.65 kg), shortest fruit

(21.97 cm), lowest fruit diameter (6.20 cm), lowest yield plant^{-1} (0.82 kg) and yield ha^{-1} (8.83 t) were found from open cultivation condition with 15 December planting (C_1D_4) (Table 6).

Table 7 presented interaction effect of growing condition and planting date had significant effect on total soluble solid (TSS) and vitamin C content. The highest total soluble solid (TSS) (6.03%) and maximum vitamin C content (13.70 mg/100g) was recorded from C_2D_1 but the lowest TSS (5.20%) was found C_1D_4. The lowest vitamin C content (12.10 mg/100 g) was recorded in C_1D_4 and of C_3D_4 (cultivation with barrier crop condition with 15 December planting).

Table 6. Yield parameters of squash as influenced by different growing conditions and planting dates.

Growing conditions× Planting dates	Yield parameters					
	Fruit plant^{-1} (no.)	Individual fruit weight (kg)	Fruit length (cm)	Fruit diameter (cm)	Yield plant^{-1} (kg)	Yield (t ha^{-1})
C_1D_1	3.10 c	1.10 ab	42.20 d	7.60 d	3.45 c	34.33 c
C_1D_2	2.63 d	1.03 ab	38.07 e	7.70 cd	2.65 e	26.00 e
C_1D_3	2.03 e	0.90 bc	32.10 g	7.07 e	1.82 f	19.00 f
C_1D_4	1.20 f	0.65 d	21.97 h	6.20 f	0.82 h	8.83 h
C_2D_1	4.30 a	1.17 a	49.00 a	8.23 a	4.97 a	49.33 a
C_2D_2	3.87 b	1.10 ab	45.17 b	8.07 ab	4.32 b	43.33 b
C_2D_3	3.30 c	0.90 bc	44.33 bc	7.90 bc	2.93 d	29.00 d
C_2D_4	2.10 e	0.70 cd	36.13 f	7.20 e	1.48 g	14.67 g
C_3D_1	3.23 c	1.10 ab	43.17 cd	7.73 cd	3.53 c	35.00 c
C_3D_2	2.53 d	1.00 ab	38.17 e	7.60 d	2.50 e	25.67 e
C_3D_3	2.10 e	0.91 bc	33.17 g	7.17 e	1.87 f	19.17 f
C_3D_4	1.30 f	0.70 cd	22.83 h	6.30 f	0.90 h	9.33 h
$LSD_{0.05}$	0.207	0.193	1.561	0.245	0.257	1.938
CV (%)	4.58	12.13	2.48	1.95	5.88	4.38

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability

C_1 = Open cultivation (Control), C_2 = Net protected cultivation, C_3 = Cultivation with barrier crop. D_1 = 1 November, D_2 = 15 November, D_3 = 1 December, D_4 = 15 December

Table 7. Quality parameters regarding TSS and vitamin C content of squash as influenced by different growing conditions and planting dates

Growing conditions× Planting dates	Quality parameters	
	TSS (%)	Vitamin C content (mg/100g)
C_1D_1	5.90 ab	13.47 b
C_1D_2	5.80 b	13.10 c
C_1D_3	5.40 cd	12.50 e
C_1D_4	5.20 d	12.10 f
C_2D_1	6.03 a	13.70 a
C_2D_2	5.93 ab	13.23 c
C_2D_3	5.53 c	12.73 d
C_2D_4	5.27 d	12.17 f
C_3D_1	5.97 ab	13.60 ab
C_3D_2	5.77 b	13.20 c
C_3D_3	5.40 cd	12.83 d
C_3D_4	5.27 d	12.10 f
$LSD_{0.05}$	0.207	0.1931
CV (%)	2.18	1.60

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability

C_1 = Open cultivation (Control), C_2 = Net protected cultivation, C_3 = Cultivation with barrier crop. D_1 = 1 November, D_2 = 15 November, D_3 = 1 December, D_4 = 15 December

CONCLUSION

From the study, it may be concluded that, growing condition and planting dates have shown statistically significant variation among the parameters studied under the experiment. Net protected cultivation showed the best performance than other growing conditions in respect of yield and quality parameters. On the other hand, early planting (01 November) gave highest performance than late planting. Squash cultivated under net protected condition with planted on 1 November produced significantly the highest number of fruits per plant (4.3) and yielded the highest (49.33 t ha^{-1}). Individual fruit weight, fruit length, fruit diameter a well as quality parameters like, TSS and vitamin C content also significantly the highest in above mentioned treatment combinations.

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IN VIVO STUDY ON PREVENTIVE EFFECTS OF *POLYALTHIA LONGIFOLIA* BIOFORMULATIONS AGAINST BLACK SCURF DISEASE OF POTATO

P. Meena[*], P. Gehlot, J.Y.T. Jain and K. Sharma

Microbial Research Lab, Department of Botany, Mohanlal Sukhadia University
Udaipur- 313001 Rajasthan, India.

ABSTRACT

Bioformulation prepared by combining *Polyalthia longifolia* leaf extract with elicitors (neem oil cake) and binders (cow dung) were tested for management of black scurf disease of potato caused by *Rhizoctonia solani*. Two different application methods- seed dipping and soil amendment were used for *in vivo* study. The preventive action was studied as a function of decrease in disease severity by PDI (Percent Disease Index) and PEDC (Percent Efficiency of Disease Control) methods. Change in growth characteristics of host plant such as number of leaves/plant, plant height, number of branches/plant, number of flower/plant, number of fruit/plant and weight of fruits were recorded in control and treated plants. Six treatments T1 (formulation no.12), T2 (formulation no.7), T3 (formulation no.26), T4 (formulation no.17) were applied in different combinations and four different control were also maintained. Potato plants were examined for symptoms infected tuber (sclerotia) were quantitatively assessed after 90 DAS (days after sowing). Results of present study indicates that treatment with bioformulation especially T4 treatment not only reduces the infection but also leads to increased growth, health and vigour of the host plant as compared to untreated and synthetic fungicide control. Results were subjected to statistical analysis of student t test, one way ANOVA and post-Hoc comparisons analysis. Significance was measured at $p<0.001$ and showed highly significant. Statistical analysis at 1% and 5% cadence levels revealed all the treatment are significant clearly indicating that treatment with bioformulations appreciably reduces the disease index as compare to control with significant improvement of growth of host plant. The T4 treatment showed significant inhibitory activity against *Rhizoctonia solani* and can help to minimize the economic loss of potato crop.

Keywords: Antifungal activity, Bioformulation, plant extract, *Polyalthia longifolia*, *Rhizoctonia solani.*

[*] Corresponding author: meenapoonam296@gmail.com

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is the most important food crop grown in more than hundred countries across the world. India ranks third in cultivation area and second in production of potatoes in the world after China. In 2020-2021 India produced around 542.3 lakh tons potatoes in 22.48 lakh ha (Horticulture Statistics Division, 2021). Majority of the Indian potatoes come from northern states of Uttar Pradesh, West Bengal, Bihar, Punjab and Gujarat.

Potato tubers comprise of 79% moisture, 21% dry matter and 60-80% starch. Nutritionally, potato is rich in vitamins (B1, B2 and B6), minerals (potassium, phosphorus and magnesium), pantothenic acid and riboflavin (Siddique *et al*., 2020).

Potato black scurf caused by the pathogen *Rhizoctonia solani* Kuhn (Teleomorph *Thanatephorus cucumeris* Donk) is one of the most important potato crop diseases globally as it has a great economic impact and considered as a serious problem in the potato tuber production. In India alone up to 10-25 % crop loss has been reported from this disease (Sharma, 2015).

Major symptoms of this disease are degenerated stem tissues, deformation of tubers and development of black scurf/sclerotia on the surface of tubers hence decline the quality of tubers (Betancourth *et al*., 2021). Farmers face economic losses upto 5-7% due to defacing of the tuber and sclerotia deposition (Shekhawat *et al*., 1993; Singh and Shekhawat, 1994). Infection on potato spread by tubers, soil or the remains of infected plants.

As soon as appropriate conditions are available low temperatures and high soil moisture begin to grow and attack the stems and grown area causing tissue damage as they are in the form of spots and ulcers on the nearby leg from the surface of the soil. Once the infection progresses these spots become brown and then black. The source of the primary infection is infected seeds, which is characterized by the presence of sclerotia covering the outer crust of the tubers, the distinguishing signs of infection with black scurf disease (Ferrucho *et al*., 2012).

Bavistin and mancozeb are the most commonly used fungicides to inhibit *Rhizoctonia solani* either by destroying their cell membrane or its permeability or by inhibiting metabolic processes and hence are extremely effective (Osman and Al-Rehiayam, 2003). Chemical control methods possess many harmful effects on the environment and human health besides causing pathogen resistance and their non-target effects disrupts natural biodiversity. Therefore, management of black scurf disease on potato is necessary. In recent years, the biological control of plant pathogens has been considered as an alternative strategy because chemical control results in the accumulation of harmful chemical residues, which may lead to serious ecological problems (Madbouly, 2018). The solution to this problem is to use alternate method that are both sustainable and harmless to the environment.

Thus, current scheme for the plant and environment protection suggests various alternative strategies to pesticides in addition to well-known disease management methods such as crop rotation, use of resistant cultivars, planting disease free seeds, biological control etc. for control of fungal diseases (Sharma *et al*., 2021; Mehta and Sharma, 2013; Hada and Sharma, 2015). One of these alternative strategies is the use of natural formulations prepared from plants or plant parts/extract. Therefore, the main objective of this study includes preparation of bioformulation by combining *Polyalthia longifolia* leaf extract with neem oilcake as elicitor and cow dung as binder and also test its efficacy in controlling the infection of *Rhizoctonia solani* in potato use *in vivo* experiment. Innovative part of the study is that the use of combination of plant extract with elicitors and binders to develop protective measure against the black scurf disease of potato.

MATERIALS AND METHODS

Test Crop and Fungus

Infected tuber with sclerotia were collected from local vegetable market of Udaipur. Sclerotia was surface sterilized with 0.1% $HgCl_2$ solution for 1 min and then three time rinsed with sterile water. Then dried it well and placed on potato dextrose agar medium in petri plates which were incubated at 22°C for 4 days. Fresh potato tubers (no sclerotia visible) were collected having same size and 3-5 eyes were used for *in vivo* experiment.

Inoculum Development

Rhizoctonia solani was cultured on potato dextrose agar (PDA) medium that had been sterilised at 15 psi for 20 minutes seven-day incubation period at 22 °C. Pure culture obtained were further used for mass culture of *Rhizoctonia solani*. Five grams of this mycelial mat was added to one liter of sterile distilled water and stirred constantly. The homogenized suspension thus prepared was used for inoculation at 25ml /gram of soil (Buttner *et al*., 2004).

Preparation of Pots and Soil

Pots (30 cm diameter) were sterilized with 20% copper sulphate solution whereas soil was autoclaved and then cooled. Sterile soil was used after 5 to 6 days. Sterile soil was mixed with inoculum and filled in the pre-sterilized pots. Since autoclaving of soil makes it nutrient deficient hence organic manure was added to the soil of each pot before sowing (El-Mougy and Abdel-Kader, 2009).

Preparation of Herbal Formulations and Standard Fungicide

In vivo study of preventive /protective action of herbal formulation was based on results of *in vitro* studies (Hada and Sharma, 2017). Herbal formulations were prepared by using *Polyalthia longifolia* leaf extracts, *Polyalthia longifolia* leaf powder, elicitor like neem oil cake (20 gm in 100 ml sterile water) and binder like cow dung (20 gm in 100 ml sterile water) were mixed with 100% alcoholic crude extract, partially purified

petroleum ether extract and dried leaf powder of *Polyalthia longifolia*. All ingredients of herbal formulation were used in following combinations:

- 100% Crude extract (20gm dried plant leaf material dissolve in 100ml alcohol) + 20gm elicitor(neem oil cake) dissolve in 100ml sterile water + 20gm binder (cow dung) dissolve in 100 ml sterile water
- 100% Partially purified extract (40gm dried plant leaf material dissolve in 280ml petroleum ether) + 20gm elicitor (neem oil cake) dissolve in 100 ml sterile water + 20 gm binder (cow dung) dissolve in 100 ml sterile water
- *Polyalthia longifolia* leaf powder+20gm elicitor (neem oil cake) dissolve in 100ml sterile water + 20gm binder (cow dung) dissolve in 100ml sterile water
- Mancozeb was used as standard antifungal and 10 mg/ml concentration was prepared in sterile water.

Treatments and Experimental Design

The study was conducted during December, 2021 to March 2022 in the Botanical Garden, University College of Science, M.L.S. University, Udaipur (Rajasthan). Seed dipping method and soil treatment were used to study preventive effect of herbal formulations (Ganie *et al*., 2013). On the basis of *in vitro* screening of 30 herbal formulations (need citation of appropriate references), following six formulation showed best activity against test fungi and hence used for *in vivo* studies in following combinations.

T1- (formulation no.12) Combination of 6 ml (100% alcoholic crude extract), 2 ml (neem oil cake) and 2 ml (cow dung).

T2- (formulation no.7) combination of 2 ml (100% alcoholic crude extract), 6ml (neem oil cake) and 2ml (cow dung).

T3-(formulation no.26) combination of 1ml (partially purified petroleum ether extract), 1ml (neem oil cake) and 8ml (cow dung).

T4-(formulation no. 17) combination of 4ml partially purified petroleum ether extract, 3ml neem oil cake, and 3ml of cow dung.

T5-combination of leaf powder (60gm): neem oil cake (20gm): cow dung (20gm)).

T6-combination of leaf powder (40gm): neem oil cake (30gm): cow dung (30gm)).

Four different controls were also maintained respectively. These were as follows:

C1- Mancozeb used for treat to healthy tubers with 10mg/ml concentration sown in soil inoculated with *Rhizoctonia solani*.

C2- Unsterilized and uninoculated soil used for sown untreated healthy tubers.

C3- Untreated healthy tubers sown in sterilized soil inoculated with *Rhizoctonia solani*.

C4- Uninoculated soil untreated healthy tubers in sterilized

Healthy tubers treated with all different formulation. 10 kg soil infected with *Rhizoctonia solani* inoculum (25ml/pot) in pre-sterilized soil pots and healthy seed tubers dipped in respective herbal formulations were planted in disinfected soil. Three tubers were planted per pot at a depth of 5 cm. The pots were left for 90 days. 220 gm. urea was applied twice as nitrogen fertilizer in each pot after 28 and 42 days from date of sowing. The tubers were harvested after 90 days from the date of sowing and observations were recorded as the number of leaves/plants, plant height, tuber size, tuber weight /pot and numbers of tubers/pot. Percent disease infestation was recorded with the comparative study of positive controls. Data were subjected to analysis of CD and CV value. Three replicates were maintained with each treatment (El-Mougy and Abdel-Kader 2009; Mirkarimi *et al*., 2013).

Disease Rating and Percent Disease Index

The disease severity was defined as the percentage of infected area of tubers with black scurf. The severity was calculated on the basis following 0-5 rating scale as showed in table 1 (Muhammad *et al*., 2020)

Table 1. The Percentage Disease Index (on 0 to 5 Standard Disease Rating Scale for Tubers)

Disease Severity Grades	Percentage of Disease
0	No disease symptoms
1	< 1% tuber surface affected
2	1 to 10% tuber surface affected
3	11 to 20% tuber surface affected
4	21 - 50% tuber surface affected.
5	> 50% tuber surface affected

The percentage disease Index (PDI) was calculated using following formula **(**Muhammad *et al*., 2020**)**

$$\text{Percent Disease Index} = \frac{\text{Sum of all individual disease ratings}}{\text{Total numbers of plants assessed} \times \text{Maximum rating}} \text{X100}$$

The Percent Efficacy of Disease Control (PEDC) was determined by using formula given by Muhammad *et al*., 2020

$$\text{Percent Efficacy of Disease Control PEDC} = \frac{\text{PDI control} - \text{PDI in treatment}}{\text{PDI in control}} \text{X100}$$

Growth Parameters

Various growth parameters like number of leaves/plants, plant height, tuber weight/pot, tuber size, number of tubers /pots have been determined using standard methods in healthy, infected, and treated plants, as reported in the Central Potato Research Institute's Technical Bulletin, ICAR, Shimla: Number of leaves/plants

RESULTS and DISCUSSION

Disease Severity

Results of effect of bioformulations on disease severity of black scurf on potato are given in Table 2. Maximum disease index/ incidence was observed with control treatment C3 (88.76%) followed by C2 (58.14%) and C4 (55.14%) respectively. Amongst all treatments and control mancozeb *i.e.* control C1 found most effective in reducing disease index. In case of all treatments maximum reduction in disease incidence was observed with treatment T4 (10.3%) followed by C1 (16.75%), T3 (20.32%), T1 (28.50%), T2 (36.97%), T6 (41.24%), and T5 (45%) treatment. Statistical analysis at 1% and 5% CD values reveals that all the treatments are significant to decrease disease severity in *in vivo* pot experiments.

Table 2. Effect of Treatments on Percentage Disease Index and PEDC

S.N.	Treatment	PDI (%)			Average ± SD	PEDC (%)
		R1	R2	R3		
1.	T1	30	29	26	28.50±2.09	74.65%
2.	T2	36	35	39	36.97± 2.30	58.34%
3.	T3	20	22	18	20.32 ±1.855	77.10%
4.	T4	11	10	9	10.30± 1.03	88.39%
5.	T5	44	46	44	45 ±1.32	49.30%
6.	T6	42	41	40	41.24± 1.19	53.53%
7.	C1	16	17	16	16.75± 0.85	81.12%
8.	C2	56	58	60	58.14±2.06	-
9.	C3	85	88	85	88.76±85.29	-
10.	C4	56	55	53	55.14±1.2	-
11.	SE m^+	–	–	–	0.919	-
12.	CD(P=0.05)	–	–	–	2.727	-
13.	CD(P=0.01)	–	–	–	3.966	-
14.	CV (%)	–	–	–	5.169	-

Growth Parameters

Results of effect of bioformulations prepared from *Polyalthia longifolia* leaf alcoholic crude extract and partially purified petroleum ether fraction, dried leaf powder, neem oil cake (elicitors) and cow dung (binders) on following growth parameters of potato crop are summarized in Table no. 2 to 7. Data clearly indicate that, treatment with bioformulations reduces disease index which results into significant improvement of growth of host plant.

Number of Leaves/Plants

In Table 3 shows the effects of different treatments and synthetic fungicides on the number of leaves/plant. The data show a slight decrease in the number of leaves per plant as a result of infection. However, treatment with herbal formulations and mancozeb resulted in a considerable increase in the number of leaves per plant. T4 (56.66) increased the number of leaves per plant the most, followed by C1 (54.66), T5 (50.33), T6 (49.33), T3 (48), and C4 (46.66). T1 and T2 results are comparable to C3 results. At 5% and 1% CD, statistical analysis demonstrated that all treatments are significant.

Table 3. Effect of Treatments on Number of Leaves/Plant

S.N.	Treatment	Number of Leaves			Average ± SD
		R1	R2	R3	
1.	T1	46	48	46	46.66±1.15
2.	T2	42	44	44	43.33±1.15
3.	T3	48	47	49	48±1
4.	T4	56	57	57	56.66±0.57
5.	T5	51	49	51	50.33±1.15
6.	T6	50	50	48	49.33±1.15
7.	C1	55	54	55	54.66±0.57
8.	C2	34	36	33	34.33±1.52
9.	C3	45	46	46	45.66±0.57
10.	C4	46	47	47	46.66±0.57
11.	SE m^+	–	–	–	0.546
12.	CD(P=0.05)	–	–	–	1.621
14.	CD(P=0.01)	–	–	–	2.357
15.	CV (%)	–	–	–	2.088

Plant Height

Table 4 showed In comparison to the control, the treatment with formulations and mancozeb increased plant height. The T4 treatment developed the tallest plants (27.33 cm), followed by T6 (26.33 cm), and T5 (25.33 cm). Among the applied treatments, it was discovered that the plant height for T3, T1, and T2 was similar to C1. All of the treatments were discovered to be significant for field trials at 5% and 1% CD values.

Table 4. Effect of Treatments on Plant Height (cm)

S.N.	Treatment	Plant Height (cm)			Average ± SD
		R1	R2	R3	
1.	T1	24	26	25	25±1
2.	T2	25	24	25	24.66±1
3.	T3	26	25	24	25±1
4.	T4	27	27	28	27.33±0.57
5.	T5	24	26	26	25.33±1.15
6.	T6	26	27	26	26.33±0.57
7.	C1	24	22	24	23.33±1.15
8.	C2	24	22	22	22.66±1.15
9.	C3	17	18	19	18±1
10.	C4	14	16	14	14.66±1.15
11.	SE m^+	–	–	–	0.540
12.	CD(P=0.05)	–	–	–	1.603
13.	CD(P=0.01)	–	–	–	2.331
14.	CV (%)	–	–	–	4.267

Total Tuber Weight /Pot

Table 5. Shows the T4 treatment was the most effective and produced the greatest increase in tuber weight when compared to the C1 standard and the other controls (C2, C3, and C4). The C1 (201.44 gm) treatment outperformed T5 (191.21 gm) and T6 (187.5 gm) among controls. T4 (247.45 gm) was shown to be the most effective treatment, followed by T3 (225.47 gm), T2 (212.26 gm), and T1 (203.9 gm). 5% and 1% CD statistical study showed that all the treatments are significant.

Table 5. Effect of Treatments on Total Tuber Weight (gm.)

S.N.	Treatment	Total Tuber Weight (gm.)			Average ± SD
		R1	R2	R3	
1.	T1	204.10	204.40	203.20	203.9±0.62
2.	T2	212.24	211.10	213.46	212.2667±1.18
3.	T3	226.29	225.16	224.96	225.47±0.71
4.	T4	248.16	247.00	247.20	247.4533±0.62
5.	T5	192.28	191.16	190.20	191.2133±1.04
6.	T6	187.48	186.16	188.86	187.5±1.35
7.	C1	202.00	201.46	200.86	201.44±0.57

S.N.	Treatment	Total Tuber Weight (gm.)			Average ± SD
		R1	R2	R3	
8.	C2	168.24	167.24	168.18	167.8867±0.56
9.	C3	128.00	126.00	127.49	127.16±1.03
10.	C4	158.00	156.00	157.15	157.05±1.00
11.	SE m^+	–	–	–	0.503
12.	CD(P=0.05)	–	–	–	1.492
13.	CD(P=0.01)	–	–	–	2.170
14.	CV (%)	–	–	–	0.477

Tuber Size

Table 6 shows the results of the impact of various treatments on tuber size. With C3, the smallest tuber size was noticed. C4 was followed by C2 in terms of observing a slight rise in tuber size. The tuber size was shown to be increased by all treatments and mancozeb. T4 (6.66 cm) showed the greatest increase in tuber size, followed by T3 (6.1 cm), T2 (5.66 cm), and T1 (5.26 cm), in that order. T5 (4.96 cm) and T6 (4.76 cm) treatments were found to be less effective than C1 (4.76 cm). All of the treatments are significant, according to statistical analysis at 5% and 1% CD.

Table 6. Effect of Treatments on Tuber Size (cm)

S.N.	Treatment	Tuber Size (cm)			Average ± SD
		R1	R2	R3	
1.	T1	5.3	5.2	5.3	5.26±0.05
2.	T2	5.7	5.7	5.6	5.66±0.05
3.	T3	6.0	6.1	6.2	6.1±0.1
4.	T4	6.7	6.6	6.7	6.66±0.05
5.	T5	5.0	5.0	4.9	4.96±0.05
6.	T6	4.8	4.8	4.7	4.76±0.05
7.	C1	5.2	5.2	5.1	5.16±0.05
8.	C2	4.7	4.6	4.7	4.76±0.05
9.	C3	3.0	2.9	3.0	2.96±0.05
10.	C4	4.1	4.0	4.0	4.03±0.05
11.	SE m^+	–	–	–	0.036
12.	CD(P=0.05)	–	–	–	0.106
13.	CD(P=0.01)	–	–	–	0.154
14.	CV (%)	–	–	–	1.273

Number of Tubers/Pot

Table 7 shows the results of the impact of various treatments and synthetic fungicide on the quantity of tubers/pot. Due to infection (C3 and C4), there was a nearly 50% decrease in the number of tubers. With T4 therapy, 18.33 more tubers were found, which a significant improvement is. T2 (15.66) and T3 (17.66) were the next two most efficient treatments. The number of tubers/pot observed for T1 (14.66) was similar to that for C1 (14.66) and C2 (15.66) among the treatments used. The treatments T5 (13.66) and T6 (11.66) had the fewest tubers per pot. All of the treatments were shown to be statistically significant for field trials at 5% and 1% CD values.

Table 7. Effect of Treatments on Number of Tubers

S .N.	Treatment	Number of Tubers			Average ± SD
		R1	R2	R3	
1.	T1	15	15	14	14.66667±0.57
2.	T2	16	16	15	15.66667±0.57
3.	T3	18	18	17	17.66667±0.57
4.	T4	19	20	19	19.33333±0.57
5.	T5	14	13	14	13.66667±0.57
6.	T6	12	12	11	11.66667±0.57
7.	C1	15	14	15	14.66667±0.57
8.	C2	14	15	14	14.33333±0.57
9.	C3	14	14	13	13.66667±0.57
10.	C4	11	11	10	10.66667±0.57
11.	SE m^+	–	–	–	0.333
12.	CD(P=0.05)	–	–	–	0.990
13.	CD(P=0.01)	–	–	–	1.439
14.	CV (%)	–	–	–	4.065

Potato is most important protective food crops of India. Black scurf disease caused by *Rhizoctonia solani* inflicts serious damage to these crops by reducing the quantity and quality of tuber yield of potato (Ghadsingh and Mandge, 2012). Rhizoctonia Solani is a very harmful fungus for potato crops, however with the use of cutting-edge technology, it is now simpler to manage this global fungus. Fungicides are one of the most often utilized techniques. In order to manage various plant infections, some plant extracts have been shown to exhibit fungicidal action (Ashraf et al., 2011; Rajamanickam and Sudha, 2013), yet these fungicides pose major risks to human health as well as environmental contamination. Because they are more practical, eco-

friendly, and secure, different disease management techniques such as breeding disease-free plants, changing agronomic procedures, using plant and natural products, and bioformulation are currently receiving more attention. According to El-Bakali et al. (2006), a successful disease control program involves cultural techniques, fungicides, biological control, and solarization. Several researchers have reported using plant extracts to treat plant diseases (Jabeen et al., 2021; Asuquo et al., 2017). Different induced defense mechanisms are present in plants to defend against pathogen attack. Neem kernel cake powder (NKCP) was studied by Kimaru et al. (2004) in relation to tomato Fusarium wilt growth. Hamid et al. (2011) successfully suppressed the potato black scurf disease using manure and soil solarization treatment.

In present study comparative effect bioformulation as well as chemical fungicide (mancozeb) to control black scurf disease of potato were evaluated by *in vivo* pot experiments. In soil containing mycelial suspension of Rhizoctonia solani, potato tuber buds treated with bioformulations and mancozeb were planted. Untreated tuber seeds planted in the same soil served as a positive control. The T4 treatment, or formulation no. 17 (partially purified petroleum ether extract (4ml): 100% neem oil cake (3ml): 100% cow dung (3ml), significantly lowers the percent disease index and also improves all growth parameters when compared to control, according to a comparative study of the effects of all bioformulation treatments on potatoes. The results of the comparison study between the preventive effects of bioformulations and synthetic fungicide show that treatment no. 4 provided better protection than mancozeb, a common fungicide. The T4 treatment considerably lowers R. solani infection as compared to other forms of treatment. Preventive effect of bioformulation on disease severity might be due to presence of antifungal secondary metabolites or compounds present in plant extract, elicitor and binder. *Polyalthia longifolia* contain several secondary metabolite like terpenoid, flavanoids, volatile oil, alkaloids, saponin, phytosterols, and tannins. (Parveen and Sharma, 2015; Mehta and sharma, 2016; Kaur *et al*., 2022 ; Karak, 2019; Salvatore *et al*., 2020; Meena *et al*., 2021). Review of literature suggests that several reports are available on the antifungal activity of plant extracts, various elicitor (ground nut oil cake, mustard oil cake, cotton oil cake, clove bud oil cake, coconut oil cake, neem oil cake and sesame oil cake) and binders (guar gum, gum acacia and cow dung) separately or individually (Mandal *et al*., 2022; Rajeswari *et al*., 2021; Modi *et al*., 2022; Meena *et al*., 2021). According to the study's findings, treatment with bioformulation, particularly T4, not only reduces *R. solani* infection but also significantly outperforms synthetic fungicide treatment in terms of the host plant's growth, health, and vigour.

CONCLUSION

The reduction in percent disease index after treatment with bioformulations was found to be comparable to that of a synthetic fungicide (Mencozeb) in the present study. Hence these bioformulations can be used as an eco-friendly alternative for management of black scurf disease of potato. Among various treatments, T4 treatment (Formulation no.17) was found to be most effective against *Rhizoctonia solani*. This treatment was found to not only reduce disease incidence but also to improve all of the host plant's growth parameters. Effective bioformulations will be subjected to further field trials for control of black scurf disease of potato to incredulous the problem of poisonous and harmful fungicides. These bioformulations can be produced at large scale and can be supplied to the farmers either in the form of powder or solutions for application.

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ENHANCING WATER USE EFFICIENCY AND CROP PRODUCTIVITY IN TOMATO CULTIVATION THROUGH VARYING IRRIGATION SCHEDULES: A STUDY IN OPEN FIELD AND POLYHOUSE OF ASSAM, INDIA.

A.M. Lotha[1], L.N Sethi[1], L. Kikon[2*] and J. Pielie[1]

[1]Department of Agricultural Engineering, Triguna Sen School of Technology, Assam University Silchar, 788011

[2]Department of Agricultural Engineering & Technology, SET, Nagaland University, DC Court Junction, Dimapur-797112, Nagaland

ABSTRACT

Tomatoes are a prevalent crop commonly cultivated in the Indian state of Assam. An experiment was carried out to assess the impact of varying irrigation schedules on water use efficiency for tomato cultivation within and outside polyhouses in hilly terrain. Four drip irrigation levels were tested: Treatment-1 (T-1) (50% of crop evapotranspiration, ETc), T-2 (75% of ETc), T-3 (100% of ETc), and T-4 (125% of ETc), analysing their effects on crop growth, yield, economic benefit and water use efficiency. Tomato plants (Lycopersicon esculentum) were grown in both polyhouses and open fields, with three replications per irrigation treatment. Measurements of fruit number, individual fruit length, and yield were taken at 5-day intervals. T-1 in polyhouses exhibited superior growth and the highest yield compared to other treatments, demonstrating elevated water use efficiency. This research underscores the potential of polyhouses to enhance year-round vegetable productivity and water use efficiency in North East India's hilly regions, offering solutions for agricultural water scarcity challenges.

Keywords: Crop evapotranspiration, Drip irrigation, Irrigation scheduling, Tomato, Water use efficiency

INTRODUCTION

Increase in global water shortages are severely constraining regional, social and economic progress due to a significant difference between water availability and demand. Agriculture's substantial water usage primarily contributes to this issue, and inadequate water supply to meet crop requirements poses a threat to food security (Zhang et al., 2022). In hilly regions, the significant elevation and presence of

* Corresponding author: lochumikikon5@gmail.com

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mountain ranges contribute to a wide range of rainfall variations (Sharma et al., 2019). Despite the abundant rainfall (exceeding 2000 mm) in the hilly terrains of Assam, these areas face pronounced challenges stemming from both water scarcity and water excess during rainy and post-rainy periods. These issues persist due to inadequate storage facilities and the absence of efficient water delivery and drainage systems.

Because it is difficult to cultivate tomatoes, capsicums, cucurbits, french beans, and other high-value crops in Northeast India's open fields, various types of covered structures have been devised to shield high-value crops from extreme cold and frost (Chakraborty et al., 2015). Many growers have switched from open-field to protected tomato cultivation due to the rising demand for quality tomatoes in both domestic and foreign markets, especially during the off-season. (Gowda et al., 2022). The tomato is one of the most popular and widely grown vegetables in the world. It is also high in vitamins and antioxidants. The environment and amount of irrigation in greenhouses have a significant impact on tomato growth, yield, and quality (Gong et al., 2022).

One of the key elements influencing the quantity and quality of agricultural products is the irrigation system (Darré et al., 2019). Water management is therefore essential for preventing crop moisture stress during the crop growth stages. Given the current global expansion of irrigated land and the limited availability of water for irrigation, there is a critical imperative to optimize water use efficiency (WUE) to increase crop yields, particularly under conditions of frequent deficit irrigation. Maximizing WUE involves deploying deficit irrigation technology, precise irrigation scheduling, and implementing enhanced agricultural practices to effectively enhance crop yields. (Alam et al., 2003, Shi et al., 2021, Zain et al., 2021, Patel et al., 2023). One of the main challenges to vegetable production in the Northeast's steep terrain is water management and scarcity throughout the winter, with micro irrigation acting as the only other option. Drip irrigation increases profitability, reduces energy, labour, runoff, avoid wetting of leaves which minimises the risk of diseases, minimises conventional water losses by deep percolation (Narayanamoorthy, 2005). Drip irrigation increases crop yield and water use efficiency (Cetin and Bilgel, 2002; Ibragimov et al., 2007; El–Metwally et al., 2022; Wang et al., 2022).

Numerous studies have been undertaken on tomato cultivation in the hilly terrain of Assam. Hazarika and Phookan, (2005) assessed the development, production, and quality of 27 tomato cultivars grown in polyhouses. Brahma et al., (2010) examined the effects of drip irrigation's N and K fertigation level on fruit quality, marketable output, growth, and economics. Sarma et al., (2020) investigated the usage of agricultural chemicals in three Assamese agroclimatic zones for the production of tomatoes. Kalita et al., (2023) carried out a field experiment in Jorhat, Assam, to investigate how tomato growth and yield are affected by changed microclimates and radiation usage efficiency. To the best of our knowledge, based on the literature review referred, no studies have been conducted on the effects of varying irrigation

schedules on water use efficiency in tomato cultivation in Assam's soil and agro-climate, particularly with regard to drip irrigation treatments using different levels of crop evapotranspiration. Therefore, this study was conducted to assess the impacts of various irrigation schedules on water use efficiency and economic returns in tomato production, both within and outside a polyhouse, in a hilly terrain.

Materials and method

Description of the experimental site

The experimental site is situated in the Department of Agricultural Engineering, Assam University, Silchar. The hilly terrain of Assam University has a total area of 968.28 m^2 with latitude of 24.68˚N and longitude of 92.75˚E with altitude of 40.80 m from Mean Sea Level.

Soil physio chemical properties

The study assessed soil physical-chemical traits like moisture content, bulk density, soil texture, pH, and electrical conductivity. Soil samples collected from 9 locations (2 in each treatment) and 2 depths (0-15, and 15-30 cm) were collected for analysis of soil. Soil moisture content was determined using the oven-drying method (Reynolds, 1970). The depth wise variation of bulk densities (dry and wet) for both the treatments were determined by the soil core method (Brady and Weil, 1999) with known height (h) and diameter (d) of soil cores. Soil particle size and texture were determined through the hydrometer method, applying the USDA textural classification triangle (Bouyoucos, 1962). A pH meter and an electrical conductivity (EC) meter were used to measure the EC and pH of the soil, respectively.

Wilting point and field capacity of a soil sample was determined by the pressure plate apparatus (Karkansis, 1983). The field samples of soil were collected and stored at pressures of 0.3 bar, 1 bar, 5 bar, and 15 bar. The sample's field capacity was determined by its moisture content at 0.3 bar of pressure, and the sample's wilting point was determined by its moisture content at 15 bar of pressure.

Experiment layout

Four different irrigation treatments were included in the fully randomized block design of the experiment. For Tomato, plant to plant distance was taken as 60 cm and row to row distance was taken as 50 cm. So, in each treatment number of replication was 3 with 4 number of tomato plants.

The irrigation practice for both inside and outside the polyhouse consists of four treatments with different levels of water amount based on crop evapotranspiration (ETc).

- Treatment 1 (T1)—50% of ETc
- Treatment 2 (T2)—75% of ETc
- Treatment 3 (T3)—100% of ETc

- Treatment 4 (T4)—125% of ETc

Each treatment had three replications, and they were all arranged randomly. Using the crop evapotranspiration (ETc) for tomatoes, which was determined using the FAO Penman–Monteith technique (Allen et al., 1998) based on the meteorological data observed inside and outside the polyhouse, the amount of irrigation water to be applied for the experiment was assessed. The FAO Penman–Monteith equation is as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\Delta u_2)} \quad \ldots (1)$$

Where ET_o = reference evapotranspiration (mm day^{-1})

R_n = net radiation at the crop surface (MJ $m^{-2}\, day^{-1}$)

G = soil heat flux density (MJ $m^{-2}\, day^{-1}$)

T = mean daily air temperature at 2m height (℃)

u_2 = wind speed at 2m height (m s^{-1})

e_s = saturation vapour pressure (kPa)

e_a = actual vapour pressure (kPa)

$e_s - e_a$ = saturation vapour deficit (kPa)

Δ= slope vapour pressure deficit (kPa)

γ = psychrometric constant (kPa℃$^{-1}$)

The actual crop ET_c for tomato was calculated with the following equation using the crop coefficient K_c developed from the FAO-56 Irrigation and Drainage paper (Allen et al. 1998).

$$ET_{c,adj} = K_s \times K_c \times ET_o \quad \ldots \quad (2)$$

Where $ET_{c,adj}$ (mm day^{-1}) is the adjusted ET_c calculated by multiplying ET_o(mm day^{-1}) by a crop coefficient $K_c$and by a soil water stress coefficient K_s. The coefficient K_s=1 because there is no soil water stress in this situation, where the soil evaporation accounts for a small portion of ET_c. For tomato crop K_c is equivalent to 0.6 at the initial stage, 1.15 at the mid-stage and 0.80 in the end of growing season which was determined according to FAO 56 (Allen et al. 1998).

Irrigation scheduling

Determining the precise amount, duration, and interval of irrigation is a key component of irrigation scheduling. Using the FAO Penmen-Monteith equation, the amount of irrigation was determined (Allen et al., 1998).

CWR ($m^3 day^{-1}$) = ET_o($mm\ day^{-1}$) × crop coefficient (K_c) × crop area (m^2) ...(3)

Where CWR= crop water requirement ($m^3 day^{-1}$)

Water Use Efficiency

The ratio of water used by plants for metabolism to water lost via transpiration is known as irrigation water use efficiency (IWUE.) This formula was used to determine IWUE (Howell *et al*., 1990):

$$\text{IWUE} = \frac{\text{crop yield } (\text{tha}^{-1})}{\text{Total irrigation water applied (mm)}} \quad \ldots (4)$$

Cropping

To assess the tomato plants' vegetative development, growth parameters such as plant height, stem diameter, number of leaves in 5-day interval, number of flowers and fruits per plant, fruit length and width in cm, individual fruit weight in gram, yield per plant in kg; yield per plot in kg and yield in tonnes/hectare in each replication and treatments i.e. inside high tech poly house and open field condition was monitored once at the time of harvesting.

Statistical Analysis

To investigate potential variations in yield, WUE, and ET_c between irrigation regimens, analysis of variance (ANOVA) was used. The associations between grain yield and irrigation level, evapotranspiration; water use efficiency and irrigation level, evapotranspiration; and irrigation level and total cost, economic return were all investigated using correlation analysis using SPSS 18.0 software.

RESULTS AND DISCUSSION

Soil physical and chemical properties

Using the USDA textural classification triangle, it was found that the soil was clay loam and loam in polyhouse and open field respectively. The average initial soil moisture content inside the polyhouse were found to be 16.13% and average initial soil moisture content in open field for were found to be 13.69%.

The average bulk density on dry basis inside the polyhouse for found to be 1.46 g/cc respectively and average bulk density on wet basis inside the polyhouse were found to be 1.98 g/cc respectively. The average bulk density on dry basis in open field were found to be 1.48 g/cc and average bulk density on wet basis in open field were found to be 1.72g/cc.

The pH of all the soil samples from each treatment were found in the range of 4.79 to 5.37 and 4.56 to 5.32 in polyhouse and open field which indicates that the soil is acidic in nature and about 50% of applied fertilizer may be available to plants. The EC of the soil samples were found in the range of 0.052-0.222 and 0.016-0.072 mS/cm in polyhouse and open field, respectively.

Reference evapotranspiration

The average reference evapotranspiration for the months of February, March, April and May were 2.73, 3.52, 4.14, 4.66 mm/day (Fig 1).

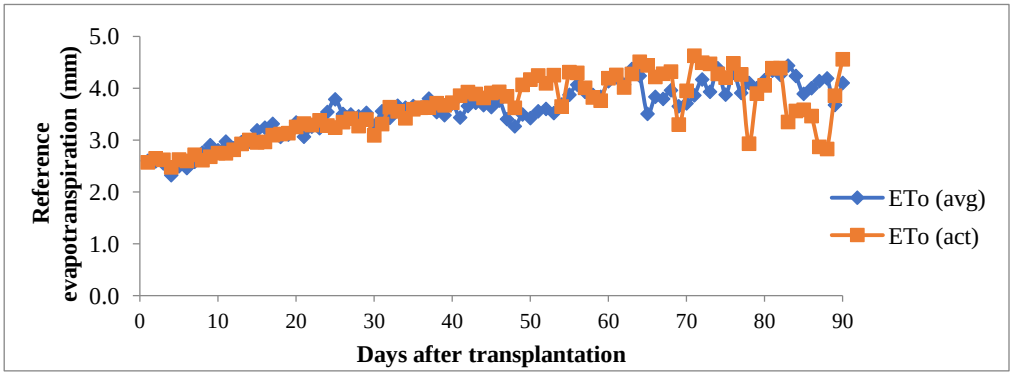

Fig. 1. Variation of reference evapotranspiration for the growing period

Effect of Irrigation System on Tomato growth and yield

Observations were recorded at 5 days interval after plantation. The average plant height which was tallest was observed in replication R-1(141.92 cm) of T-1 in polyhouse and average plant height was lowest in R-1 (39 cm) of T-3 in open field. The average stem diameter which was highest was observed in R-2 (10.20 mm) of T-1 in polyhouse and average stem diameter was lowest in R-2 (5.84 mm) of T-4 in open field.

The average number of leaves which was highest was observed in R-2 (43.56) of T-1 in polyhouse and average number of leaves was lowest in R-3 (20.11) of T-4 in open field. The average number of fruits which was highest was observed in R-3 (47.20) of T-1 in polyhouse and average number of fruits was lowest in R-3 (22.85) of T-4 in open field. It was observed that average length of fruit in R-2 (54.97 mm) of T-1 in polyhouse recorded biggest among all, while the length of Tomato observed in R-3 (38.28 mm) of T-4 in open field was smallest. Similarly, it was observed that, the width of fruit in R-1 (53.13 mm) of T-1 in polyhouse recorded biggest among all, while the width of Tomato plant observed in R-3 (32.21 mm) of T-4 in open field was smallest. The highest yield was observed in R-1 (0.84 kg) of T-1 in polyhouse and lowest yield was observed in R-2 (0.17 kg) of T-4 in open field.

Our study demonstrated that under polyhouse conditions, T-1 (50% of ETc) resulted in a greater total yield of 16.73 kg compared to other irrigation levels. Conversely, under open field conditions, T-3 (100% of ETc) showed a greater total yield of 13.81 kg (Fig. 2). Burato et al., (2024) carried out open field trial in Foggia, Italy and found that IRR (full irrigation, restoring 100% ETc) showed slightly higher results in total and marketable yield compared to RDI (Regulated deficit irrigation, restoring 50%

ETc). S. Locatelli et al., (2024) calculated the fresh yield under full irrigation (FI) was 45.94 Mg ha^{-1} and under deficit irrigation (DI) at 75% of FI was 41.94 Mg ha^{-1} for the mineral and unfertilized treatments, indicating a yield reduction of 8.7% with DI in a polyethylene green house at University of Paldova, Italy. The variation in results can be attributed to the unique topographical and climatic conditions of Assam's hilly terrain which could influence water availability and plant water needs differently compared to other regions. The variation in results may also stem from differences in experimental design, irrigation scheduling, replication techniques, and statistical analysis.

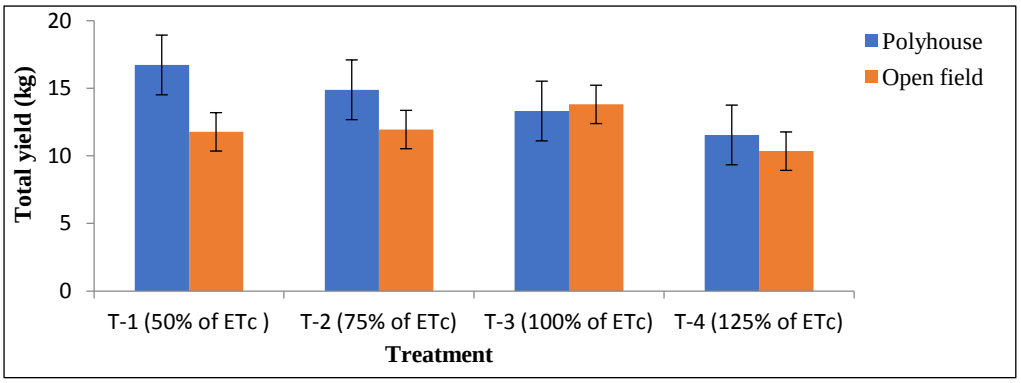

Fig. 2. Treatment wise variation of total fruit yield observed in each treatment in polyhouse and open field

Water use efficiency

It was found that the water use efficiency was highest for T-1 (0.09 ton/ha mm) in polyhouse and lowest for T-4 (0.04 ton/ha mm) in open field (Table 1, Fig. 3 and Fig 4). Burato et al., (2024) found that in comparison to the IRR (full irrigation, restoring 100% ETc) regime, remarkable water savings (21.46%, average of two years) were made under RDI (Regulated deficit irrigation, restoring 50% ETc) without significantly affecting total and marketable yield.

Francaviglia and Bene (2019) proved that WUE in was generally higher for treatments involving reduced irrigation (50% of ETc) compared to full irrigation (100% of ETC) for tomato production in Italy.

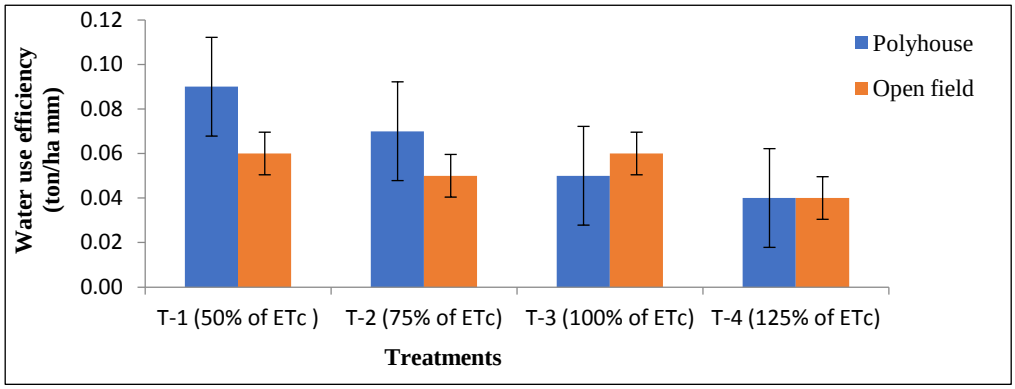

Fig. 3. Treatment wise variation of water use efficiency observed in each treatment in polyhouse and open field

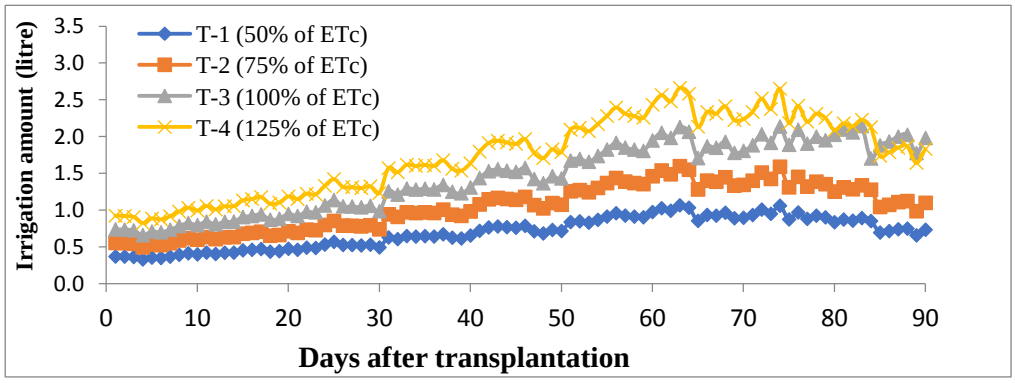

Fig. 4. Irrigation water applied in each treatment in polyhouse and open field

Table 1. Treatment wise water use efficiency observed in each treatment plot

Treatment	Yield (t ha^{-1})		Irrigation water applied (mm)	Water Use Efficiency (t ha^{-1} mm^{-1})	
	Polyhouse	Open field		Polyhouse	Open field
T-1 (50% of ETc)	34.28	24.14	397.2	0.09	0.06
T-2 (75% of ETc)	30.51	24.49	454.68	0.07	0.05
T-3 (100% of ETc)	27.3	28.3	507.33	0.05	0.06
T-4 (125% of ETc)	23.67	21.21	539.08	0.04	0.04

Statistical Analysis

ANOVA test of Tomato fruit yield and water use efficiency has been done. The results shows that the significance value is 0.012 which is less than 0.05% significance implying significant Tomato fruit yield (Table 2). The result shown in Table 3 shows that the significance value is 0.021 which is less than 0.05% significance implying significant water use efficiency.

Table 2. ANOVA parameter analyses comparing yield per plot in polyhouse and open field

ANOVA					
Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.082	1	3.082	7.525	0.012
Within Groups	9.009	22	0.410		
Total	12.091	23			

Table 3. ANOVA parameter analyses comparing water use efficiency in each treatment in polyhouse and open field

ANOVA					
Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.001	3	0.000	2.381	0.0210
Within Groups	0.001	4	0.000		
Total	0.002	7			

Economics and cost of production for Tomato

The experiment was conducted considering the existing constructed protected structures and drip irrigation system only their installation costs is not included in the cost of production.

Data on crop productivity was collected for 120 days starting on the transplantation date (Table 4 and Table 5).

The gross return ($/ha), net return per unit area ($/ha) net profit per unit production ($/ton) and BC ratio values were found significantly higher in T-1 in polyhouse and lowest in T-4 in open field (Table 4 and Table 5).

Table 4. Cost of production and economic analysis for Tomato in each treatment in polyhouse

Cost of Production of Tomato in each treatment in Polyhouse (USD, $)				
Components	Polyhouse			
	T-1	T-2	T-3	T-4
Nursery/Seedlings	0.24	0.24	0.24	0.24
Land preparation	0.36	0.36	0.36	0.36
Manures and Fertilizers	0.18	0.18	0.18	0.18
Plant protection	0.24	0.24	0.24	0.24
Land revenue	0.30	0.30	0.30	0.30
Hired Human Labour	1.20	1.20	1.20	1.20
Total Cost for 4.88 m^2 Area	2.58	2.58	2.58	2.58
Total cost in $/ Ha	5.1	5.1	5.1	5.1
Economics of Production of tomato in each treatment				
Yield (kg/plot)	0.20	0.18	0.16	0.14
Selling Price ($/kg)	0.60	0.60	0.60	0.60
Cost of Cultivation ($/Ha)	5276.88	5276.88	5276.88	5276.88
Total Yield (kg/ha)	410.62	365.45	326.92	283.48
Gross Returns ($/Ha)	20530.72	18272.72	16346.04	14173.91
Net returns per unit area ($/Ha)	15253.84	12995.84	11069.16	8897.03
B:C Ratio	2.89	2.46	2.10	1.69

Table 5. Cost of production and economic analysis for Tomato in each treatment in open field

Cost of Production of Tomato in each treatment in Open field (USD, $)				
Components	Open field			
	T-1	T-2	T-3	T-4
Nursery/Seedlings	0.24	0.24	0.24	0.24
Land preparation	0.36	0.36	0.36	0.36
Manures and Fertilizers	0.18	0.18	0.18	0.18
Plant protection	0.24	0.24	0.24	0.24
Land revenue	0.30	0.30	0.30	0.30
Hired Human Labour	1.20	1.20	1.20	1.20

Total Cost for 4.88 m^2 Area	2.58	2.58	2.58	2.58
Total cost in $/ Ha	5.1	5.1	5.1	5.1
Economics of Production of tomato in each treatment				
Yield (kg/plot)	0.14	0.14	0.17	0.12
Selling Price ($/kg)	0.60	0.60	0.60	0.60
Cost of Cultivation ($/Ha)	5276.88	5276.88	5276.88	5276.88
Total Yield ($/ha)	289.12	293.30	338.95	254.03
Gross Returns ($/Ha)	14456.18	14664.80	16947.36	12701.32
Net returns per unit area ($/Ha)	9179.30	9387.92	11670.48	7424.44
B:C Ratio	1.74	1.78	2.21	1.41

CONCLUSION

The crop growth parameters, yield and water use efficiency for tomato crop revealed the crop with drip irrigation at T-1 inside the polyhouse was found best in plant height, stem diameter, leaves at all stages of development than other irrigation treatments The water use efficiency was highest for the T-1 (0.09 ton/ha mm) in polyhouse.

The agricultural production economic study revealed that the initial cost for cultivation in poly house is quite higher but the net return was found highest from T-1 in poly house than open field. The T-1 in polyhouse resulted significantly more benefit cost ratio for growing of Tomato as compared to open field. Therefore, the polyhouse cultivation with drip irrigation at 50% of crop evapotranspiration (ETc) can be the most appropriate irrigation treatment for tomato crop with better crop growth, higher yield and high-water use efficiency in hilly terrain of North Eastern Region.

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DISCLOSURE STATEMENT

The authors report there are no competing interests to declare.

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CHARACTERIZATION OF SOME *BRASSICA RAPA* AND THEIR F_1 GENOTYPES FOR MORPHOLOGICAL TRAITS

N.J. Shelly[1*], M.S.R. Bhuiyan[2], F. Mahmud[2], J. Rahman[2] and M.A. Alam[3]

[1 & 2] Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.
[3]Bangladesh Agriculture Research Institute, Gazipur, Bangladesh.

ABSTRACT

The study was conducted in the research field of Sher-e Bangla Agricultural University, Dhaka, Bangladesh from November 2020 to February 2021 to characterize seven *Brassica rapa* and their 42 F_1 genotypes for morphological traits. Most of the F_1s showed intermediate characteristics between their parents for leaf, flower and pod characters. The parent, Brown Special matured within the shortest time (80.66 days) with moderate yield (5.88g plant^{-1}). All the F_1s had higher yield potential than their parents, except BARI Sharisha-15×BARI Sharisha -14 and BARI Sharisha-15×BARI Sharisha-17. The F_1 (Tori-7×Brown Special) matured within the shortest time (80.00 days) with yield of 13.24g plant^{-1}. The F_1s (Brown Special×BARI Sharisha-14), (Yellow Special×Brown Special), (BARI Sharisha-14×Tori-7), (Brown Special×BARI Sharisha-15) matured in 82.00, 83.00, 83.00 and 85.00 days, respectively with yield 11.59, 15.79, 13.27 and 26.02 g plant^{-1}, respectively. While the F_1s, (BARI Sharisha-15×Brown Special) and (Tori-7×Yellow Special) matured in late, 92.88 and 96.00 days, respectively, but had very high yield potential of 22.34 and 27.67 g plant^{-1}, respectively. Therefore, these genotypes possessed excellent potential for use in future trial.

Keywords: *Brassica rapa*, Duration, F_1 genotypes, Qualitative and quantitative traits, Yield.

INTRODUCTION

Brassica is a plant of mustard family (*Brassicaceae*). *B. rapa* L. is a diploid species of this family and is a major oilseed crop, but also used as vegetable, spice, and medicine (Huang *et al*., 2022). Its oil is cholesterol free, contains significant amount of ω-3 and ω-6 fatty acids, low levels of saturated fatty acids, 38-40% complete protein and a carrier of fat-soluble vitamins (Rashid, 2013). It also has high medicinal values due to the presence of some important anticancer, anti-inflammatory and antioxidant compounds including glucosinolates, carotenoids, flavonoids, ketones,

* Corresponding author: shely.sau302@gmail.com

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aldehydes, vitamin C, selenium, etc. (Jan *et al*., 2018). Its adventitious chemical composition and relatively low price makes it a valuable food additive. In Bangladesh rapeseed and mustard are cultivated in total 0.522 million hectares area which produces 0.683 million MT and *B. rapa* occupies the frist position in respect of area and production (AIS, 2022). Though *B. rapa* has high nutritional and medicinal values and occupied a biggest area, but its production is very low, indicates little attention for its improvement. Improvement usually obtained with lengthy breeding programs, which involves different gene pools, selection and utilization of selected individual for developing best genotypes. The yield, duration and quality of *Brassica* oils has extensively modified by using conventional breeding (Thakur *et al*., 2016) and the success of breeding program increases with increased variation within the present genotypes (Anjali *et al.,* 2022). Breeders can differentiate the extent of variability and similarity within the existing germplasm using morphological, biochemical and molecular approaches, which can be exploited in future breeding program (Avtar *et al.,* 2016, Carvalho *et al*., 2019 and Mishra *et al*., 2019). However, morphological characterization is the first approach in the description and classification of germplasms (Singh *et al*., 2018). Previously many researchers used phenotypic traits for assessing genetic diversity (Singh *et al.,* 2010). Thus, characterization is an important prerequisite to evaluate phenotypic diversity within the prevailing genotypes (Neeru *et al*., 2017). Therefore, the objectives of the present study was to explore the morphological features of some *B. rapa* and their F_1 genotypes.

MATERIALS AND METHODS

The study was conducted in the research field of SAU, Dhaka, Bangladesh from November 2020 to February 2021. Seven *B. rapa* genotypes viz., Brown Special and Yellow Special (from Sher-e-Bangla Agricultural University), Tori -7, BARI Sharisha-6, BARI Sharisha-14, BARI Sharisha-15 and BARI Sharisha-17 were collected from Bangladesh Agriculture Research Institute) were collected based on their high yield potential and short duration. Then 42 F_1s obtained from the full di-allel crosses among the collected genotypes grown with their parents in RCBD with three replications and studied the morphological characteristics. Characterization carried out based on different qualitative and quantitative traits. For mean performance, mean values of ten randomly selected plants for each traits under each population in each replication subjected to statistical analysis. Mean, range and co-efficient of variation were estimated using MSTAT-C and OPSTAT.

RESULTS AND DISCUSSION

B. rapa genotypes were characterized based on their qualitative and quantitative traits.

Leaf characteristics

For all genotypes, leaves were simple and alternate. Brown Special, Yellow Special, Tori -7 and BARI Sharisha-6 had an open (~ 65 º), BARI Sharisha-14 and BARI Sharisha-15 had semi prostrate (~ 45 º) and only BARI Sharisha-17 had prostrate (< 30 º) type leaf angle. Tori -7 and BARI Sharisha-15 had lyrated and the remaining genotypes had runcinated leaf blade. Leaf blade edge was lobed but crenated for BARI Sharisha-14, Yellow Special, Tori-7 and BARI Sharisha-6, semi crenated for Brown Special and serrated for BARI Sharisha-17 and BARI Sharisha-15. BARI Sharisha-14, BARI Sharisha-17 and BARI Sharisha-6 had acute while semi acute for Brown Special and Yellow Special but Tori-7 and BARI Sharisha-15 had rounded leaf apex (Plate 1). Brown Special, Tori -7, BARI Sharisha-17 and BARI Sharisha-15, had sparse leaf hair while in BARI Sharisha-14, Yellow Special and BARI Sharisha-6 had very sparse leaf hairs (Table 1). The basal leaf length and width ranged from 9.07 to 21.08 cm and 4.57 to 9.65 cm and measured highest in BARI Sharisha-6 (21.08 and 9.65 cm respectively). The petiole length and width ranged from 3.70 to 7.60 cm and 0.53 to 1.10 cm, respectively and measured highest in BARI Sharisha-6 (7.60 and 1.10 cm respectively). The leaf lobes number ranged from 6.00 to 9.00 (Table 2). These results matched with the findings of Young-Mathews (2012), PROTA (2018), Minnesota Wild Flowers (2021) and iNaturalist org. (2021).

Table 1. Characterization of *B. rapa* genotypes based on qualitative leaf characteristics

Genotypes	Leaf types	Leaf arrangement	Leaf angle	Leaf blade shape	Leaf apex shape	Leaf blade edges	Leaf hairiness
P_1 (BARI Sharisha-14)	Simple	Alternate	Semi prostrate (~ 45 º)	Runcinate	Acute	Lobed and crenated	Very sparse
P_2 (Brown Special)	Simple	Alternate	Open (~ 65 º)	Runcinate	Semi acute	Lobed and slightly crenated	Sparse
P_3 (Yellow Special)	Simple	Alternate	Open (~ 65 º)	Runcinate	Semi acute	Lobed and crenated	Very sparse
P_4 (Tori -7)	Simple	Alternate	Open (~ 65 º)	Lyrate	Round	Lobed and crenated	Sparse
P_5 (BARI Sharisha-17)	Simple	Alternate	Prostrate (< 30 º)	Runcinate	Acute	Lobed and serrated	Sparse
P_6 (BARI Sharisha-15)	Simple	Alternate	Semi prostrate (~ 45 º)	Lyrate	Round	Lobed and serrated	Sparse
P_7 (BARI Sharisha-6)	Simple	Alternate	Open (~ 65 º)	Runcinate	Acute	Lobed and crenated	Very sparse

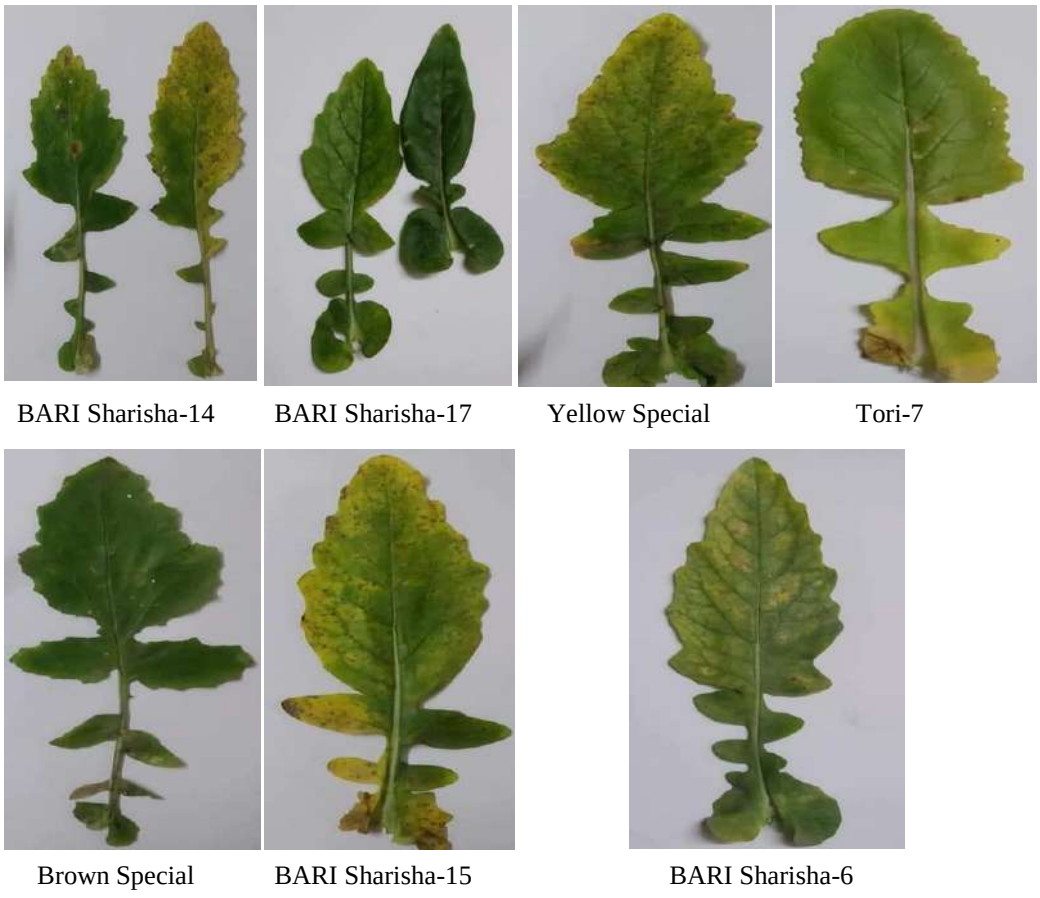
Table 2. Characterization of *B. rapa* genotypes based on quantitative leaf character

Genotypes	Basal leaf length (cm)	Basal leaf width (cm)	Number of leaf lobes	Petiole length (Basal leaf) (cm)	Petiole width (Basal leaf) (cm)
P_1 (BARI Sharisha-14)	9.07 g	4.57 f	9.13 a	3.70 e	0.59 f
P_2 (Brown Special)	18.41 b	7.87 b	8.66 ab	6.40 b	0.95 b
P_3 (Yellow Special)	14.73 e	6.35 d	6.53 b	4.50 d	0.71 d
P_4 (Tori -7)	17.78 c	7.08 c	6.06 b	5.25 c	0.80 c
P_5 (BARI Sharisha-17)	11.30 f	5.10 e	7.88 b	3.80 e	0.53 g
P_6 (BARI Sharisha-15)	15.89 d	6.60 cd	6.66 b	4.55 d	0.65 e
P_7 (BARI Sharisha-6)	21.08 a	9.65 a	8.33 ab	7.60 a	1.10 a
Minimum	9.07	4.57	6.06	3.70	0.53
Maximum	21.08	9.65	9.00	7.60	1.10
Mean	15.46	6.74	7.28	5.11	0.76
CV%	2.14	4.37	17.17	3.59	3.86
LSD	0.59	0.52	1.63	0.32	0.05

Flower and pod characteristics

The flowers were yellow and radially symmetrical for all genotypes (except BARI Sharisha-15, whitish yellow) (Plate 2 and Table 3). Flower length ranged from 0.70 to 1.10 cm and was highest in Tori-7 (1.10 cm). Petal length and width ranged from 0.58 to 0.94 cm and 0.28 to 0.45 cm respectively. The highest petal length measured in Tori-7 (0.94 cm) and petal width in BARI Sharisha-6 (0.45 cm) (Table 3). The pods were elongated, cylindrical, round slender and flattened in shape. A single prominent lengthwise vein distinguishes it from other *Brassica* species. Brown Special and Tori-7 had long, BARI Sharisha-6 and BARI Sharisha-15 had semi erect and rest of the genotypes had erect pod angle. The pod length and width and beak length ranged from 2.80 to 5.08 cm, 0.40 to 1.10 cm and 0.93 to 1.90 cm, respectively. The highest pod length measured in Brown Special (5.08 cm) and the pod width in BARI Sharisha-17 (1.10 cm). The beak length was the highest in BARI Sharisha-6 (1.90 cm) and the lowest in BARI Sharisha-15 (0.93 cm) (Plate 3 and Table 3). These results remained within the findings of Velez-Gavilan (2018), Vibrans (2018) and Hilty (2019).

Plate 1. Middle leaves of *B. rapa* parent genotypes at 50% flowering stage



BARI Sharisha-14 BARI Sharisha-17 Yellow Special Tori-7

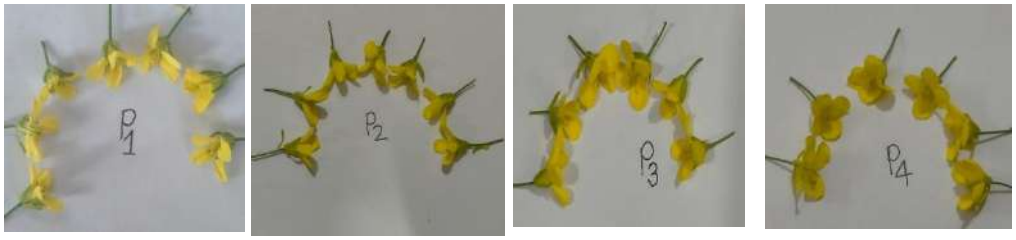
Brown Special BARI Sharisha-15 BARI Sharisha-6

Table 3. Characterization of *B. rapa* genotypes based on qualitative and quantitative flower and pod characteristics

Genotypes	Qualitative characteristics			Quantitative characteristics					
	Flower colour	Siliqua/Pod shape	Siliqua/Pod angle	Flower length (cm)	Petal length (cm)	Petal width (cm)	Siliqua length (cm)	Siliqua width (cm)	Beak length (cm)
P_1 (BARI Sharisha-14)	Yellow	Cylindrical	Erect	0.70 g	0.58 g	0.28 f	2.80 e	0.96 b	1.20 c
P_2 (Brown Special)	Yellow	Rounded	Long	0.92 c	0.80 c	0.40 c	5.08 a	0.56 d	1.31 bc
P_3 (Yellow Special)	Yellow	Flattened	Erect	0.86 e	0.75 e	0.37 d	3.66 cd	0.78 c	1.45 b
P_4 (Tori -7)	Yellow	Round and slender	Long	1.10 a	0.94 a	0.42 b	3.98 c	0.40 e	1.16 c
P_5 (BARI Sharisha-17)	Yellow	Cylindrical	Erect	0.78 f	0.65 f	0.33 e	3.00 e	1.10 a	1.35 bc

Genotypes	Qualitative characteristics			Quantitative characteristics					
	Flower colour	Siliqua/Pod shape	Siliqua/Pod angle	Flower length (cm)	Petal length (cm)	Petal width (cm)	Siliqua length (cm)	Siliqua width (cm)	Beak length (cm)
P_6 (BARI Sharisha-15)	Whitish yellow	Flattened	Semi-erect	0.90 d	0.78 d	0.40 c	3.41 d	0.63 d	0.93 d
P_7 (BARI Sharisha-6)	Yellow	Flattened	Semi-erect	0.98 b	0.86 b	0.45 a	4.46 b	0.75 c	1.68 a
Minimum	-	-	-	0.70	0.58	0.28	2.80	0.40	0.93
Maximum	-	-	-	1.40	0.94	0.45	5.08	1.10	1.68
Mean	-	-	-	0.93	0.76	0.38	3.84	0.74	1.33
CV%	-	-	-	0.78	0.64	1.00	5.31	6.50	8.48
LSD	-	-	-	0.05	0.06	0.07	0.36	0.08	0.20

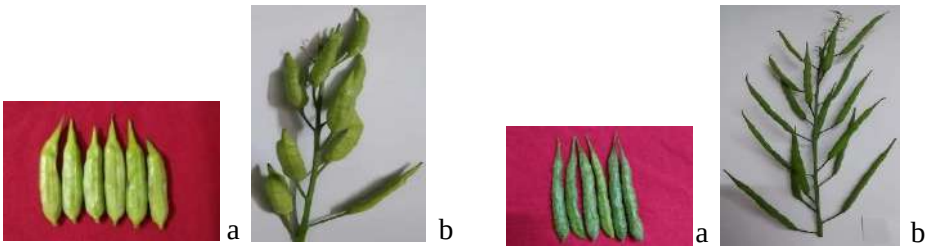
Plate 2. Flowers of *B. rapa* parent genotypes



BARI Sharisha-14 Brown Special Yellow Special Tori-7

BARI Sharisha-17 BARI Sharisha-15 BARI Sharisha-6

Plate 3. Siliqua/pods of parent *B. rapa* genotypes



BARI Sharisha-14

Brown Special

Yellow Special

Tori-7

BARI Sharisha-17

BARI Sharisha-15

BARI Sharisha-6

Morphological characterization of F_1s

The results of characterization and frequency distribution of each descriptor of the F_1s genotypes presented in Table 4.

Table 4. Characterization and frequency distribution of 42 F_1s for different qualitative and quantitative traits.

S. No.	Plant descriptors	State of expression	Number of F_1s belonging to each class	Frequency (%)
1.	Leaf length	Long	7	16.66
		Intermediate	31	73.81
		Short	4	9.52
2.	Leaf width	Large	5	11.90
		Intermediate	34	80.95
		Narrow	3	7.14
3.	Leaf angle	Open	32	76.19
		Semi-prostrate	6	14.29
		Prostrate	4	9.52
4.	Leaf blade shape	Lyrate	10	23.81
		Runcinate	32	76.19
5.	Leaf apex shape	Acute	22	52.38
		Semi acute	10	23.81
		Rounded	10	23.81
6.	Leaf blade edges	Lobed and crenated	30	71.43
		Lobed and Serrated	12	28.57
7.	Leaf hairiness	Very sparse	14	33.33
		Sparse	26	61.90
		Absent	2	4.76
8.	Number of leaf lobes	High	6	14.29
		Medium	30	71.43
		Low	6	14.29
9.	Petiole length	Long	6	14.29
		Intermediate	34	80.95
		Short	2	4.76
10.	Petiole width	Broad	12	28.57
		Intermediate	30	71.43
11.	Flower colour	Yellow	42	100.00
12.	Petal length	Long	6	14.29
		Medium	34	80.95
		Short	2	4.76
13.	Petal width	Broad	6	14.29
		Medium	34	80.95

S. No.	Plant descriptors	State of expression	Number of F_1s belonging to each class	Frequency (%)
		Narrow	2	4.76
14.	Siliqua/pod shape	Cylindrical	2	4.76
		Rounded	11	21.43
		Thin and Rounded	7	16.66
		Flattened	16	42.86
		Thin and Flattened	6	14.29
15.	Siliqua/pod length	Long	25	59.52
		Intermediate	15	35.71
		Short	2	4.76
16.	Siliqua/pod width	Broader	2	4.76
		Medium	27	64.29
		Narrow	13	30.95
17.	Siliqua/pod angle	Long	16	38.10
		Erect	10	23.81
		Semi-erect	16	38.10
18.	Beak length	Long	6	14.29
		Intermediate	32	76.19
		Short	4	9.52

Leaf characteristics

All the F_1s had simple and alternate leaves. 76.19% F_1s had open (~ 65 º), 14.29% had semi-prostrate (~ 45 º) and 9.52% had prostrate (< 30 º) leaf angle. 23.81% F_1s had lyrated and 76.19% had runcinated leaves. 52.38% F_1s had acute, 23.81% had semi-acute and remaining 23.81% had rounded apex shape. 71.43% had lobed and crenated and 28.57 % had lobed and serrated type. 33.33 % F_1s had very sparse, 61.90 % had sparse and in remaining 4.76 % had no leaf hair (Table 4).16.66 % F_1s had long (> 20 cm), 73.81% had intermediate (< 20 cm) and 9.52% had short (< 10 cm) leaf length. 11.90% F_1s had the larger (> 7 cm), 80.95% had intermediate (< 7 cm) and 7.14% had narrower (< 4 cm) leaf width. 14.29% F_1s had high (> 10), 71.43% had medium (> 5 but < 10) and 14.29% had low (< 5) leaf lobes. 14.29% F_1s had long (> 8 cm), 80.95% had intermediate (< 8 cm) and 4.76 % had short (< 4 cm) petioles length. While 28.57% F_1s had broad (> 1 cm) and 71.43% had intermediate (< 1 cm) petiole width (Table 4). Yadav (2013), iNaturalist org. (2021), Native Plant Trust (2021) and Minnesota Wild Flowers (2021) also found similar results in different *B. rapa* varieties.

Flower and pod characteristics

All the F_1s had bright yellow flower though one parent (BARI Sharisha-15) had whitish yellow flowers. 14.29% F_1s had long (> 1 cm) with broad (> 0.5 cm) petal, 80.95 % had medium length (< 1 cm) and width (< 0.5 cm) and 4.76 % had short (< 0.5 cm) and narrow (< 0.2 cm) petal. 4.76% F_1s had cylindrical, 26.19% had rounded, 16.66% had thin and rounded, 38.10 % had flattened and 14.29 % had thin and flattened pod (Table 4). 38.10% F_1s had long, 23.81% had erect and 38.10% had semi-erect pod angle (Table 4). 59.52% F_1s had long (> 3.5 cm), 35.71% had intermediate (< 3.5 cm) and 4.76 % had short pod length (< 2.0 cm) while 4.76 % had larger (> 1 cm), 64.29 % had medium (< 1 cm) and 30.95 % had narrower pod width (< 0.5 cm). 14.29 % F_1s had long (> 1.5 cm), 76.19 % had intermediate (< 1.5 cm) and 9.52 % had short (< 0.8 cm) beak (Table 4). Young-Mathews (2012), Velez-Gavilan (2018), Vibrans (2018) and Hilty (2019) also found similar results for these traits in different *B. rapa* genotypes.

Yield and yield related quantitative characters

Mean performance of different yield related traits of parents and their F_1s estimated and are presented in Table 5. Days to 80% maturity ranged from 80.66 to 110.00 days and 80.00 to 103.00 days in parents and F_1s, respectively. The parent, Brown Special and the F_1-(Tori-7×Brown Special) matured within the lowest time (80.66 days and 80.00 days, respectively). Plant height ranged from 73.46 to 148.56 cm in parents and 110.60 to 148.00 cm in F_1s. Tori-7 (73.46 cm) and the F_1-(BARI Sharisha-17×BARI Sharisha-14) (110.60 cm) showed the lowest plant height. The number of branches plant^{-1} ranged from 5.72 to 15.83 in parents and 6.03 to 35.75 in F_1s. The parent, Tori-7 (15.83) and the F_1-(Brown Special×BARI Sharisha-15) (35.75) showed the highest number of Siliqua plant^{-1} and ranged from 97.66 to 250.53 in parents and 101.00-1029.00 in F_1s. Tori-7 and the F_1-Brown Special×BARI Sharisha-15 produced the highest number of siliqua. Thousand seed weight in parents ranged from 2.82 to 4.78 g and 2.10 to 5.69g in F_1s. BARI Sharisha-6 (4.78 g) and the F_1-BARI Sharisha-6×BARI Sharisha-17 (5.69 g) produced the heaviest seeds. Seed yield plant^{-1} ranged from 4.25 to 8.41 g in parents and 4.21 to 27.67 g in F_1s. The highest seed yield recorded in BARI Sharisha-6 (8.41 g plant^{-1}) and in the reciprocal F_1-Tori-7×Yellow special had 27.67 g plant^{-1} (Table 5). These results remained within the findings of Naznin *et al.* (2015), Karmokar (2018), Ullah (2018) and Ferdous (2019) but exceeded in F_1s, which may be due to environmental factors.

Table 5. Mean performance of six yield and yield contributing traits of *B. rapa* genotypes

Sl. No.	Genotypes	Days to 80% Maturity	Plant height (cm)	Number of branches plant^{-1}	Number of siliqua plant^{-1}	1000 seed weight (g)	Seed yield plant^{-1} (g)
A.	Parents						
1.	P_1 (BARI Sharisha-14)	85.00	95.66	7.75	97.66	3.35	5.20
2.	P_2 (Brown Special)	80.66	109.38	10.88	210.63	3.62	5.88
3.	P_3 (Yellow Special)	88.00	112.26	5.72	137.73	4.62	5.36
4.	P_4 (Tori-7)	81.66	73.46	15.83	250.53	2.82	4.25
5.	P_5 (BARI Sharisha-17)	96.00	100.90	7.25	102.66	4.00	6.97
6.	P_6 (BARI Sharisha-15)	90.33	114.30	9.99	165.40	4.76	6.43
7.	P_7 (BARI Sharisha-6)	110.00	148.56	9.53	175.20	4.78	8.41
B.	Crosses						
1.	$P_1 \times P_2$	90.00	132.30	18.9	386.68	4.25	18.67
2.	$P_1 \times P_3$	89.00	124.80	8.03	190.24	3.92	12.09
3.	$P_1 \times P_4$	83.00	128.96	15.7	428.53	4.11	13.27
4.	$P_1 \times P_5$	88.00	111.63	6.03	101.00	3.47	10.20
5.	$P_1 \times P_6$	90.00	122.96	8.83	183.36	4.30	12.04
6.	$P_1 \times P_7$	92.00	125.53	9.99	232.73	4.39	14.11
7.	$P_2 \times P_3$	87.00	118.62	12.53	270.86	4.24	18.34
8.	$P_2 \times P_4$	86.00	112.86	21.00	305.13	2.98	15.75
9.	$P_2 \times P_5$	94.00	125.80	22.63	420.33	3.74	23.55
10.	$P_2 \times P_6$	85.00	148.00	35.75	1029.00	4.02	26.02
11.	$P_2 \times P_7$	84.33	122.13	14.06	276.26	5.04	12.44
12.	$P_3 \times P_4$	84.00	120.96	17.49	506.73	3.44	15.02
13.	$P_3 \times P_5$	88.00	116.46	10.33	160.13	4.72	15.80
14.	$P_3 \times P_6$	94.24	120.33	11.34	211.86	4.08	12.25
15.	$P_3 \times P_7$	96.66	128.60	10.00	230.73	3.20	13.70
16.	$P_4 \times P_5$	95.50	114.98	25.53	617.05	4.40	16.37
17.	$P_4 \times P_6$	96.00	133.73	29.52	620.26	2.81	15.54
18.	$P_4 \times P_7$	86.66	125.13	19.86	385.86	4.14	13.53
19.	$P_5 \times P_6$	91.33	126.60	9.13	180.13	3.19	10.55
20.	$P_5 \times P_7$	89.38	130.50	7.46	166.99	3.71	9.53
21.	$P_6 \times P_7$	93.00	134.00	13.58	341.23	5.41	12.66
C.	Reciprocals						
22.	$P_2 \times P_1$	82.00	128.51	14.06	312.93	3.08	11.59

Sl. No.	Genotypes	Days to 80% Maturity	Plant height (cm)	Number of branches plant^{-1}	Number of siliqua plant^{-1}	1000 seed weight (g)	Seed yield plant^{-1} (g)
23.	$P_3 \times P_1$	86.00	117.33	8.20	123.83	5.20	9.69
24.	$P_3 \times P_2$	83.00	129.26	15.19	350.00	4.15	15.79
25.	$P_4 \times P_1$	94.25	134.53	20.06	426.46	4.02	16.19
26.	$P_4 \times P_2$	80.00	116.46	21.06	401.73	4.37	13.24
27.	$P_4 \times P_3$	96.00	130.00	25.73	555.93	5.42	27.67
28.	$P_5 \times P_1$	91.00	110.60	13.07	120.53	4.37	11.82
29.	$P_5 \times P_2$	89.00	119.00	11.12	314.46	3.60	11.15
30.	$P_5 \times P_3$	93.00	121.90	8.70	168.70	3.00	9.66
31.	$P_5 \times P_4$	90.00	124.00	19.66	453.00	5.37	16.23
32.	$P_6 \times P_1$	88.00	118.66	17.32	171.30	3.53	8.37
33.	$P_6 \times P_2$	92.88	121.26	33.00	591.20	5.58	22.34
34.	$P_6 \times P_3$	89.00	129.40	7.92	164.93	3.10	9.52
35.	$P_6 \times P_4$	85.00	139.96	32.46	823.86	3.01	19.61
36.	$P_6 \times P_5$	95.00	120.96	12.92	169.36	2.81	7.80
37.	$P_7 \times P_1$	93.00	141.53	14.43	234.50	2.44	12.21
38.	$P_7 \times P_2$	87.00	130.16	12.37	258.62	4.42	14.04
39.	$P_7 \times P_3$	95.00	128.53	9.10	131.40	2.10	10.36
40.	$P_7 \times P_4$	90.00	137.86	18.53	463.40	3.10	16.60
41.	$P_7 \times P_5$	103.00	139.20	11.90	225.08	5.69	13.33
42.	$P_7 \times P_6$	99.00	136.66	8.93	240.06	3.27	9.32
	Minimum	80.00	73.46	5.72	97.66	2.10	4.21
	Maximum	110.00	148.56	35.75	1029.00	5.69	27.67
	Mean	44.38	124.01	14.91	306.58	3.93	90.02
	CV (%)	1.48	2.09	14.75	2.47	4.78	1.18
	LSD	1.06	4.20	1.63	12.32	0.30	1.73

CONCLUSION

Most of the F_1s showed intermediate type characteristics among their parents. The F_1s, BARI Sharisha-15×Brown Special, Tori-7×Yellow Special, Tori-7×Brown Special, Brown Special×BARI Sharisha-14, Yellow Special×Brown Special, BARI Sharisha-14×Tori-7 and Brown Special×BARI Sharisha-15 had both high yield potential and short duration. Therefore, these genotypes could be used for further evaluation.

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PERFORMANCE EVALUATION OF SELF-PROPELLED RICE TRANSPLANTER FOR IMPACT STUDY ON RICE CULTIVATION

A. Deres[*1] and M. Katahira[2]

[1]Ethiopian Institute of Agricultural Research, Fogera National Rice Research and Training Center
[2]Yamagata University Faculty of Agriculture Tsurouka, Japan

ABSTRACT

Rice is cultivated through mechanical transplanting or direct seeding methods worldwide. Our investigation focused on evaluating the performance of mechanical transplanting and surveying yield, and yield components. The study was conducted at the Yamagata University Faculty of Agriculture at the Takasaka Farm. A Kubota (NSU-87) transplanter with 'Heanuki' rice seedlings was used. We evaluated the performance of the transplanter by the ratio of the effective field capacity (hah-1) to the theoretical field capacity (hah-1). The average field capacity and efficiency of the eight rows of self-propelled paddy transplanter was 0.184 ha/h and 76.6%, respectively, with an area of 0.024 ha at an average operating speed of 1 km/h. The average planting depth (30.36 mm), number of seedlings per hill (3.66), number of seedlings per square meter (102.16), and hill-to-hill distance (15.09 cm) were surveyed and measured. The average grain yield (5.5 tons/ha) was calculated. The average values of (411.2) panicles per square meter, (68.4) grains per panicle, (89.6) percent of filled grains, and (22.25) 1,000-grain weight were obtained. Kubota type (NSU-87) transplanter was satisfactory, at the parameters of fieldwork capacity, fieldwork accuracy, grain yield, and yield components. A self-propelled transplanter is essential for rice cultivation, and it is recommended for saving the amount of seed, ease (weed control and field monitoring), easy operation system, and better crop stand establishment.

Keywords: Fieldwork capacity, Grain yield, Plant growth, Transplanter, Yield components

[*] Corresponding author: asnakewderes@gmail.com

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INTRODUCTION

Rice serves as a primary food source for over half of the world's population. Rice cultivation is a complex process that involves multiple steps to produce the final product. Currently, rice cultivation is performed in different systems worldwide. The two most important cultivation methods are direct seeding and transplantation where young rice plants grown in nurseries are planted in puddled soils (Pandey et al., 2000, p. 3).

Various types of transplanters are currently employed in Asia for establishing rice crops. Mechanical rice transplanters come in different capacities, such as 4 rows, 6 rows, and 8 rows, which vary based on the type of work they perform (Manikyam et al., 2020). A mechanical rice transplanter significantly decreases the manual work resulting in a higher density of plants and a reduced water depth (1-2 cm) during the transplantation process in the nursery (Haider Z et al., 2019). By taking advantage of the latest advancements in rice production machinery, farmers can make more informed decisions that benefit their livelihoods and the planet. By utilizing the benefits of transplanting in conjunction with precision agriculture and drone technology, farmers can continue to improve their crop management practices and ultimately increase their overall productivity and profitability (Dixit et al., 2007). Kanai (1979) stated that most planters in Japan are designed for the use of rice plants whose roots are composed of soil. Mechanical rice transplanting is the process of transplanting young seedlings using a self-propelled machine, and the seedlings are grown in a mat nursery (Rickman et al., 2015).

Wei et al. (2017) reported that extensive mechanization efforts have been made to achieve high rice yields, which has contributed to reducing labor requirements and improving production efficiency. As the agricultural sector continues to face challenges such as labor shortages and the aging of farmers, it becomes crucial to invest in technologies that can improve production and productivity. Research on the performance evaluation of rice transplanting machines and their effects on field capacity, operational systems, and labor needs is crucial for the sustainable future of rice farming.

MATERIALS AND METHODS

Study area and the study equipment

This study was conducted in Tsurouka City, Yamagata Prefecture, Japan, where rice is grown once in a year during May to October. The experiment was performed at the Takasaka farm station at the Yamagata University.

The self-propelled rice transplanter equips with a Seedling Feed Stopper, Float, Planting Fingers, and Side marker to ensure precise and efficient transplanting. It is capable of planting seedlings at a consistent depth, which is essential for uniform growth and maturity. In addition to its precision planting capabilities, the transplanter is designed for efficiency, allowing farmers to quickly transplant large areas of paddies. It has a 30 cm row spacing and 2.4 m width (Figure 1).

Figure 1. Self-propelled (Kubota NSU-87) transplanter

The main components of the rice transplanting machine

(1) Seedling Rack

(2) Seedling Mat Stopper

(3) Seedling Feed Stopper

(4) Float

(5) Planting Fingers

(6) Side marker

Seedling preparation

A self-propelled rice transplanter requires seedlings grown in the tray-type nurseries. The fertile soil was used for growing the seedlings. The soil was sieved and placed as a single layer in the tray. Water was regularly sprinkled on trays for good germination, and the trays were maintained under atmospheric conditions. The 'Haenuki' Japanese rice variety was grown in a thin layer of 30 cm × 60 cm × 3 cm soil in seedling boxes in a greenhouse. The seedlings were carefully monitored for growth and health, ensuring they were strong and ready for transplanting. Once the seedlings were at the optimal stage for transplanting, they were carefully removed from the trays and placed into the transplanter for planting in the field (Figure 2).

Figure 2. Rice Seedlings

Soil moisture content (mc %)

The moisture content of the experimental field was recorded before and after plowing at dry soil conditions (paddy). We randomly selected three sample plots before and after plowing then collected the soil sample at each sample plot and weighed. The samples were kept oven dry at 105℃ for one day and weighed. The soil moisture content is calculated by using the following equation as a percentage of the dry soil weight,

$$\text{Mc \%} = \frac{Mass\ of\ water}{Mass\ of\ dried\ soil} \times 100 \quad \text{.....1}$$

Field preparation

The experimental field was prepared by using a power tiller and irrigated before initial puddling. Before transplanting, the field was flooded and puddled, after that, the excess water was removed through drainage. The depth of the standing water was 4–8 cm during the initial puddling. The field was left for 5–6 days after initial puddling with water to decompose the previous crop residues. The final puddling was performed with the same power tiller. After the final puddling, the field was left for three days to settle the soil and regain its strength.

Soil pulverization ratio

Soil pulverization ratio is the ratio of the soil weight fraction composed of soil clods less than or equal to 25 mm which passes from the sieve mesh of 25 mm to the total weight of clods produced by plowing. After plowing, it was randomly selected three sample plots and soil samples on the experimental field Khadr (2008). The procedure was to weigh the total weight of each collected soil sample and sieve by 25 mm diameter of sieve mesh. It recorded the weight of greater than 25 mm diameter and less than or equal to 25 mm diameter of soil clod. It is an important method to determine the soil pulverization ratio. The soil pulverization ratio was calculated which was noted in Khadr (2008).

$$\text{Soil pulverization ratio} = \frac{Mass\ of\ clods \leq 25mm\ daimeter}{Total\ weight\ of\ sampling\ clods} \times 100 \quad \text{.....2}$$

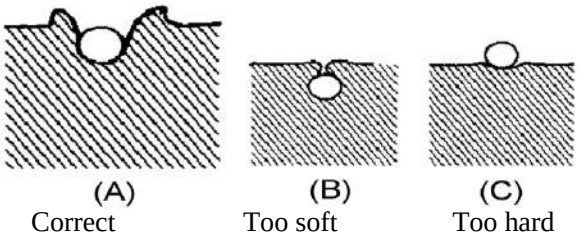
Soil hardness

It is essential to ensure the soil hardness is optimal for the best performance of the transplanting machine and overall fieldwork efficiency. Soil hardness is an indicator of the soil's compaction status; large pores are necessary for water and air movement to allow roots and organisms to explore the soil. A soil hardness tester was used to measure the soil hardness depth (mm) and pressure (kg/cm^2) of the experimental field before and after puddling (figure 3).

Figure 3. Soil hardness tester

Soil penetration

The correct soil hardness is crucial for the successful transplanting of seedlings. If the field is too hard, the seedlings will struggle to take root and may not survive. Conversely, if the field is too soft, the seedlings may not be able to establish themselves properly, leading to poor rice posture and soil return. After puddling, the soil penetration of the field was measured by using a Golf ball-type instrument. A golf ball is a circular shape and it weighs 45.95 g as shown in figure 4. The weight of the golf ball is crucial in determining the depth of the sunk ball after being dropped from a one-meter height. The results of the experiment will help determine the impact of different field conditions on the growth and development of the seedlings. Proper preparation of the field will ensure reliable and consistent data for analysis.



https://www.yanmar.com/media/th/com/maintenance/catalog/100492.pdf

Figure 4. Golf ball type soil hardness tester Figure 2. 5b Diagrammatic status of soil hardness

The performance of the transplanting machine

Fieldwork efficiency

The performance of an agricultural machine is measured by the rate and quality at which the operations are accomplished (Hunt, 1979). There are many different parameters reflecting machine performance, such as field capacity, efficiency, and fuel consumption**.**

Operational speed (km/h)

The operational speed is the time elapsed between the observed departure times at the involved stops. The operational speed (km/h) of the planter was measured by using a GPS logger instrument attached to the planting machine.

Effective field capacity, ha/h

The effective field capacity is the performance of the actual rate of land or crop processing in a given time based on the total field time. The effective field capacity is the ratio of the actual area covered to the total time taken. Therefore, the effective field capacity of the transplanter is calculated by the following equation: (Hunt, 1979),

$$\text{Effective field capacity, hah-1} = \frac{\text{The total area covered,ha}}{\text{Total time is taken,h}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Theoretical field capacity, ha/h

The theoretical field capacity of an implement is the rating of field coverage that would be obtained if the machine is performing 100 percent of the time at the rated forward speed and always covering 100 percent of the rated width. The theoretical field capacity of the transplanter was evaluated. The planting width (m) and operational speed (km/h) of the planter were measured.

Therefore, the theoretical field capacity is calculated by the following equation: (Hunt, 1979);

$$\text{Theoretical field capacity, hah-1} = Width\ (m) \times Speed(km/h) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Field efficiency, %

The field efficiency is the ratio of the effective field capacity to the theoretical field capacity, expressed as a percentage.

Therefore, the field efficiency is calculated by the following equation: (Hunt, 1979);

$$\text{Field efficiency, \%} = \frac{\text{Effective field capacity,(ha/h)}}{\text{Theoretical field capacity,(ha/h)}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

The field working accuracy of the transplanting machine

Test checkpoints

Three test checkpoints were randomly selected in the experimental field, and the working accuracy of the transplanter was evaluated. Each checkpoint contained 10 hills laid on two rows (5 hills per row).

Planting depth of the seedlings

The depth of transplanting was measured by uprooting the seedlings immediately after transplanting. The seedlings were held close to the puddled soil surface for uprooting. The distance from that point to the tip of the root was measured by a scale to determine the depth of transplanting. Ten randomly selected observations were taken to determine the depth of transplanting.

Rice seedlings per hill

The number of seedlings per hill was measured by directly counting the number of seedlings picked by the planting finger and transplanted in the field per hill after transplanting. Ten hills were randomly selected for observation, and the average was determined to represent the number of seedlings per hill.

Paddy hills planted or planting rate: hills/m^2

The number of paddy hills per sample area was counted directly by the number of seedlings picked by the planting finger and transplanted in the field per sample area after transplanting and converted to the number of hills per square meter.

Hill-to-hill distance

The hill-to-hill distance was measured using a metric scale after transplanting. Ten hill observations were randomly selected from the three sample checkpoints, and the mean was calculated to represent the hill spacing.

Missing hills

A hill without seedlings is called a missing hill. The missing hills were checked at the test checkpoints, and the average values were calculated. The percentage of missing hills was calculated by taking the ratio of the total number of missing hills to the total number of paddy hills planted in a square meter area, as expressed in the following equation (Islam and Rahman, 2014):

$$\text{Missing hills, \%} = \frac{Number\ of\ missing\ hills\ per\ \ m^2}{Total\ number\ of\ hills\ \ per\ m^2} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Floating hills

Seedlings that are either floating on the surface or just placed on the surface of the mud are called floating hills. The number of floating hills in the square-meter area was calculated from the average of all the readings.

The percentage of floating hills was calculated by the following equation (Islam and Rahman, 2014):

$$\text{Floating hills, \%} = = \frac{Number\ of\ floating\ hills\ per\ m^2}{Total\ number\ of\ hills\ per\ m^2} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Buried hills

Seedlings that are completely buried under the soil after transplanting are called buried hills. The number of buried hills in a square-meter area was calculated from an average of all the readings. The percentage of buried hills was calculated by the following equation (Islam and Rahman, 2014):

$$\text{Buried hills, \%} = = \frac{Number\ of\ buried\ hills\ per\ m^2}{Total\ number\ of\ hills\ per\ m^2} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

Planting efficiency

Planting efficiency is an important measure of the success of a transplant operation. It provides valuable information on the overall effectiveness of the planting process and can help identify areas for improvement. This data is crucial for ensuring the sustainability and productivity of agricultural practices. It is the ratio of the number of hills with seedlings (planted + floating + buried) to the total number of hills expressed as a percentage1.

It was calculated by the following equation (Islam and Rahman, 2014):

$$\text{Planting efficiency, \%} = \left(1 - \frac{Number\ of\ missing\ hills\ per\ m^2}{Total\ number\ of\ hills\ per\ m^2}\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

Yield and yield component investigation

Measuring grain yield

To estimate the grain yield of the experiment, three subtest plots were randomly chosen during the harvesting stage. Sixty hills were harvested per subtest plot for the determination of yield and yield components.

Measuring yield components

Panicle number per unit area

The number of fully mature panicles in the experimental test plot area was counted and converted to panicle numbers per square meter. The number of fully exerted and grain-bearing panicles at maturity is called the panicle number per unit area.

Number of grains per panicle

The number of grains per panicle was counted at 5 hills per test plot sample.

Percentage of filled grains

The proportion of filled grains to all grains is called the percentage of filled grains. To estimate the percentage of filled grains in the experiment, all test samples were threshed, and the filled grains (F) were separated from the unfilled grains (U) by using the salt-water solution method with a hydrometer (specific gravity of 1.06). The filled (F) and unfilled (U) test sample grains were counted. This measurement is important for determining the overall quality and potential yield of the rice crop. Additionally, it can provide valuable information on factors such as weather conditions, pest damage, and nutrient availability that may affect grain filling in the plants. Monitoring and analyzing the percentage of filled grains can help farmers make informed decisions to improve their crop management practices and optimize their harvest. Therefore, the percentage of filled grains could be calculated by the following equation:

$$\text{Percentage of filled grains} = \frac{\text{Number of filled grains}}{\text{Number of filled grains} + \text{Number of unfilled grains}} \times 100 \quad \text{……..10}$$

The weight of 1,000 brown rice grains

The weight of filled grains is commonly reported based on 1,000 grains. The weight of the 1,000 brown rice grains was measured by a weight balance, and the average values (grams) were taken.

Data analysis

The soil moisture content, soil pulverization ratio, soil hardness, soil penetration, fieldwork efficiency, fieldwork accuracy, grain yield, and yield component data were recorded and organized in Microsoft Excel 2016. Data generated from the experiment was subjected to statistical software JASP 0.18.3.0. The above parameters were analyzed by descriptive statistics and the T-test at $p < 0.05$ was considered to be significantly different.

RESULTS AND DISCUSSION

Soil and field conditions

Plowing and tilling of land is done to predetermined levels that allow rice plants to develop a good root system. The experimental field area was 0.024 ha and well prepared by Kubota and Iseki types of tractors with rotary tillers. Soil moisture content (mc %) before and after plowing, soil pulverization ratio (%), soil hardness, and soil penetration were measured. Before transplanting, the field was flooded and puddled, the excess water was removed through drainage. The depth of the standing water was 4–8 cm during the initial puddling.

Moisture content %

It was observed the average moisture content (35%) at plowed and unplowed (30%) of the experimental field in the dry condition, and the result did not show a significant difference (Table 1).

Table 1. The average moisture content before and after plowing

	Group	N	Mean	SD	Cv	P -value
Weight moist soil (g)	Plowed	3	123.713	23.101	0.187	0.106
	Unplowed	3	95.577	3.907	0.041	
Weight dried soil (g)	Plowed	3	91.373	15.107	0.165	0.119
	Unplowed	3	73.24	4.785	0.065	
Weight water (g)	Plowed	3	32.34	8.051	0.249	0.107
	Unplowed	3	22.337	2.221	0.099	
Mc %	Plowed	3	0.35	0.035	0.099	0.287
	Unplowed	3	0.307	0.05	0.164	

The values are the means (n=3), Mc, Moisture content, (SD) standard deviations, Cv, coefficient of variance, Student's t-test at $P < 0.05$

Soil Hardness (SH) T-Test: There are statistically significant differences between the puddled and un-puddled conditions with more than two times soil hardness observed in the puddled condition (29.66 mm) compared to the un-puddled condition (14.5 mm) as shown in Table 2.

Pressure (Pr) T-Test: There is a significant difference in the pressure exerted by the rice transplanter between the puddled and un-puddled conditions, with more than ten times the pressure observed in the puddled condition (31.66kg/cm^2) compared to the un-puddled condition (2.96 kg/cm^2) as shown Table 2.

Soil penetration T-test: There is a significant difference in soil penetration between the two conditions, with two times higher soil penetration observed in the puddled condition (16.33 mm) compared to the un-puddled condition (7.33) as shown in Table 2.

Table 2. The effect of soil cultivation on the performance of the rice transplanting machine

	Group	N	Mean	SD	Cv	P -value
Soil Hardness (mm)	Puddled	3	29.66	1.528	0.051	< 0.001
	Un puddled	3	14.5	2.291	0.158	
Pressure (kg/cm^2)	Puddled	3	31.66	7.638	0.241	0.003
	Un puddled	3	2.96	1.002	0.338	
Soil penetration (mm)	Puddled	3	16.33	2.082	0.127	0.009
	Un puddled	3	7.33	2.517	0.343	

The values are the means (n=3), Mc, Moisture content, (SD) standard deviations, Cv, coefficient of variance, Student's t-test at $P < 0.05$

Soil pulverization ratio

The experimental land was prepared by tractor with rotary tiller implement. It was collected the average soil sample (6.91 kg) from this (1.4 kg) soil particle size greater than 25 mm diameter and (5.51kg) soil particle size less than or equal to 25 mm diameter as shown in Table 3. The presence of a significant amount of soil particles less than 25 mm in diameter indicates that the soil may also have good drainage properties. It was obtained the average soil pulverization ratio (79.89%). This result is closely supported by Bozbey and Garaisayev's (2010) soil pulverization levels studied and "Fine pulverization" was defined as 80-90% with soil samples passed through a 25 mm diameter sieve mesh.

Table 3. Soil pulverization ratio

Descriptive statistics	Total sample weight (kg)	Soil particle Size >25 cm diameter (kg)	Soil particle size ≤ 25 cm diameter (kg)	SP%
Mean	6.91	1.4	5.51	79.89
Standard Deviation	0.58	0.32	0.35	0.03
Minimum	6.25	1.05	5.2	76.22
Maximum	7.35	1.7	5.9	83.2

Sp% mean Soil pulverization ratio

Fieldwork efficiency of the transplanting machine

The experiment was performed under wet (puddled soil) field conditions with Kubota NSU-87 transplanting machine. The machine has eight rows, a 2.4 m planting width, and a 30 cm row spacing. The actual field capacity (ha/h) of the machine is the ratio of the covered area (ha) to the total time taken (hr.), and the theoretical field capacity (ha/h) refers to the planting width (m) with the average operating speed (km/h). It was observed (0.184 ha/h) actual field capacity and (76.66%) fieldwork efficiency with an average operating speed of 1 km/h in Table 3.4. The field efficiency result is almost similar to Nenavath Manikyam et al. (2019) field efficiency of a self-propelled rice transplanter at 75.16%. Field efficiency might be influenced by the downtime during operation as well as the skill and experience of the operator. Our finding is supported by Oduma et al. (2015), who reported that the field efficiency of machines is affected by field conditions, frequent breakdowns, and other downtime during operation.

Table 4: Fieldwork efficiency of the transplanting machine

Items	Observation
Area, ha	0.024
Planting width, b(m)	2.4
Total working time, Tw(h)	0.13
Average operating speed, V(km/h)	1
Field efficiency	
C = Area /Tw	0.184
Ct = b×v	0.24
η = C/Ct ×100%	76.66%

Ƞ, Efficiency (%), C, Field capacity (ha/h), Ct, Theoretical field capacity (ha/h)

Fieldwork accuracy of the transplanting machine

Paddy transplanting was performed using a self-propelled eight-row paddy transplanter. The number of seedlings transplanted per hill, the number of seedlings per square meter, hill-to-hill spacing (cm), and the depth of the transplanted seedlings (mm) in the three subtest plots were measured and observed the missing, floating, or buried hills per square meter. The age of the nursery (mat type) was 26 days. We observed the average number of seedlings planted per hill (3.66), the number of paddy seedlings planted/ square meter (102.16), the hill-to-hill spacing (15.09 cm), and the seedling planting depth (30.36 mm) as shown in Table 5.

These findings suggest that the spacing and depth of transplanted seedlings in our study align closely with the results of previous research conducted by Nenavath Manikyam et al. (2019) who found the average hill-to-hill spacing (15.2 cm) and seedling depth (25-30 mm). Overall, the consistency in seedling spacing, depth, and age further supports the notion that these parameters play a crucial role in achieving optimal yields in rice paddy fields. However, we did not observe missing, floating, or buried hills per square meter in the experimental test plots, which indicates that the machine is efficient and effective, and this demonstrated that the transplanting machine was able to consistently plant seedlings at the desired depth, ensuring that they had the best chance of establishing themselves in the field. The results of this evaluation confirmed that the machine was operating with a high level of accuracy and precision, meeting the requirements for successful transplanting in the experimental field.

Table 5. Working accuracy of the transplanting machine

Descriptive statistics	Planted/hill	Planted/m^2	Hill spacing (cm)	Hill depth (mm)
Mean	3.66	102.16	15.09	30.36
Std. Deviation	0.516	14.442	0.94	3.66
Minimum	3	80	13.88	26.2
Maximum	4	116	16.61	37

The effect of the transplanting method on yield and yield components

Grain yield (kg/ha)

Grain yield was sampled from 60 hills per test plot in three subtest plots in the experiment. The average grain yield was adjusted to 15% of the Japanese standard grain moisture content. The maximum grain yield was obtained (5.7 tons/ha) and the minimum grain yield was recorded (5.2 tons/ha) as shown in Table 3.6. It was observed the average grain yield (5.5 tons/ha).

Yield components

The number of panicles per square meter, the number of grains per panicle, the percentage of filled grains, and the weight of 1000 grains are shown in Table 3.6. The average yield component data were collected from the growth test plots, i.e., 20 hills per test plot with three replications. It recorded the maximum number of panicles per square meter, number of grains per panicle, percentage of filled grains, and 1000-grain weight 446.2, 77, 93, and 22.5 respectively. It was observed the average number of panicles per square meter (441.2), the average number of grains per panicle (68.4), the average percentage of filled grains (89.6), and the average 1000-grain weight (22.25 grams) as shown in Table 6.

Table 6. Effect of the transplanting method on the yield components

Descriptive Statistics	Yield (ton)	Panicle/m^2	Grains/ Panicle	% Filled grains	1000 Grains Weight (gram)
Mean	5.5	411.2	68.4	89.6	22.25
Std. Deviation	202.861	25.691	5.313	0.035	0.247
Minimum	5.2	378.7	62.1	85.5	21.9
Maximum	5.7	446.2	77	93.0	22.5

CONCLUSION

A self-propelled eight-row paddy transplanter (Kubota: NSU-87) was used for transplanting. The average field capacity and field efficiency of the eight rows of self-propelled paddy transplanters were 0.184 ha/h and 76.66%, respectively.

The fieldwork capacity and working accuracy of the transplanting machine might be influenced by the operating system (operating speed), seedling age, field and soil conditions, etc. The average grain yield (5.5 tons/ha) was obtained. In conclusion, the performance of the mechanically self-propelled paddy transplanter was found to be efficient and quite satisfactory in terms of fieldwork efficiency and accuracy.

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BIOCONTROL EFFICACY OF NATIVE *Trichoderma* STRAINS ISOLATED FROM FARM AND FOREST SOIL AGAINST COLLAR ROT (*Sclerotium rolfsii*) OF LENTIL

P. Adhikari*, S.M. Shrestha, H.K. Manandhar and S. Marahatta

Agriculture and Forestry University, Rampur, Chitwan, Nepal

ABSTRACT

Lentil, *Lens culinaris* is an important pulse crop of Nepal which is susceptible to collar rot disease caused by *Sclerotium rolfsii* during its early growth stages. The fungus attacks the collar region of the plant, causing rotting of the stem resulting in stunted growth, wilting and reduced productivity. Additionally, it weakens the plant, making them more susceptible to other diseases and stresses such as drought. The pathogen can survive in the soil for extended periods by producing sclerotia. *Trichoderma* species are known for their antagonistic ability against diverse plant pathogens, including *S. rolfsii*. This study was conducted to identify promising native *Trichoderma* isolates for controlling collar rot of lentil during 2020 and 2021 in Chitwan, Nepal. A total of 104 *Trichoderma* isolates collected from farm and sal, *Shorea robusta* forest soil and examined in vitro by dual culture technique against *S. rolfsii* in a completely randomized design. Of them, 30 isolates were selected to study biocontrol potential under a screen house by inoculating both the pathogen and *Trichoderma* onto lentil seedlings. Subsequently, four promising *Trichoderma* isolates were selected representing different agro-ecological regions for the field trial in a randomized complete block design to assess their ability to control *S. rolfsii* in field conditions. Results showed that *Trichoderma* isolates T_{73}, Forest soil (96.96%); T_{74}, Forest soil (94.49%) and T_{62}, Darchula (88.92%) had shown strong inhibition of *S. rolfsii* growth, with forest soil isolates exhibiting higher antagonistic potential. In the screen house assay, all *Trichoderma* isolates increased seed germination, enhanced plant growth, and reduced disease incidence as compared to the control. *Trichoderma* isolates T_{49}, Bhaktapur, and T_{31}, Banke showed the highest percentage of disease control and percentage yield increase in the field conditions. These findings highlight the consistent potential of *Trichoderma* for biocontrol of collar rot diseases in lentil.

Keywords: Collar rot, Disease incidence, Lentil, *Sclerotium rolfsii, Trichoderma*

* Corresponding author: adhikari_pk@yahoo.com

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INTRODUCTION

Lentil (*Lens culinaris* Medik.) holds significant importance as a pulse crop in Nepal. It can be grown successfully relatively dry areas with low soil nutrients. However, lentil cultivation is challenged by various abiotic and biotic factors causing both qualitative and quantitative yield reduction in field conditions. Temperature, relative humidity, and soil characteristics are the key factors affecting pests and diseases infestation and thereby on the productivity. In Nepal, severe lentil diseases like vascular wilt (*Fusarium oxysporum* f.sp. *lentis* Vasudeva & Srinavasan), Stemphylium blight (*Stemphylium botryosum* Walr.), collar rot (*Sclerotium rolfsii* Sacc.), rust (*Uromyces fabae* Pers.), and Botrytis grey mold (*Botrytis cinerea* Pers.), causing substantial grain yield losses, especially in the Terai as well as in the hill regions (Pandey et al., 2000). Vascular wilt and collar rot are prevalent across major lentil-growing areas. Collar rot, a major disease-causing yield loss up to 60% in farmer's fields (Darai et al., 2010), is increasingly affecting leguminous crops such as lentil, chickpea (*Cicer arietinum* L.), bean (*Phaseolus vulgaris* L.), soybean (*Glycine max* L.) etc. in various districts of Nepal (Adhikari et al., 2022a). The pathogens prolonged saprophytic survival in the soil makes chemical management less effective and economical. Addition of compost and straw of either oat or corn, as suggested by Bulluck and Ristaino (2002), enhance beneficial soil microbe populations that can reduce *Sclerotium rolfsii* incidence. Also, bioagents such as *Trichoderma* offer an alternative for the management of soil-borne diseases since they produce biologically active compounds. *Trichoderma* spp. offer biocontrol against plant pathogens through various mechanism such as competition, enhance plant growth and development, inducing systemic resistance, antibiosis, or mycoparasitism (Harman et al., 2004; Harman, 2000). Several *Trichoderma* species secrete both volatile and non-volatile chemical compounds that counteract plant pathogenic fungi (Kumar & Ashraf, 2017). *Trichoderma* species not only control plant pathogens but also promote root development and improve nutrient assimilation in plants (Harman et al., 2004). According to Vinale et al. (2008) secondary metabolites like Koninginins, 6-pentyl-α-pyrone, and harzianic acid, produced by *Trichoderma,* enhance plants overall growth. According to Benítez et al. (2004) *Trichoderma* spp. play a role in making phosphates, micronutrients, and mineral cations like iron, manganese, and magnesium more soluble by producing organic acids, such as gluconic, citric acids, and fumaric acids. This in turn, makes these nutrients available for plant metabolism. Also, these bio-control agents can prompt local or systemic resistance in plants by initiating early defense response triggered by the secondary metabolites produced by them (Contreras-Cornejo et al., 2016).

Although *Trichoderma* effect on various plant diseases has been investigated, limited research has explored the effect of *Trichoderma* isolated from diverse agricultural land and sal forest on *S. rolfsii*. The study is primarily focused to identify *Trichoderma* isolates that are effective against *S. rolfsii* under field conditions.

MATERIALS AND METHODS

Isolation of *Trichoderma* spp. from soil samples

Trichoderma were isolated from farm and sal (*Shorea robusta* Gaertn.) forest soil using *Trichoderma* selective medium (TSM). The ingredients used in the medium were $MgSO_4.7H_2O$ (0.2g), K_2HPO_4 (0.9g), KCl (0.15g), NH_4NO_3 (1.0g), Glucose (3.0g), Agar-agar (20g), Distilled water (1 liter), Streptomycin sulphate (0.02g), Captan (0.2g) and Rose Bengal (0.15g). The plates were incubated at 25ºC and examined daily for the growth of *Trichoderma* colonies for 5 days. The entire process was carried out under laminar flow station. Appearance of *Trichoderma* colonies were observed on 5th day of inoculation. Each colony that appeared in the TSM plate were transferred to PDA tubes.

Isolation of pathogen

Lentil roots with disease symptoms were washed and cut into 1 cm sized sections. The cut root samples were surface sterilized by dipping in 1% sodium hypochlorite for 1 min, rinsed with sterile distilled water, and plated on moist chamber. The plates (9 cm diameter) were incubated at 25 ± 1ºC in an incubator until sclerotia were produced (5 days) and the sclerotia produced were transferred to PDA to get pure culture. The pure culture was maintained at 4ºC.

Screening of Trichoderma isolates against S. rolfsii

One hundred four isolates of *Trichoderma* isolated from various farm land and sal (*Shorea robusta* Roth.) forest soil were subjected to *in vitro* testing using dual culture to assess their interactions with *S. rolfsii* (Adhikari et al., 2022b). The study was carried out in CRD with three replications. Inhibition percent of pathogen mycelial growth was calculated by: P = [(Growth of pathogen in control - growth of pathogen with the antagonist)/Growth of pathogen in control] × 100.

Biocontrol of collar rot of lentil under field conditions

Four *Trichoderma* isolates such as T_{40}, Jumla; T_{87}, Forest soil; T_{31}, Banke and T_{49}, Bhaktapur were selected to evaluate their efficacy against collar rot of lentil (var. Simrik) under field conditions. The isolates were selected in such a way that they represent three agro-ecological zones (mountain, mid-hills and terai) and one forest environment based on their their biocontrol efficacy *in vitro*. The field experiment was conducted in Mangalpur, Chitwan (27°39'58"N 84°22'07"E) during cropping season of 2020 and 2021. The experiment was conducted in two-factorial randomized complete block design (RCBD) with three replications. The individual plot size was 1.0 x 2.0 square meter, 1.0 m space was kept between the plots and 10 cm from row to row. Sowing of lentil was done on 24th November 2019 and 4th November 2020. In the first year of experiment, disease incidence was low and thus in second year the sowing date was shifted early to get the maximum disease incidence in the experimental plots. Recommended dose of fertilizers was applied prior to seed sowing. Urea, DAP and MOP were applied in the field at the rate of 6, 9 and 7 g per

plot, respectively. *Trichoderma* isolates were applied as seed treatment at the rate of 1.0 ml conidial suspension (10^8 CFU/ml) per gram seed and soil treatment at the rate of 1.0 lit conidial suspension (10^8 CFU/ml) per plot. Each experimental plot was inoculated with mass culture of *S. rolfsii* at the rate of 10 g per plot. Disease incidence was recorded and calculated based on the following formula.

$$\text{Disease incidence (\%)} = \frac{\text{No.of infected plants}}{\text{total no.of plants observed}} \times 100$$

Similarly, percent disease control (PDC) was calculated using the following formula.

$$\text{PDC (\%)} = \frac{\text{Disease in treated plot} - \text{Disease in control plot}}{\text{Disease in control plot}} \times 100$$

The crop was harvested manually by uprooting individual plant. Yield was recorded and expressed as kg/ha.

$$\text{PYI(\%)} = \frac{\text{Yield in treated plot} - \text{Yield in control plot}}{\text{Yield in control plot}} \times 100$$

Statistical analysis

The data recorded were tabulated in Microsoft Excel and analyzed using R-studio version 4.1.0. Mean comparison was done by Duncan's Multiple Range Test (DMRT) at 1 and 5% levels of significance. Count data were subjected to square root transformation (Gomez &Gomez, 1984). Graphs were prepared by using MS Excel 2016 and Minitab 14.

RESULTS AND DISCUSSION

Inhibition percentage of *Trichoderma* isolates

The mean percentage inhibition of *Trichoderma* isolated from agricultural land and Forest soil varied significantly. Only four isolates viz., T_{62}, Darchula (88.92 %); T_{63}, Darchula (87.93%); T_{30}, Palpa (86.16%); and T_{53}, Makwanpur (85.11%)isolated from agricultural land showed inhibition percentage of more than 85%. Majority of *Trichoderma* isolates of agricultural land exhibited inhibition percentage between 60-80%. While *Trichoderma* isolated from forest soil showed inhibition percentage between 60-99% except for one isolate (Figure 1).

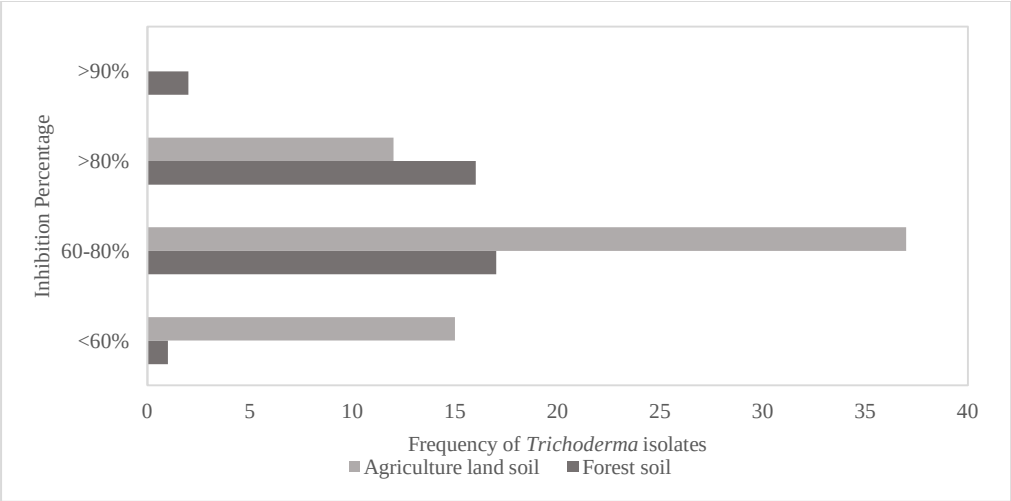

Figure 1. Percentage inhibition exhibited by Trichoderma isolated from agricultural land and forest soil

About thirty *Trichoderma* isolates showed inhibition percentage above 80% against *S. rolfsii*. Similar results have been reported by various researchers Kamel et al. (2020); Adhikari et al. (2022); Das et al. (2023); Kangjam et al. (2023). According to Vinale et al. (2008) *Trichoderma* employ mycoparasitism and antibiosis against the fungal pathogen. During mycoparasitic interactions with the pathogen, *Trichoderma* produces range of enzymes that break down the cell wall. The enzymes include chitinase, cellulose, glucanase etc. causing the cell wall to rupture and release oligomers (Kubicek et al., 2001; Howell, 2003; Woo et al., 2006; Vinale et al., 2008). However, the efficacy of different *Trichoderma* isolates to suppress the plant pathogen is inconsistent. Different strains of the same *Trichoderma* species can exhibit varied levels of pathogen inhibition, according to Anees et al. (2010) and Scherm et al. (2009). Consequently, antagonism is not an inherent trait of a species. Those particular strains that can promptly and effectively activate genes associated with the antagonistic activities in the presence of a host tend to be more potent antagonists (Scherm et al., 2009).

In this study, the majority of *Trichoderma* isolated from forest soil exhibited higher inhibition percentage as compared to those from agriculture soil. Within the forest ecosystem, both *Trichoderma* and *S. rolfsii* co-evolve and adapt together. Unlike the disturbances present in agriculture soil, forest soil remains relatively undisturbed, potentially leading to more potent *Trichoderma* strains that could be virulent towards the pathogen. According to Buckling and Rainey (2014) antagonistic coevolution plays a critical role in population dynamics of prey and parasite and evolution of virulent parasite.

Biocontrol of collar rot of lentil in the field

The *Trichoderma* isolates used in the experiment significantly (P≤0.05) affected grain yield of the crop. The highest grain yield (1621.66 kg/ha) was recorded in soil application of *Trichoderma* isolate T_{31}, Banke in the first year (Table 1). Similarly, Percentage yield increment was highest in T_{31}, Banke isolate (39.05%) followed by T_{40}, Jumla (30.72%) and T_{87}, Forest soil (30.48%) in first year. In the second year of the experiment, soil application of T_{49}, Bhaktapur isolate showed higher grain yield (1743.44 kg/ha) as compared to other isolates and control. Percentage yield increment (PYI) was highest in T_{49}, Bhaktapur isolate (87.41%) followed by T_{31}, Banke isolate (79.15%) as soil treatment.

Table 1. Effect of *Trichoderma* isolates grain yield and PYI of lentil under field conditions, Mangalpur, Chitwan, 2020/21

Treatments	First year (2020)		Second year (2021)	
	Yield (kg/ha)	PYI (%)	Yield(kg/ha)	PYI (%)
T_{40}, Jumla, seed treatment	1426.67^{a}	44.35	1532.63^{ab}	64.75
T_{40}, Jumla, soil treatment	1355.00^{ab}	37.10	1219.76^{bc}	31.12
T_{87}, Forest soil, seed treatment	1281.66^{ab}	29.68	1248.96^{abc}	34.26
T_{87}, Forest soil, soil treatment	1421.66^{a}	43.84	1434.39^{ab}	54.19
T_{31}, Banke, seed treatment	1296.66^{ab}	31.20	1317.74^{abc}	41.65
T_{31}, Banke, soil treatment	1621.66^{a}	64.08	1666.54^{ab}	79.15
T_{49}, Bhaktapur, seed treatment	1348.33^{ab}	36.43	1336.87^{abc}	43.71
T_{49}, Bhaktapur, soil treatment	1333.33^{ab}	34.91	1743.44^{a}	87.41
Control	988.33^{b}	-	930.26^{c}	-
S.Em±	120.07		149.67	
F- test	*		*	
LSD (=0.05)	359.97		448.72	
CV (%)	15.82		18.76	

Note: PYI: Percentage Yield Increase

The *Trichoderma* isolates used in the study were significantly (P≤0.05) effective to control collar rot of lentil under field conditions. In the first year, *Trichoderma* isolate T_{31}, Banke, exhibited higher percent disease control (65.20%) as compared to other isolates (Table 2). The appearance of disease was observed 15 days after seedling emergence (DAE). At 22 DAE, the highest disease index was recorded in those plots where *Trichoderma* isolate T_{40}, Jumla (13.33%) was applied as a soil treatment. The control plot exhibited significantly highest disease index (37.77%) in 29 DAE than *Trichoderma* treated plots. However, at 36 DAE highest disease index was observed

in control (50.00%), followed by T_{49}, Bhaktapur isolate (38.88%) and T_{40}, Jumla isolate (38.88%) as a seed treatment. The highest AUDPC value was noted in control (894.44) followed by seed application of T_{40}, Jumla isolate (661.11) and lowest in T_{31}, Banke (303.33) as seed treatment.

Table 2. Effect of *Trichoderma* isolates on collar rot incidence of lentil in the field condition, Mangalpur, Chitwan, 2020

Treatments	First year (2020)					Second year (2021)				
	DI			PDC (%)	AUDPC	DI			PDC (%)	AUDPC
	22 DAE	29 DAE	36 DAE			22 DAE	29 DAE	36 DAE		
T_{40}, Jumla, seed treatment	8.88	16.66^{ab} (0.49)	38.88^{a} (0.67)	27.40	661.11	21.11^{b}	28.89^{b}	34.44^{b}	48.48	455.00
T_{40}, Jumla, soil treatment	13.33	16.66^{ab} (0.39)	22.22^{b} (0.48)	47.22	478.33	20.00^{b}	33.33^{b}	42.22^{b}	35.72	622.22
T_{87}, Forest soil, seed treatment	6.66	14.44^{b} (0.27)	21.11^{b} (0.47)	56.34	392.78	23.33^{b}	26.67^{b}	33.33^{b}	49.75	583.33
T_{87}, Forest soil, soil treatment	1.11	14.44^{b} (0.27)	22.22^{b} (0.48)	55.32	353.89	27.77^{b}	33.33^{b}	38.89^{b}	41.22	610.55
T_{31}, Banke, seed treatment	2.22	8.89^{b} (0.21)	18.89^{b} (0.44)	57.65	303.33	23.33^{b}	30.00^{b}	35.56^{b}	46.72	501.66
T_{31}, Banke, soil treatment	7.77	11.11^{b} (0.33)	17.78^{b} (0.43)	65.20	334.44	21.11^{b}	31.11^{b}	35.56^{b}	46.72	773.88
T_{49}, Bhaktapur, seed treatment	5.55	24.44^{ab} (0.51)	38.88^{a} (0.67)	26.78	645.56	20.00^{b}	28.89^{b}	36.67^{b}	45.69	523.33
T_{49}, Bhaktapur, soil treatment	6.66	15.55^{ab} (0.39)	23.33^{b} (0.48)	51.23	431.67	21.11^{b}	25.56^{b}	32.22^{b}	50.79	501.61
Control	11.11	37.77^{a} (0.66)	50.00^{a} (0.78)	-	894.44	44.44^{a}	62.22^{a}	66.67^{a}	-	812.77
S.Em±	5.53	0.08	0.057			4.41	4.04	4.14		
F- test	ns	*	**			*	***	***		
LSD (=0.05)		0.263	0.17			13.24	12.12	12.42		
CV (%)	13.62	18.30	18.05			18.00	18.02	18.16		

Note: Figures in the parentheses are square root transformation values. DI: Percentage Disease Index, DAE: Days After Emergence, PDC: Percentage Disease Control, AUDPC: Area Under Disease Progress Curve.

However, in the second year, collar rot incidence was observed 7 days after the emergence of lentil seedlings. The disease index was significantly high in control plot at 22 (44.44%), 29 (62.22%) and 36 (66.67%) DAE than in *Trichoderma* treated plots. The higher percent disease control was recorded in soil treatment with *Trichoderma* isolate T_{49}, Bhaktapur (50.79%) followed by *Trichoderma* isolate T_{87},

Forest soil (49.75%) as seed treatment. The highest AUDPC value was recorded in control (812.77) followed by soil application of T_{31}, Banke isolate (773.88).

Results showed that *Trichoderma* isolates significantly enhanced seed germination, reduced plant mortality and reduced disease incidence over the control. The findings aligned with Arya et al. (2021); Hasna et al.(2020); Kashem et al. (2011). According to Khattabi et al. (2004), the effectiveness of *Trichoderma* isolates as antagonists in natural soil is indicated by their competitiveness and *in vitro* activity.

In field condition, collar rot incidence was low in first year as compared to second year. In first year, lentil was grown in the fallow land where there was no crop in previous years. When agricultural land are abandoned for a long period, the abundance of pathogenic fungi decrease over time (Hannula et al., 2017). Pathogen was inoculated in the first year, as a result, population of the pathogen increased in the field. These sclerotia and mycelium present in soil might have caused more disease incidence in second year. Paparu et al. (2020) found weak but positive correlations between the number of sclerotia produced and Southern blight of common bean. This may be one of the reason in difference in percentage disease incidence between two years. Similarly, another reason may be the sowing date and agrometeorological factor. In first year, lentil was sown in late November and in second year in the first week of November. Mishra et al. (2021) also reported maximum disease incidence of *Sclerotinia* stem rot in lentil sown in 5^{th} and 15^{th} November. According to Roy et al. (2021), collar rot occurrence tends to be lower in crops sown later (during the initial week of December) in certain regions of Eastern India.

Since *Trichoderma* was applied as seed treatment and soil treatment, there was no significant difference between two application methods for disease incidence and percentage disease control. However, soil treatment had shown better results over seed treatment. Similar findings were also documented by Hasna et al. (2020) and Kashem et al. (2011), who observed diminished disease incidence in chickpea and lentil respectively, when *T. harzianum* was introduced into the soil. According to Hasna et al. (2020), *Trichoderma* sp. is inherently a soil inhabitant, which allows it to establish and proliferate more quickly in soil compared to the seed surface. In contrary, Biswas and Sen (2000) reported that seed treatment with conidial suspension proved more effective in decreasing disease incidence than soil application. Despite the promising outcomes of *Trichoderma* soil treatment in controlling soil borne plant pathogens, the significance of seed treatment remains paramount. Juliatti et al. (2019) emphasized that seed microbiolization is a crucial method of bio-control agent application, as it demands a smaller quantity of biological material in comparison to the amount needed for soil application.

CONCLUSION

Trichoderma isolates, especially those obtained from forest soil, demonstrate significant potential for biocontrol against the fungal pathogen *S. rolfsii* causing collar rot in lentils. The study indicates that *Trichoderma* isolates from forest soil generally exhibited higher inhibition percentages compared to those from agricultural land, potentially due to co-evolutionary adaptations within undisturbed forest ecosystems. These isolates, when applied as soil treatments, showed substantial improvements in grain yield and disease control in lentil crops, suggesting their effectiveness as biocontrol agents in agricultural practices. However, the efficacy of *Trichoderma* isolates varied, highlighting the importance of strain selection for optimal biocontrol outcomes.

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ASSESSMENT OF TREND AND INSTABILITY OF AREA AND PRODUCTION OF MUNG BEAN IN BANGLADESH

J.K. Prioty*, K.S. Rahman and M.A.M. Miah

ASICT Division, Bangladesh Agricultural Research Institute, Gazipur

ABSTRACT

Instability is an inherent aspect of agriculture due to its reliance on weather conditions, resulting in substantial fluctuations in crop area, production and yield. Mung bean (*Vigna radiata*) is one of Bangladesh's most important pulses. It is highly valued for its nutritional composition and also helps improve soil health. This study focused on analyzing the changes in the cultivation area, production and yield of mung bean in Bangladesh through growth rate and instability analysis based on secondary data over a 40-year period (1981-2020). The entire timeframe was divided into four sub-periods:1981-1990,1991-2000,2001-2010 and 2011-2020 allowing for analysis using various statistical tools. Growth rates were calculated by fitting an exponential growth function, while instability was assessed using the Cuddy-Della Valle index. The analysis revealed that the area and production of mung beans had increased. The change in area and yield contributed respectively 51.3% and 46.8% to changes in the mean production of mung bean at the national level. Though the mung bean yields increased significantly, the rate of growth is slow, and it is insufficient to meet our country's demand. The analysis also revealed that the area, production, and yield of mung bean were not stable during the study period.

Keywords: Cuddy-Della Valle index; growth decomposition; growth rate; trend analysis.

INTRODUCTION

Pulses play a crucial role in Bangladesh as important food crops. They offer significant nutritional value to the human diet (Das et al., 2016), with rapid growth, providing animal feed, and generating profitable returns for farmers (Miah et al., 2009). Moreover, pulses contribute to agricultural and environmental sustainability by enriching the soil with nitrogen, carbon, and organic matter (Sarker and Kumar, 2011). A favorable climatic condition exists in Bangladesh for growing different types of pulses all over the country. Due to their high protein content and

* Corresponding author: jamilaprioty@gmail.com

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affordability, pulses are often referred to as the "poor man's meat," making them an ideal staple food for low-income populations. The per capita consumption of pulse in our country is only 15.7 g/day (HIES, 2016) which is much lower than the desirable intake of 50 g/day (DDP, 2013).

Mung bean (*Vigna radiata* L.) popularly known as green gram is an ancient and well-known pulse crop that belongs to the *Papilionoideae* family and originated from South East Asia. It is widely cultivated throughout Asia, including India, Pakistan, Bangladesh, Sri Lanka, Thailand, Laos, Cambodia, Vietnam, Indonesia, Malaysia, South China, and the Republic of Formosa (Mogotsi, 2006). It is a source of high-quality protein which can be consumed as whole grains, dhal, or sprouted form and is an excellent complement to rice concerning balanced human nutrition. Dry beans are sometimes used for animal food, mainly poultry, and their biomass is used as fodder (Winch, 2006). Thus, it has great value as food and fodder. Mung bean supplies a substantial amount of nitrogen to the succeeding non-legume crops (i.e. rice) grown in rotation (Sharma and Prasad, 1999). Mung bean is grown around the year (three times) in Bangladesh. At present, this crop is being cultivated after harvesting *Rabi* crops (i.e. wheat, mustard, lentil, etc.). As a short-duration crop, it can be fitted in as a cash crop between major cropping seasons. The present area under mung bean cultivation is 44.25 thousand ha with a total production of 41.19 thousand tons and an average yield of 93.08 t/ha (BBS, 2021). In recent years, due attention has been given to mung bean cultivation in Bangladesh. As a result, mung bean acreage in this country has gradually increased. Of course, there is real hope and a bright possibility of solving the crucial national food crisis by cultivating mung beans.

Instability is an inherent aspect of agriculture due to its reliance on weather conditions, resulting in substantial fluctuations in crop area, production and yield. This instability also extends to mung bean crops. However, there is a lack of comprehensive studies addressing the growth and instability of mung beans in Bangladesh. Therefore, this current study aims to analyze the growth and instability in the area, production, and yield of mung bean, while also identifying the contributing factors that affect mung bean production. The outcomes of this study will offer valuable insights and guidelines for researchers, policymakers, and planners in the country, enabling them to make informed decisions regarding mung bean cultivation and management to determine the growth rates of area, production, and yield of mung bean in Bangladesh and to measure the change and instability in area, production, and yield of mung bean.

MATERIALS AND METHODS

Sources of Data

The study was based on secondary data collected from various published sources. Times series data on the area, production, and yield of mung bean for 40 years from 1981 to 2020 were collected from different issues of the *Yearbook of Agricultural Statistics of Bangladesh*.

Analytical Procedures

Various statistical measures were used to analyze the data to examine the nature of change, instability, and degree of relationship in area, production, and yield of mung bean crops in Bangladesh.

Trend analysis: Trend analysis aims to find out the extent and causes of the instability of the area and production of mung bean over time. This information may lead research managers as well as policymakers to prepare appropriate policy documents for the improvement of mung bean for the country. A simple line graph and bar diagram were used to show the trends in area, production, and yield of mung bean in Bangladesh.

Index number: We can measure the relative changes in area, production and yield of mung bean that are changed or produced within a stipulated period by using an index number. At first, the entire study period is divided into four sub-periods: 1981 to 1990, 1991-2000, 2001-2010, and 2011-2020. The reason for the division was to know the changes that occurred in the area, production, and yield of mung bean after a 10-year period. The 10 years (e.g. 1981-1990) average value of area, production, and yield was considered the base year.

Annual growth rates: Growth rates are the percent change of a variable over time. It is important because it can help researchers and policymakers predict future growth. For simplicity and widely used even in the recent past (Das and Mishra 2020; Chaudhary et al., 2016) the compound growth rates of area, production, yield, and price of mung bean were worked out by fitting an exponential function of the following type (equation 1):

$Y=ae^{bt}$ or $LnY = Lna + bt$ ---------- (1)

Where, Y is the area/production/yield of mung beans, 't' is the time in a year, and 'a' is the constant, $e^b - 1$ is the compound growth rate which is expressed in percentage.

The component analysis model has been utilized to assess the respective influences of area and yield on overall output changes for individual crops. This model has been extensively employed by researchers in the literature to investigate the growth performance of various crops (Siju and Kombairaju, 2001; Kakali and Basu, 2006).

The model can be represented as follows:

$\Delta P = A\,\Delta Y + Y\,\Delta A + \Delta A\,\Delta Y$ ----------(2)

Where:

ΔP represents the change in production.

A signifies the area effect.

Y denotes the yield effect.

ΔA represents the change in area.

ΔY represents the change in yield.

This equation suggests that the total change in production is attributed to the effects of area and yield, which can be further decomposed into three distinct effects: yield effect, area effect, and interaction effect.

Instability index: Instability means the quality or state of being unstable or lack of stability. Agricultural instability can be measured by different methods, such as the coefficient of variation (CV), dispersion, Cuddy Della Valle Index (CDI), Coppock Instability index, etc. The present study applied the Cuddy and Valle (1978) Index for examining the nature and degree of instability in the area, production, and yield of mung bean in Bangladesh. The use of CV as a measure to show the instability in any time series data has some limitations. It does not explain properly the trend component inherent in the time series data. If the time series data exhibit any trend, the variation measured by CV can be overestimated, i.e. the region which has growing production at a constant rate will score high in instability of production if the CV is applied for measuring instability (Bisht & Kumar,2018). As against that, CDI first attempts to de-trend the CV by using the coefficient of determination (R^2). Thus it is a better measure to capture instability in agricultural production. A low value of this index indicates low instability in farm production and vice-versa. The estimable form of equation (3) is as follows:

$$CV_t = (\text{CV}) \times \sqrt{1 - R^2} \quad \text{---------- (3)}$$

Where CV_t is the coefficient of variation around the trend; CV is the coefficient of variation around the mean in percent; and R^2 is the coefficient of determination from time trend regression adjusted by the number of degrees of freedom.

$$\text{CV} = \frac{Standard\ deviation}{Mean} \times 100$$

$$R^2 = 1 - \frac{Unexplained\ variation}{Total\ variation}$$

RESULTS AND DISCUSSION

Trends of Area and Production of Mung Bean

Figure 1 shows that the area and production of mung bean for the period from 1981/82 to 1985/86 were very low compared to the succeeding years. Besides various positive sides, most of the mung bean areas in the aforesaid period were replaced by cereals (Abedin and Anwarul, 1991). After that mung bean cultivation is gaining

popularity among farmers day by day. The reasons for its higher adoption were: i) short duration crop; ii) many HYVs were available to the farmers; iii) highly responsive to irrigation and fertilizer use; iv) possible to cultivate three seasons due to its photo-insensitive nature; and v) profitable replacement of *Aus* rice and upland jute by mung bean (Miah et al. 2004). It revealed that the Pulse Research Centre of BARI developed four improved mung bean varieties namely BARI Mung-2, BARI Mung-3, BARI Mung-4, and BARI Mung-5 during 1987-1997 (Razzaque et al., 2000). Besides, several HYV of mung bean varieties were also developed by BINA and Bangladesh Sheikh Muzibur Rahman Agricultural University (BSMRAU). Therefore, both area and production of mung bean were very high for the period of 1987/88-1999/00 due to the higher adoption of improved varieties and technologies of mung bean at the farm level. In the period 2001/02 to 2009/10, the overall area and production of mung beans in the country decreased due to insect infestation, insecticides not working properly, a lack of training about improved mung bean cultivation, and the high price of insecticides (Islam et al., 2013). After that period, it again shows an increasing trend.

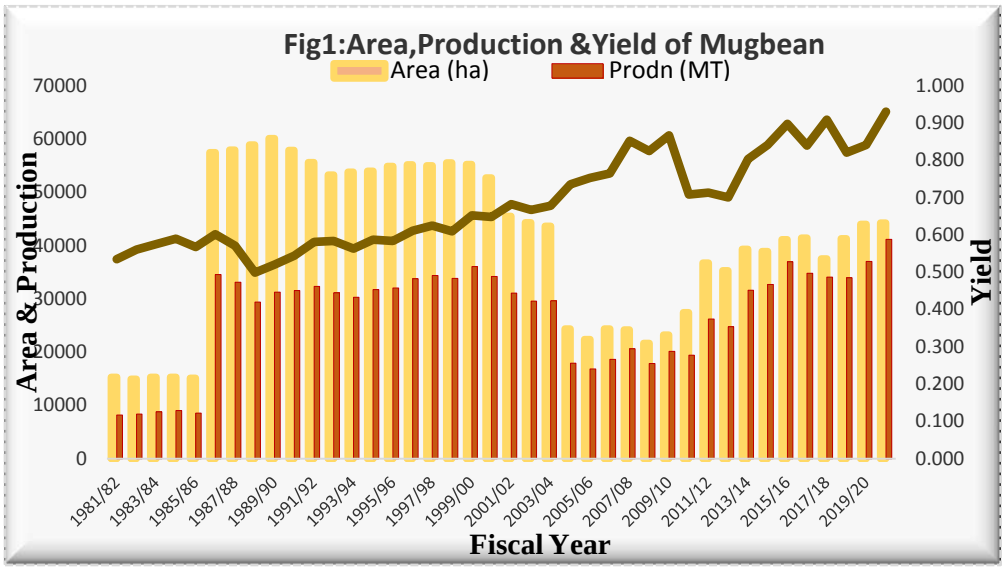

Figure 1. Trend of area, production and yield of mung bean in Bangladesh, 1981/82-1999/20

Source: Researchers estimated using data from various issues of BBS in different years.

The overall indices indicated a moderate increase in the cultivated area during other decades compared to the base period of 1981-1990, except for the period of 2001-2010 (refer to Table 1). Conversely, the productivity indices revealed a consistent upward trend during other decades compared to the base period, albeit with some minor fluctuations (see Table 1). Moreover, the yield of mung bean experienced

growth during these periods, primarily attributed to the adoption of improved varieties and the implementation of advanced management technologies specific to mung beans (Table 1).

Table 1. Index of area, production and yield of mung bean

Time period	Area (%)	Production (%)	Yield (%)
1981-1990	100 (36846)	100 (20297)	100 (0.556)
1991-2000	148	163	109
2001-2010	82	109	135
2011-2020	109	164	149

Note: Figures within parentheses indicate a 10-year average value in the base year of the indices.

Source: Various issues of BBS

Annual Growth of Mung Bean Production

The overall annual growth rates scenario reveals that the area, production, and yield of mug beans registered positive growth rates during 40 years' period (1981-2020) although the area growth rate was not significant at all (Table 2). The growth rates of different periods show that some growth rates registered in the area were found positive and significant from 1981 to 1990 and 2011-2020. Similarly, highly significant positive growth rates of production were observed from 1981 to 1990, 1991-2000, and 2011-2020. Both area and production growth rates (-7.58 & -5.41) were found significantly negative during 2001-2010 due to insect infestation, insecticides not working properly, a lack of training about improved mung bean cultivation, and the high price of insecticides (Islam et al., 2013). However, the growth rates of yield were positive and highly significant for all periods except the period 1981-1990 (-0.67). The highly significant growth rates of yield were mainly due to the adoption of improved mung bean variety and technology. This indicates that more adoption of the modern varieties of mung bean is needed in the farmers' fields.

Table 2. Annual growth rates of area, production and yield of mung bean, 1981-2020

Time period	Area	Production	Yield
1981- 1990	20.47***	19.80***	-0.67
1991- 2000	-0.002	1.44***	1.45***
2001- 2010	-7.58**	-5.41**	2.18**
2011- 2020	2.04***	4.42***	2.38***
1981- 2020	0.45	1.85***	1.40***

Note: '***' & '**' represent significant at 1% and 5% levels of significance, simultaneously

Sources of Growth of Mung Bean Production

Change in the mean area appeared to be the largest source of change in the mean production of mung bean in all the periods except 1991-2000. At the national level, changes in the mean area and yield were the main two sources of changes in mung bean production in Bangladesh. The change in area and yield contributed 51.3% and 46.8% to the changes in mean production of mung bean at the national level. This means that the positive change in production has been attributed to the positive change in area (Table 3).

Table 3. Growth decomposition in the production of mung bean during 1981-2020

Time period	Effect (%)				
	Area (A)	Yield (Y)	Interaction	Residual	Total
	ΔA*Y	A*ΔY	ΔA*ΔY	ΔCOV(A,Y)	ΔQ
1981-1990	109.4	-3.7	5.7	-11.4	100
1991-2000	-119.3	215.4	-3.8	7.7	100
2001-2010	123.6	-10.7	12.8	-25.7	100
2011-2020	58.9	41.2	0.2	-0.3	100
1981-2020	51.3	46.8	-1.9	3.8	100

Source: Author's calculation using BBS data from 1981 to 2020.

Instability of Mung Bean Cultivation

The estimates of instability in area, production, and yield of mung bean are presented in Table 4. The instabilities of the mung bean area (4.3%) and production (4.08%) at the national level were not so high, but the instability of the area was a little bit higher than the production instability. On the other side, the instability related to productivity was about -17.75% during 1981-2020 meaning that mung bean productivity was almost stable over the stipulated period.

Table 4. Instability indices for area, production and yield of mung bean, 1981-2020

Time period	Instability (%)		
	Area (ha)	Production (t)	Yield (t/ha)
1981-1990	3.36	3.58	-9.22
1991-2000	0.17	0.29	-4.43
2001-2010	1.98	1.71	-24.31
2011-2020	0.4	0.75	-32.05
1981-2020	4.3	4.08	-17.75

Source: Author's calculation using BBS data from 1981 to 2020.

CONCLUSION

High growth rates and little production instability are necessary for sustainable agricultural performance, which has significant policy consequences. This study focuses on the analysis of mung bean production growth in Bangladesh, revealing positive and statistically significant growth rates in yield and overall production. However, it is important to note that the observed growth is relatively modest. Agricultural production in Bangladesh is susceptible to natural disasters, resulting in inherent production instability. The findings further corroborate this assertion. But the instability in the area, production, and yield of mung bean is low at the national level. Based on this study's findings, several recommendations can be made to promote sustainable growth in mung bean production in Bangladesh.

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EFFECT OF PLANT SPACING AND VARIETY ON GROWTH, YIELD AND QUALITY OF MAIZE IN SOUTHERN COASTAL REGION IN BANGLADESH

S. Akther[*1], A. K. Hasan[2], A. Kader[2], R. W. Bell[3], M. A. Hossen[4] and M. Mainuddin[5]

[1]Bangladesh Agricultural Research Institute (BARI), Gazipur 1701, Bangladesh
[2] Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
[3] Murdoch University, Western Australia, 6150.
[4]Ministry of Land, Dhaka, Bangladesh.
[5] Water Security Program, CSIRO, Environment, Canberra ACT 2601, Australia

ABSTRACT

An experiment was conducted at the farmer's field of Dacope upazila under Khulna district during the two consecutive rabi seasons of 2019-20 and 2020-21 to find out the effect of plant spacing and variety on yield and quality of maize in coastal region. The experiment comprised two set of treatments viz., (a) Plant spacing: 60 cm x 20 cm (S_1); 55 cm x 20 cm (S_2); 50 cm x 20 cm (S_3) and 45 cm x 20 cm (S_4) and variety (b) BARI hybrid Maize-16 (V_1); Sunshine (V_2) and NK 40 (V_3) in split plot design (where plant spacing in the main plot and variety in the sub plot) with three replications. The results showed that the variety Sunshine planted with 60 cm × 20 cm plant spacing (S_1V_2) produced significantly the tallest plant and maximum number of leaves plant^{-1}. BARI hybrid Maize-16 planted with 60 cm × 20 cm plant spacing (S_1V_1) showed significantly the highest yield attributes and carbohydrate content. NK 40 planted with 60 cm × 20 cm plant spacing (S_1V_3) produced significantly the maximum protein content. But the treatment combination S_4V_1 (BARI hybrid Maize-16 with planted with 45 cm × 20 cm plant spacing) produced significantly the highest grain yield (8.43 t ha^{-1}) due to higher number of plant population.

Keywords: Maize, Plant spacing, Variety, Yield and Quality.

INTRODUCTION

Maize (*Zea mays* L) is one of the most important food grains in the world as well as developing countries like Bangladesh. It is the 3rd most important cereal crops in

[*] Corresponding author: likhibari79@gmail.com

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Bangladesh. The area, production and demands of maize are increasing rapidly in our country. About 4.26 million ton of maize grain is produced from 478 000 ha of land (BBS, 2023). It is one of the cash crops in Bangladesh which has the potential to pull farmers out of poverty. Maize is a versatile crop due to its multi various uses as feeds, food and industrial raw material. It serves as food for human, feed for livestock and raw material for industry (Ullah and Farooqi, 2010). Every part of the maize plant is useful. The top green portion of the plant after harvest of the cob is fed to cattle as fodder, and the dry portion of the stem along with fibrous roots are used as fuel. Maize is more nutritious than rice in terms of protein, phosphorus and carotene content. Fats and mineral contents are also higher. It is rich in Vitamin B and trace elements. Because of more nutritious status; it could be good source of nutrients for under-nourished and malnourished population in Bangladesh (Farhana *et al*., 2014).

Maize (*Zea mays* L.) can be considered as a very promising crop after transplant aman rice in the coastal area of Bangladesh as the crop can adapt the situation of both salinity and drought stress. Maize is becoming an important crop in the rice based cropping system (Matin *et al*., 2017).

Maize yield and quality are both dependent on variety and plant spacing. Closer plant spacing is another important thing in coastal region because, closer plant spacing makes maximum canopy coverage, which reduce evaporation from the soil surface and encourage downward flux of soil water will help to control root zone salinity. If well adapted hybrid variety (like, NK 40) of maize can be grown during early of the season by dibbling method, this will enable the crop to utilize the residual soil moisture and the farmers will be able to harvest their crops earlier to avoid cyclonic storm in May. The yield of maize can be increased by adopting improve production technology like suitable plant variety and proper plant spacing.

Major cropping pattern of this area is T. aman-Fallow-Fallow with low cropping intensity. By introducing different crops it is possible to increase the cropping intensity. Maize cultivation has a great opportunity in coastal area of Bangladesh after harvesting transplant aman rice, where rice is main crop. There is limited information on how plant spacing and variety affect maize production in Bangladesh. The selected 3 varieties are slight to moderate saline tolerant and BARI hybrid maize-16 can tolerate 9 dSm^{-1} salinity (BARI, 2019). So, the present study was conducted to find out the effect different plant spacing and variety on yield and quality (carbohydrate and protein content) of maize in coastal area of Bangladesh.

MATERIALS AND METHODS

Research Location

The field experiments were conducted at Khatail under the Dacope upazila of Khulna district during the *Rabi* seasons (December-April) of 2019-2020 and 2020-2021. The experimental site is located at 22°57´ N latitude and 89° 51´ E longitude within Polder number 32. This site belongs to non-calcareous dark grey floodplain soil under

the Ganges Tidal Floodplain agro-ecological zone "known as AEZ-13". The initial soil chemical properties for the experimental site, are given in Table 1. The weather data during the study period are presented in Table 2.

Month wise soil salinity levels during crop growing period at experimental sites are presented in Table 3. The salinity of adjacent canal water and soil were recorded (Figure 1).

Table 1. Initial soil chemical properties of experimental site (0-15 cm) at Khatail, Dacope, Khulna during 2019-2020 and 2020-2021

Year	P^H	OM	Total N	Ca	Mg	K	P	S	B	Cu	Fe	Mn
		(%)		(meq/100 g)				mg/kg				
2019-2020	8.1	1.14	0.06	5.3	1.9	0.25	8.0	17.0	0.1	1.9	54	10.8
2020-2021	7.9	1.12	0.07	5.2	1.8	0.23	8.2	17.2	0.1	1.8	52	10.6

Table 2. Mean monthly weather data during the crop growing period

Periods	Maximum temperature (^oC)	Minimum temperature (^oC)	Average RH (%)	Total rainfall (mm)
2019				
December	24.5	15.1	80.0	15
2020				
January	24.1	14.0	80.0	30
February	26.9	15.0	65.4	2
March	32.8	20.6	57.2	10
April	33.7	24.0	67.3	179
May	34.2	25.2	72.0	244
December	26.1	15.0	80.0	0
2021				
January	26.1	14.2	79.0	0
February	29.5	15.9	73.0	3
March	34.3	22.4	71.0	0
April	36.4	24.9	67.0	2
May	35.4	26.0	73.0	124

Source: Bangladesh Meteorological Department, Khulna.

Table 3. Month wise soil salinity level during crop growing period at experimental sites

Date	Soil Salinity (dS m^{-1})					
	2019-2020			2020-2021		
	0-15 cm	16-30 cm	31-45 cm	0-15 cm	16-30 cm	31-45 cm
15 December	2.5	1.9	1.6	2.6	1.8	1.7
30 December	2.7	2.1	1.9	2.8	2.0	1.9
15 January	3.2	2.8	2.6	3.1	2.6	2.5
30 January	3.5	3.1	2.9	3.4	2.9	2.8
15 February	5.4	3.7	3.0	5.5	3.5	3.2
1 March	5.6	3.9	3.2	5.4	3.4	3.1
15 March	6.3	5.6	4.6	5.9	5.2	4.1
1 April	6.7	5.9	5.2	6.1	5.6	4.6
15 April	6.5	5.8	5.1	6.4	5.8	5.0
1 May	6.1	5.3	5.0	6.3	5.5	5.0

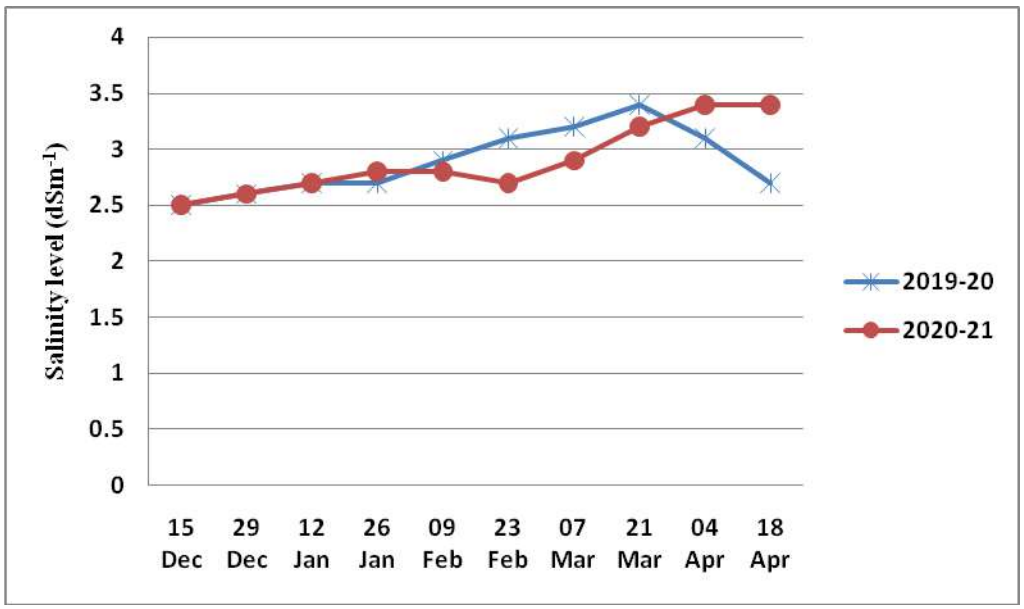

Fig. 1. Monthly salinity (electrical conductivity) of canal water used for irrigation in crops during 2019-2020 and 2020-2021 at Khatail, Dacope, Khulna.

Experimental Design

The experiment consisted of two factors. Factor A: Plant spacing (*4*) *viz*. (i) 60 cm × 20 cm (S_1); (ii) 55 cm × 20 cm (S_2); (iii) 50 cm × 20 cm (S_3) and (iv) 45 cm × 20 cm (S_4) and Factor B: Variety (3): (i) BARI hybrid Maize-16 (V_1); (ii) Sunshine (V_2) and (iii) NK 40 (V_3). The experiment was conducted in Randomized Complete Block Design (RCBD) with three replications. The size of each unit plot 4 m × 3 m (= 12 m^2). The distance between block to block 1.0 m and plots to plot distance was 0.5 m. Total area was nearly 600 m^2.

Crop management

No land preparation was done as the seeds were sown at zero tillage condition keeping the preceding crop residues in the field. The seeds were sown on 15 December 2019 (first year) and 16 December 2020 (second year). The seeds were treated with vitavex (Carboxin 17.5% + Thiram 17.5%) @ 3 g kg^{-1} seed and sown at 3 cm depth of soil by dibbling method and two seeds were placed per hill and were later thinned to one plant per hill. Treated seeds were sown in both the years in 60, 55, 50 and 45 cm apart rows and plant to plant distance was 20 cm. Fertilizers were applied according to Fertilizer Recommendation Guide (FRG, 2018). Total amount of TSP (250 kg ha^{-1}), MoP (220 kg ha^{-1}), Gypsum (200 kg ha^{-1}), Zinc sulphate (10 kg ha^{-1}), Boric acid (10 kg ha^{-1}) and 1/3rd portion of the urea (550 kg ha^{-1}) as well as cowdung (10 t ha^{-1}) were applied during sowing time by broadcasting between rows. The rest urea was top dressed in 2 split applications: 1/3rd at 30 DAS and the other 1/3rd at 65-70 DAS followed by irrigation. Rice straw of previous crop was spread over the plot after seed sowing. This straw used as mulch which conserves soil moisture and thus reduces evaporation loss. Weeding was done twice at 25 DAS and 55 DAS. Only one healthy seedling $hill^{-1}$ was kept and the rest were thinned out at 14 DAS. For uniform germination, a light irrigation was given by sprinkler after sowing of seeds. Irrigation was applied from canal water for three times (30 DAS, 45 DAS and 70 DAS). The crops were attacked by cutworm (*Agrotis ipsilon*) at early growth (vegetative) stage. The cutworm was controlled by spraying Karate 2.5 EC (Lambda Cyhalothrin 2.5 % EC) @ 1.0 ml L^{-1} of water at afternoon of the day. There was no major incidence of insects or diseases. One guard was appointed at each location to protect the crop from the probable damage by grazing animals and thieves.

Data collection and analysis method

The following data were collected from the experiment

Plant height (cm): Plant height of five randomly selected tagged plants was measured from ground surface to the tip of the plant with the help of meter scale and the average data was recorded as plant height (cm).

Number of leaves: All the leaves were counted from the five randomly selected and tagged plants and the average data obtained as total number of leaves $plant^{-1}$.

Number of row cob^{-1}: Number of rows cob^{-1} was counted for 10 cobs from each plot and average of 10 cobs was calculated.

Number of kernel row^{-1}: In the same selected cobs, the numbers of kernel (seed) in each row of the cob were separated by hand and were counted manually. The average was worked out and expressed as number of kernel row^{-1}.

Hundred Seed weight (g): One hundred seeds were counted at random from the harvested produce of each treatment, weighed and recorded in grams.

Grain yield (tha^{-1}): The seed yield plot^{-1} was recorded from the central area of 6 m^2 from each plot and then plot^{-1} yield was converted into t ha^{-1} yield as follows:

Grain yield (t ha^{-1}) = (Grain yield plot^{-1} kg × 10000)/(Size of plot in m^2 ×1000).

Carbohydrate content (%): The carbohydrate content was estimated in percentage by using Phenol sulphuric acid method (Whistler and BeMiller, 1997).

Protein content (%): The protein content of maize was estimated in percentage by using Near Infrared Reflectance (NIR) spectroscopy technique. (Buning and Diller, 2000).

Statistical analysis of data:

The recorded data were statistically analyzed as a two-factors split plot design. All data were analysed statistically using software programme MSTAT C and means were separated by Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Effect of plant spacing

The result presented in Table 4 shows that significant effect of plant spacing on plant height, number of leaves plant^{-1}, number of row cob^{-1}, number of kernel row^{-1}, 100 seed wt. and Yield ha^{-1}. The tallest plant (158.8 cm) was obtained from S_1 (60 cm × 20 cm) while S_4 (45 cm × 20 cm) gave shortest plant. The maximum number of leaves plant^{-1} (14.84) was found from S_1 while the minimum number of leaves plant^{-1} (12.32) was found from S_4. Enujeke (2013) also observed similar result with the present sutdy and reported that widest plant spacing resulted higher number of leaves plant^{-1}. The highest number of rows cob^{-1} (15.82) was recorded from S_1 which is statistically identical (15.46) with S_2 and the lowest number of rows cob^{-1} (14.44) was recorded from S_4. The maximum number of kernel row^{-1} (35.21) was found from S_1 while the minimum number of kernel row^{-1} (31.66) was found from S_4. Shafi *et al*. (2012) also found similar results. The boldest grain was recorded from S_1 (37.76 g/100 grain) while the smallest grain was recorded from S_4 (31.66 g/100 grain). The highest grain yield (7.96 t ha^{-1}) was recorded from S_4 while the lowest grain yield (7.51 t ha^{-1}) was recorded from S_1 which is statistically similar with S_3 (7.64 t ha^{-1}) and S_2 (7.63 t ha^{-1}). Abuzar *et al*. (2011) reported that grain yield increased with decreased plant spacing. Shafi *et al*. (2012) also support this result.

Table 4. Effect of plant spacing on the crop characters, yield contributing character and yield of maize in Dacope. Values are mean data of 2019-20 and 2020-21

Plant spacing	Plant height (cm)	Leaves plant^{-1} (no.)	Rows cob^{-1}(no.)	Kernel row^{-1}(no.)	100 grain weight(g)	Yield (t ha^{-1})
S_1	158.8 a	14.84 a	15.82 a	35.21 a	37.76 a	7.51 b
S_2	148.9 b	13.78 b	15.46 a	33.95 b	37.59 ab	7.63 b
S_3	140.6 c	13.76 b	14.67 b	32.58 c	37.23 bc	7.64 b
S_4	131.9 d	12.32 c	14.44 b	31.66 d	36.84c	7.96 a
LSD	2.013	0.320	0.603	0.739	0.450	0.156
CV (%)	1.21	2.03	3.46	1.92	1.04	1.76

In a column means having similar letter (s) are statistically identical at P= 0.05. S_1 = 60 cm × 20 cm, S_2 = 55 cm × 20 cm, S_3 = 50 cm × 20 cm, S_4 = 45 cm × 20 cm

The result presented in Table 5 show that there was significant effect of plant spacing on carbohydrate and protein content. The highest carbohydrate (70.06%) and protein content (7.83%) was recorded from S_1 and the lowest carbohydrate (67.85%) and protein content (7.54%) was recorded from S_4.

Table 5. Quality parameters regarding Carbohydrate and Protein content of maize as influenced by different plant spacing. Values are mean data of 2019-20 and 2020-21

Plant spacing	Quality parameters	
	Carbohydrate (%)	Protein (%)
S_1	70.06 a	7.83 a
S_2	69.62 b	7.73 a
S_3	69.32 b	7.66 a
S_4	67.85 c	7.54 b
LSD	0.411	0.173
CV (%)	0.51	1.95

In a column means having similar letter (s) are statistically identical at P= 0.05. S_1 = 60 cm × 20 cm, S_2 = 55 cm × 20 cm, S_3 = 50 cm × 20 cm, S_4 = 45 cm × 20 cm

Effect of variety

The result presented in Table 6 show that significant effect of variety on plant height, number of leaves plant^{-1}, number of row cob^{-1}, number of kernel row^{-1}, 100 seed wt. and Yield ha^{-1}. The tallest plant (157.2 cm) was obtained from V_2 (Sunshine) while

V_3 (NK 40) gave shortest plant (133.9 cm). The maximum number of leaves plant^{-1} (13.89) was found from V_2 while the minimum number of leaves plant^{-1} (13.55) was found from V_3 which was similar with V_1 (BARI hybrid Maize-16) (13.59). The highest number of rows cob^{-1} (15.48) was recorded from V_1 whereas the lowest number of rows cob^{-1} (14.59) was recorded from V_3.The maximum number of kernel row^{-1} (33.71) was found from $V_1$and V_2while the minimum number of kernel row^{-1} (32.63) was found from V_3. The boldest grain was recorded fromV_1 (37.95 g/100 grain) while the smallest grain was recorded from V_3 (36.61 g/100 grain). The highest grain yield (8.09 t ha^{-1}) was recorded from V_1 while the lowest grain yield (7.15 t ha^{-1}) was recorded from V_3. The variation of yield due to varietal effect was also observed by Ullah *et al*. (2016) and Hasan *et al*. (2018).

The result presented in Table 7 show that there was significant effect of variety on carbohydrate and protein content. The highest carbohydrate (73.57%) was found from V_1 and the lowest carbohydrate (66.59%) was found from V_3. The maximum protein content (7.83%) was recorded from V_3 which is identical with V_2 (7.70%) and the lowest protein content (7.53%) was recorded from V_1. The variation in protein and carbohydrate percentage among different maize varieties can be attributed to several factors related to genetics, environmental conditions and agronomic practices.

Table 6. Effect of variety on the crop characters, yield contributing character and yield of maize in Dacope. Values are mean data of 2019-20 and 2020-21

Plant spacing	Plant height (cm)	Leaves plant^{-1} (no.)	Rows cob^{-1} (no.)	Kernel row^{-1} (no.)	100 grain weight (g)	Yield (t ha^{-1})
V_1	143.2 b	13.59 b	15.48 a	33.71 a	37.95 a	8.09 a
V_2	157.2 a	13.89 a	15.22 b	33.71 a	37.50 b	7.82 b
V_3	133.9 c	13.55 b	14.59 c	32.63 b	36.61 c	7.15 c
LSD	1.319	0.265	0.195	0.625	0.366	0.054
CV (%)	1.05	2.24	1.49	2.17	1.13	0.81

In a column means having similar letter (s) are statistically identical at P= 0.05. V_1 = BARI hybrid Maize-16, V_2 = Sunshine and V_3 = NK 40

Interaction effect of plant spacing and variety

Interaction effect of plant spacing and variety showed significant effect on plant height, number of leaves plant^{-1}, number of row cob^{-1}, number of kernel row^{-1}, 100 seed wt. and Yield ha^{-1} (Table 8). The tallest plant (173.7 cm) was obtained from S_1V_2 while S_4V_3 gave shortest plant (125 cm). The maximum number of leaves plant^{-1} (15.14) was found from S_1V_2 while the minimum number of leaves plant^{-1} (12.14) was found from S_4V_3. The highest number of rows cob^{-1} (16.03) was recorded from S_1V_1which is statistically identical with S_1V_2 and S_2V_1whereas the lowest number of

rows cob^{-1} (13.70) was recorded from S_4V_3. The maximum number of kernel row^{-1} (35.72) was found from S_1V_1 while the minimum number of kernel row^{-1} (30.57) was found from S_4V_3. The boldest grain was recorded from S_1V_1 (38.53 g/100 grain) while the smallest grain was recorded from S_4V_3 (36.18 g/100 grain). The highest grain yield (8.43 t ha^{-1}) was recorded from S_4V_1which was identical with S_4V_2 (8.18 t ha^{-1}) while the lowest grain yield (7.07 t ha^{-1}) was recorded from S_1V_3which was identical with S_3V_3 (7.08 t ha^{-1}).

Table 7. Quality parameters regarding carbohydrate and protein content of maize as influenced by different variety. Values are mean data of 2019-20 and 2020-21

Plant spacing	Quality parameters	
	Carbohydrate (%)	Protein (%)
V_1	73.57 a	7.53 b
V_2	67.47 b	7.70 a
V_3	66.59 c	7.83 a
LSD	0.429	0.125
CV (%)	0.71	1.92

In a column means having similar letter (s) are statistically identical at P= 0.05. V_1 = BARI hybrid Maize-16, V_2 = Sunshine and V_3 = NK 40

Table 8. Effect of plant spacing on the crop characters, yield contributing character and yield of maize in Dacope. Values are mean data of 2019-20 and 2020-21

Plant spacing	Plant height (cm)	Leaves plant^{-1} (no.)	Rows cob^{-1} (no.)	Kernel row^{-1} (no.)	100 grain weight (g)	Yield (t ha^{-1})
S_1V_1	156.2 c	14.54 bc	16.03 a	35.72 a	38.53 a	7.84 c
S_1V_2	173.7 a	15.14 a	15.98 a	35.57 ab	37.70 bcd	7.62 d
S_1V_3	143.3 e	14.85 ab	15.45 ab	34.35 bc	37.03 def	7.07 f
S_2V_1	144.2 e	13.92 d	15.72 a	34.30 c	38.28 ab	8.04 b
S_2V_2	165.0 b	14.31 cd	15.40 ab	34.20 c	37.80 abc	7.69 cd
S_2V_3	137.4 e	13.11 f	15.25 ab	33.35 cd	36.68 efg	7.16 ef
S_3V_1	139.2 f	13.37 ef	15.30 ab	32.62 d	37.65 bcd	8.05 b
S_3V_2	153.1 d	14.12 cd	14.93 b	32.88 d	37.50 cd	7.80 cd
S_3V_3	129.4 h	13.79 d	13.95 c	32.25 d	36.53 fg	7.08 f
S_4V_1	133.4 g	12.53 fg	14.88 b	32.20 d	37.32 cde	8.43 a
S_4V_2	136.8 f	12.27 g	14.57 bc	32.20 d	37.02 def	8.18 a
S_4V_3	125.4 i	12.14 g	13.70 c	30.57 e	36.18 g	7.27 e

Plant spacing	Plant height (cm)	Leaves plant^{-1} (no.)	Rows cob^{-1} (no.)	Kernel row^{-1} (no.)	100 grain weight (g)	Yield (t ha^{-1})
LSD	2.637	0.531	0.639	1.250	0.733	0.1076
CV (%)	1.05	2.24	1.49	2.17	1.13	0.81

In a column means having similar letter (s) are statistically identical at P= 0.05. S_1 = 60 cm × 20 cm, S_2 = 55 cm × 20 cm, S_3 = 50 cm × 20 cm, S_4 = 45 cm × 20 cm, V_1 = BARI hybrid Maize-16, V_2 = Sunshine and V_3 = NK 40

Table 9. Quality parameters regarding carbohydrate and protein content of maize as influenced by different plant spacing and variety in Dacope. Values are mean data of 2019-20 and 2020-21.

Plant spacing x Variety	Quality parameters	
	Carbohydrate (%)	Protein (%)
S_1V_1	74.61 a	7.65 b
S_1V_2	68.39 d	7.84 a
S_1V_3	67.24 de	7.98 a
S_2V_1	74.14 a	7.61 b
S_2V_2	68.03 de	7.74 ab
S_2V_3	66.74 ef	7.85 a
S_3V_1	72.97 bc	7.54 bc
S_3V_2	67.51 e	7.68 b
S_3V_3	67.49 e	7.77 ab
S_4V_1	72.58 c	7.35 d
S_4V_2	65.97 fg	7.54 bc
S_4V_3	64.99 g	7.71 ab
LSD	1.40	0.155
CV (%)	0.71	1.92

In a column means having similar letter (s) are statistically identical at P= 0.05. S_1 = 60 cm × 20 cm, S_2 = 55 cm × 20 cm, S_3 = 50 cm × 20 cm, S_4 = 45 cm × 20 cm, V_1 = BARI hybrid Maize-16, V_2 = Sunshine and V_3 = NK 40

Table 9 presented interaction effect of plant spacing and variety had significant effect on carbohydrate and protein content. The highest carbohydrate (74.61%) was found from S_1V_1 which was statistically identical with S_2V_1 (74.14%) and the lowest carbohydrate (64.99%) was found from S_4V_3. The maximum protein content (7.98%) was recorded from S_1V_3 which is identical with S_1V_2 (7.84%) and S_2V_3 (7.85%) whereas the lowest protein content (7.35%) was recorded from S_4V_1.

CONCLUSION

From the study, it may be concluded that, yield contributing characters, yield and grain quality of maize can be effectively manipulated by different plant spacing and variety. The highest rows cob^{-1}, kernel row^{-1} and 100 grain weight were observed from S_1V_1 treatment combination but S_4V_1 (BARI hybrid Maize-16 planted with 45 cm × 20 cm plant spacing) produced significantly the highest grain yield (8.43 t ha^{-1}) due to higher number of plant population. The highest carbohydrate content (74.61%) was recorded from S_1V_1 and the maximum protein content (7.98 %) found from S_1V_3 treatment combination.

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PLANT BIODIVERSITY IN HOMESTEAD AREA AT SADAR UPAZILA OF RANGAMATI DISTRICT IN BANGLADESH

S. Das[1], M.S. Uddin[1*], M.S.A. Talucder[1,2] and T.T. Moon[3]

[1]Climate-Smart Agriculture Lab, Department of Agroforestry and Environmental Science, Sylhet Agricultural University, Sylhet, Bangladesh
[2]Interdisciplinary Research for Future Agriculture, Sylhet Agricultural University Sylhet, Bangladesh
[3]Department of Entomology, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh

ABSTRACT

Diversified plant species in homestead areas play an important role to ensure the food and nutritional security of rural communities. An exploratory survey and field observation was carried out at Sadar upazila of Rangamati district in Bangladesh to identify the existing plant biodiversity in the homestead areas of six unions along with municipal area of Rangamati Sadar upazila. A total of 120 households were randomly selected for collecting data using face-to-face interviews from July to September 2020. A total of 163 plant species were identified at different homesteads of the study area. Among different categories of plant species, 13 (7.98%) timber, 32 (19.63%) fruits, 19 (11.66%) medicinal species, 31 (19.02%) different vegetable species, 56 (34.36%) different flowering and ornamental species, 08 (4.91%) spices and condiments and 04 (2.45%) other plant species were recorded. The front yard was dominated by most of the plant species whereas the kitchen side was dominated by vegetables. The highest diversity was found in vegetables (H'= 0.96) followed by medicinal plant and fruit species (H'= 0.83), timber, and flower and ornamental species (H'= 0.82). A moderate diversity was found at the back side (H'=0.69) followed by the boundary side (H'=0.68), front yard (H'=0.65) and, approach road (H'=0.60). The study concludes that homestead agroforestry is a unique area for maintaining both plant diversity and productivity which could be a good option to meet up the demand of food and nutrition of the people in hilly areas.

Keywords: Homestead area, Plant diversity, Shannon-Weaver diversity index, Dominant species, medicinal plants.

[*] Corresponding author: sharaf.aes@sau.ac.bd

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INTRODUCTION

Chittagong Hill Tracts is a special region in the southeastern part of Bangladesh, rich in hills, mountains, rhythms, diverse cultures, and people. This region is unique from other regions not only in terms of geographical location but also in terms of population and cultural diversity. Though earlier as one district, now the entire Chittagong Hill Tracts consist of three districts: Rangamati, Khagrachari, and Bandarban. In terms of area, the Chittagong Hill Tracts are one-tenth of the total area of the country; that is 13,184 square kilometers. In terms of biodiversity, Chittagong Hill Tracts are completely different from other districts (Banglapedia, 2021). There are 14 small ethnic groups living in Chittagong Hill Tracts, including Bengalis, speaking different languages. These communities are somehow dependent on forest resources. Generally, a country needs to have 25% or more forest area of its total land area (Huda and Roy, 2001), but forest area (% of land area) in Bangladesh was 14.47 % in 2021 (World Bank, 2024) as compared to 17.4%, five years back (Rahman, 2016). Bangladesh ranks lowest in per capita forest area, which is about 0.015 ha (Islam et al., 2012). The Chittagong Hill Tracts account for more than half of Bangladesh's forests (Baten et al., 2010). Rahman et al., (2017) reported that the CHT is one of the most biologically diverse part of Bangladesh which makes up almost 43% of total forestlands in Bangladesh.

Homestead agroforestry consisting diversified plant ecosystem plays an important role in the economy of Bangladesh. Plants and trees grown on the homestead areas are important source of food, fodder, fuel, and wood. About 25.49 million homesteads are present in our country. Most of the vegetables produced in Bangladesh come from those homesteads and 45.3% of the fuel sources are from wood/bamboo (BBS, 2020). Trees play an important role in the rural and national economy. The most of the rural people cultivate their homesteads with different fruits and woody perennials in an unplanned way. So, the identification and documentation of plant species is required to obtain a clear picture of the home gardens. The frequency and growth of a species are indicators for its adaptability and suitability to a site (Dutta and Iftekhar, 2004).

A large number of farmers in the hilly areas still depend on jhum cultivation, which they have been practicing since long. This type of farming system creates a severe disturbance in the soil through maximum tillage, rapid decrease in primary and/or secondary forest, landslides, and erosion of topsoil. (Rangamati Hill District Council, 2011). Repeated jhum cultivation replaced forest species with secondary vegetation such as shrubs, exotic weeds, and hardy grasses (Arya, 2000). Thus, it causes loss of plant biodiversity and reduction of forest area. Homestead agroforestry systems with diversified plant species can be a good option over conventional agriculture and monoculture of forest which can offer increased productivity, economic benefits and more biodiversity. A few studies have been conducted on homestead biodiversity in different parts of Bangladesh (Alam and Masum, 2005; Baul et al., 2021; Muhammed

et al., 2011; Roy et al., 2011; Prova et al., 2023). However, there is no systematic documentation of plant biodiversity at different homestead areas in Rangamati hill districts. Hence, the study was undertaken to estimate the existing plant biodiversity in the study area.

MATERIALS AND METHODS

The study was conducted in six (6) unions and one municipal area under the sadar upazila of Rangamati district from July to September 2020 to identify the existing diversified plant species in different homestead areas. Data were collected through personal interviews. A sample of 120 respondents was interviewed to collect data. Plant species diversity was measured using Shannon-Weaver Diversity Index (SWDI)-H′ as stated below.

$$H' = -\sum_{i=1}^{n} Pi \times \log Pi$$

Where Pi is the proportion of the number of entries (plant species) belonging to the ith class and n is the number of phenotypic classes of plants. The H′ ranges from 0 to 1, where, 1 indicates the maximum and 0 indicates no diversity. The H′ value was calculated following Yu Li et al. (1996) modified by Uddin et al. (2021). The exact characters' were defined as the classes for qualitative characters, while the classes for quantitative characters were defined according to the procedure suggested by Yu Li et al. (1996). The relative frequencies of different classes were used to calculate the diversity index. The H′ for each of the characters was calculated by using Microsoft Excel.

This index is the direct method of measuring plant diversity while other indices are indirect measures. The higher the diversity index meaning the more diverse the population. When the H′ values are ≥ 0.75 means high diversity, if H′ values are equal to 0.50-0.75 means moderate diversity and if the H′ values are <0.50 means low diversity (Jamago, 2000; Kete, 2001; Thuy, 2002; Uddin et al., 2006).

RESULTS AND DISCUSSION

Plant species diversity

Diversified plant species were observed in the homestead area. A total of 163 plant species were recorded, including 13 timber species, 32 fruit species, 19 medicinal species, 31 vegetables, 56 flowering and ornamental plants species, 8 spices and condiments, and 4 other plant species (Table 1).

Table 1. Plant species diversity of Rangamati Sadar upazila under Rangamati district

Plant species	No of existing plant species	Percentage
Timber tree	13	7.98
Fruit tree	32	19.63
Medicinal plant	19	11.66
Vegetables	31	19.02
Flowering and ornamental plants	56	34.36
Spices & condiments	08	4.91
Other plant species	04	2.45
Total	163	100

The flowering and ornamental plant species were dominant, followed by fruit species compared to medicinal plant and timber species. Uddin et al. (2021) reported a total of 137 plant species in the Moulvibazar district which 45 were vegetable, 36 fruit species, 35 timber, and 21 medicinal and other plant species. Baul et al. (2021) reported a total of 71 tree and bamboo species of specific or multipurpose value, representing a rich reservoir of tree floral composition and diversity in the homestead forests of Bandarbans district. On the other hand, Muhammed et al. (2011) reported that a total of 43 woody perennials and 38 vegetables species were found in the study sites of Mymensingh district. Banana, betel nut, jackfruit, mango, mahogany, teak and acacia constituted the major floral composition. The abundance of horticultural species was higher than that of the timber species in all the study sites. However, among the newly planted homestead plants, timber species are gradually increasing. This trend of floral dynamics indicates a probable change in future homestead plant structure and composition. Their study confirms that the homestead forests of Bangladesh are rich in plant species diversity even distributed sporadically in small areas. With appropriate models, based on both traditional and scientific knowledge, homestead forestry could emerge as an effective means for both economic well-being and biodiversity conservation in Bangladesh. While, Alam and Masum (2005) identified a total of 142 plant species belonging to 61 families in the offshore island of Bangladesh, of which 76 species were recorded as tree species, 25 shrub species and 41 herb species. Again, out of the plant species, 34 species were fruit producing species, 24 timber species, 21 fuel wood species, 15 medicinal species, 11 ornamental species, 32 vegetable species and 5 species of spices. Most of the farmer (76%) preferred to plant fruit tree species for future plantation followed by timber species (62%). Diversity and abundance of fruit species was found higher in all homesteads. Prova et al. (2023) identified 50.0% fruits, 26.3% vegetables, 15.8% timber and 7.9% medicinal plants in Sylhet district.

Major timber species at homestead

Out of 13 timber species Bamboo, Gamar (*Gmelina arborea*), Rajkoroi (*Albizia richardiana*), and Shegun (*Tectona grandis*) were found as dominant in the study area. Among the ten major timber species, Bamboo was found dominant (75%) followed by Gamar (69.17%), Albizia (65.83%), and Shegun (62.5%). Sadaat (2007) also reported similar type of timber species diversity and he observed a total of 21 timber species in Gaibandha district. Uddin et al. (2021) observed 35 timber species in Kamalganj upazila of Moulvibazar district. Muhammed et al. (2011) reported that a total of 43 woody perennials in Mymensingh district among which mahogany, teak and acacia constituted the major floral composition. While, Alam and Masum (2005) identified a total of 24 timber species, 21 fuel wood species in the offshore island of Bangladesh.

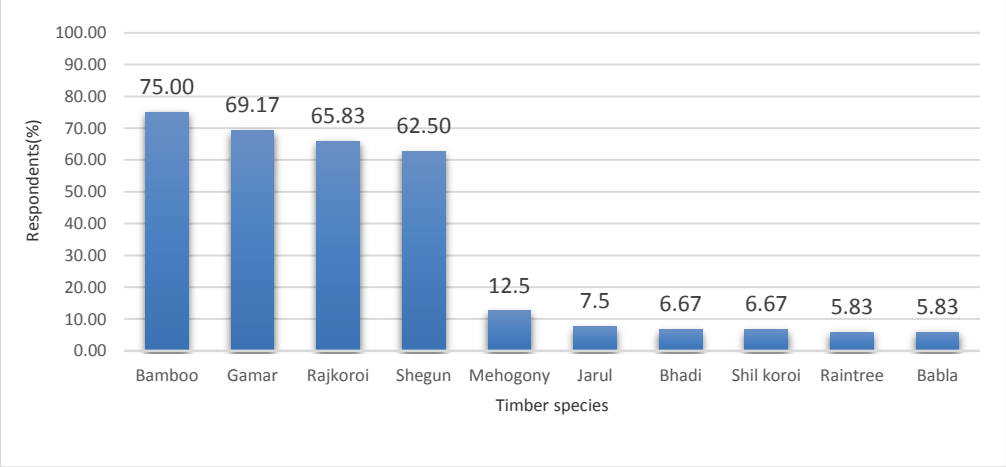

Figure 1. Major ten timber species in homestead of Rangamati Sadar upazila

Major fruit species at homestead

Among the 32 fruit species Coconut, Jackfruit, Java plum, Mango, Banana, and Litchi were dominant and found up to 70-80.83% in the study area (Figure 2). Belali (2011) observed a total of 28 fruit species in Narayangonj district which was more or less similar to the present study. Uddin et al. (2021) also observed 36 fruit species in Kamalganj upazila of Moulvibazar district. On the other hand, Alam and Masum (2005) identified a total of 34 species of fruits in the offshore islands of Bangladesh. Most of the farmers (76%) preferred to plant fruit tree species for future plantation followed by timber species (62%). Diversity and abundance of fruit species was found higher in all homesteads their studied areas.

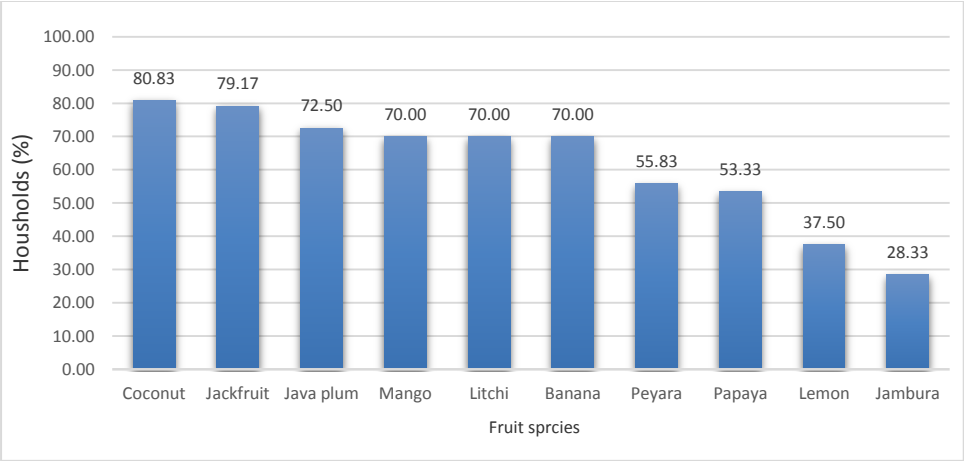

Figure 2. Major ten fruit species at homestead of Rangamati Sadar upazila

Major medicinal species at homestead

Among the 19 medicinal and other plant species Tulsi/Basil, Alovera, Neem, Tumeric, Basak, Mehedi and Drumstick were dominant and found in 18.33-94.17% of respondents' houses (Figure 3). A similar type of medicinal species diversity was by Yasmin et al. (2010) identified 35 medicinal species at Tangail district. Uddin et al. (2021) recorded 21 medicinal and other plants in the Kamalganj upazila of Moulvibazar district. While, Alam and Masum (2005) identified a total of 15 medicinal plant species in the offshore island of Bangladesh.

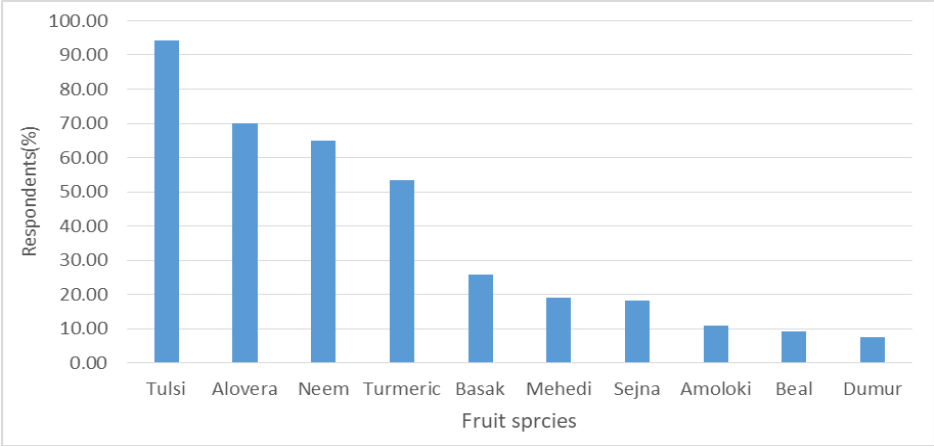

Figure 3. Major ten medicinal species at homestead of Rangamati Sadar upazila

Major vegetable species at homestead

A total of 31 different vegetable species were observed at different homesteads of the studied areas. Dominant vegetable species were Makoi (74.17%), Okra (65%) and Roselle, Indian spinach and Chili (63.33%) (Figure 4). Muhammed et al. (2011) reported that a total of 38 vegetables species were found in the study sites of Mymensingh district. The authors also reported that banana, constituted the major floral composition among vegetables. While, Alam and Masum (2005) identified a total of 32 vegetable species in the offshore island of Bangladesh.

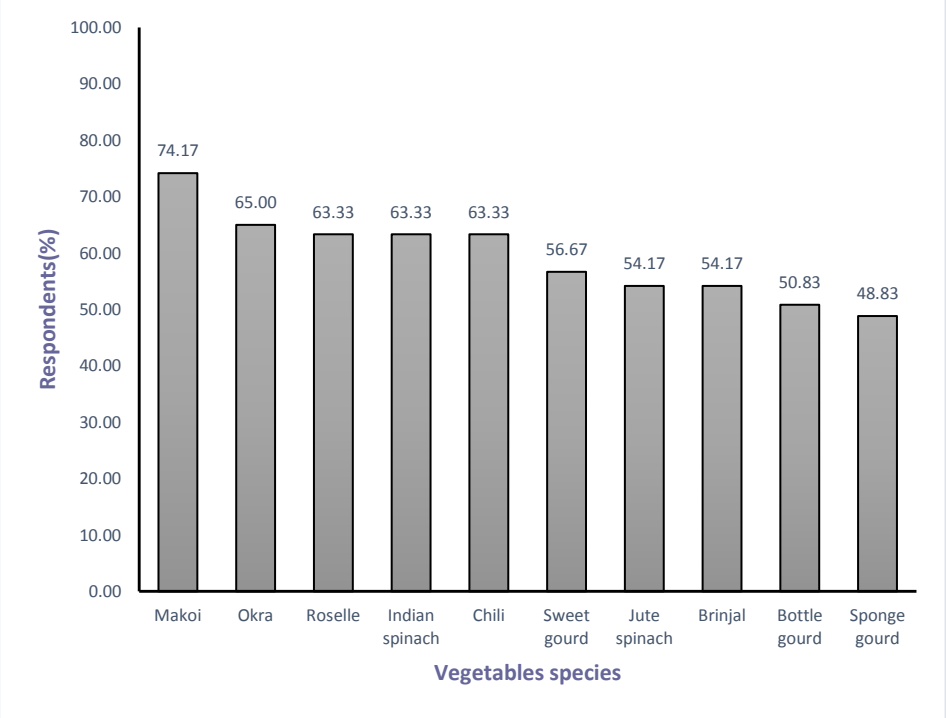

Figure 4. Major ten vegetable species at homestead of Rangamati Sadar upazila

Major flowering and ornamentals

Out of 56 different flowering and ornamental plant species, the dominant species were the Chinese rose (71.67%), Marigold (28.33%), and Zinnia (20.00%) (Figure 5). While, Alam and Masum (2005) identified a total of 11 ornamental plants species in the offshore island of Bangladesh.

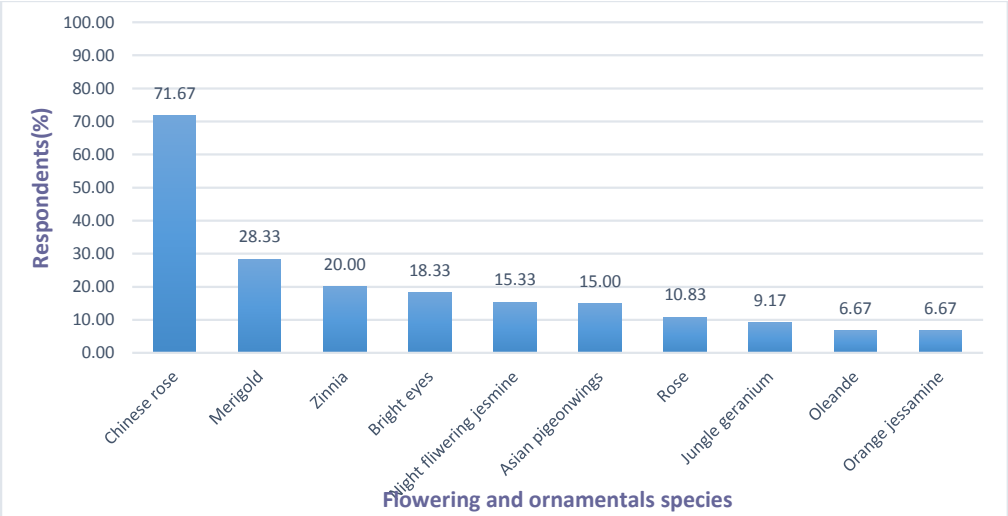

Figure 5. Major ten flowering and ornamentals species in homestead of Rangamati Sadar upazila

Spices and condiments and other plant species

The distribution of spices and condiments and other plant species is presented in. The table shows that a total of 8 species of spices and condiments were recorded and the presence of chili (63.33%) was the highest followed by turmeric (53.33%). A total of 4 other plant species was recorded and among them the Betel nut (74.17%) was the highest compared to Arabian coffee (7.5%) maize (6.67%) and cashew (4.17%) (Table 2). While, Alam and Masum (2005) identified a total of 5 species of spices in the offshore island of Bangladesh.

Table 2. Spices & condiments and other plant species present in Rangamati Sadar upazila of Rangamati district

SL. No.	Local Name	English Name	Scientific Name	No. of Respondent	Percentage (%)
Spices & condiments species					
1.	Morich	Chili	*Capsicum frutiscens*	76	63.33
2.	Holud	Turmeric	*Cucuma longa*	64	53.33
3.	Bilati Dhania	Mexican Coriander	*Coriandrum sativum*	23	19.17
4.	Pudina	Fild mint	*Mentha spicata*	8	6.67
5.	Tej pata	Bayleaf	*Cinnamomum tamala*	7	5.83
6.	Ada	Ginger	*Zingiber officinale*	6	5.00

SL. No.	Local Name	English Name	Scientific Name	No. of Respondent	Percentage (%)
7	Daruchini	Cinnamon	*Cinnamomum verum*	3	2.5
8	Lemon grass	Lemon grass	*Cymbopogon citratus*	1	0.83
Other plant species					
1.	Supari	Betel nut	*Areca catechu*	89	74.17
2.	Arabian coffee	Arabian coffee	*Coffea arabica*	5	7.50
3.	Moikka	Maize	*Zea mays*	8	6.67
4.	Kajubadam	Cashew	*Anacardium occidentale*	5	4.17

Distribution of existing plant species in homestead areas

Distribution of different plants species at different homestead areas are presented in Tables 3, 4, 5, 6, 7, 8, and 9.

Table 3). The result revealed that a maximum number of timber tree species were present at the boundary side (6), followed by the front yard of the homestead (5), compared to the back side (3), approach road (3), and kitchen side (3). Mahogany (48.57%) and Bot (37.14%) trees dominated at the front yard while Bamboo (67.07%)>Shegun (28.04%)> at the backside and Gamhar (58.97%)>Jarul (12.82%)> at Boundary side (Table 3). Uddin et al. (2021) also reported that Koroi>Acacia dominated over other timber tree species in the front yard, and Acacia>Mahogony>Koroi was dominated at the backyard, boundary, and approach road. Prova et al (2023) observed raintree as a dominant timber species in all of the homestead areas in Sylhet district.

Table 3. Distribution of timber plant species with frequency at different homestead areas of Rangamati Sadar upazila in Bangladesh.

Homestead area	No. of species	Dominant species
Front yard	5	Mahogany (48.57%)>Banyan tree (37.14%)>Albizia (11.42%)>Shegun (Teak) (1.42%)>China banyan tree (1.42%)
Back side	3	Bamboo (67.07%)>Shegun (Teak) (28.04%)>Bhadi (*Garuga pinnata*) (3.65%)> Kodamba (1.21%)
Boundary side	6	Gamhar (58.97%)>Jarul (12.82%)>Rain tree, Tall Albizia, Mandar (7.69%)> Babla/ gum arabic tree (5.18%)
Approach road	3	Babla/ gum arabic tree (50%)>Rain tree (40%)>Kodomba (10%)
Kitchen side	3	Albizia (58.24%)>Bamboo (38.46%)>Mandar (3.29%)

Distribution of Timber species

A total of 13 timber trees were scattered and distributed in different homestead areas.

Distribution of fruits species

Table 4 revealed that the majority of fruit specie was observed in the front yard of the homestead (13) followed by the back yard (10), and kitchen side (10), compared to boundary side (9) and approach road (7). Mango (41.42%)>Jujube (24.28%)>Bullock's Heart (17.14%) dominated on kitchen side, Papaya (40%)>Coconut (21.17%)>Jackfruit (20%)> in boundary side and Banana (29.41%)>Java pulm (27.94%) >Pomelo (16.17%)> in approach road. Uddin *et al.* (2021) also reported that Mango, Jackfruit, Lemon, and Coconut were dominating fruit species in the front yard, back yard, and boundary side in the Moulvibazar district. The dominant fruit species were identified by Prova et al. (2023) which was mango at the front yard, jackfruit at the backyard and banana at the boundary side of homestead area in Sylhet district.

Table 4. Distribution of fruit plant species with frequency at different homestead areas of Rangamati Sadar upazila in Bangladesh

Homestead area	No. of species	Dominant species
Front yard	13	Jackfruit (18.71%)>Mango (16.20%)>Coconut (15.64%)>Java pulm (14.80%)>Litchii (12.29%)>Papaya (10.89%)>Pomelo (6.98%)> Rambutan (1.95%)>Olive (1.39%)>Hog Plum (0.55%)>Wax apple (0.29%)> Aonla (0.27%)
Back side	10	Banana (26.38%)>Papaya (21.29%)>Coconut (14.83%)>Bullock's Heart (10.32%)>Karambola (9.03%)>Olive (1.93%)>Hog Plum (1.29%)>Indian pulm (0.64%)>Aonla (0.64%)
Boundary side	9	Papaya (40%)>Coconut (21.17%)>Jackfruit (20%)>Pineapple (7.05%)>Indian persimmon (3.52%)> elephant apple, Tamarind, Pomegrante (2.35%)>Bermij fruit (1.17%)
Approach road	7	Banana (29.41%)>Java pulm (27.94%) >Pumelo (16.17%)>Lime (15.44%)> Orange (6.61%)> Karanda (2.20%)
Kitchen side	8	Mango (41.42%)>Jujube (24.28%)>Bullock's Heart (17.14%)> Passion fruit, Dragon fruit (5.71%)> Burmese grape (2.86%)> elephant apple (1.42%)> Tai tamarind (1.42%)

Distribution of medicinal plant species

A total of 19 medicinal plants were present in different homestead areas of Rangamati Sadar Upazila. Maximum medicinal plant species were identified in the front yard (7) followed by the back yard (5) and boundary side (5), approach road (5),

and kitchen (4). Tulsi/Basil (34.43%)> Neem (27.15%)> Alovera (25.16%) were dominating medicinal plant species in the front yard, approach road, and kitchen side. On the other hand, Turmeric (31.57%)> Malabar nut (26.31%)> Neem (21.05%)> were dominated species in the back yard, Malabar nut (39.25%)> Kalomegh/Green Chiretta (35.71%)> Cluster fig (17.85%) at the boundary of the homestead areas (Table 5). Uddin et al. (2021) also reported that Tulsi was the dominated medicinal plant species in the front yard and kitchen side of the Kamalganj upazila of Moulvibazar district. On the other hand, Prova et al. (2023) observed holy basil at the front yard and neem at the backyard as the dominated medicinal plant species in Sylhet district.

Table 5. Distribution of medicinal plant species with frequency at different homestead areas of Rangamati Sadar upazila in Bangladesh

Homestead area	No. of species	Dominant species
Front yard	7	Tulsi/Basil (34.43%)> Neem (27.15%)> Alovera (25.16%)> Wood apple (6.67%)> Gynura (3.11%)>false daisy (1.98%)> Devil's Cotton (1.32%)
Back side	5	Turmeric (31.57%)> Malabar nut (26.31%)> Neem (21.05%)> Mehedi (17.51%)> Green chireta (3.50%)
Boundary side	5	Malabar nut (39.25%)> Kalomegh (35.71%)> Cluster fig (17.85%)> North Indian rosewood, Golden shower (3.57%)
Approach road	5	Tulsi/Basil (50%)> Drumstick (31.57%)> Indian trumpet flower (26.31%)> Neem (21.05%)> Filed mint/Pudina (8.33%)
Kitchen side	4	Tulsi/Basil (49.20%)> Fild mint, Cluster fig (23.80%)> Drumstick (22.22%)

Distribution of vegetable species

A sum of 31 vegetable species were identified in different homestead areas. Among different homestead areas, most of the vegetable species were found in the kitchen side (14) followed by the front yard (8), back yard (8), boundary side (8), and 7 in approach road (Table 6). Bottle gourd was dominating vegetable species in the front yard, approach road, and kitchen side. Prova et al. (2023) reported 38 vegetable species in homestead areas of Sylhet district of which bean (22.60%), ash gourd (21.70%) and moringa (19.10%) were reported as dominated vegetable species in different homestead areas of their study area.

Table 6. Distribution of vegetables plant species with frequency at different homestead areas of Rangamati Sadar upazila in Bangladesh

Homestead area	No. of species	Dominant species
Front yard	8	Bitter gourd (26.89%)> Sweet gourd (24.46%)> Chilli (18.62%)> Sponge gourd (14.82%)> Jute spinach (10%)> Cucumber (2.7%)> Skunkvine (1.37%)> Amaranth (1.03%)
Back side	8	Bottle gourd (30.26%)> Raddish (19.73%)> Sweet gourd (18.42%)> Jute spinach (15.78%)> Salgom(6.57%)> Indian yam (3.94%)>Papaya, Snake gourd (2.63%)
Boundary side	7	Okra (24.34%)> Yard long bean (20%)> Spiny gourd (19.13%)> Country bean (17.39%)> Pathar kuchi, Red amaranth (6.95%)> Raddish (5.21%)
Approach road	7	Spiny gourd (43.33%)> Bottle gourd (16.75%)> Brinjal (16.12%)> Wax gourd (15.05%)> Ridged gourd (13.44%)> Potato (7.52%)> Tomato (4.83%)
Kitchen side	13	Makoi (22.08%)>Indian spinach (18.85%)> Roselle (11.41%)> Brinjal (8.68%)>Mexican coriander (5.70%)> Yard long bean (4.96%)>Bottle gourd (4.46%)> Mexican coriander (5.70%) >Sweet potato (2.72%) >Snake gourd, Sponge gourd (1.98%)> Skunkvine (0.99%))>Tara (0.49%)

Distribution of ornamentals and flowering plant species

A total of 56 ornamental and flowering plants were recorded in different homestead areas of Rangamati Sadar upazila. Maximum flowering and ornamental plant species were found in the front yard (22) and the next in kitchen side (14), boundary side (11), and approach road (11) and the lowest was at the Back yard (7) (Table 7). China rose was dominating flowering plant species in the front yard and boundary side.

Table 7. Distribution of flowering and ornamental plant species with frequency at different homestead areas of Rangamati Sadar upazila in Bangladesh

Homestead area	No. of species	Dominant species
Front yard	22	China rose (16.91%)> Bright eyes (14.66%)> Orange jessamine (0.75%)>Oleander (6.76%)> Parijat (6.01%)> Chrysanthemums (5.63%)>Night flowering jasmine (4.51%) > Red spider (3.38%)> Globe amaranth, Star flower (3.00%)>Hajaribeli (1.90%)> May flower (1.87%)> Champa, Beli(1.12%)>Erect prickly pear, Water lily, Orange jessamine, Adenium, Bougainvillea (0.75%)>Copperpod, Sacred tree, Spanish cherry (0.37%)

Homestead area	No. of species	Dominant species
Back side	7	Jasmine, Rongon/Ixora (23.80%)> Lotus, Night jasmine (14.28%)>Rain lily (9.52%)>Boss flower (4.76%)> Hazari mogra plant (9.52%)
Boundary side	11	China rose (40.19%)> Marigold (24.50%)> Dwarf white bauhinia (7.84%)>Indian shot (6.86%)> Oleander (4.90%)>Four o'clock flower (3.92%)> Jasmin (2.94%)>Yellow bamboo (1.98%)>Hiptage, Orange jasmine, Ruellia (1.96%)
Approach road	11	Pinwheel flower (50.61%)>Begonia (9.87%)>Dwarf white bauhinia (8.64%)> Daisy (6.17%)> Rose, Christ thorn (4.93%)> Morning Star lily, Tuberose (3.70%)>Plumeria, Water lily, Burflower tree (2.49%)
Kitchen side	14	Zinnia (23.33%)>Asian pigeonwings (22.87%)> Sun flower (11.17%)>Garden cosmos (9.57%)>Jungle geranium, Dolonchapa/ White Ginger Lilly (7.44%)> Cactus (6.38%)> Dog rose (2.65%) Violet lily (2.17%)>Copperpod, Bougainvillea, Gondoraj/Gardenia (1.59%)> Palm (1.06%)> Areca palm (0.53%)

Distribution of spices and condiments

A total of 8 types of spices and condiments were recorded in different homestead areas of the study area. Among these front yard and boundary side had three 3 types of spices and condiments while other homestead areas had 2 types of spices and condiments. Among the spices and condiments, cinnamon was most dominant followed by bay leaf (Table 8).

Table 8. Distribution of spices & condiments plant species with frequency at different homestead areas of Rangamati Sadar upazila in Bangladesh

Homestead area	No. of species	Dominant species
Front yard	2	Bayleaf (25%)> Cinnamon (25%)> Chilii (50%)
Back side	2	Cinnamon (60%)> Lemon grass (40%)
Boundary side	3	Bayleaf (50%)> Cinnamon (25%)> Lemon grass (25%)
Approach road	2	Ginger (88.23%)> Bayleaf (11.76%)
Kitchen side	2	Cinnamon (60%)> Mexican coriander (40%)

Distribution of other plant species

A total of 4 different types of other plants were recorded in different homestead areas of Rangamati Sadar upazila. Most of them were recorded in the front yard (3) and the lowest was in the approach road (2) (Table 9).

Table 9. Other plant species present at different homestead area of Rangamati Sadar upazila

Homestead area	No. of species	Dominant species
Front yard	3	Arabian-coffee (81.81%)> Maize (9.09%)> Betel nut (9.09%)
Back side	2	Betel nut (80%)> Cashew (20%)
Boundary side	2	Maize (75%)> Arabian-coffe (25%)
Approach road	1	Betel nut (100%)
Kitchen side	2	Maize (66.67%)> Arabian-coffe (33.33%)

Shannon-Weaver Diversity Indices of plant species in different unions

Considering SWDI, high plant species diversity was found in Rangamati Sadar Upazila. Among all the plant species, the highest diversity was found in vegetables (H'= 0.96) followed by fruit and medicinal species (H'= 0.83), timber, and flower & ornamentals species (H'= 0.82) (Table 10). Uddin et al. (2021) reported a high diversity of fruit, timbers, medicinal, and other plant species ranging from 0.74-0.89 in Kamalganj upazila of Moulvibazar district. Prova et al. (2023) reported the highest diversity in fruit species and next was timber species in Sylhet district.

Table 10. Shannon-Weaver Diversity Indices (SWDI) of plant species at different unions of Rangamati Sadar upazila under Rangamati district

Unions/ Municipal	SWDI of Plant Species							Mean
	A	B	C	D	E	F	G	
Pouroshova	0.65	0.71	0.79	0.89	0.74	0.90	0.96	0.81
Bandukbhanga	0.93	0.89	0.49	0.98	0.99	0.99	0.46	0.82
Jibtali	0.52	0.60	0.93	0.97	0.64	0.00	0.00	0.52
Mogban	0.96	0.89	0.91	0.99	0.79	0.79	0.34	0.81
Balukhali	0.89	0.92	0.98	0.98	0.90	0.00	0.34	0.71
Sapchari	0.96	0.96	0.87	0.97	0.78	0.00	0.52	0.72
Kutukchari	0.81	0.86	0.84	0.95	0.87	0.87	0.87	0.72
Mean	0.82	0.83	0.83	0.96	0.82	0.38	0.50	0.73

Note: A= Timber species, B = Fruit species, C = Medicinal plant species, D = Vegetables species, E = Flower & ornamentals species, F = Spices & condiments and G = Other plant species

Timber species were high (H'= 0.81-0.96) in all unions except in Pouroshova (H'=0.65) and Jibtali (H'=0.52). The highest timber species diversity was found in Mogban and Sapchari (H'=0.96) followed by Bandukbangha and Balukhali (H'=0.93 and 0.89). Uddin et al. (2021) and Prova et al. (2023) reported a high diversity of timber species in the Moulvibazar district and Sylhet district respectively which supports the present findings.

Fruit species were found highly diverse (H'= 0.86-0.96) in all unions except in Pouroshova and Jibtali unions where the diversity was moderate (H'=0.71 and 0.60). The highest fruit species diversity was found in Sapchari (H'=0.96) followed by, Balukhali, Mogban, and Bandukbangha (H'=0.92, 0.89, and 0.89) respectively (Table 10). High diversity (H'=0.79-0.99) of fruit species was also reported by Uddin et al. (2021) in Kamalganj upazila, which was at par to the findings of Prova et al. (2023) in Sylhet district while, Uddin et al. (2006) found moderate to high diversity in coconut in the Philippines.

For medicinal species the SWDI was high (H'= 0.79-0.98) in all unions except in Bandukbangha (H'=0.49). The highest medicinal species diversity was found in Balukhali (H'=0.98) followed by Jibtali, Mogban, Sapchari, and Kutukchari (H'=0.93, 0.91, 0.87, and 0.84) (Table 10). Uddin et al. (2021) reported a high diversity of medicinal plants (H'=0.77-0.96) in the Kamalganj upazila of Moulvibazar district in Bangladesh.

Shannon-Weaver Diversity Indices (SWDI) of vegetable species was high (H'= 0.89-0.99). The highest vegetables species diversity was found in Mogban (H'=0.99) followed by Bandukbangha and Balukhali (H'=0.98) and Jibtali and Sapchari (H'= 0.97) (Table 10).

The SWDI of flower & ornamentals species was high (H'= 0.78-0.99) in all locations except moderate in Pouroshova (H'=0.74) and low in Jibtali (H'=0.64). The highest flower & ornamental species diversity was found in Bandukbangha (H'=0.99) followed by Balukhali, Kutukchari, and Sapchari (H'=0.90, 0.87 and 0.79). The SWDI of spices & condiments species were high in four unions (H'= 0.79-0.99) and no was found in three unions (H'=0.00). The highest spices & condiments and other species diversity were found in Bandukbangha (H'=0.99) followed by Rangamati Pouroshova (H'=0.90) (Table 10).

The SWDI of other plant species was high in Pouroshova (H'=0.96) and Kutukchari (H'=0.87) and was low in three unions (H'=0.34-0.46) (Table 10).

Shannon-Weaver Diversity Indices of plant species in different homestead areas

Among all the homestead areas, the highest plant species diversity was found in the backside (H'=0.69) followed by Boundary side (H'=0.68), Front yard (H'=0.65), Approach road (H'=0.60) and Kitchen side (H'=0.57) all of which were moderate diversity (Table 11). Among the different plant species, the highest diversity was recorded for vegetables (H'=0.82) followed by fruit species (H'=0.80). The lowest diversity was recorded for other plant species (H'=0.09).

Table 11. Shannon-Weaver Diversity Indices (SWDI) of plant species at different homestead areas of Sadar upazila under Rangamati district

Homestead area	SWDI of Plant Species							Mean
	A	B	C	D	E	F	G	
Front yard	0.67	0.83	0.55	0.50	0.59	0.97	0.47	0.65
Back side	0.57	0.81	0.91	0.85	0.94	0.72	0.00	0.69
Boundary side	0.95	0.74	0.79	0.93	0.75	0.60	0.00	0.68
Approach road	0.85	0.85	0.80	0.97	0.74	0.00	0.00	0.60
Kitchen side	0.72	0.75	0.84	0.86	0.82	0.00	0.00	0.57
Mean	0.75	0.80	0.78	0.82	0.77	0.46	0.09	0.64

Note: A= Timber species, B = Fruit species, C = Medicinal species, D = Vegetables species, E = Flower & ornamentals species, F = Spices & condiments and G = Other species

CONCLUSION

The front yard was dominated by most of the plant species specially fruit, medicinal plants and flowering plants Timber in boundary side and vegetables were dominated in the kitchen side. The diversity of vegetable species was the highest among the seven categories of plant species. High diversity of plant species was observed in the studied area. Fruit species diversity was high in all of the studied unions of Rangamati district which could meet up the nutritional requirements of the peoples. Considering plant species diversity present in all the unions, the Jibtali, Bandukbanhga, and Sapchari unions could be improved through increasing planting of more spices & condiments and other plant species. This will increase the overall plant biodiversity and thus meet up of the nutritional requirements of the local community.

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COMPARATIVE COST AND RETURN ANALYSIS OF EIGHT MAJOR VEGETABLES IN CHAR LAND ECOSYSTEM OF BANGLADESH

H. Jahan[1*], M.W. Rahman[2], B. Banik[1], A. Rezwan-Al-Ramim[1], L. Bhowmik[1], M.E. Hossain[3] and M. Asaduzzaman[2]

[1]Department of Agricultural Economics, Bangladesh Agricultural University, Mymensingh.
[2]Department of Rural Sociology, Bangladesh Agricultural University, Mymensingh.
[3]Department of Agricultural Finance and Banking, Bangladesh Agricultural University, Mymensingh.

ABSTRACT

Bangladesh has tremendous opportunities to harness the potential of the agriculture sector like in vegetable sector which is contributing to our export sector too. Thus, the main focus of this study is to assess the financial profitability of selected eight major vegetables. The cost and return scenario of eight major vegetables that most of the farmers cultivate in the char land area such as brinjal, tomato, chili, bitter gourd, pumpkin, okra, bottle gourd, and amaranth were done for the study. Study areas were chosen in the districts of Mymensingh, Jamalpur, and Sherpur in Bangladesh following a simple random sampling procedure where 240 farmers were surveyed. The results show that the highest and lowest net return found for bottle gourd and okra, were Tk. 195,118 ha^{-1} and Tk. 32,894 ha^{-1}, respectively. Further, in terms of gross return, bottle gourd production is the most profitable but in terms of net return both the brinjal and tomato are in the same position. The benefit-cost ratio (BCR) was the highest (1.98) for bottle gourd followed by tomato (1.96). Among the cost items, labor cost occupies more than half of the total cost which proves that vegetable production is labor-intensive cultivation. The ranking by variable and total cost revealed that farmers frequently choose the lowest-cost production method and the okra is the most preferred product in that method. However, a ranking of the probability of all vegetables was also done. This ranking will help farmers to take their decision according to their resource availability.

Keywords: Vegetable production; Profitability; Benefit Cost Ratio; Char land; Bangladesh.

[*] Corresponding author: hasneen.jahan@bau.edu.bd

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INTRODUCTION

Bangladesh is one of the predominantly agro-based developing countries in the world where agriculture has been the core sector of Bangladesh's economy and rural people depend on it for their livelihood directly or indirectly (Islam et al., 2020). By reducing poverty and guaranteeing food security, the sector is the backbone of our economy. The sector has however remained resilient in terms of profitability and productivity despite the ever-increasing population, which is expected to increase from 147.6 million in 2010 to 164.7 million in 2020 (The Daily Star, 2022). The exports and imports of vegetable products were 21,800 and 6,16,037 Million Tk. in the year 2020-21, respectively (BBS, 2022). As Bangladesh is the third largest vegetables producing country in the world (Maruf et al., 2021), the country needs to utilize the enormous scope for exporting vegetables to the mainstream export market by fulfilling import country/foreign buyers' requirements (Bangladesh Foreign Trade Institute, 2016).

Bangladesh's climate is exceptional for growing vegetables. Rabi (winter from October to March) and Kharif (hot, humid season from April to October) are the two separate seasons that make up the entire year because of the comparatively low temperatures, high humidity, and abundant rainfall most vegetable crops can be grown (Mostofa et al., 2010). Because of economic expansion, growing incomes, and urbanization, food demand in Bangladesh and around the world is fast changing. Traditional commodities are being replaced by high-value food commodities such as fruits, vegetables, spices, and fish (Zaman et al., 2010), Bangladesh is no exception. There are plenty of winter and summer vegetables that are grown by Bangladesh gardeners such as cabbage, cauliflower, tomato, brinjal, pumpkin, bitter gourd, spin gourd, ribbed gourd, ash gourd, okra, etc. Some major vegetables such as brinjal, pumpkin, okra, and red amaranth are found to grow in both seasons. Vegetables are important sources of vitamins, and minerals and are associated with a lower risk of cardiovascular disease in humans (Hasan, 2021). Apart from nutritional value, it has an important share of the agricultural GDP, about 9.71%, helps to employment generation, increases income, and reduces poverty as well (Islam et al., 2020), (Chanda et al., 2020). Thus, the economic benefit of vegetable cultivation should be explored particularly focusing on the farmer's viewpoint.

The profitability of a crop is influenced by yield, product price, input costs, and the farmer's managerial skills. Evidently, change in any of the aforementioned variables affects profitability (Chowdhuri et al., 2014). The right intercrops, regional food customs, and market demands are crucial for maximizing profit (Uddin et al., 2009). One of the key elements that farmers consider when allocating land for the growing of vegetables is price. Since wholesale and retail prices occasionally do not reflect the actual price that farmers receive, it is anticipated that the risks associated with yield and price changes will serve as dissuading considerations for areas planted with different vegetables within a specific season (Mostofa et al., 2010). However, many

economic studies such as Uddin et al. (2009), Akter et al. (2011), Chowdhuri et al. (2014), Islam et al., 2020 have so far been reported about single, double or triple vegetable cultivation along with their cost and return but there is no framework for eight vegetables. Therefore, the present study aims to observe the actual financial benefits of vegetable cultivation of char land people in some selected areas of Bangladesh. For this reason, cost and return analyses are done for the main eight vegetables, i.e., brinjal, tomato, chili, bitter gourd, pumpkin, okra, bottle gourd, and amaranth. The findings of the study may be useful for the researcher, policy-maker, and government representatives as they contribute to the extensive cultivation of vegetables.

MATERIALS AND METHODS

The current study was conducted in three districts of Bangladesh: Mymensingh, Jamalpur, and Sherpur. A total of 240 farmers, 80 sample from each district, were interviewed following the simple random sampling technique using a semi-structured interview schedule. Pre-testing with 10 farmers and a few Focus Group Discussions (FGDs) were done before constructing the interview schedule to learn about farmers' general perceptions and knowledge of vegetable production. Microsoft Excel (Microsoft Corporation) allowed data cleaning, while STATA 16 (StataCorp LLC, Texas, USA) facilitated data analysis.

A cost-return analysis namely gross return, gross margin, net return, and benefit-cost ratio (undiscounted) were done for major eight vegetables (Brinjal, Tomato, Chili, Bitter gourd, Sweet gourd, Bottle gourd, Okra, and Amaranth).

$$GRi=\sum_{i=1}^{n} QmiPmi + \sum_{i=1}^{n} QbiPbi$$

Where,

GRi = Gross return from ith product (Tk/ha)

Qmi = Quantity of the ith main product (kg/ha)

Pmi = Average price of the ith main product (Tk/kg)

Qbi = Quantity of the ith by product (kg/ha)

Pbi = Average price of the ith by product (Tk/kg)

i = 1,2,3, … n

$$GMi = Py.Y - \sum_{i=1}^{n} (Pxi\ Xi)$$

Where,

GMi = Gross margin for ith product (Tk/ha)

Py = Per unit price of the product (Tk/kg)

Y = Quantity of the product per hectare (kg)

Pxi = Per unit price of ith inputs (Tk)

Xi = Quantity of the ith inputs per hectare (Kg)

i = 1,2,3, …, n (number of inputs).

$$\pi = Py.Y - \sum_{i=1}^{n} (Pxi\ Xi) - FC$$

Where,

π = Net return (Tk/ha)

Py = Per unit price of the product (Tk/kg)

Y = Quantity of the product per hectare (kg)

Pxi = Per unit price of ith inputs (Tk)

Xi = Quantity of the ith inputs per hectare (Kg)

FC= Fixed cost

i = 1,2,3, …, n (number of inputs).

$$BCR = GR \div GC$$

Where,

GR = Gross return; and

GC = Gross cost (i.e., TFC + TVC).

If BCR>1, the production is economically profitable, otherwise not.

RESULTS AND DISCUSSION

Cost structure of vegetable production

Variable costs are those costs that directly vary with the volume of production. Fixed costs, on the other hand, do not vary with the change in volume of production. For calculating the total per hectare total production cost of eight vegetables, these costs are taken into consideration. Human labor cost is one of the most important costs and the sources of supply of human labor in the research areas were both i) hired labor and ii) family labor were measured in terms of man-day which consisted of eight (08) hours of work by an adult male.

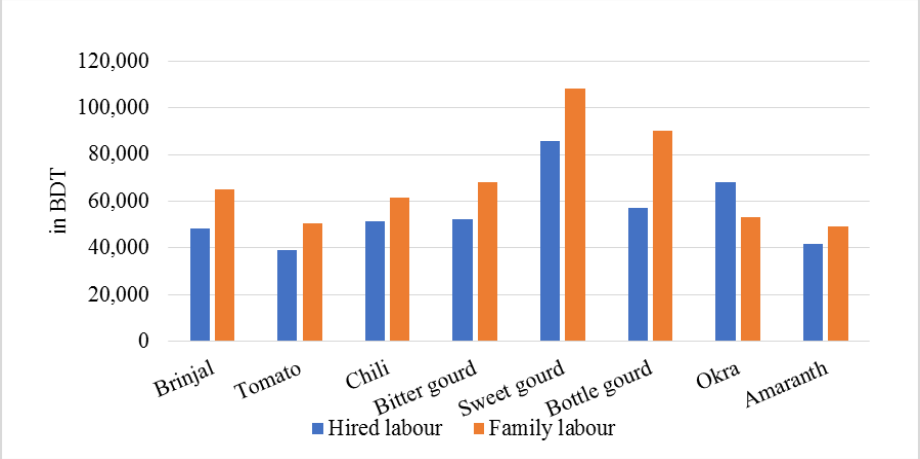

Figure 1. Comparison of hired labor and family labor costs

Figure 1 reveals that family labor plays more significant role than hired labor. The highest hired and family labour cost per hectare of the area was for sweet gourd production where total hired labor cost was estimated at Tk. 85,892/- per hectare of which 55% was for male labor and 45% was for female labor and total family labor cost was estimated at Tk. 108,324/- per hectare of which 70% was for male labor and 30% was for female labor. Additionally, Table 1 reveals that the two highest tillage costs were Tk. 13,011/- ha^{-1} and Tk. 12392/- ha^{-1} for brinjal and bitter gourd production, respectively and Tk. 9302/- per hectare for amaranth production showed the lowest tillage cost. The brinjal seed was costly of Tk. 14,665/- per hectare while the cheapest was amaranth seeds at Tk. 1,895/- per hectare. Among these cultivations, per hectare cost of fertilizers was more in brinjal production than others. Farmers also use a small amount of manure in addition to fertilizers in their fields. Per hectare cost of pesticides for brinjal production was highest at Tk. 13,782/- ha^{-1} and lowest for amaranth at Tk. 1355/- ha^{-1}. Timely irrigation is a very important factor for crop cultivation. As the study area is situated in the riverine zone of Bangladesh, there is plenty of water for crop cultivation. The lease value of land varied from one place to another depending on location, soil fertility, the topography of the soil, distance from the sources of water, etc. For bitter gourd, it was a little bit higher (Tk. 23,254/- ha^{-1}) than others as it takes more time (around 4 months) to be harvested. The lowest (Tk. 15,718/- ha^{-1}) lease value for amaranth takes less time to be harvested than the other vegetables. Total cost was calculated by adding up total variable cost and total fixed cost. The highest total cost was found at Tk. 208,860/- for bitter gourd and okra closely followed by brinjal production cost of Tk. 208,855/-. The lowest total cost was Tk. 134,066/- for amaranth production.

Share of cost items in the total cost

Akter et al. (2011), and Islam et al. (2020) revealed the share of labor, seeds, fertilizers, cow dung, insecticides, and miscellaneous cost in total cost. The present study reveals that vegetable production is labor-intensive cultivation and more than half of the cost share occupies by the labor cost for all vegetables. The two highest share of labor cost was estimated at 78% and 74% for sweet gourd and bottle gourd respectively. For amaranth and okra, it was found 59% of the total cost and 58% for chili and bitter gourd. The other two significant cost items were land use cost and fertilizer cost.

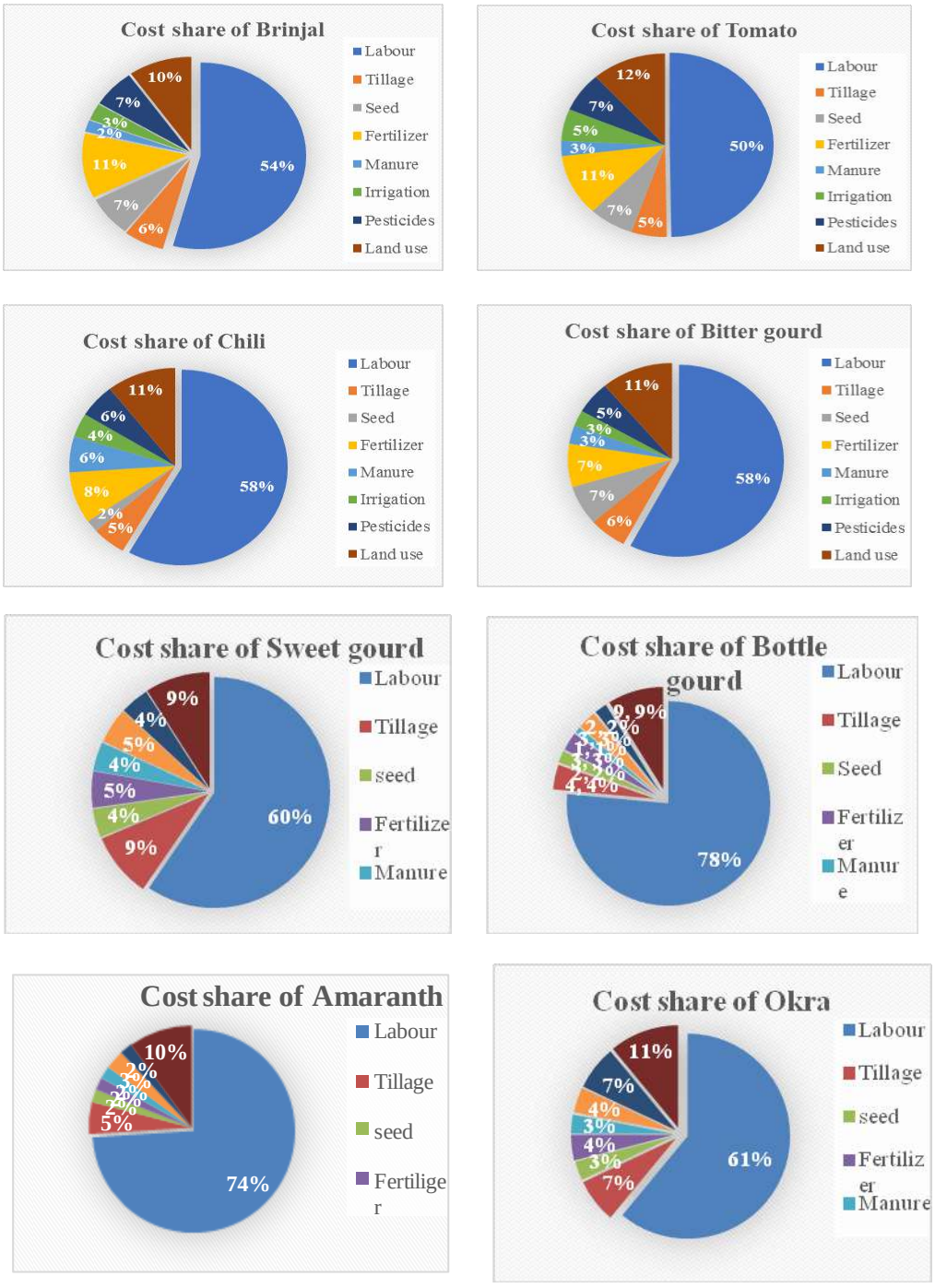

Figure 2. Share of different cost items in total cost for selected vegetable

From Figure 2, the share of land use cost which is lease value in most cases occupied 10-12% of the total cost. Tillage cost is almost the same (5-6%) for all the vegetables. The share of seed cost was insignificant in case of chili, sweet gourd, bottle gourd, okra, and amaranth production (2%). Share of irrigation cost occupied 3-6% of the total cost implies that irrigation is not a very big issue for the farmers in the char land area. So, it can be concluded that as labor cost is the most significant cost item for vegetable production; availability of labor is a big concern here and family labor is a great support to overcome this problem.

Return from vegetable cultivation

Per hectare production of brinjal was found at 15,244 kg where the average price was Tk. 25/- per kg. Thus, the gross return for brinjal was estimated at Tk. 381,100/-. In this way, the maximum gross return was found for bottle gourd (Tk. 393,882/-) and the minimum gross return was found for amaranth (Tk. 181,842/-). The argument for using gross margin analysis is that the farmers are more interested to know their return over variable costs. The analysis reveals that the gross margin and net return of all the vegetables are positive. So, the production of these eight vegetables at least covers the variable costs of the production and production was profitable. Therefore, it can be said that farmers are interested to cultivate vegetables in the study areas. Per hectare net return for bottle gourd, tomato, and brinjal was higher at Tk. 195,118/-, Tk. 172,775/- and Tk. 172,245/-, respectively than others in full cost basis. BCR of brinjal, tomato, chili, bitter gourd, sweet gourd, bottle gourd, okra, and amaranth were found at 1.82, 1.96, 1.65, 1.6, 1.41, 1.98, 1.16, and 1.36, respectively. The results imply that brinjal farmers received Tk. 1.82 in return from investing Tk. 1.00 in brinjal production. The same explanation is applied to other vegetables also.

Table 1. Per hectare cost and return of major vegetables

Item	Brinjal	% of gross Cost	Tomato	% of gross Cost	Chili	% of gross Cost	Bitter gourd	%of gross Cost	Sweet gourd	% of gross Cost	Bottle gourd	% of gross Cost	Okra	% of gross Cost	Amara-nth	%of gross Cost
Gross Return																
Main Product	381100		352,044		320,758		333,725		348,090		393,882		241,754		181,842	
A. Gross Return	381100		352,044		320,758		333,725		348,090		393,882		241,754		181,842	
Variable Cost																
Hired Labour (male)	40950	19.6	32680	18.22	39480	20.3	40,500	19.39	47564	19.21	46799	23.54	53,857	25.79	33583	25.05
Hired Labour (female)	7250	3.47	6235	3.48	12000	6.17	11,750	5.63	38328	15.48	10399	5.23	14,144	6.77	8291	6.18
Tillage	13011	6.23	9958	5.55	10000	5.14	12392	5.93	9337	3.77	9613	4.84	9342	4.47	9302	6.94
Seed/Seedlings	14655	7.01	12480	6.96	3891	2	13850	6.63	3681	1.49	3200	1.61	3847	1.84	1895	1.41
Urea	5605	2.68	4460	2.49	4712	2.42	3173	1.51	2025	0.82	1303	0.66	1359	0.65	1875	1.40
TSP	7952	3.8	5157	2.88	4225	2.17	3476	1.66	2244	0.91	1738	0.87	1845	0.88	2181	1.63
MOP	4142	1.98	4140	2.31	3020	1.55	3276	1.56	1127	0.46	851	0.43	1156	0.55	765	0.57
DAP	5829	2.79	5460	3.05	4676	2.4	5408	2.59	1773	0.72	1824	0.92	1872	0.90	1495	1.11
Manure	4225	2.02	4720	2.63	11557	5.94	6442	3.08	1997	0.81	3296	1.66	2608	1.25	4423	3.30
Irrigation	6123	2.93	10036	5.59	7718	3.96	5675	2.72	6450	2.61	4370	2.20	4814	2.30	3794	2.83

Item	Brinjal	% of gross Cost	Tomato	% of gross Cost	Chili	% of gross Cost	Bitter gourd	%of gross Cost	Sweet gourd	% of gross Cost	Bottle gourd	% of gross Cost	Okra	% of gross Cost	Amara-nth	%of gross Cost
Pesticides/Insecticide	13782	6.59	12446	6.94	10944	5.62	11464	5.49	4532	1.83	3322	1.67	4353	2.08	1355	1.01
B. Total Variable Costs	123,524	59.14	107,772	60.12	112,223	57.7	117,406	56.21	119,057	48.09	86,716	43.63	117,406	56.21	68,958	51.44
Family Labour (male)	53550	25.63	39130	21.82	51240	26.34	56,700	27.15	78420	31.67	75084	37.78	37,082	17.75	35548	26.52
Family Labour (female)	11500	5.5	11610	6.48	10500	5.39	11,500	5.51	29904	12.08	16007	8.05	16,251	7.78	13842	10.32
Lease Value of Land	20281	9.71	20760	11.58	20514	10.54	23,254	11.13	20209	8.16	20958	10.54	19461	9.32	15718	11.72
C. Total Fixed Cost	85,331	40.85	71,500	39.88	82,254	42.29	91,454	43.79	128,533	51.91	112,049	56.37	91,454	43.79	65,108	48.56
D. Gross Cost (B+C)	208,855	100	179,272	100	194,477	100	208,860	100	247,590	100	198,765	100	208,860	100	134,066	100
E. Gross Margin (A-B)	257,576		244,272		208,535		216,318		229,033		307,167		124,348		112,884	
F. Net Return (A-D)	172,245		172,772		126,281		124,865		100,500		195,118		32,894		47,776	
G. BCR (Undiscounted)	1.82		1.96		1.65		1.6		1.41		1.98		1.16		1.36	

Chowdhuri et al. (2014) revealed that cabbage cultivation was more profitable than brinjal and country bean as per hectare yield, gross returns, gross margin, net return, and benefit-cost ratio were higher than others. Islam et al. (2020) resulted that cauliflower and cabbage production was profitable and farmers earned the highest profit from cabbage. Hasan et al. (2020) found that bean, brinjal, and tomato production were profitable according to net margin and BCR. Bala et al. (2011) estimated that gross returns and net returns per hectare were highest for tomato, followed by cauliflower, cabbage, and peas.

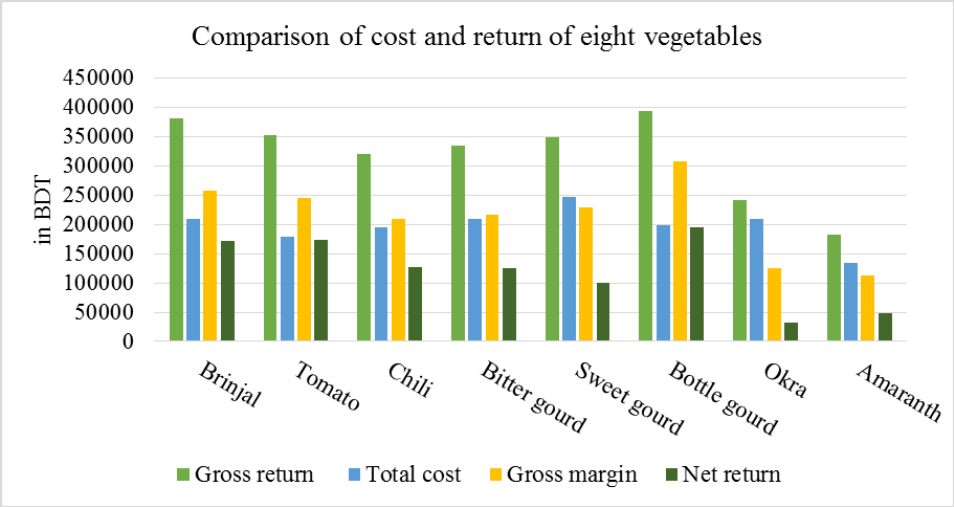

Figure 3. Comparison of costs and return of eight vegetables

Figure 3 shows that in terms of gross return and net return, bottle gourd production is the most profitable followed by brinjal and tomato. However, as a whole all the vegetables are profitable and farmers are happy cultivating these vegetables. The outcome is expected and consistent with several previous studies, for instance, cauliflower, tomato, and cabbage cultivation resulted by Akter et al. (2011) that all of these three vegetables were profitable but the cabbage were comparatively more profitable than the others. From the previous studies, it is no doubt that vegetables can play a significant role in earning cash money, and also their cultivation method is simple. It is also demonstrated that Bangladesh appears to have a high potential for increasing vegetable crops, and char people are attempting to better their standard of living by cultivating vegetables having huge her profitability.

Comparative profitability and costs of different vegetable production

Farmers are logical decision-makers and choose their crops based on several criteria. Some farmers are concerned about total cost, some are about total return, and some are about gross margin. Therefore, it is worthwhile to see the ranking of vegetables from a different perspective to understand the factors that drive farmers to choose their crop to cultivate.

Ranking of vegetables based on total cost and variable cost incurred

The vegetable ranking based on the lowest total variable cost requirement was Amaranth (1^{st}), Bottle gourd (2^{nd}), tomato (3^{rd}), and so on. The ranking based on total cost was Amaranth (1st), tomato (2^{nd}), Chili (3^{rd}), and so on. It is revealed that farmers often go for the least cost production method and in that method, amaranth is the most preferable vegetable for farmers.

Table 2. Ranking of vegetables according to total variable cost and total cost

Name of the vegetable	Total Variable Costs (Tk/ha)	Rank of lowest TVC	Total Cost (Tk/ha)	Rank of lowest TC
Amaranth	68,958	1	134,066	1
Bottle gourd	86,716	2	198,765	4
Tomato	107,772	3	179,272	2
Chili	112,223	4	194,477	3
Bitter gourd	117,406	5	208,860	6
Sweet gourd	119,057	6	247,590	7
Okra	117,406	5	208,860	6
Brinjal	123,524	7	208,855	5

3.4.2. Ranking of vegetables based on gross margin and net return

With respect to the highest gross margin bottle gourd ranked 1st followed by brinjal (2), tomato (3), and sweet gourd (4). The ranking based on the highest net return

received from the vegetables shows bottle gourd ranked 1st followed by tomato (2), brinjal (3), and chili (4). It can be concluded that some farmers might be interested in gross margin and some might be in net return and accordingly their decisions vary for choosing vegetables to cultivate.

Table 1. Ranking of vegetables according to gross margin and net return

Name of the vegetable	Gross Margin (Tk/ha)	Rank of Highest GM	Net Return (Tk/ha)	Rank of highest NR
Bottle gourd	307,167	1	195,118	1
Brinjal	257,576	2	172,245	3
Tomato	244,272	3	172,772	2
Sweet gourd	229,033	4	100,500	6
Bitter gourd	216,318	5	124,865	5
Chili	208, 535	6	126,281	4
Okra	124,348	7	32,894	8
Amaranth	112,884	8	47,776	7

CONCLUSION

Under the agriculture sector, the vegetable sub-sector is essential to Bangladesh's development. To maintain profitable farming with long-term food security, it is critical to establish a lucrative, sustainable, and environmentally friendly agricultural system. There may be countless studies on vegetables, but we are giving the study of major eight vegetables based on farmers' preferences in order to depict the outcome of cost-benefit analysis. According to the study's cost and return analysis, the majority of the costs were incurred for human labor. If current inputs and production technologies are made available to all farmers on time, vegetable production may grow, allowing farmers to enhance their farm revenue and better their life. According to the findings, the benefit-cost ratios of major eight vegetables were greater than one, implying that production of the selected vegetables was profitable in the study areas. This study revealed that it is possible to conclude that there is a significant opportunity in the study areas to boost tomato and brinjal productivity on the basis of the benefit-cost ratio in order to increase farmers' income, employment, and nutritional status. It was also clear that bottle gourd, tomato, and brinjal were successful industries that might produce income and employment opportunities for Bangladesh's rural population.

Based on the findings of the study, several policy recommendations can be prescribed. To encourage collaboration between research, extension services, farmer groups, financial institutions, and NGOs to provide funding and knowledge on high-value vegetable production. To raise community awareness to attract private

investment, ensure quality seed production, and motivate farmers to adopt modern technology through training. To develop insect and disease-resistant varieties and emphasize soil testing and proper fertilizer application to reduce production costs. Government support for free transportation of vegetables and cold storage facilities is crucial. Policymakers should explore options for fair market prices, and financial institutions should provide credit to vegetable producers.

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PERFORMANCES OF TROPICAL HOLSTEIN FRIESIAN (*Bos taurus)* X *THRABAM* (*Bos indicus*) F_1 DAUGHTERS MANAGED UNDER BHUTANESE FARMING ENVIRONMENT

N.B. Tamang*, D.B. Rai, A.N. Koirala and A.K. Bhujel

National Dairy Development Centre, Ministry of Agriculture and Livestock, Thimphu; Bhutan

ABSTRACT

Local *Thrabam* cattle were inseminated with semen of four sire-lines of Tropical Holstein Friesian (THF) at selected sites of three agro-ecological zones of Bhutan. To understand their performances, progeny born from each sire-line were recorded and milk yield of F_1 daughters were measured. Management practices were observed through farm visits. Result indicated that insemination in natural heat produced significantly higher calves than in induced heat ($p<0.005$). Average daily milk yield of F_1 daughters was 5.2±2.5 l/day. Some farmers mated F_1 daughters at about one year of age, before animal reached the desired body weight. This disturbed growth of dam and few such dams faced calving difficulties. Cattle were managed through open grazing during the day (81%) and sheltered at night. Only 25% of farms provided supplementary feed to milking animals/calves. Minimal calf mortality (2.93%) with no reported adult mortality indicated the crossbreds adapt well to the local environment. The present study concluded that for more calf-crops, insemination in natural heat should be advocated and mating of F_1 daughter at tender age needs to be discouraged. Under prevailing management system, F_1 daughters were performing optimally. However, with the increase in THF inheritance level, cattle management needs to be improved to maximize output.

Keywords: F_1 daughters; Milk yield; Tropical Holstein Friesian; *Thrabam* cattle

INTRODUCTION

Dairy development in Bhutan started during first Five Year Plan (FYP) in 1960s with the introduction of Jersey breeding bulls for upgradation of local *Thrabam* cattle population (Siri breed, *Bos indicus*) and pursed over successive FYPs. In 1974, Brown Swiss (BS) cattle were introduced to Bhutan for crossbreeding with local

* Corresponding author: nbtamang1967@gmail.com

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cattle in temperate areas. However, demand of BS dwindled over the years and need for alternate dairy breed was felt necessary. Accordingly, in 2014, Royal Government of Bhutan approved procurement of Holstein Friesian (HF) cattle into the country as alternate dairy breed. Since then farmers have been procuring HF cows/heifers from India to improve their herds. The HF cattle population as of now is small (1009 heads), localized in pockets of 17 out of 20 districts of the country (MoAF, 2020).

To fast-track HF gene introgression into local *Thrabam* cattle population, frozen semen (four sire-lines) of Tropical Holstein Friesian (THF, *Bos taurus*) was acquired from Thailand. Artificial insemination (AI) of *Thrabam* cows with THF semen was initiated in late 2017 with the objectives to compare potency of four different THF sire-lines based on number of progeny born at test sites, measure milk yield of first filial (F_1) daughters (THFx*Thrabam*, 50:50) to derive reliable estimates of its milking potential and understand reproductive performance, management system and adaptability of F_1 daughters under Bhutanese farming environment.

MATERIALS AND METHOD

Site/locations of the study area

Three different Agro-Ecological Zones (AEZ) namely Barsong *Gewog* (sub-district) at 1200-1800 *masl*, Sergethang *Gewog* at 600-1500 *masl* of Tsirang district and Tading *Gewog* at 150-600 *masl* of Samtse district were identified as study sites/location (Table 1).

Table 1. Selected study sites in different AEZs

Sl No	Dzongkhags	Gewogs	AEZs	Altitude (*masl*)	Rainfall (mm)	*Thrabam* population	HF population
1	Tsirang	Barsong	Dry Sub-tropical	1200-1800	850-1200	635	0
2	Tsirang	Sergithang	Humid Sub tropical	600-1500	1200-2500	683	0
3	Samtse	Tading	Wet Sub-tropical	150-600	2500-5500	2521	0

Data source: Livestock Statistics, 2017; National Biodiversity Strategies and Action Plan, Bhutan, 2014

Insemination of Thrabam cows/heifers

Breedable *Thrabam* cows/heifers were selected and inseminated in induced heat as well as in natural heat with almost equal number of inseminations done from all four sire-lines (*pound, push, puzzle and poplar*) in each study location/site. The animals inseminated with THF semen were ear tagged, identified with unique identification number.

Data collection

Records of insemination and corresponding progeny born from four different sire-lines at each study sites were maintained from November 2017 to March 2023. All F_1 daughters that have calved and in milk production stage in each location (Barsong, Sergithang and Tading) were traced in close consultation with concerned Livestock Extension staffs. The individual animals in lactation were visited farm to farm to measure the morning and evening milk yields (one time). Milk yield was accurately measured using graduated measuring cylinder (Figure 1). However, for the cows which were in late stage of lactation and/or cows dried off, farmer's recall method was applied to derive best estimate of milk yield. Feeding and management practices of the F_1 daughters were observed, discussed with the owners and noted.

Figure 1. Milk yield measurement at study sites

Data analysis

- The variables: progeny born in induced and natural heat were analyzed using two sample t-tests (Minitab Version-18); total progeny born from four different THF sire-lines were analyzed using one way ANOVA and Tukey's HSD; and milk yield of THF x *Thrabam* F_1 daughters at different study sites were averaged.
- Qualitative data acquired through informal discussion with individual cattle owners were sorted and converted to percentage.

RESULTS AND DISCUSSIONS

Progeny born through THF semen inseminations in natural and induced heat

The success rates of AI in induced heat and natural heat were 18.09% and 37.10%, respectively, the latter being more effective (Table 2). Two sample t-test revealed that mean progeny born (success rate) from insemination in natural heat was significantly higher than inseminations of breedable female in induced heat (p<0.001).

Table 2. Success rate/progeny born from induced and natural heat

Study sites (location)	AI in induced heat/progenies born				AI success rate (%)	AI in natural heat/progenies born				AI success rate (%)
	Total AI	♀	♂	Progenyborn		Total AI	♀	♂	Progeny born	
Barshong	138	12		31	22.5	200	58	36	94	47
Sergithang	93	7	10	17	18.3	120	38	20	58	48.3
Tading	200	19	11	30	15	142	22	19	41	28.9
Overall	431	38	40	78	18.09	462	118	75	193	37.1

The results indicated that insemination in natural heat was better than in induced heat. Therefore, preferences may be given to inseminate cows/heifers on natural heat, observing heat signs for right time of insemination. Tamang et al. (2020) supported the view that owing to poor health/body condition of animals in village farms of Bhutan, AI in induced estrous/heat using hormonal drugs does not necessarily result in conception even when animals are inseminated by skilled technician. Rather selection of healthy animals with optimum body condition score and right season for estrous induction is suggested for better results.

Potency/progeny born from different THF sire-lines

A total of 271 progenies were born out of 893 inseminations done, giving overall AI success rate of 30.3% (Table 3). Among the progenies born, 57.5% were female. Progeny born were lower for *Puzzle* and *Push* than *Pound* and *Popular* sire-lines but result was not statistically significant (p=0.503). Nevertheless, Tukey's pair-wise comparison revealed that puzzle sire-line had significantly lower mean progenies born, proportionate to quality of semen assessed through post-thaw motility (PTM) test upon arrival of the consignment in 2017. The PTM of semen for *Puzzle, Push, Pound* and *Popular* was 30%, 35%, 45% and 55%, respectively (NDRDC, 2017). Among three study sites, Barsong had a significantly higher mean progeny born than other sites (p<0.037), probably due to proficiency and dedication of AI Technician.

Table 3. Progeny and AI success rate by THF sire-lines in three study sites

THF sire-lines	Total AI	Progeny (♀)	Progeny (♂)	Progeny total (♀+♂)	AI Success rate (%)
Push	232	39	22	61	26.29
Puzzle	258	40	23	63	24.4
Pound	216	44	31	75	34.7
Popular	187	33	39	72	38.5
Total	893	156	115	271	30.3

Milk Yield of F_1 daughters (THF x Thrabam 50:50)

Average daily milk yield of THF x *Thrabam* F_1 daughters was 5.2±2.5 l/day and estimated first lactation milk yield was 1576 litres (**Table 4**). Highest peak milk yield in the study area was 11.5l/day whereas lowest was 1.5l/day. First lactation milk yield of F_1 daughters of *Puzzle*, *Push* and *Pound* sire-lines was reported to be 5482kg, 4520kg and 5520kg, respectively in Thailand (DPO, 2016) which was higher than present finding. Better yield in Thailand could be due to higher THF inheritance or better animal management than in Bhutan. This yield in Bhutan was acceptable owing to management system with calf suckling and the animal was provided with little or no supplementary feeding. Moreover, 50% inheritance from *Thrabam*, a draught purpose cattle breed of Bhutan with average daily milk yield of 1.52±0.13l/day (Tamang and Perkins, 2014) could have affected the yield of these crossbreds. Nevertheless, milking potential F_1 daughter was comparable with F_1 Jersey x *Thrabam* crosses in Bhutan with an average yield of 4.9±1.33l/day (Rai et al., 2020).

Table 4. Milk Yield of THF x Thrabam, F_1 daughters in three study sites

Study sites	Average Daily Milk Yield (l)					
	n	Morning (l)	Evening (l)	Total l/day	±SD	Lactation yield (l) (305 days)
Sergithang	4	3.2	2.0	5.3	2.2	1601
Barsong	6	2.8	2.4	5.2	4.4	1571
Tading	6	3.5	1.9	5.1	0.8	1556
Average		3.2	2.1	5.2	2.5	1576

Note: 305 days standard lactation yield is estimated; l means litre/day

Study on Friesian x Zebu cross cattle population showed that crossbreds with an intermediate grade 50% Holstein x 50% Zebu *(Bos indicus)* produced a lactation yield of 1637±35 kg in 246±5 days in Venezuela (Vaccaro et al., 1999) which was similar to findings of the present study. Present finding however was lower than 11.01±0.399 kg (3358 kg, lactation milk yield) for Friesian x Kanana F_1 crosses in Sudan (Ahmed, 1992); mean first lactation milk yield of 5541±1202 kg obtained for first lactation Turkish Holstein (Teke and Murat, 2013) and mean lactation milk yield of 4075±109kg for Holstein fraction of <0.625 in central Thailand (Koonawootrittriron, et al., 2006). Cows giving higher milk yield in other countries could be due to better breed mixture or management that could have favoured expression of genetic ability.

Reproductive performances of F_1 daughters

Average age at first service obtained through recall method was 28.2±9.6 months and age at first calving was 37.2±9.8 months (n=16). However, well-managed F_1 daughter was reported to show estrous/heat signs as early as 10 months of age and some farmers (18.75%) mated them as early as 13 months that calved at about 22 months. While other animals in poor health, and under low level of nutrition, first mating was possible at the age of 42.7 months. The early mating practice (before the animal reached two-third of adult body weight) under current low input production system at the village farms,, had affected the growth of the dam, faced calving difficulties (dystocia) that resulted in death of calves (two incidences) apart from low milk yield obtained from such cows. Friesian crossbred cattle (Friesian 50% x Sanga 50%) at Ghana, the mean age at first calving was 41.2 ± 1.2 months (Obese et al., 2013) longer than the present finding which was suggested to be due to poor plane of nutrition. Average age at first calving in the Thai multi-breed dairy population with Holstein bloodline was 30.3 ± 5.3 month (Koonawootrittriron et al., 2006). Similarly, age at first calving for Turkish Holsteins in the Mediterranean Region in Turkey was 29.81 months (Teke and Murat, 2013). Hence, it could be deduced that age at first calving for F_1 daughters (THF x *Thrabam)* under Bhutanese farming environment is satisfactory as it falls between the findings of other countries.

Management of F_1 daughters (THF x Thrabam)

The cattle in the study sites were mostly open grazed during the day (81%) and tethered in a shelter near the house during the night mostly in semi-permanent sheds, while others (19%) practiced tethering in crop land or managed through stall feeding. However, unlike more conventional management system where herder/farmers followed traditional patterns of cattle migration within and beyond the district boundary (Gyeltshen and Bhattarai, 2003), such practice was uncommon in the study areas.

Green grasses including locally available forages, improved Napier grass, tree fodder and agricultural by-products were commonly fed of the crossbreds. Milking animals and calves were also provided with gruel (cooked rice or maize bran, mixed with chopped banana stem or grasses). Feeding concentrate feed to milking animals and calves were practised only by about 25% of the farmers of the study areas. In similar studies, Tamang and Perkins (2005) reported that feeding of concentrate feed was rare in the village farms in Bhutan and most farmers (61%) fed cooked porridge mixing salt with locally available grains, rice bran and brew residues to milking cows and calves.

Adaptability of THF crosses to Bhutanese farming environment

Most of THF x Thrabam F_1 crosses (cows, heifers, young bulls and calves) were in good health with average body condition score of 2.8 (*n*=46) (in the scale of 1 to 5). Mortality of calves including accidental death was reported to be low at 2.95%

(*n*=271),while adult mortality was not reported indicating that crossbreds were adapted to prevailing farming environment. Calf mortality in the current study was considerably lower than 24% reported by Tamang and Perkins (2005) under free grazing management system in humid sub-tropical region of western Bhutan.

CONCLUSION

The study concluded that AI in natural heat obtained higher AI success rate/progeny birth than AI in induced heat; hence AI in induced heat is preferable for Bhutanese farming system. F_1 daughters produced more milk/day than purebred *Thrabam* cows. This encouraged farmers to own such crossbred cattle. Early mating of F_1 heifers before reaching desired body weight resulted in stunted growth of dam, faced calving difficulties (dystocia) and compromised daily milk yield. Such practice is inappropriate for Bhutanese farming system and needs to be discouraged. Overall, F_1 crosses of THF x *Thrabam* had low mortality rate hinting that these crossbreds adapted well to Bhutanese farming environment.

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COASTAL FARMERS' ATTITUDE TOWARDS CLIMATE SMART AGRICULTURE IN BANGLADESH

M.A.T. Mia[*1], M.R. Islam[2], M.S. Ali[2] and R. Roy[2]

[1]Department of Agricultural Science, Dhaka Residential Model College, Dhaka
[2]Department of Agricultural Extension & Information Systems, Sher-e-Bangla Agricultural University, Dhaka

Abstract

Climate smart agriculture (CSA) aims to improve food security, help communities adapt to climate change and contribute to climate change mitigation by adopting appropriate practices. Attitude is a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour. Therefore, this study aims to assess the extent of attitude of farmers toward CSA and explore the contributions of the selected characteristics of the coastal farmers to their attitude. Data were collected by using an interview schedule from 354 coastal farmers of 3 districts namely, Satkhira, Khulna and Bagerhat through Multistage Random Sampling Method during December 2021 to March 2022. Descriptive and inferential statistics were applied. To explore the contribution of the predictor variables to the outcome variables, full model regression analysis was employed. Results indicate that the highest proportion (61.01%) of the farmers had medium favourable attitude towards CSA as compared to 18.65% and 20.34% having low favourable and high favourable attitude towards CSA respectively. Farmers' education, annual agricultural income, training exposure, benefit obtained from CSA and knowledge on CSA had positive significant contributions to their attitude toward CSA. On the other hand, farm size and decision-making ability had negative contributions to their attitude toward CSA. For wider adoption of CSA may require farmers' capacity building through non-formal education, more exposure to training and proper knowledge.

Keywords: CSA, attitude, coastal farmers, favourable

INTRODUCTION

The coastal zone contributes approximately 16 percent of the total rice production of the country, covering about 70 percent of the total paddy-cropped area (Huq *et al*.,

[*] Corresponding author: touhid19@gmail.com

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2005). The entire coastal regions of Bangladesh are increasingly susceptible to flooding tropical cyclones and associated saltwater intrusion (Roy *et al*., 2019; Ramírez-Villegas and Thornton, 2015). The impacts of coastal hazards have been diminishing the potentials of these regions and thus drawing national and international concerns for protecting the coastal agriculture through implementing numerous initiatives such as formulating the Master Plan for the Southern Agricultural Development (MoA and FAO, 2013).

Addressing climatic challenges will require radical changes in agricultural systems. These systems have to become more efficient and resilient at every scale from the farm level to the global level. They have to become more efficient in resource use (use less land, water, inputs to produce more food sustainably) and become more resilient to changes and shocks. In this situation, FAO has introduced the concept of climate smart agriculture (CSA) as a way forward for food security in a changing climate. CSA aims to improve food security, help communities adapt to climate change and contribute to climate change mitigation by adopting appropriate practices, developing enabling policies and institutions and mobilizing needed finances (Mahashin and Roy, 2018). CSA is an approach for transforming and reorienting agricultural development under the new realities of climate change (Lipper *et al.*, 2014). FAO (2013) defined CSA as "agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces and/ or removes Greenhouse gases (mitigation) where possible, and enhances achievement of national food security and development goals". In these definitions, the principal goal of CSA is identified as food security and development (Lipper *et al.*, 2014; FAO, 2013); while productivity, adaptation, and mitigation are identified as the three interlinked pillars necessary for achieving this goal.

Attitude is a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour" (Eagly & Chaiken, 1993). It is used to investigate human behavior concerning a topic: How the respondents feel about it (IDAF, 1994). It has been reported in many studies and literature (e.g., Rahman, 2018; Mondal, 2014; Zulkifly *et al.,* 2013) that attitude of an individual plays a significant role in the adoption or rejection of an innovation. The favourable attitude of farmers towards CSA helps to achieve food security and broader development goals under a changing climate and increasing food demand. Therefore, assessing attitude towards CSA will make us understood whether any intervention is needed or not to change their attitude. This study is carried out with three objectives: assessing the extent of the farmers' attitude towards CSA, describing selected characteristics of the coastal farmers, and exploring the influences of the selected characteristics of the farmers to their attitude towards CSA.

MATERIALS AND METHODS

Study area

The study area of this research was three coastal upazilas namely Tala, Dacope and Morrelgonj of the districts of Satkhira, Khulna and Bagerhat respectively. Some basic facts of the study area like agroecological zone (AEZ), area, population, literacy rate, major crops, etc. are presented in Table 1 as stated in BBS (2021).

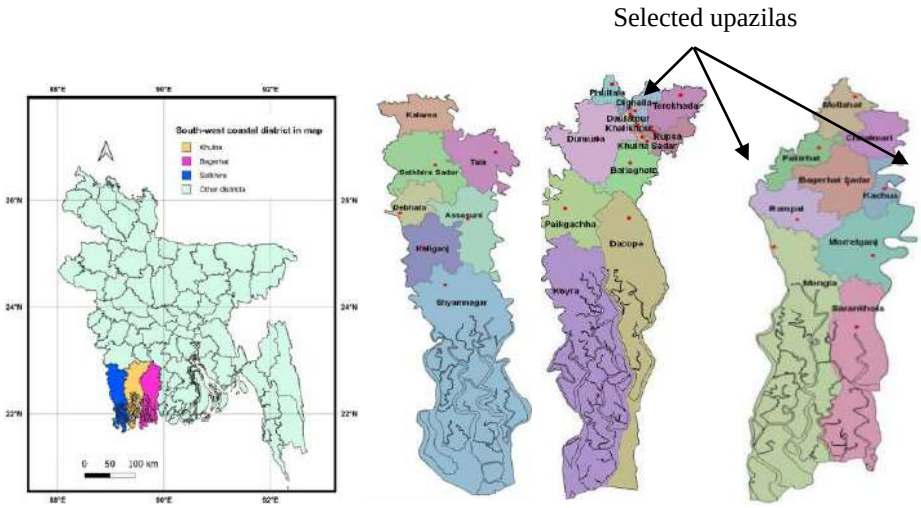

Fig 1. A map of Bangladesh (left side) with its administrative districts. Right side: maps of three districts (Satkhira, Khulna and Bagerhat) with three upazilas (Tala, Dacope and Morrelgonj) from where data were collected

Table 1. Basic Facts of the Study Area

Study area	AEZ	Area (km^2)	Population (000)	Literacy	Major crops	Existing major CSA practices	Cropping intensity
Morrelgonj, Bagerhat	13	460.90	295	60.7%	Paddy, Potato, sugarcane	Plastic irrigation pipe, Salinity resistant variety, Mulching, etc.	132
Dacope, Khulna	13	991.58	152	56%	Paddy, Watermelon, Potato, pumpkin	Plastic irrigation pipe, Rain water harvesting, Watermelon cultivation, etc.	114
Tala, Satkhira	11	344.15	300	50.9%	Paddy, Jute, Brinjal, Sugarcane	Ridge planting, Raised bed planting, mulching, etc.	198

Population and Sample of the Study

Out of 19 coastal districts of Bangladesh 3 districts, viz. Satkhira, Khulna and Bagerhat were purposively selected as study area. Three upazilas were randomly selected from these districts taking one upazila from each district. Nine villages from these three upazilas were again selected randomly taking 3 villages from each upazila. A total of 4489 farm families were found from selected nine villages and this number was considered as the population of the study. As the number of farmers in each of the villages was not the same, from each of the locations a 'proportionate random sampling' technique was used and sample size was found 354. To make a respective sample from the population following formula was used as developed by Kothari (2004).

$n = [Z^2 \text{ P QN}] / [(N-1)\, e^2 + Z^2 \text{ P Q}]$

Where, n = Sample size

Z = Table value at 1 d.f. (1.96)

P = Probability (assume 0.5)

Q = Remaining from probability (1-P) = 0.5

N = Total population = 4489

e = The level of precision (5%)

By putting the values in the above formula, the sample size was determined as follows-

$$n = \frac{\mathrm{Z^2PQN}}{(\mathrm{N}-1)\mathrm{e^2} + \mathrm{Z^2PQ}}$$

$$n = \frac{(1.96)^2 \times 0.5 \times 0.5 \times 4489}{(4489-1) \times (0.05)^2 + (1.96)^2 \times 0.5 \times 0.5}$$

$$n = 353.95 \approx 354$$

Variables and Instruments for Data Collection

Data were collected by households' survey, using an interview schedule from 354 coastal farmers during December 2021 to March 2022. Coastal farmers' knowledge on CSA was the main focus of this study and it was considered as the dependent variable. Education, farm size, annual agricultural income, farming experience, extension contact, training exposure, innovativeness, credit availability, access to market, decision making ability, benefit obtained from CSA and knowledge on CSA were considered as the predictor/independent variables of this study.

Measurement of the variables

Measurement of attitude towards CSA: In the present study, an attempt was made to develop an attitude scale for measuring the attitude of coastal farmers towards

CSA. Attitude scale was constructed by following the method of Likert's Technique of Summated Ratings Scale suggested by Edwards (1957) with slight modification. Initially 45 statements related to attitude towards CSA were collected through consultation with the agricultural scientists and extension experts and from review of available related literatures of home and abroad. Then these statements were carefully examined in the light of 14 criteria suggested by Edwards (1957) for screening. After screening, 30 statements were selected for administering pretest. The statements were analyzed on the basis of pre-test data obtained by administering to 24 farmers. The critical ratio (t-value) was calculated as suggested by Edwards (1957). The statements having 't' values ≥ 1.75 were finally selected for the attitude towards CSA scale. As such 18 statements were selected in the final scale of attitude towards CSA including 9 positive and 9 negative statements. The nature of responses of the respondents to the statements were 'strongly agree', 'agree', 'undecided', 'disagree' and 'strongly disagree' and scores were assigned as '4', '3', '2', '1' and '0' respectively for the positive statements and the reverse scores were given for the negative statements. The possible range of score of attitudes towards CSA was from 0-72, where 0 indicated very highly unfavourable attitude and 72 indicated very highly favourable attitude towards CSA. Based on the previous studies, for example, Roy *et al*. (2021), the measurement procedure of independent variables is given in Table 2 below.

Table 2. Measurement of independent variables

Variables	Measurement
Education	Number of years of schooling
Farm size	Total quantity of farming land in ha, including gardening and fishery
Annual agricultural income	Total yearly earning from farming
Farming experience	Number of years a farmer was involved in farming
Extension media contact	Total scores of a respondent on his nature and frequency of 14 selected extension media
Training experience	Total number of days that a respondent had undertaken different types of training related to agriculture/climate smart agriculture
Innovativeness	Scores assigned for respondent farmer as 5, 4, 3, 2, and 1 for innovators, early adopters, early majority, late majority and laggards respectively
Credit availability	Percentage of loan received against his/her sought amount
Access to the market	Score by using a 3-point rating scale of buying inputs and selling goods for his farming activities

Variables	Measurement
Decision making ability	Score obtained by using a 3-point rating scale of the six selected items
Benefit obtained from CSA	Score obtained using 4-point rating scale of 20 selected benefits.
Knowledge on CSA	Total score of a respondent obtained from a set of 20 questions related to CSA

Data Entry and Analysis

Data from all the interview schedules were coded, tabulated and analyzed in accordance with the objectives of the study. Data checking tools like outliers checking and removing multi-collinearity were employed. Pearson product moment correlation test was initially done and found no strong correlation ($r > 0.8$) between two or more predictors in the regression model. The analysis was performed using SPSS software version 21. Descriptive analysis such as range, numbers and percentage distribution, mean and standard deviation (SD) were used. Full model regression analysis was used in order to find out the contribution of the predictor variables to the outcome variable.

RESULT AND DISCUSSION

Attitude towards climate smart agriculture

Attitude scores of the coastal farmers varied from 38 to 57 against the possible range of 0 to 72, with a mean of 49.19 and standard deviation 5.28. Based on the observed attitude scores, the respondents were classified into three categories (mean ± SD) namely 'low favourable attitude', 'medium favourable attitude', and 'high favourable attitude'. The distribution of the respondents under each of the four categories has been shown in Table 3. Table 3 reveals that the highest proportion (61.01%) of the farmer had medium favourable attitude towards CSA as compared to 18.65% and 20.34% having low and high favourable attitude towards CSA respectively. The most (79.76 %) of the respondent farmers had low to medium favourable attitude towards CSA.

Table 3. Distribution of the farmers according to their attitude towards CSA

Categories	Number	Percent	Mean	SD	CV
Low favourable attitude (<44)	66	18.65	49.19	5.28	10.73
Medium favourable attitude (44-54)	216	61.01			
High favourable attitude (>55)	72	20.34			
Total	354	100			

Source: Authors

The majority of the farmers had medium knowledge on CSA (Table 4) and knowledge had positive contribution to their attitude towards CSA (Table 5) for which majority of the farmers might be influenced in forming favorable attitudes towards CSA. On the other hand, due to facing unfavourable environment for a long time, farmers were practicing CSA for their farming activities and getting benefits from it (Table 4) which might influence majority of the coastal farmers having favorable attitudes towards CSA.

Farhad and Kashem (2004) found majority (68%) of the respondents having medium attitude while 17% low attitude and 15% high attitude in using IPM in vegetable cultivation. Samad (2010) found majority (69.84 %) of the farmers having favorable attitude towards aerobic rice cultivation. Sarkar (2002) and Hussain (2001) found almost similar result in their respective studies.

Selected Characteristics of the Coastal Farmers

Table 4 indicates that only 12.71% of the farmers were illiterate and the rest 87.29% were literate which was composed of secondary education (59.32%), primary education (20.06%), higher secondary education (5.37%) and tertiary education (2.54%). Over time, government's initiative, different NGO's education programmmes (e.g., BRAC school) and for social involvement and need of the farmers, they somehow obtained literacy for which literacy is little greater than the national average. The small farm holder constituted the highest proportion (60.5%) followed by medium farm holder (22.6%), marginal farm holder (10.2%) and large farm holder (6.8%). About half of the respondents (50.56%) had low annual agricultural income; their annual agricultural income is up to Tk.150000. The next group were medium income farmers (40.68%) while the lowest proportion belongs to high income group (8.76%). Mittra and Akanda (2019) found similar result in their study that majority (62.2%) of the coastal farmers had low annual income. About 73.45% of the coastal farmers did not receive any training while 20.06% received low training, 3.95% received medium training and 2.54% received high training on agricultural matters. Majority (69.49%) of the respondents had medium decision-making ability, while 19.49% and 11.02% had high and low decision-making ability respectively. Hossain (2017) found almost similar result that majority (62.9%) of the respondents had medium decision-making ability. The highest proportion (75.42%) of the farmers belonged to medium benefits obtained from CSA, while 9.32% and 15.26% had low and high benefits obtained from CSA group respectively. Majority (75.14%) of the farmers had medium-level knowledge followed by 14.13% had poor knowledge and 10.73% had high-level knowledge on CSA. Israel (2019) and Ochieng (2015) found almost similar result regarding knowledge on climate change that majority (72% and 81% respectively) of the respondents had poor to medium level knowledge on climate change.

Table 4. Salient features of the selected characteristics of the farmers (n=354)

Characteristics	Measuring unit	Range		Categories	Number	Percent	Mean	SD
		Possible	Observed					
Education	Year of schooling	Unknown	0-15	Illiterate (0-0.5)	45	12.71	7.53	3.51
				Primary education (1-5)	71	20.06		
				Secondary education (6-10)	210	59.32		
				Higher secondary education (11-12)	19	5.37		
				Tertiary education (>12)	9	2.54		
Farm size	Score	1-5	2-5	Marginal farmer (0.021-0.2)	36	10.20	3.26	0.73
				Small farmer (0.21-1.0)	214	60.5		
				Medium farmer (1.01-3.0)	80	22.6		
				Large farmer (> 3.0)	24	6.8		
Annual agricultural income	Score	1-10	1-10	Low-income farmer (<150)	179	50.56	3.94	1.85
				Medium income farmer (151-300)	144	40.68		
				High income farmer (>300)	31	8.76		
Farming experience	Year	Unknown	10-50	Low experienced farmer (<15)	65	18.36	24.60	9.9
				Medium experienced farmer (15-35)	247	69.77		
				High experienced farmer (>35)	42	11.87		
Extension media contact	Score	0-42	15-31	Low contact farmer (< 18)	62	17.51	23.13	4.66
				Medium contact farmer (18-28)	243	68.64		
				High contact farmer (>28)	49	13.85		
Training exposure	No. of days	Unknown	0-7	No trained farmer (0)	260	73.45	0.61	1.26
				Low trained farmer (1-2)	71	20.06		
				Medium trained farmer (3-4)	14	3.95		
				High trained farmer (>4)	9	2.54		
	Score	1-5	1-5	Innovator (5)	39	11.03		
				Early adopter (4)	122	34.46		

Characteristics	Measuring unit	Range		Categories	Number	Percent	Mean	SD
		Possible	Observed					
Innovativeness				Early majority (3)	140	39.54	3.39	0.92
				Late majority (2)	45	12.71		
				Laggard (1)	8	2.26		
Credit availability	Score	0-100	0-83	No credit farmer (0)	288	81.36	9.84	21.16
				Low credit farmer (<50)	18	5.08		
				Medium credit farmer (50-70)	43	12.15		
				High credit farmer (>70)	5	1.41		
Access to market	Score	0-20	10-17	Low access (<11)	29	8.19	13.47	1.79
				Medium access (11-15)	266	75.14		
				High access (>15)	59	16.67		
Decision making ability	Score	6-18	11-17	Low decision making (<12)	39	11.02	13.76	1.77
				Medium decision making (12-15)	246	69.49		
				High decision making (>15)	69	19.49		
Benefit obtained from CSA	Score	0-60	34-55	Low benefit (< 40)	33	9.32	45.91	5.09
				Medium benefit (40-51)	267	75.42		
				High benefit (> 51)	54	15.26		
Knowledge on CSA	Score	0-40	17-32	Poor knowledge (up to 20)	50	14.13	25.45	3.86
				Medium-level knowledge (>20-30)	266	75.14		
				High level knowledge (>30)	38	10.73		

Source: Author

Contributions of selected characteristics of the farmers to their attitude towards CSA

Results presented in Table 5 show the summarized results of full model multiple regression analysis with 12 independent variables on the farmers' attitude towards

CSA. The value of R^2 is 0.410, which means that all of the 12 variables accounted for 41.0% of the variation in attitude towards CSA of the coastal farmers. The regression equation so obtained is presented below-

$$\mathbf{Y = b_0 + b_1X_1 - b_2X_2 + b_3X_3 + b_6X_6 - b_{10}X_{10} + b_{11}X_{11} + b_{12}X_{12}}$$

Or, $Y = 27.617 + 0.167X_1 - 1.548X_2 + 0.450X_3 + 0.336X_6 - 0.879X_{10} + 0.261X_{11} + 0.638X_{12}$

i.e., Attitude = 27.617 + 0.167 (education) - 1.548 (farm size) + 0.450 (annual agricultural income) + 0.336 (training exposure) - 0.879 (decision making ability) + 0.261 (benefit obtained from CSA) + 0.638 (knowledge on CSA)

For every one year of passing in schooling, an extra 0.167 attitude score was obtained. For increase every one score of farm size, a score of 1.548 attitude was decreased. For instance, a farmer having land area of 0.021 to 0.2 hectare, had attitude score 1.548 more than those who had land area of 0.21 to 1.0 hectare. For increasing annual income of every Tk.50000 (1 score = Tk. 50000), an extra 0.450 attitude score was obtained. For increasing every one score of training exposure, an extra 0.336 attitude score was obtained. The more the number of days a farmer will receive training, the more they will obtain attitude score. For increasing every one score of decision-making ability, a score of 0.879 of attitude was decreased. This might be due to that the farmers did not feel to take decision from others and decided themselves whether the decision might be right or wrong, because increased decision-making ability indicated less dependency on others while taking decision. For increasing every one score of benefit obtained from CSA, an extra 0.261 attitude score was obtained. For increasing every one score of knowledge on CSA, a score of 0.638 attitude score was obtained.

Table 5. Summary of full model multiple regression analysis showing the contribution of selected characteristics of the farmers to their attitudes toward CSA

Variables entered	'b' Value	Value of 't' (with probability level)
Education (X_1)	0.164*	2.046 (0.041)
Farm size (X_2)	-1.548**	-3.366 (0.001)
Annual agricultural income (X_3)	0.450*	2.443 (0.015)
Farming Experience (X_4)	0.048	1.772 (0.077)
Extension contact (X_5)	0.105	1.665 (0.097)
Training exposure (x_6)	0.336*	2.069 (0.039)
Innovativeness (x_7)	0.318	1.192 (0.234)
Credit availability (x_8)	0.004	0.421 (0.674)

Variables entered	'b' Value	Value of 't' (with probability level)
Access to market (x_9)	0.188	1.392 (0.165)
Decision making ability (X_{10})	-0.879**	-5.035 (0.000)
Benefit obtained from CSA (X_{11})	0.261**	5.194 (0.000)
Knowledge on CSA (X_{12})	0.638**	7.996 (0.000)
Multiple R = 0.640, R-square = 0.410, Adjusted R-square = 0.389, F-ratio = 19.744 at 0.000 level of significance, Standard error of estimate = 4.18553, Constant = 27.617		

*Significant at 0.05 Level, **Significant at 0.001 Level

CONCLUSION

The respondent farmers of the study area had favourable attitude towards CSA with different degrees. The highest proportion (61.01%) of the farmer had medium favourable attitude while high favourable attitude possessing farmers (20.34%) became a little greater than that of low favourable attitude (18.65%) towards CSA. Farmers having smaller farm tended to show more favourable attitudes towards CSA than that of large farm size. Farmers' education, annual agricultural income, training exposure, benefit obtained from CSA and knowledge on CSA had positive significant contributions to their attitudes towards CSA; while farm size and decision-making ability had negative significant contributions to their attitudes towards CSA.

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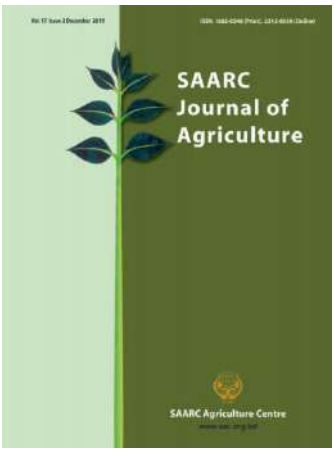

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ACKNOWLEDGEMENTS

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1. Khan, M.M.H. (2018). Abundance, damage severity and management of guava mealybug, Ferrisia virgata CkII. SAARC Journal of Agriculture, 16(2): 73-82.
2. Khan, M.M.H., Islam, M.M., Asaduzzaman, M. and Uddin, M.N. (2018). Mutants and weather parameters affecting the population dynamics of three major insect pests of mungbean. SAARC Journal of Agriculture, 16(2): 1-12.

REFERENCE TO A JOURNAL PUBLICATION WITH AN ARTICLE NUMBER

1. Van der Geer, J., Hanraads, J.A.J. and Lupton, R.A. (2018). The art of writing a scientific article. Heliyon, 19: e00205.

BOOK/ POLICY BRIEF

1. Gyeltshen, K. and Sharma, S. (2019). Integrated plant nutrition system modules for major crops and cropping systems in South Asia. SAARC Agriculture Centre, Dhaka, Bangladesh. Pp. 176.
2. Ali, Y., Shrestha, R.B., Bokhtiar, S.M. and Samanta, A.K. (2019). Food safety in South Asia: Challenge, opportunity and policy perspectives. SAARC Agriculture Centre, Dhaka, Bangladesh. Pp. 184

3. George, G. and Hassan, M.S. (2020). Policy brief on "Guidelines for ensuring sustainability of fisheries and aquaculture in South Asia". SAARC Agriculture Centre, Dhaka, Bangladesh. Pp. 1-4.

CHAPTER IN A BOOK

1. Bhatta, R., Anandan, S. and Giridhar, K. 2019. Livestock feeds and feeding practices in India. In: Samanta, Ashis Kumar, Bokhtiar, Shaikh Mohammad and Ali, Mohammad Younus (Editors). Livestock feeds and feeding practices in South Asia. SAARC Agriculture Centre, Dhaka, Bangladesh. Pp. 64 - 100.

CONFERENCE/SYMPOSIUM/ PROCEEDINGS

Joshi, B.K. (2004). Crossing frequency and ancestors used in developing Nepalese mid and high hill rice cultivars: Possible criteria for yield improvement and rice genes conservation. Proceedings of 4th National Conference on Science and Technology held at Kathmandu, Nepal. Pp. 502-523.

REFERENCE TO A WEBSITE

Cancer Research UK. (2003). Cancer statistics reports for the UK. https://www.cancerresearchuk.org/about-cancer/bowel-cancer. Accessed on 8th June, 2019.

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