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Agriculture Research and Innovation Division
Department of Agriculture
Ministry of Agriculture and Livestock
Thimphu : Bhutan

Editorial

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FOREWORD

The Department of Agriculture is delighted to launch the 7th volume of the Bhutanese Journal of Agriculture (BJA). BJA is a print open-access English language journal on agriculture and publishes research articles annually with the primary purpose of providing a national platform for agriculture professionals to publish and share their scientific work, a mechanism to disseminate technologies, knowledge and information in the agriculture sector.

Our editorial team, comprising members from within the Department of Agriculture and College of Natural Resource (CNR), is endeavoring hard to ensure that the quality of the articles published confirms to international standards. Concerted efforts are underway to continuously improve the quality of the journal and we are glad that with every passing issue, we have come out a step better. The experiences has undoubtedly enriched our colleagues who seem to be closing the gap in designing their research, using appropriate data collection methods, selecting correct data analytical tools and putting efforts for effective communication to convey their research outputs that is acceptable to the scientific community.

Following our successful DOI (Digital Object identifier) registration as a member with an authorized DOI provider in 2022, the journal papers in this volume are provided with DOIs. This will enable easy indexing and accessibility of our papers online while ensuring their long-term storage in the digital space as well as enhance our journal's credibility.

I thank the authors, reviewers and BJA Editorial Board for their contribution and continuous efforts in successfully taking out this edition. I would also like to emphasize that scientific peer reviewed publications are now a mandatory indicator for advancement of your career and hence encourage all to make sincere efforts to publish your research work. I wish everyone a resourceful reading.

Tashi Delek and best wishes!

(Yonten Gyamtsho)
DIRECTOR

EDITORIAL

The Bhutanese Journal of Agriculture (BJA) published by the Department of Agriculture (DoA) focuses and encourages the publication of original research work that helps generate scientific knowledge, information and technologies that contributes to agricultural science ultimately benefiting the Bhutanese farming communities. Located in the unique Himalayan setting Bhutanese agricultural system is largely subsistence, integrated and influenced by micro-climate that requires specific adaptation of technologies, skills, information, and knowledge to make agriculture sector more resilient and a productive enterprise. The COVID-19 pandemic has highlighted and demonstrated the need to develop a resilient national food system that is sustainable and less dependent on imports. Bhutanese consumers have started appreciating the value and positive attributes of the foods produced domestically under safe and pristine environment. To strengthen the national food systems, there are urgent needs to adapt and promote resilient farming technologies. The research articles published in the BJA are expected to contribute towards making available new technologies, knowledge, and information to the agriculture professionals who are serving our farming communities for ensuring national food and nutritional security.

This edition of the journal received 14 manuscripts that were reviewed by 9 experts including the editorial board members. The review reports were deliberated by a panel of reviewers in a three-day technical workshop which is a special feature of the BJA to ensure that best articles are selected, and justice is done in selecting or rejecting the manuscript. Through a rigorous revision process including strict compliance with the journal guidelines, only eight manuscripts have been accepted which are featured in this volume.

Once again, we thank all authors, reviewers, facilitators and the journal editorial board for their concerted effort and diligence in making this volume happen. On behalf of the editorial board, I would like to extend our sincere gratitude to all contributing institutions including the Agriculture Research and Development Centres at Wengkhar, Samtenling and Bajo, National Centre for Organic Agriculture, Yusipang. National Plant Protection Centre, Agriculture Machinery and Technology Centre and College of Natural Resources (CNR). I would like to put on record my appreciation to the Agriculture Research and Innovation Division and the DoA for providing the resources required to not only conduct the research but also to make this edition a success. We hope that all the agriculture professionals will appreciate the value of documenting evidence-based outputs, knowledge, information, and experiences for sharing with other peers through the BJA. We believe that our efforts shall never go in vain but serve as the resource to help realize our mission to secure safe and nutritious food for all Bhutanese people.

I wish you an intuitive reading.

(Tirtha Bdr. Katwal)
Editor-In-Chief

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Assessing the Use of Butachlor 5G in High and Mid Altitude Rice Growing Areas in Bhutan: A Case Study

Nidup Dorji[a], Kinley Dema[a], Kelzang Dawa[a], Tshelthrim Zangpo[a], Jigme Wangchuk[a], Yeshey Dema[a]

ABSTRACT

Rice is a vital cereal crop in Bhutan, cultivated widely for domestic consumption. Rice production is gradually decreasing due to diverse reasons including labour shortages and insufficient irrigation water. With the shortage of farm labour, weed management is challenging and Bhutanese farmers have long relied on Butachlor 5G for weed control. However, prolonged use of a single herbicide can lead to herbicide resistance in weeds. This study aimed to determine the extent of use of the weedicide and to assess the development of Butachlor resistance in paddy weeds through farmers' perceptions. The study, conducted in four western rice-growing areas, surveyed 190 farmers using semi-structured questionnaires. The findings revealed that Butachlor has been extensively used for over three decades, with most farmers applying it more than the recommended dosage. Despite this, 86.85% of respondents reported a decrease in Butachlor's effectiveness over the years. More than half of the respondent (50.53%) believed that weeds had developed resistance to Butachlor, a concern that correlated with the increased dosage used. The findings suggest a diminishing efficacy of Butachlor, potentially attributed to the development of herbicide resistance. Of significance, the study identifies Potamogeton distinctus as the most prevalent weed, followed by Schoenoplectiella juncoides and Pontederia vaginalis in the surveyed areas.

Keywords: *Butachlor; Herbicide; Paddy; Resistance; Weed*

1 Introduction

Rice is the important cereal crop in Bhutan and it is largely cultivated for domestic consumption. Rice is grown in all agro-ecological zones of Bhutan, across all 20 Dzongkhags, except the alpine zone in the north. In 2021, the area under rice production was 24055 acres with a total production of 40508 MT (NSB, 2021). However, the production of paddy is observed to decrease gradually due to urbanization and rapid socio-economic development.

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The major challenges faced by rice producers are labour shortage, lack of irrigation and weed management. Weed management has emerged as a significant challenge in rice production in Bhutan due to labour shortage and limited irrigation availability.

Weeds are identified as a major biological constraint that hinders attainment of optimal rice productivity in major rice producing countries of South Asia (Rao & Matsumoto, 2017). In Bhutan, rice yield losses of up to 50% due to weeds have been reported from lowland rice production (Karma & Ghimiray, 2006). The Royal Government of Bhutan introduced the weedicide Butachlor in granular formulation in the 1980s to manage grass and sedge weeds in paddy fields. Over the past 2-3 decades, Butachlor 5% GR has been the primary herbicide solution adopted by paddy growers across various regions of Bhutan. Despite a decline in the overall cultivated area, there has been a noticeable and consistent increase in the demand for Butachlor. This trend underscores the herbicide's effectiveness in weed management and its widespread acceptance among farmers.

However, as the reliance on a single herbicide continues, it is essential to monitor and assess the long-term implications on soil health, potential herbicide resistance in weed populations, and environmental sustainability. Diversification of weed management strategies and continued research into alternative, sustainable practices are imperative for maintaining the effectiveness of weed control measures and ensuring the sustainable paddy farming in the country.

The persistent use of a singular herbicides has been recognized as a potential catalyst for herbicide resistance in weeds (Cobb, 2022). In the context of Bhutan, Butachlor, classified as a pre-emergence selective herbicide within the Chloroacetanilide group, has been extensively employed to combat annual grasses and sedges in paddy fields. The targeted weeds include *Echinochloa spp*., *Paspalum distichum*, *Cynodon dactylon*, *Cyperus iria*, *Cyperus difformis*, *Schoenoplectiella juncoides*, and *Fimbristylis littoralis*.

Despite three-decade-long use of Butachlor for weed control in paddy, the development of resistance of weeds to this weedicide has not been studied. Recognizing this critical gap, this present study was undertaken to gather the perceptions of farmers and assess the emergence or absence of Butachlor resistance in the targeted paddy weed species. This study aimed to provide a comprehensive understanding of the on-the-ground experiences of farmers who have relied on Butachlor for weed management. Furthermore, the study aimed to provide valuable insights into the existing status of Butachlor resistance in paddy weeds, as well as to assess

whether farmers are adhering to the recommended usage guidelines for Butachlor that is crucial for devising sustainable weed management strategies.

2 Materials & Method

2.1 Study site

The study was conducted across four rice-growing areas in Punakha, Wangduephodrang, Paro, and Thimphu. Seventeen gewogs were selected for the study from four dzongkhags (Table 1).

Table 1. Gewogs selected for the study under each Dzongkhag

Dzongkhag	**Gewogs**
Wangdue Phodrang	Bjena, Gasetsogom, Gasetsowom, Kazhi, Nahi, Ngyisho, Rubesa, Thoedtsho
Punakha	Barp, Dzomi, Kabesa, Shelngana
Paro	Dopshari, Lamgong, Lungye, and Tsento
Thimphu	Maedwang

Butachlor has been widely used by paddy growers in these areas to control weeds in their paddy fields for over two decades (Figure 1), and its application and demand from the fields have been increasing over the years (Figure 2).

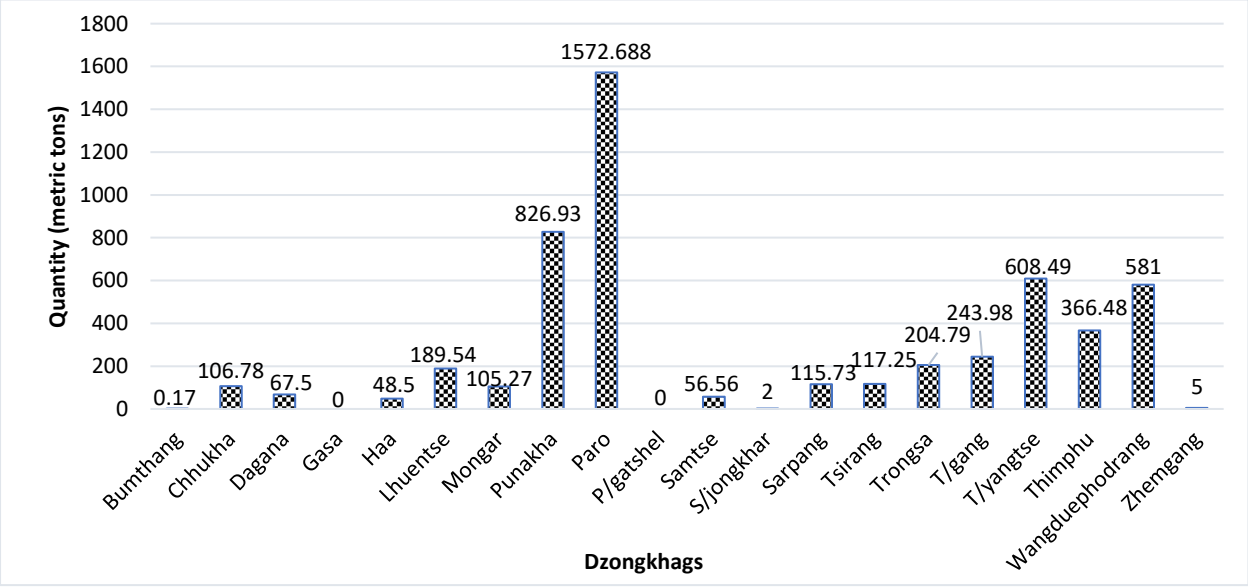

Figure 1. Dzongkhag wise butachlor 5% GR distribution in 13 years

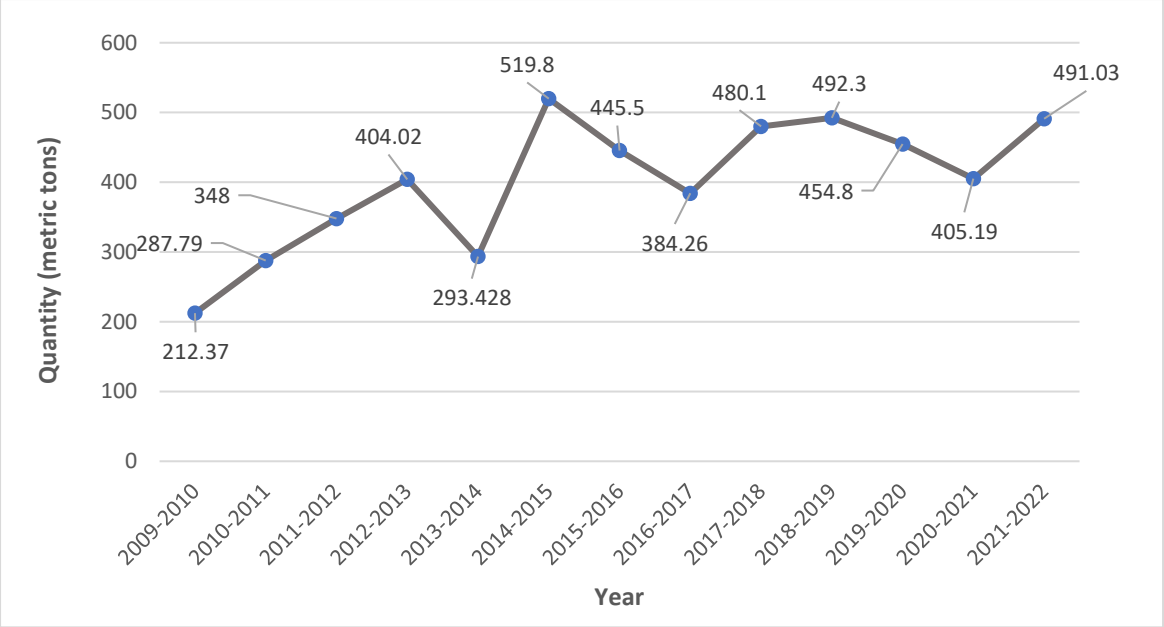

Figure 2. Butachlor distribution trend for 13 years

2.2 Sample size

The Probability Cluster Sampling method was used to sample a representative farmer for the interview. A total of 190 farmers were randomly sampled from 17 gewogs under four dzongkhags for the interview (Table 2).

Table 2. Number of samples and gewogs by dzongkhags

Dzongkhag	Gewogs (no.)	Number of farmers (no.)
Punakha	4	50
Paro	4	50
Thimphu	1	40
Wangduephodrang	8	50
Total	17	190

2.3 Data collection

Farmers' perceptions of the development of weedicide resistance (Butachlor) of weeds were collected through a combination of qualitative and quantitative questionnaires. The survey questionnaire was created using the open-source digital application known as Epicollect5, which facilitated an easy and convenient survey process. The survey took place in August and October 2022, with one farmer from each sampled household being interviewed according to the questionnaire.

2.4 Data analysis

The collected data were analysed using Microsoft Excel and the Statistical Package for Social Sciences (SPSS) version 22. Descriptive statistics, frequency analysis, and graphs were utilized to determine weed management practices employed by farmers and perception of weed resistance development to Butachlor. Correlation analyses were also conducted to examine the relationship between the dosage of Butachlor application and the development of resistance in weeds.

3 Result & Discussion

3.1 Demography

Table 3 and Table 4 present the demographic details of the respondents, including their age and gender. The results indicate that out of the total respondents (n=190), 61.6% (n=117) were female while 38.4% (n=73) were male. The average age of the respondents was 50.9 years, with the youngest respondent being 24 years old and the oldest respondent being 84 years old.

Table 4 presents the household size, agricultural experience, and education background of the respondents. The results show that the maximum household size was 8 persons per household, while the minimum was 1 person. The average household size was three persons per household, including only permanent residents and excluding school-going children.

In terms of education, most of the respondents had no formal education, accounting for 63.2% (n=120) of the total respondents. Non-formal education was received by 20% (n=38) of the respondents, while 16.8% (n=32) had attended formal education in schools. The survey also revealed that most of the respondents had extensive agricultural experience, with 95.3% (n=181) having more than 5 years of experience. Only a small percentage, 4.7% (n=9), had been involved in agriculture farming for less than 5 years.

Table 3. Age of respondent and household size

		Age	HH_size
N	Valid	190	190
Mean		50.90	3.56
Median		52.00	3.00
Minimum		24.00	1
Maximum		85.00	8

Table 4. Gender, education background and agriculture experience

Gender	Number (n)	Percentage (%)
Male	73	38.4
Female	117	61.6
Education Background		
Uneducated	120	63.2
Non-formal	38	20
Educated	32	16.8
Agriculture Experience		
< 5 years	9	4.7
>5 years	181	95.3

The gender disparity reflects the significant role of women in agricultural activities, particularly in rice cultivation, which is labour-intensive. The high participation of women in the survey underscores their importance in the agricultural sector and highlights the need for gender-sensitive approaches in agricultural development programmes. The age distribution suggests that the study involved a diverse group of participants with varying levels of experience and perspectives.

The inclusion of respondents from different age groups can provide a holistic understanding of how farming practices and perceptions may evolve over time. A smaller household size appears to be closely associated with labour shortages, which, in turn, contributes to the heightened reliance on herbicides for weed management in paddy fields(Gianessi, 2013). Furthermore, it is noteworthy that a significant proportion of farmers with no formal education may also play a role in the increased use of herbicides, possibly owing to a lack of historical records or knowledge regarding herbicide application in previous years.

3.2 Land holding

According to the survey, the households owned a total of 269.88 acres of wetland, of which 238.38 acres (88.4%) were cultivated. The average landholding for wetland and dryland was 1.42 acres and 0.42 acres, respectively, while the maximum landholding was 6 acres for wetland and 4.67 acres for dryland. Among the respondents, 85 leased in 103.56 acres of wetland, and 31.5 acres (11.6%) were left fallow due to various reasons. The primary reason for leaving the land fallow was the shortage of irrigation water (n=27), followed by labour shortage (n=8), crop damage by wildlife (n=6) and fragmented land (n=2) (Figure 3).

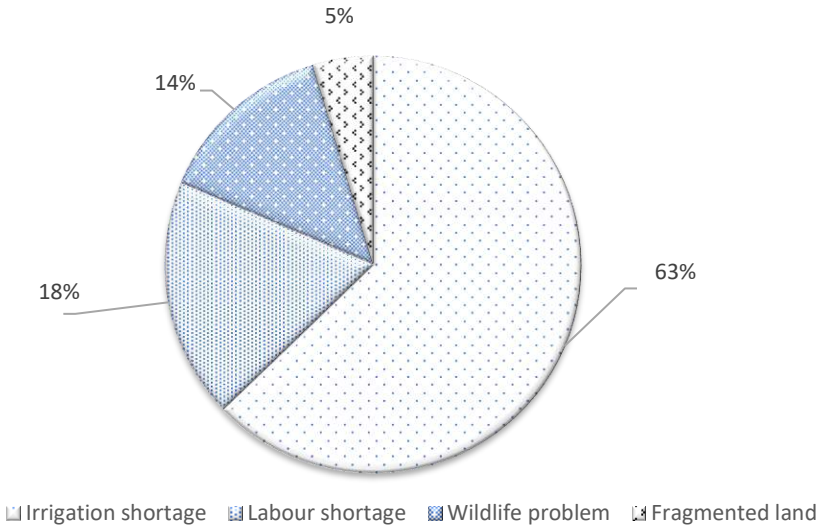

Figure 3. Reasons for keeping the land fallow

Landholding and land use patterns are crucial factors in agricultural practices, as they can significantly impact farming strategies and overall productivity. The presence of fallow land due to irrigation water shortages signals the need for improved water management practices, such as efficient irrigation system to optimize land use and minimize the weed management constraints. Since flooding of rice field is the most effective cultural practice for weed control in lowland rice and maintaining constant water height of 8-15 cm prevents the germination of most weed seeds and kills most emerged weed seedlings (Ismaila, Wada, Daniya, & Gbanguba, 2013). In many smallholder schemes, limited irrigation water can be major constraints to effective weed control (Johnson, 1996). Additionally, addressing labour shortages and wildlife-related challenges may require community-based solutions and support to enhance the rice productions.

3.3 Important weeds in Paddy

The weed species *Potamogeton disctinctus*, locally known as *shochum* in Bhutan was the most recorded species. As shown in Figure 4, out of the 190 farmers surveyed, 176 reported *P. distinctus* in their paddy fields, and it was also found to be the most dominant weed. The second most recorded weed species was *Schoenoplectiella juncoides* (n=172), followed by *Pontederia vaginalis* (n=138), *Acmella uliginosa* (n=114), *Cyperus difformis* (n=106), *Echinochloa crusgalli* (n=89), *Cynodon dactylon* (n=72), and *Bidens tripartita* (n=68). The least common weed species was *Alternanthera sessilis* (n=8). Thirty-two respondents reported the presence of other weed species, including *Fibristylis spp*., *Lemna minor*, *Eriocoulon spp*., *Echinochloa colona*, and *Cyperus rotundus*.

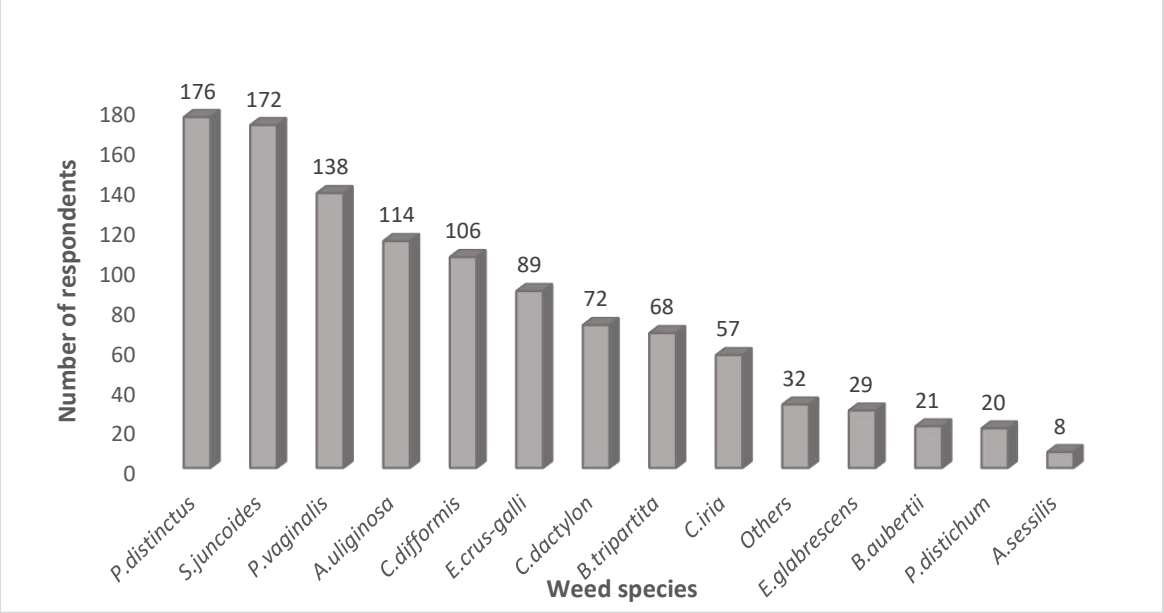

Figure 4. Ranking of important weed species in paddy

The result provided valuable insights into the most important weed species encountered by paddy farmers in the surveyed regions. The dominance of *P. distinctus* suggests that it is a prevalent and persistent weed species in the paddy field of western Bhutan (Dorji, Lhamo, Chophyll, & Tobgye, 2013). Its ability to establish itself in paddy fields can significantly interfere with rice growth and yield. The prevalence of diverse weed species underlines the complexity of weed populations in paddy fields and the need for multifaceted weed management strategies. Recognizing the prevalence and dominance of these diverse weed species is crucial for designing effective weed management strategies that can help minimize weed-related yield losses and promote sustainable paddy cultivation practices (MacLaren, Storkey, Menegat, Metcalfe, & Dehnen-Schmutz, 2020). Further research may delve into the biology, ecology, and control measures specific to these important weed species to enhance the resilience and productivity of paddy farming systems in Bhutan.

3.4 Weed management practices

Farmers in the study area used various methods to manage weeds in their paddy fields as presented in Figure 5. The majority (93%, n=177) practiced an integrated weed management approach that involved hand weeding, cultural methods such as good tillage and ploughing in winter, and herbicide application. A small proportion (6%, n=12) used a combination of hand weeding and herbicide, while only 1% relied solely on manual weeding, which is considered the best management practice despite its laborious and challenging nature.

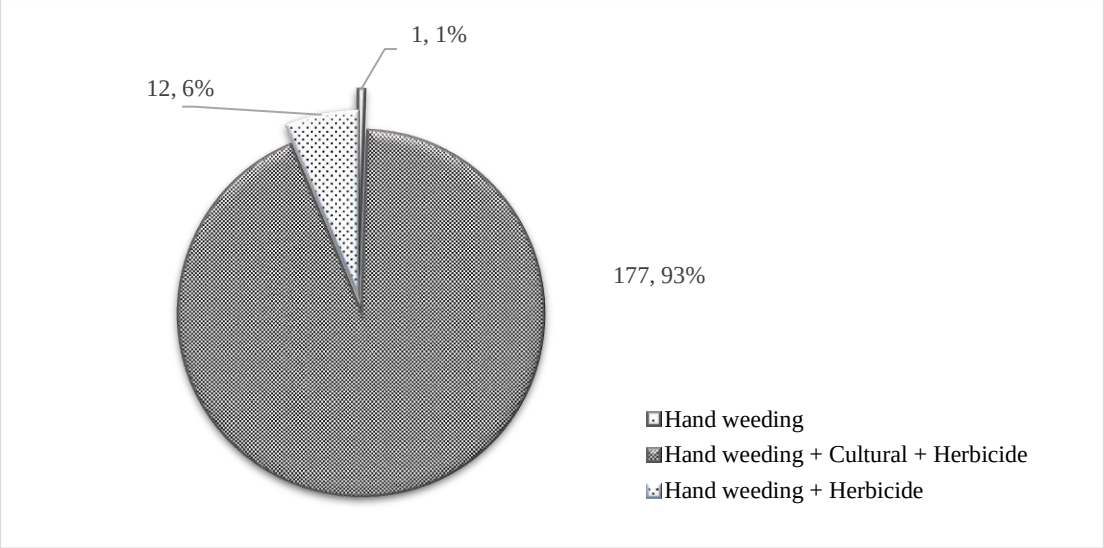

Figure 5. Types of weed management practiced

The farmers used different herbicides to manage weeds in their paddy fields (Table 5). Among the three herbicides commonly used, Butachlor 5% GR and Ethoxysulfuron 15% WDG are used by 168 farmers (88.4%). Butachlor 5% GR was used by 10% (n=19), while one farmer in Shelgana, Punakha dzongkhag, used only Ethoxysulfuron 15% WDG. Two farmers in Rubesa, Wangdue Dzongkhag, used all three herbicides (Butachlor 5% GR, Ethoxysulfuron 15% WDG, and Glyphosate 41 SL) to manage weeds. The two diverse herbicide use patterns suggest that farmers are open to exploring different options to address weed-related challenges. This approach may reflect specific weed management needs or variations in weed species and resistance patterns across different paddy fields.

Table 5. Types of herbicides used by farmers

Herbicides type	Respondents number	%
Butachlor 5% GR	19	10
Ethoxysulfuron 15%WDG	1	0.5
Butachlor + Ethoxysulfuron	168	88.4
Butachlor + Ethoxysulfuron + Glyphosate	2	1.1

3.5 Butachlor usage

The survey findings reveal that butachlor has been used in the field for more than three decades, with a maximum usage period of 40 years and a minimum of 3 years, as reported by farmers. The average duration of butachlor usage was 21 years. However, despite its widespread use, most of the farmers 55.27% (n=105) were not aware of the actual dosage recommended by the

National Plant Protection Centre (NPPC), which is 10 kg per acre. Only 85 respondents (44.74%) knew the recommended dosage of butachlor. The results in Figure 6 showed that 85% (n=161) of the respondents applied butachlor more than the recommended dosage, while only 10% (n=19) used the recommended dosage, and 5% (n=10) used it in lesser amounts than the recommended dosage.

All the respondents reported applying butachlor once during a paddy season, with 147 applying it within 2-5 days after transplanting (DAT), and 26 applying it on the same day of transplantation. However, 5 respondents applied it before transplantation, and 12 farmers applied it within 5 to 15 days after transplanting, which is not recommended by NPPC.

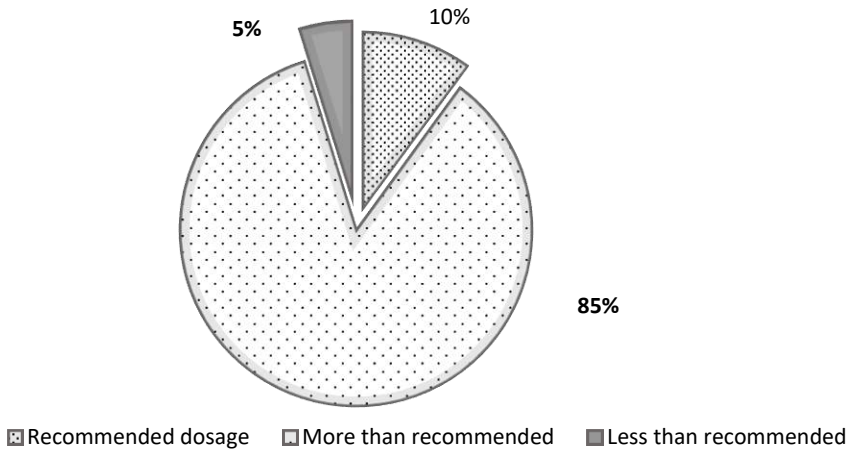

Figure 6. Dosage of butachlor used by farmers

In the study, 65.79 % of the respondents (n=125) reported an increase in the dosage of Butachlor by 30-40% from the recommended amount over the years. Only 26.85 % (n=51) respondents reported using a consistent amount each year, while 7.37% (n=14) had decreased their application rate by switching to Ethoxysulfuron 15% WDG application due to significant issues with broadleaved weeds. The farmers had increased the dosage of butachlor application since the recommended dosage did not effectively control the weeds, potentially attributed to increased weed diversity or development of weed resistance over time.

Among the total respondents, 86.85% (n=165) reported a decline in the effectiveness of Butachlor over time, with 11.05% (n=21) indicating no change in the effectiveness of Butachlor. Whereas none of the respondent reported an increase in effectiveness. A small percentage, 2.10% (n=4) of respondents, expressed uncertainty about Butachlor's effectiveness. The ineffectiveness of Butachlor may be attributed to the intensive and continuous use of the same herbicide for more than two decades. This prolonged practice has

the potential to foster herbicide resistance, thereby contributing to the diminished effectiveness of the herbicide in controlling weeds (Ofosu et al., 2023)

Despite significant proportions of respondents, 86.85% (n=165), reporting a decline in the effectiveness of Butachlor over time, 138 respondents said they would not be able to grow paddy without it, while 45 respondents believed they could cultivate paddy without its application. Seven respondents were unsure.

Regarding the replacement of Butachlor, 118 (62.10%) of the respondents believed it was time to switch to other effective weedicides; 58 (30.53%) believed Butachlor did not need to be replaced, and 14 (7.37%) were unsure whether it should be replaced or not.

The results from the Butachlor usage emphasize the complex dynamics surrounding Butachlor usage in paddy farming. While Butachlor has been a long-standing and indispensable tool for weed management, its misuse and declining effectiveness necessitate a careful re-evaluation of its use. A comprehensive approach, encompassing farmer education and research on alternative weed management strategies are vital to prevent weed resistance development and effective weed management in paddy (Monteiro & Santos, 2022).

3.7 Farmers' perception on butachlor's efficacy

As presented in Figure 7, 51% (n=96) of the respondents reported that the weeds have developed resistance to butachlor, whereas 33% (n=63) reported that weeds have not developed resistance to butachlor, and 16% (n=31) were unsure about the development of resistance to butachlor.

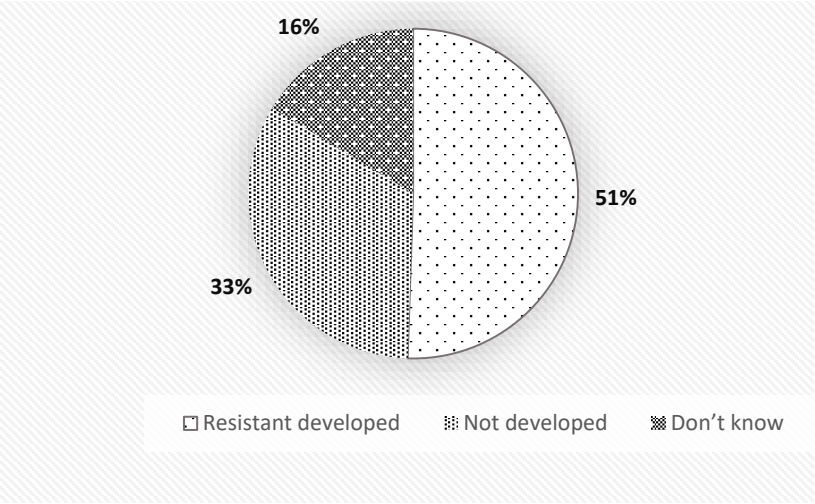

Figure 7. Farmers' perception on resistant development of butachlor to weeds of paddy

To assess the relationship between the variables of dosage increase or decrease and resistance development, Pearson correlation coefficient was computed. The result revealed a weak positive correlation between the two variables, with r (190) = .229, and the correlation was statistically significant (p=.002). These findings suggest that as dosage increases, there is a weak positive association with resistance development.

Several factors may contribute to this observed correlation. Firstly, increasing the dosage of herbicides can exert a selection pressure on weed populations, favouring the survival and proliferation of individuals with natural resistance or adaptive mechanisms. Over time, this can lead to a higher prevalence of resistant weed biotypes (Hanson et al., 2011). Secondly, the relationship could be influenced by other factors, such as weed management practices, weed species present, and the history of herbicide use in the specific fields. It is essential to consider other variables and potential confounding factors that might contribute to this phenomenon. In the surveyed areas, where Butachlor has been utilized for over two decades with a steady increase in application rate of Butachlor, farmers' hypotheses regarding resistance development appear plausible. Supporting this, instances of Butachlor-resistant *E. crus-galli* have been documented in China (Huang and Lin, 1993), with a notable increase in resistance observed after 8-12 years of Butachlor application and corresponding dosage escalation.

The implications of these findings are significant for sustainable weed management in paddy fields. Farmers and agricultural authorities should be aware of the potential consequences of indiscriminate herbicide use, particularly in terms of the development of resistance in weed populations. Integrated weed management strategies that incorporate multiple approaches, including herbicide rotation and cultural practices are necessary to mitigate the development and spread of herbicide-resistant weeds (Ofosu et al., 2023).

4 Conclusion

This study reveals that farmers use Butachlor 5% GR in higher doses than recommended dose, primarily to control grasses and sedges in paddy fields. The study also found that the effectiveness of Butachlor 5% GR has declined over time, and the farmers perceive it because of weed resistance development. However, further research is necessary to validate these claims and findings. The shortage of water for irrigation is the primary reason for leaving the land fallow, followed by the labour shortages. Among the major weeds reported by farmers, *Potamogeton distinctus* was the most common, followed by *Schoenoplectiella juncoides*, *Pontederia vaginalis*, and *Acmella uliginosa*.

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Evaluation of Locally Fabricated Ridger Attached to Power Tiller and Mini Tiller for Bed Making and its Breakeven Analysis

Pem Lham[b], Zangmo[b], Namgay[b]

ABSTRACT

Growing vegetables in raised beds offers several advantages, including proper drainage, weed control, and higher yields, among others. However, Bhutanese farmers construct these beds manually due to the lack of appropriate equipment's, which is labor-intensive and tedious. To address this issue, ridgers attached to power tillers and mini tillers were designed and evaluated. Power tiller attached ridger was tested at three forward speeds 1.1, 1.4 and 2.4km/h and mini tiller attached ridger was tested for the interaction of the same speeds and two different depths to determine the bed height, furrow width and field capacity of the machines. The result shown that power tiller ridgers showed increased capacity of 4.51 acre/day at higher speed of 2.4km/h, while mini tiller ridgers maintained a relatively constant capacity ranging from 3.44 acre/day to 3.46 acre/day at forward speed ranging from 1.1km/h to 2.4km/h. The result indicated that forward speed had a minimal effect on bed height formation. Deeper tillage resulted in higher bed heights within recommended range of 20-30cm. Furrow width slightly increased with higher speeds. Power tiller and mini tiller bed making is 55 and 38 times more efficient than manual labor, and the investment in these implements can be recovered after using them for 1.03 and 0.55 acres, respectively, indicating their economic viability. Incorporating ridgers into vegetable cultivation practices has the potential to improve productivity and alleviate the burden on farmers in Bhutan.

Keywords*:* *Raised bed; Machine capacity; Break even use; Forward speed.*

1 Introduction

Agriculture holds significant importance in Bhutan, contributing significantly to employment and the country's economy. However, scaling up commercial agriculture poses a challenge due to rugged topography, issues with land fragmentation, and the prevalence of small landholders

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engaged in subsistence farming. Despite its modest size, Bhutan has diverse agro-ecology stemming from considerable variations in altitude (Katwal, 2013), indicating the nation's potential to enhance production through the adoption of improved farming practices.

Today vegetable production is picking up in the country, where the self-sufficiency in vegetables stands at 84%, contributing to an overall food self-sufficiency rate of 68.30% (Tshering, 2022). Additionally, vegetables continue to play a remarkable role in human nutrition and health due to their nutrient's contents such as dietary fiber, phytochemicals, vitamins, and minerals (da Silva Dias & Imai, 2017). There has been a noticeable increase trend in the consumption of vegetables in recent times in Bhutan and the import figures has also increased despite the increase in domestic vegetable production (Guidebook on vegetable cultivation, 2020). The demand for vegetable consumption will continue to increase with increase in population, income, and change in healthy dietary habits.

In Bhutan majority of the farmers continue to adopt traditional practices of land preparation for vegetable cultivation which are highly labour intensive and tedious. The vegetable cultivation processes include land preparations and making beds of suitable heights to prevent water logging and improved aeration (Lham, Norbu, Phuntsho & Zangmo, 2022). Studies found that crop cultivation on raised beds is a good technique in farming systems. On-farm research found that growing crops on raised system saved 20-34% irrigation water, 16-69% planting cost, and ensured higher crop yield compared to conventional system (Hossain, Islam, Hossain, Meisner, & Rahman, 2010). Raised bed method helps in reducing irrigation requirements of crops and increase crop production even in soils having low permeability, seasonal water logging, salinity, and shortage of water supply (Qureshi, McCornick, Qadir, & Aslam, 2008). Various studies have reported on the performance of different crops under raised beds farming. Rajput et al., (2009) observed about 55 % increases in crop yield in raised bed system as compared with the flatbed system due to improved soil drainage, effective weed control, enhanced water retention, and optimal nutrient distribution. Many crops, such as peanut, cotton, sweet potato and other vegetables are planted on raised beds with furrow irrigation, a method which not only has the potential to save water but is also convenient for water management (Bouaziz, A., & Chekli, H. (2000). Hence, cultivating vegetables using raised beds has demonstrated a substantial increase in overall yield.

Making raised beds manually is a labor-intensive and tedious task, resulting in higher production cost and disrupting the timely cultivation process due to the unavailability of farm labour, consequently impacting crop yields. To meet growing demands for vegetables while

addressing labor shortages and reducing labor-intensive tasks, it is imperative to adopt innovative, science-based agricultural technologies aimed at enhancing vegetable production. Carrying out timely operation and reducing cost of production are prerequisite for enhancing the production and productivity of vegetables as well as to make vegetable cultivation commercially viable and profitable for the farmers. Kumari, N., Singh, P. K., & Singh, P., (2020) found out that the ridge making activity done through mini tiller took 95% less time in compared to human and 50% in compared to pair of bullocks. The total cost saving in ridge making activity by mini tiller is 93.59% in compared to human and 56.38% in compared to bullock pair.

To overcome the challenges associated with manual bed-making and to enhance mechanization efficiency, there is a need for the development of innovative agricultural machinery implements, specifically a ridger designed for making beds. This implement would be attached to power tillers or mini tillers, which are widely used in Bhutanese farming communities. The popularity of these smaller farm power tools stems from their adaptability to the steep terrains found in Bhutan's agricultural areas. Moreover, individual ownership of these machines is more viable for farmers due to their cost-effectiveness and practicality. According to (JICA, 2016) among the farm machineries, power tillers in land preparation are the most popular, the use of power tillers has substantially reduced farm drudgery besides reducing farm labour requirements. It is recommended that marginal farmers with small land holdings consider utilizing compact farm power tools such as a 7 HP mini tiller and a lightweight power tiller for their agricultural operations (Kumari, N., Singh, P. K., & Singh, P., 2020). This suggestion closely aligns with the prevailing trend in Bhutan that the average land holding in Bhutan is about 3.7 acres per household (Renewable Natural Resources Census of Bhutan, 2019).

During the operation, the speed of the bed-making machine can impact the size of beds formed. It is considered that the forward speed of the machine is one of the important and direct factors that affect the machine’s quantity and quality, through which the productivity of agricultural machinery is determined (Kakahy, A. N. N., Alshamary, W. F. A., & Kakei, A. A. 2021). Abdul Karim, T.T and Mumtaz, I.H, (2011) pointed that the increase in the speed of the tractor led to the increase in the traction force, the efficiency of conduction capacity, the volume of the disturbed soil, and the practical productivity reached the lowest. Therefore, adjusting and optimizing the speed of bed-making machinery is crucial in achieving consistent and desirable bed sizes for effective vegetable cultivation.

The power tiller and mini tiller attached ridger for bed making is designed within the country and it is important to do a breakeven analysis to determine the economic advantages of these machines. This analysis is essential for effective resource allocation and hence justifying investments by end users especially Bhutanese farmers. According to Haquel, M. A., Alaml, M., & Sarker, T. R., (2014) break even analysis gives an insight to the minimum annual use of a particular machine that would justify the economic operation of that machine over the other options available.

This study aimed to design and evaluated a ridger for bed-making compatible with both power tillers and mini tillers. Its primary objective was to explore how the forward speed of the machine affects the dimensions of the formed bed and its field capacity, particularly concerning the ridger attached to power tillers. Furthermore, the study aimed to examine the interaction between implement depths and forward speeds on bed dimensions and field capacity, specifically for the ridger attached to mini tillers.

2 Materials and Method

2.1 Design of the implements

Two types of ridgers were developed for power tillers and mini tillers. The sizes vary due to the distinct power sources; however, the design and operational principles are the same. The ridgers for bed making were specifically designed to create raised beds of height 20 to 30 centimeters. These implements can make a bed while moving forward and accurately adjusting to any desired bed widths on its return based on the specific requirements for different crop types. This approach allows for making raised beds of any desired width, catering to individual preferences and crop requirements.

The ridger attached to the mini tiller can be adjusted to two different depths D1 (47.5cm measured from the base of the implement to the center of the hole of the shaft) and D2 (43cm measured from the base of the implement to the center of the hole of the shaft) respectively allowing for making of beds at varying heights.

The frame and other working parts were made of Mild Steel sheet of thickness 3mm and the parts were assembled with nuts and bolts. The process basically involved making the parts by cutting, grinding, and welding followed by fitting and assembling. The prototype was tested in the field.

Figure 1. Ridger for power tiller Figure 2. Ridger for mini tiller

2.2 Field experiment

The experiment was conducted in Rukubji where vegetables were dominantly cultivated. Rukubji is located in Wangduephodrang district at 27.5141° N, 90.2748° E. The experiment was conducted in the month of May 2021. The soil composition at the site was predominantly loam with moisture content of 20% at the time of experiment conducted. A separate experiment was conducted for power tiller and mini tiller attached ridger for bed making. The experiment followed a completely randomized design for testing power tiller attached ridger treated under three different forward speeds and the experiment involving mini tiller attached ridger was conducted adopting factorial design incorporating two factors, implement depth tested at two levels D1 and D2 and forward speed tested at three levels with each factor being replicated three times. This factorial design facilitated the examination of the main effects of implement depth and speed, as well as potential interactions between these two factors.

A total of nine plots were selected as the experimental units for applying the three treatments for power tiller, and 18 plots were selected for applying interaction of two different factors (speed and depth) for mini tiller. As per the recommendation outline in the guidebook on vegetable cultivation, 2018) bed width of 0.7m was maintained for both the machines: Forward speeds i) 1.1km/h operated at gear position 1 ii) 1.4km/h operated at gear position 2 and iii) forward speed of 2.4km/h operated at gear position 3 were determined for both the machines by recording the time taken to cover a distance of 10 meter using the formula;

$$V = \frac{Sx3.6}{t} \qquad (1)$$

Where;

V= forward speed (km/h), S= travelled distance (m), t= time of the experiment (sec)

1m/sec= 3.6km/h

2.3 Experiment with making bed manually

An experiment on bed making manually was conducted adopting completely randomized design by a man with three replications to determine the time taken to make a bed of length 10m, 0.7m wide and 20-30cm height in the well ploughed field which is compatible with the bed dimensions made by the machines. The capacity of the man in making the desired dimension raised bed was calculated using the formula:

$$\mathrm{MC} = \frac{\mathrm{A}}{\mathrm{T}} \mathrm{x}7 \qquad (2)$$

Where,

MC=Man capacity, A=total area covered (acre), T=Total time taken to cover that total area (h), 7= working hours in a day.

2.4 Data collection

The data collected during the experiment were bed height, machine capacity and furrow width. Representative values for bed height and furrow width were taken by randomly selecting points along a 10-meter-long bed formed during the experiment. The width of the furrow is measured from the edge of one bed to the opposite edge of the adjacent bed. The time taken to make raised bed manually was recorded inclusive of the rest taken by the man and other miscellaneous time lost. Soil sample from certain depths were collected using soil corer to assess the moisture content of the soil using the formula:

$$\mathrm{MC} = \frac{\mathrm{W}i - \mathrm{W}d}{\mathrm{W}d} \mathrm{x}100 \qquad (3)$$

Where,

$\mathrm{MC} = \text{Moisture content } (\%)$, W$i$ = Initial weight (g), Wd = Dry weight (g)

2.5 Statistical Analysis

All the data collected were subjected to an analysis for variance (ANOVA) using excel software. Differences among treatment means were examined using the "Turkey Post hoc Test" at 5% significance level.

2.6 Cost analysis

Breakeven point was calculated to compare the operating costs of bed making using a ridges and the costs associated with manually making a bed for vegetable cultivation.

2.6.1 Fixed cost

These costs depend on how long a machine is owned rather than how much it is used. The fixed costs for farm machinery include depreciation, interest on investment, insurance, and taxes/registration.

Table 1. Field capacity of farm machineries used for the study (Directory of certified farm machinery, 2022)

Name of machine	Capacity for plowing (acre/day)	Capacity for rotary (acre/day)	Capacity for bed making (acre/day)
Vikyno Power tiller (MK-120)	1.56	2.94	4.51
Mini tiller (KDT-610CE)	0.54	2.36	3.46

Depreciation cost

This cost reflects the reduction in value of a machine with the use (wear) and time (obsolescence). According to Kepner et al (2005), the annual depreciation was calculated using straight line method as follows.

$$D = \frac{P-S}{LH} \qquad (4)$$

Where,

P= Purchase price of the machine, S=Salvage value (10% of P), L=Useful life of machine (years), H=Annual use of machine (hours)

Interest on investment

As per Bank of Bhutan (assessed on 27th September 2023) the fixed interest rate on agriculture term is 10.85%. It is calculated using the formula;

$$I = \frac{P+S}{2} x \frac{i}{H} \qquad (5)$$

Where,

i = prevailing interest rate

As per the Road Safety and Transport Authority Regulation 2021, farm machinery was exempted from the registration and renewal fees.

Insurance and taxes

Insurance and taxes for agricultural use is 2% per annum (Norbu, 2018)

$$\text{In} = \frac{2\% \text{ of P}}{\text{H}} \qquad (6)$$

Where,

In=Insurance and taxes per hour

2.6.2 Operating cost (variable cost)

It varies in proportion to the amount of machines used. Operating costs include repair and maintenance cost, fuel cost, oil cost and labour cost.

Repair and maintenance cost

Repair and maintenance expenditures are necessary to keep a machine operable due to wear, part failure, replacement of tyres and tubes and accidents. The accumulated repair and maintenance costs (TAR) at any point in a machine's life can be estimated from the following formula (Singh & Mehta, 2015);

For two-wheel drive tractor (power tiller and mini tiller);

$$\text{TAR} = 0.120\text{X}^{1.5} \qquad (7)$$

For plough, planter, harrow, ridger and cultivator:

$$\text{TAR} = 0.301\text{X}^{1.3} \qquad (8)$$

$$\text{X} = \frac{\text{H}}{\text{H x L}}\text{x}100 \qquad (9)$$

Fuel cost

The price of fuel (Diesel) was taken by observing the market price, State Trading Corporation of Bhutan Limited, Bhutan Petroleum (16 August-31 August 2023) recorded at Nu.80.19/liter for Thimphu. Average fuel consumption was estimated by the following formula (Singh & Mehta, 2015);

$$A_d = 0.15 \text{ x B} \qquad (10)$$

A*d*= Average diesel consumption (both power tiller and mini tiller are diesel operated engine),

B= Rated power (KW)

**for the machines used in our experiment (power tiller: 9kw and mini tiller: 4kw)*

Oil cost

Oil consumption should be taken as 2.5 to 3% of the fuel consumption (Sarker, Alam, Haque, & Zaman).

2.6.3 Total operating cost

It is the sum of fixed cost and operating cost

2.6.4 Overhead cost

It should be assumed as 20 % of the sum of fixed and variable costs (Singh & Mehtha, 2015)

2.6.5 Manual operating cost

The manual operating cost was calculated, taking into account the local wage rate of Rukubji of Nu. 800 per day, with the understanding that one individual is needed to make a raised bed.

2.6.6 Breakeven use

Determining the use of farm equipment is the most important decision in farm management, in this regard computing break-even-use of a farm machine is a must. The break-even-use is the amount of use where the cost of using a machine owned would be the same as the cost of doing the same operation manually (bed making for our experiment). Owning a machine would be financially viable when used beyond the break-even point.

Break-even-use can be determined by the following formula:

$$\text{BEU} = \frac{\text{Total Fixed cost}}{\text{manual operating cost} - \text{total operating cost}} \qquad (11)$$

If manual operating cost is more than total operating cost, it is profitable to do the activity by machine than manually.

3 Results and Discussion

3.1 Effect of forward speed and depth of implement on the heights of bed formed

Figure 3 shows the bed heights formed by ridger attached to power tiller and mini tiller at three different forward speeds: 1.1 km/h, 1.2 km/h, and 2.4 km/h. A very small variation in bed height across different forward speeds was observed for power tiller attached ridger which suggests that forward speed may have a limited effect on bed height formation in our experimental setup. This may be attributed to the design of the ridger's hitching system which was fixed at one point and was engineered to maintain consistent heights across different speeds. Further statistical analysis also suggested that there was no significant difference among the bed heights formed.

On the other hand the impact of interaction of forward speed and depth of the implement on bed height formed using mini tiller-attached ridger showed that at the lower forward speeds, both D1 and D2 depths tend to yield slightly higher bed heights and there was a slight reduction in bed heights with increase in forward speeds to which Ismail and Ismail, (2013) suggested was due to increase in the collapsed soil, and consequently more quantity of soil falling on the profile sides as forward speed of the machine increases. Overall D1 depth consistently resulted in taller bed heights because of its deeper depth maintained compared to depth D2. The interaction effect between depth and speed on bed height formed was not statistically significant and forward speed did not yield a significant difference in bed heights formed. However, we observed a significant difference in bed heights between depths D1 and D2, specifically, deeper tillage (D1) resulted in taller beds compared to shallower tillage (D2).

Nonetheless, as per Nueces County AgriLife Extension. (2020), and Iowa State University Extension and Outreach. (n.d.) 20 to 30cm of bed height is usually adequate to be effective for vegetable cultivation, which is comparable for the heights formed at all the speeds and depths for both power tiller and mini tiller.

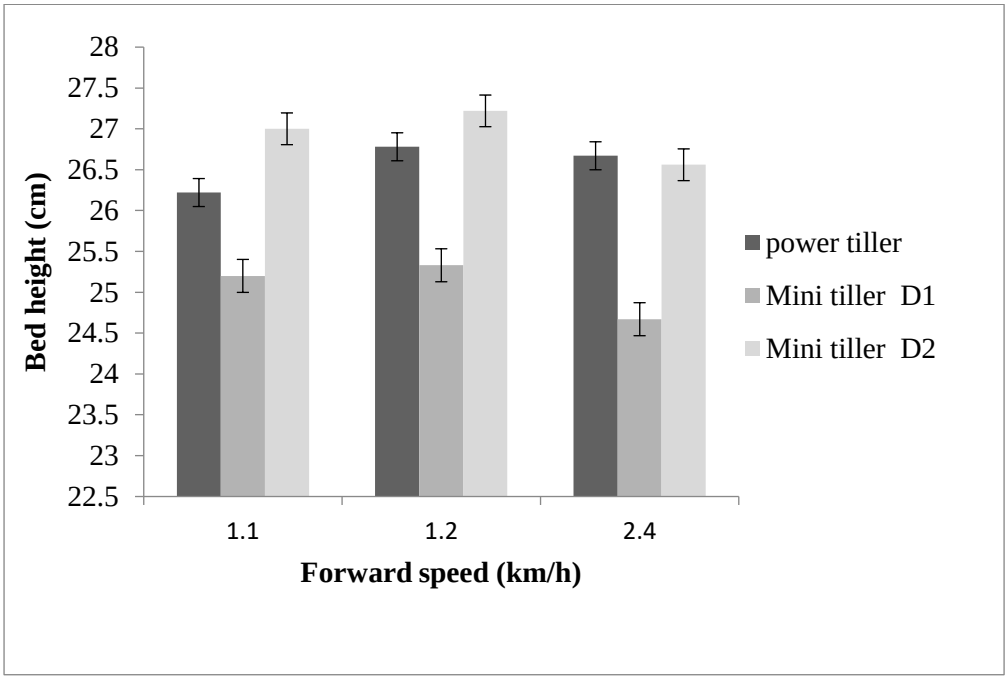

Figure 3. Effect of forward speed and depth on the bed height. Error bars represent standard error of mean.

3.2 Effect of forward speed and depth of implement on the furrow width.

Table 2 shows the impact of forward speed on the furrow width of the bed formed. It is evident that with the increase in forward speed the furrow width consistently increased for both power

tiller and mini tiller attached ridger for making raised bed. Furrow width made by power tiller attached ridger at forward speed of 1.1km/h was significantly narrower than at higher speeds. Regarding the mini tiller attached ridger, no significant differences in furrow widths were observed at both the depths. However, the forward speeds of 2.4km/h played a significant role in the furrow width formed with the widest width of 56.89 and 56.55 cm for depths D1 and D2, respectively. As per the guidebook on vegetable cultivation 2016-2021, it is recommended to maintain the width of the furrow within the range of 50-60cm to facilitate easy weeding and other cultural practices. Our experimental results align with this recommendation except the furrow width formed at the forward speed of 1.1km/h using power tiller attached ridger which recorded 47.67cm only.

Table 2. Furrow width formed at different speed and depth

SN	Forward speed	Power tiller	Mini tiller	
			D1	D2
1	1.1	47.67	54.47	53.33
2	1.2	52.12	54.52	56.89
3	1.4	54.89	55.11	56.55

3.3 Effect of forward speed and depth of the implement on the capacity of the machine

For power tiller attached ridger, its capacity increased significantly with increase in forward speeds. The highest capacity of 4.51acres/day was recorded at the highest speed of 2.4km/h (Figure 4) considering standard working hour of seven hours per day as per the directory of certified farm machinery, 2022. This can be attributed to enhanced efficiency, greater power output of the machine and reduced idle time with increased forward speed. Experiment carried out by Issa, Zhang, El-Kolaly, Yang, & Wang, (2020) also revealed that, the machine capacity increased rapidly by increasing the machine forward speeds and stated the machines forward speed greatly affecting the actual field capacity is the key factor to approach the machine optimum performance.

On the other hand, for mini tiller attached ridger, the machine capacity remained relatively constant across all the forward speeds and depths. This may be due to the cage wheel used for mini tiller which increased the slippage with increase in speed (Hensh, Chattopadhyay, & Das, 2022). The traction developed at the soil-tyre interaction surface provided the required force to overcome the speed and rolling resistance. At a higher speed, the traction of the soil-tyre interaction was not able to supply the required force, which caused an increase in the wheel slippage. The same behavior of the increasing wheel slippage with the increase in the speed

was also reported by Narang & Varshney, (2006), Schreiber & Kutzbach, (2008) and Moitzi et al., (2014).

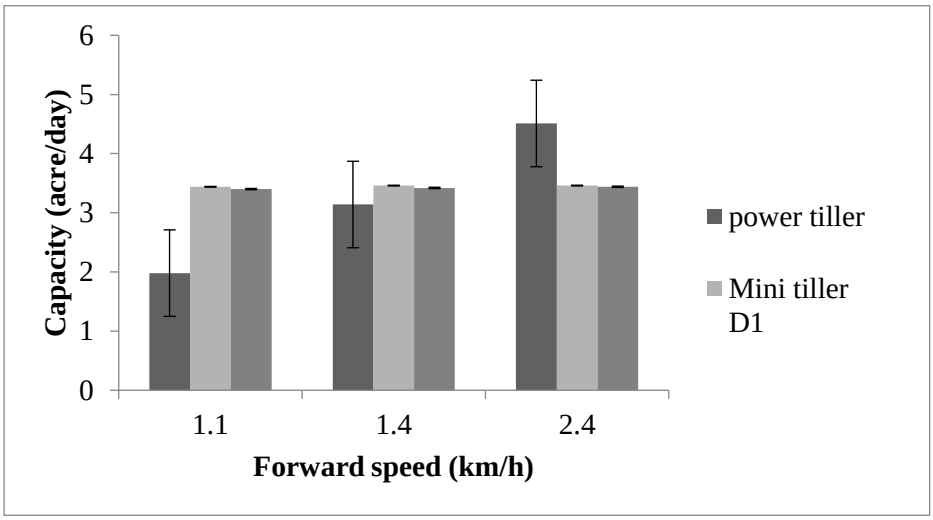

Figure 4. Effect of forward speeds and depths on capacity of the machine. Error bars represent standard error of mean.

3.4 Comparing Bed-Making Machine Productivity to Manual Bed-Making

On an average, a man took 9 minutes 6 seconds to make a raised bed of desired bed dimension which would cover an area of 0.083 acres/ day. While the field capacity of making bed of the same dimension using power tiller at forward speed of 2.4km/h was 4.51 acres/day and that of mini tiller at forward speed of 1.4km/h was 3.14 acres/day which is about 55 and 38 times more efficient than manual labor respectively.

3.5 Economic analysis of the machines

The break-even point for locally fabricated ridgers was noted at 1.03 acres for power tiller-operated bed making and 0.55 acres for mini tiller-attached bed making. As shown in Figure 5, when compared with the cost of manual operation, the break-even point indicated the minimum annual usage that rendered a machine economically viable for bed making at 1.03 and 0.55 acres for power tiller and mini tiller, respectively. This study aligns with the findings of Haquel, M. A., Alam, M., & Sarker, T. R. (2014), where the break-even point of the power tiller bed planter was recorded at 1.2 acres compared to manual operation. Manual operation costs became very expensive mainly due to its very low throughput capacity, as well as its rate of coverage (Table 3). In contrast, power tiller and mini tiller achieved a flat trend owing to

their high throughput capacities. Therefore, the use of machines is economically justified compared to manually making raised beds.

Table 3. Useful life (IS 9164, 1979) and calculated operation cost of farm machines used for the study.

Name of machine	Price (Nu.)	Useful life(years)	Useful hour/year	Fixed cost (Nu./h)	Operating cost (Nu./h)	Total operating cost (Nu./h)	Total cost of bed making (Nu./h)
Power tiller	300,000	10	800	63.63	261.78	325.41	
Ridger	8200	8	125	7.99	2.90	10.89	**336.30**
Mini tiller	150,000	10	800	31.81	196.23	228.04	
Ridger	6600	8	125	6.43	2.33	8.76	**236.80**
Manually	500	5	100	4.89	114.28	119.26	**119.26**

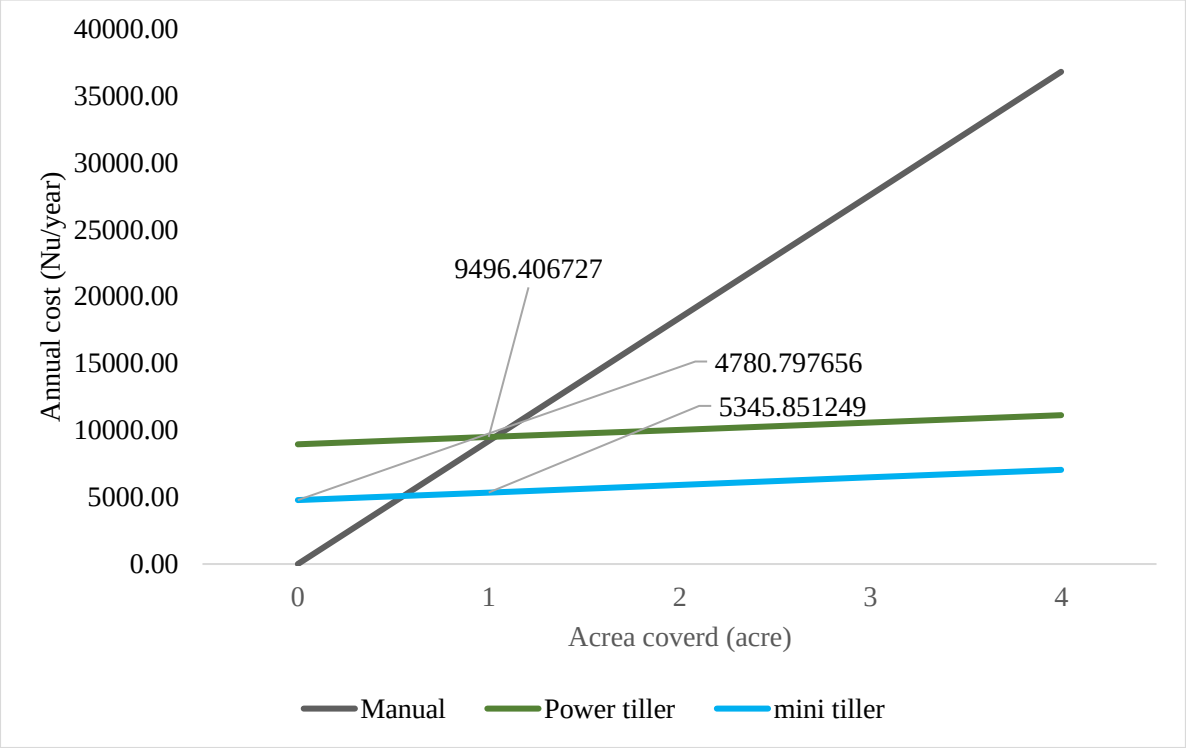

Figure 5. Break even analysis of bed making machines

4 Conclusion

The findings of this study indicates that forward speed had minimal impact on bed height formation for both power tiller and mini tiller attached bed making, with subtle variations observed across speeds. Deeper tillage resulted in higher bed height compared to shallower tillage, while furrow width slightly increased with higher speeds, maintaining a consistent

range except at 1.1 km/h for the power tiller. This study recommends operating the mini tiller attached ridger at 1.1 km/h at any depths, while the power tiller attached ridger is recommended to operate at a speed of 2.4 km/h to achieve optimum bed dimensions and higher field capacities. These insights offer valuable guidance for optimizing the performance of both types of ridgers in bed making across various crops and soil conditions. Mechanized bed making with power tiller and mini tiller significantly outperforms manual labour. Moreover, the breakeven analysis also demonstrates the economic justification of using machines for bed making over the manual labor. This suggests that investing in these locally fabricated machines for bed making would be commercially viable after utilizing them for the specified acreages, indicating the advantages of mechanized bed making in vegetable production.

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Degree of Mechanization in Paddy Cultivation: A Review of Available Data From 2018-2022

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ABSTRACT

Mechanization plays a crucial role in paddy cultivation, however mechanization in Bhutan has rarely been studied. This study aimed to determine the degree of mechanization for different paddy production operations in Bhutan. The degree of mechanization was computed based on the available secondary data. It serves as a quantitative indicator for assessing the extent of mechanization of agriculture operation. The findings showed that the degree of mechanization in paddy production was highest for threshing (69%) followed by land preparation at 67% and milling at 63%. Other operations like weeding, transplanting and reaping were still done predominantly using manual power which is very laborious and cost intensive. The weeding operation exhibited the lowest mechanization at 0.05%, followed by transplanting at 6% and reaping at 19%. There is need to intensively promote mechanization in rice farming.

Keywords: *Mechanization degree; Paddy cultivation; Bhutan; Agriculture operations*

1 Introduction

In Bhutan, rice is the main food crop and is essential to daily life, culture, custom, and religion (Ghimiray et al., 2008). Rice constitutes the most prevalent cereal in the country's dietary intake, despite its lower production volume compared to other cereals (Ghimiray et al., 2008). Rice is grown in 9495.31 ha, with a total production of 40,081 MT of rough rice, with the national average yield at 4.2 MT/ha (NSB, 2021). Rice self-sufficiency ranged between 34.7% and 51.03% (Tashi, Dendup, Ngawang, & Gyeltshen, 2022). This indicates that more than half of rice consumed is imported primarily from India to cover the deficit. If the current production and consumption trends continue, the ratio of rice self-sufficiency is likely to decline steadily in the coming years (Shrestha, 2004; Tashi et al., 2022). Reverting to fallow land, implementing improved high-yielding varieties, increasing irrigation, implementing

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improved plant and soil management techniques, implementing labour-saving technologies, promoting upland rice, and rice double cropping are possible ways to increase production. However, limited arable land to increase rice self-sufficiency is a bigger challenge in Bhutan. The main cereal crops cultivated in Bhutan encompass paddy, maize, wheat, barley, buckwheat, millet, and quinoa. Paddy takes the lead in annual production, yielding an impressive 54,088.41 MT, followed closely by maize with an annual output of 40,964.62 MT(NSB, 2021). Rapid urbanization and migration of agricultural labour to other jobs, and high labour wages are some of the emerging challenges for sustainable rice production as well as food security.

Labour shortages and high labour charge are most pressing issue in paddy cultivation. Farm mechanization has been identified as a significant measure to address this issue. Agricultural mechanization can simply be defined as the use of any machine to accomplish a task or an operation involved in agricultural production (Odigboh, 2000).

For centuries, Bhutan relied on traditional manual farming with hand tools and oxen. Mechanization began in 1964 with Japanese expert Dasho Keiji Nishioka introducing modern techniques (Dorji & Penjore, 2011). With strong support from government and continued Japanese grant support for effective promotion of farm mechanization, the Agriculture Machinery Centre (AMC) was established in 1983. Grants played a vital role in farm mechanization. Farm equipment, which are received as grant aid, were sold to farmers or provided through government hiring services with a subsidy rate of 55-73% approved by the government. The proceeds are either used for agriclture development or for the procurement of other farm machinery to supply to the farming community. The subsidy component includes cost price, transportation, installation, technical backstopping, training, lower interest loan, tax waiver (Thinley, Wangchen, & Sakurai, 2011). Bhutan received two Kennedy Round (KR) Grant aids for overs 25 years starting from 1984, General Grants in 2016 and 2019, and Japanese Non Project Grant Aids in 2008 and 2010. Around 3,423 power tillers and 5,078 other machines were acquired under these grants.

The engagement of private sector has boosted mechanization through enhanced access to farm machinery sales and repair services. The most popular private agricultural farm firm, Ms Sherub Enterprise started the sale of hand tools and small cultivators as early as 1995. Since then, numerous new private enterprises have emerged since 1995, expanding the market considerably. The government has continuously partnered with private farm machinery

suppliers with free certifiction of various machineries and has excampted taxes on all kinds of agricultural machineries. The government also partners with banks to provide affordable loan at low interest rates for farmers to buy agricultural machinery.

Agriculture mechanization reduces drudgery, increases the safety and comfort of the working environment; it enhances productivity, cropping intensity and production. It increases income for agricultural workers and improves social equality and overall living standards. If properly used, mechanization also conserves and properly utilizes natural resources and reduces the cost of production. It allows for timely farm operations and produces better quality agricultural commodities.

The statements above emphasize how important mechanization is for farming. In Bhutan, using machines has helped paddy cultivation in recent decades. Machines save labour and make working conditions better for farmers. Having such benefits, mechanization has potential to attract young people to take up paddy cultivation in Bhutan.

While mechanization plays a pivotal role in agricultural production, there has been limited exploration of the scope of mechanization specifically in paddy cultivation within Bhutan. This knowledge gap underscores the importance of investigating the degree of mechanization in paddy cultivation in Bhutan. The degree of mechanization serves as a quantitative indicator for evaluating the progress of mechanization implementation in farmlands. It is defined as the ratio of the mechanized area achieved to the total cultivated area (Almasi, S. Kiani, & Loui-mi, 2000). The degree of mechanization also implies the extent to which a particular operation within the crop production system is mechanized (e-Krishi-Shiksha, 2022).

This study aimed to determine the mechanization degree for paddy cultivation in Bhutan. By knowing mechanization degree and its trend, it permits to assess the level of adoption among the cultivators. Moreover, such a study would be useful for evaluating the progress of mechanization in rice cultivation and seek improvement in productivity and efficiency, besides assisting the government to formulate relevant policies.

2 Materials and method

The computation of the degree of mechanization in paddy cultivation and its trends was conducted utilizing available secondary data. The machinery inventory data was obtained from AMC, covering the period from 1982 to 2016. Until 2016, AMC managed the sales and national hiring of farm machinery. Subsequently, the Farm Machinery Corporation Limited

(FMCL), a state-owned enterprise, took over these responsibilities. The data collection process involved examining FMCL's sales and hiring reports from 2016 to 2022, along with sales records from prominent private farm machinery dealers in the country for the years 2018 to 2022.

2.1 Degree of Mechanization

Degree of mechanization implies the extent to which a given operation in the crop production system is mechanized. Degree of mechanization is the ratio of mechanization area accomplished to the total area to be cultivated (Almasi et al., 2000; Ghadiryanfar, Keyhani, & Akram, 2009; El Pebrian & Mohiddin, 2021).

The formula of mechanization degree is expressed in percent (%) as:

$$\text{DOM} = \frac{\text{CAF}*\text{N}*\text{Cap}*\text{H}*\text{D}}{A*R} * 100 \quad \text{----------} \quad \text{----------1}$$

CAF- Crop area factor defined as ratio of crop area to total area
DOM – degree of mechanization
N – number of machines in the state
Cap – effective field capacity of the machine, acre/hr.
H – hours of daily work
D – number of days available for performing the operation in a year
R – replications of the machine required
A – crop area, acre

Main assumptions for determining the degree of mechanization for paddy cultivation in Bhutan are:

1. The estimation of the degree of mechanization did not consider the hand tools and animal power used, as they are the basic implements of farmers who rely on manual labour.
2. Each machine replication frequency (R), machine capacity (CAF), working days (D) and life of machine have been generalized based on information collected from National hiring scheme report, farmers, and researchers, as reflected in (Table 1).
3. One working day means eight working hours.
4. The total paddy area (total wet land) amounting to 58569.25 acre (NSB, 2018) was used in this calculation.

5. Degree of mechanization degree of irrigation, pest control and drying has not been worked out due to data limitation.
6. The machinery employed for land development included tractors and power-tillers only.
7. All recorded machines for land development were assumed to be used for paddy cultivation.

Paddy degree of Mechanization was calculated and discussed with respect to these agriculture operations namely Land preparation, Transplanting, Weeding, Reaping, Threshing and Milling.

3 Result and Discussion

3.1 Land preparation

The method of land preparation for rice cultivation in Bhutan is similar to many other Asian rice growing countries. Land preparation typically involves ploughing to till the soil, harrowing to break the soil clods into smaller mass and incorporate plant residue, and puddling to create soft, flooded layer before transplanting rice by churning and tilling the flooded field. Machines used for these three operations involve engine powered tractor, power tiller and mini tiller with specific implements like mould board or disc plough for ploughing, harrow or rotavator for harrowing and rotavator for puddling. Since most of the mini tiller in the country are used for dry land cultivation, it has not been considered in this study. Table 1 presents the details of operations in rice cultivation, while Figure 1 shows the area cultivated and harvested from 2017-22.

Operation/Machines		Field Capacity (ac/hr.)	Daily Working (hrs.)	Working Days Per Year (days)	Replication	Machine Life
Tillage	tractor private hiring	0.30	8	30	3	10
	power tiller private hiring	0.10	8	10	3	10
	tractor govt. hiring	0.10	8	70	3	10
	power tiller govt. hiring	0.30	8	70	3	10
Plantation	transplanter	0.30	8	20	1	6
	direct seeder	0.30	8	30	1	6
Weeding	manual weeder	0.11	8	2	2	10
Harvesting	Reaper	0.30	8	20	1	6
	combine harvester	0.30	8	30	1	10
Threshing	power thresher (kg/hr.)	275	7	25	1	10
	pedal thresher (kg/hr.)	50	7	30	1	10

	combine threshing capacity (kg/hr.)	350	7	30	1	10
Milling	power rice mill (kg/hr.)	150	8	10	1	10
	indigenous rice mill (kg/hr.)	240	8	7	1	10

Table 6. Field capacity, daily working, working day per year, replication and life for different machine used in paddy cultivation

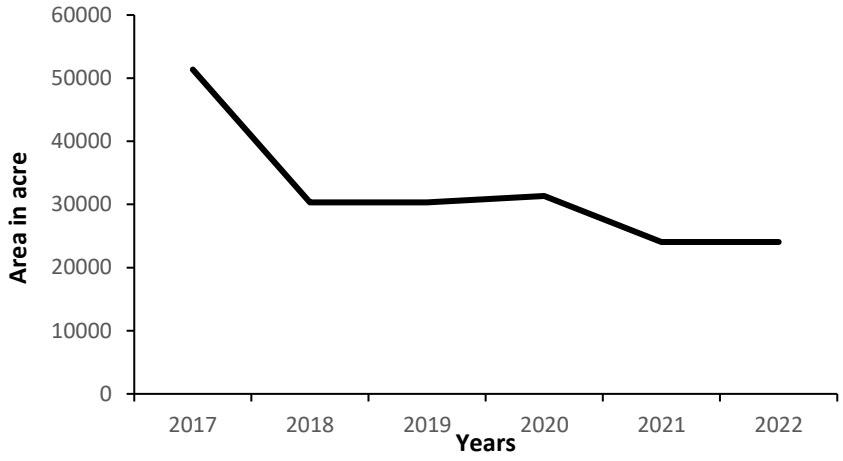

Figure 8. Total paddy harvested area over years

Currently, the degree of mechanization for land preparation stands at 67% (Figure 2). The degree of mechanization in land preparation during paddy cultivation is among the highest, comparable to the mechanization observed in threshing and milling operations. This can be attributed to the widespread availability of power tillers, with an average annual sale of 590 units by private companies. Additionally, the availability of both tractors and power tillers for hire service facilitated by FMCL as well as private hiring service further contributes to high mechanization.

Figure 2 clearly shows that power-tiller is widely used compared to tractor. Because of Bhutan's rugged topography, rice fields are generally narrow terraces (Ghimiray et al., 2013), therefore power tiller and Mini tiller are more suitable compared to tractor. Due to its small turning radius and simple maneuverability for power tillers, they operate better and are more accurate on mountains than four-wheel tractors (Sakai, 2000).

Similarly, degree of mechanization for land preparation has a higher percentage compared to other operation in country like Sri Lanka 100% (Gamlath, Gunathilke, & Chamara, 2018) and Philippines 62% (Malanon & Cruz, 2018).

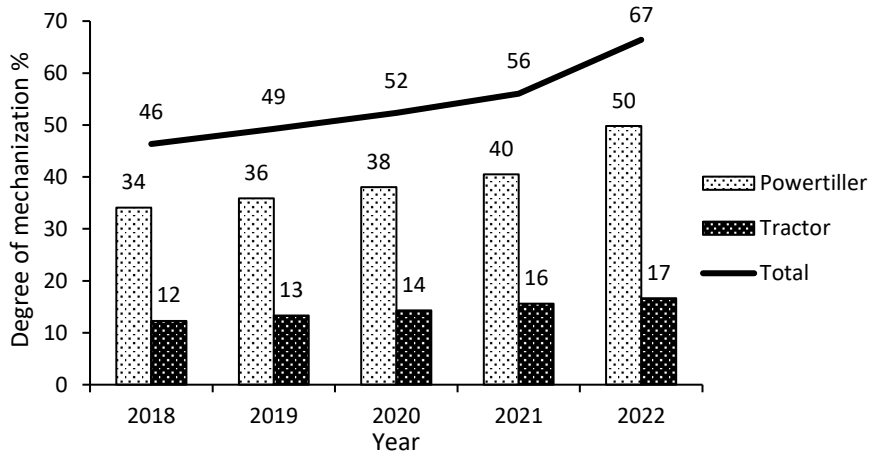

Figure 2. Degree of mechanization of paddy land preparation over years

In Bhutan, mechanization for land development in paddy cultivation has not been fully optimized. Small land holding, undulating topography, socioeconomically vulnerable farmers, limited repair and maintenance service and spare parts availability are major obstacles that stand in the way of the widespread adoption of land development mechanization.

3.2 Transplanting

In Bhutan paddy is transplanted either manually at random or in lines, or by using transplanter machine. Rice is also established by directing seeding using a drum seeder. Degree of mechanization for paddy transplanting stands at a very low level of 6% (Figure 3). This suggests there are very few numbers of engine operated rice transplanter (148) and drum seeders (48) at present. Machine transplanting is mostly done by farmers in Paro, Wangdue and Punakha (DoA, 2019). Transplanters are highly labour effective compared to other methods with reduced labour of 6-man days per acre of field (Dixit, Khurana, Singh, & Singh, 2007).

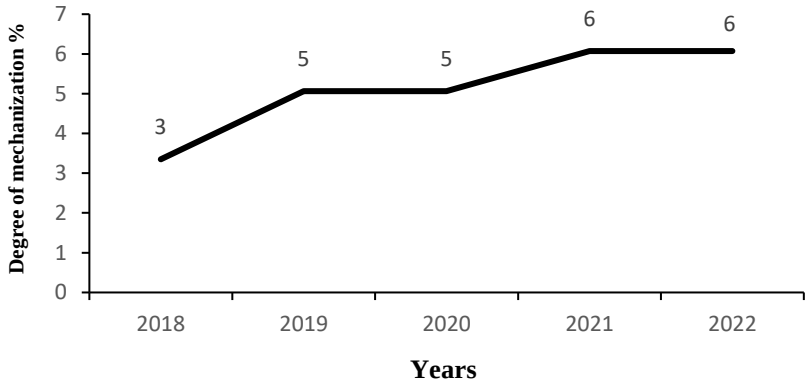

Figure 3. Degree of mechanization for paddy transplanting

Direct seeding of rice is a process of establishing a rice crop from seeds sown in the field rather than by transplanting rice seedlings from the nursery (Akhgari & Kaviani, 2011). There is a cost advantage of 53% for drum seeding ($163/ha) compared to manual line transplanting with reduced labour of 15.5-man days (Dendup & Chhogyel, 2018). Despite the proven labour efficiency and benefits of line planting provided by these machines, they have not gained popularity within the country. The low adoption rate is attributed to its newness and cost factor, resulting in slower adoption. Additionally, farmers who have adopted this technology encounter challenges in maintaining initial irrigation water levels and managing weeds, as reported in their feedback. Transplanting paddy is considered one of the most labour-intensive operations in paddy cultivation. Labour requirement and cost of operation is 33-man days at $ 345/ha for manual line transplanting while it is 29-man days at $306/ha for manual random transplanting (Dendup & Chhogyel, 2018). Scarcity of labour during peak season of transplanting is another major issue.

Based on information gathered from farmers and researchers in Bhutan, the limited adoption of agricultural machines can be attributed to several factors. These include deeply ingrained traditional farming practices and the mindset of farmers, a shortage of trained operators and mechanics, as well as the government's limited provision of machines for hiring. Moreover, long waiting times or unavailability of these machines during peak planting seasons contribute to their restricted usage. Additionally, the machines may not be suitable for small, stoney, irregularly shaped farms, making them less appealing to farmers. Finally, the lack of availability of these machines in the local market also impedes their widespread adoption.

3.3 Weeding

Weeding is uprooting of unwanted plants grown along with paddy in the fields. On average, Bhutanese farmers weed twice in a rice season. The current weed management practices by farmers includes physical, cultural, chemical, and integrated methods (Tshewang, Sindel, Ghimiray, & Chauhan, 2016). In Bhutan, the use of machines or mechanical weeders for weeding purposes is minimal. Among the limited options available, there are manual mechanical tools like the cono weeder, and engine-operated weeders. The availability of these machines is notably limited, with as few as 31 cono weeders and only three power weeders in circulation.

Currently, the level of mechanization in paddy weeding stands at only 0.05% (Figure 4), despite the introduction of mechanical weeders in the early 1990s. However, user adoption has

remained very low till date and has not increased. The low adoption of weeders in Bhutan is mainly due to the paddy plantation method, which is mostly done manually with random planting. The mechanical weeder requires line planting which otherwise damages the crop plants. The paddy transplanter and drum seeder are suitable for planting in straight lines, however their adoption is also low as shown in Figure 3.

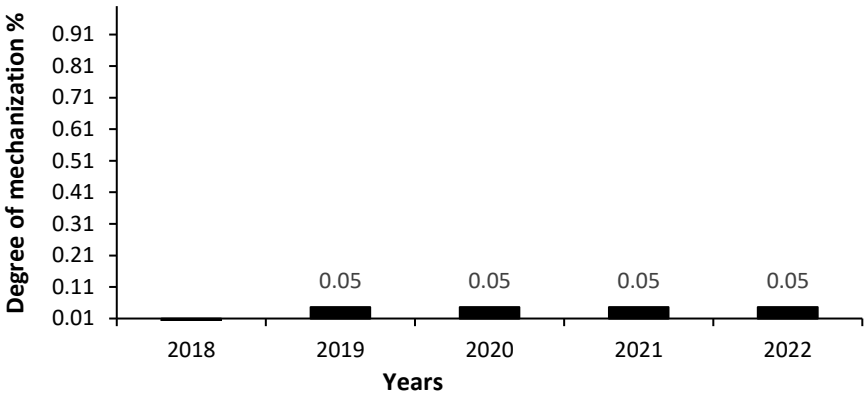

Figure 4. Degree of mechanization for weeding operation in paddy cultivation

Furthermore, in Bhutan, herbicide is most widely used to control weeds in rice. For more than two decades, it has been in use, and its application has consistently increased over time. Generally, there has been extensive adoption of herbicides in rice production systems throughout Asia due to higher profitability (Tshewang et al., 2016). Similar studies conducted in Philippines and Sri Lanka revealed that the degree of mechanization for paddy weeding is remarkably low, standing at only 1% in the Philippines (Malanon & Cruz, 2018) and 2.94% in Sri Lanka (Gamlath et al., 2018). The key reasons for their limited mechanization are due to the factors outlined above. The implementation of row planting or use of transplanter is essential to encourage the use of mechanical weeders which will reduce the labour required in weeding operation as well as reduce the use of herbicides.

3.4 Reaping

The harvesting operation involves cutting of the paddy after it is matured. The harvesting is done both manually using sickles and by use of machine. Harvesting machines such as combine harvester and walk-behind power reaper are used by the farmers. Among these, the walk-behind reaper is particularly valued and commonly owned by individual farmers due to its practicality and efficiency in smaller-scale farming. On contrast, the combine harvester is typically only owned by government hiring services.

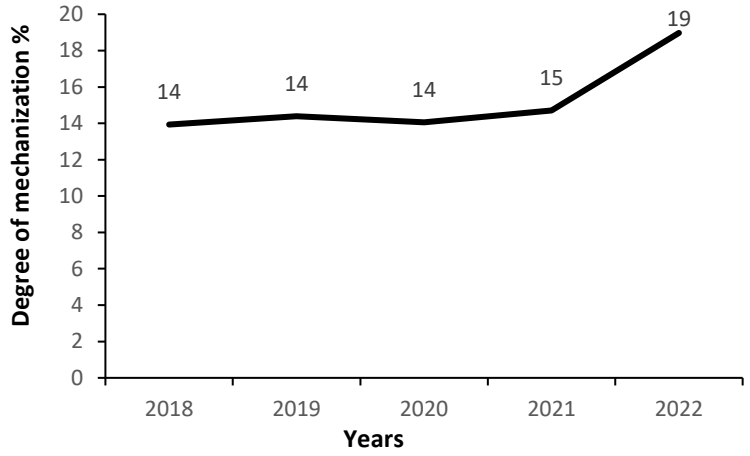

Figure 5. Degree of mechanization for harvesting operation in paddy cultivation

The data presented in Figure 5 indicates constant paddy mechanization degree in harvesting for past three years from 2018 to 2020 and a modest increase only in the year 2022. With the available harvesting machines in the country reaper (176) and combine (37), the current degree of paddy mechanization in harvesting has reached 19%. The low degree of machination in paddy harvesting is because the use of combine harvester in Bhutan is limited due to small terraces, sloppy fields and expensive hiring charges and machines cost. The walk behind reaper is also not much feasible in small and sloppy fields.

The issue can be addressed by promoting affordable hiring services for harvesting machinery like combines and ensuring their availability during peak seasons to marginal farmers and by ensuring the availability of small reapers feasible for small terraces and sloppy fields. Developing paddy fields suitable for bigger machines such as combines and reapers can also pave the way for increased mechanization in the future.

3.5 Threshing

Threshing involves detaching the grains from the panicles. In Bhutan, the machines used for threshing include the pedal thresher, power thresher, and the threshing unit of a combine harvester. The combine harvester is owned only by FMCL and hire charges are high.

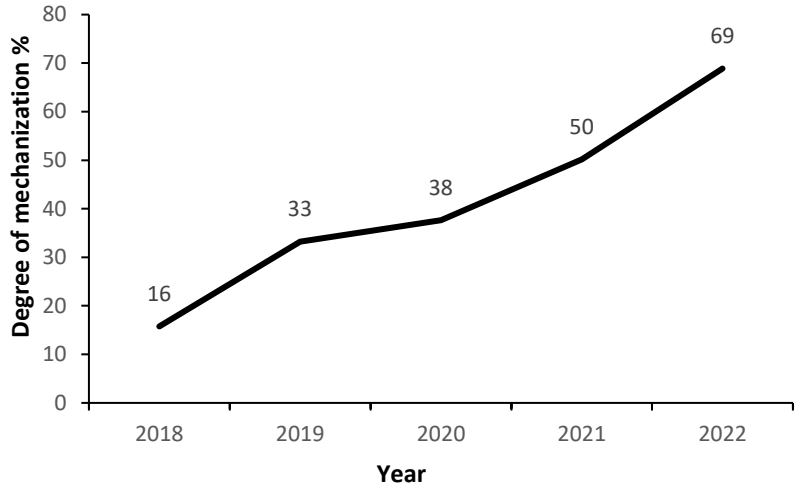

Figure 6. Degree of mechanization for threshing in paddy cultivation

Figure 6 indicates that the level of mechanization in paddy threshing reached 69% in 2022, showing a steady increase over the past five years. The significant rise in the number of machines since 2018 is due to the entry of five new private suppliers in the market. Prior to that, only two companies were selling pedal and power threshers. However, the efficient use of mechanized threshers in paddy farming has not been fully achieved, and in certain regions of the country, especially in the southern areas, traditional methods of threshing paddy are still the preferred choice.

According to Figure 1, there is a consistent decrease in the overall cultivated area over time, with only 41% of the total wetland being cultivated in 2021. At the current stage of cultivation, the existing machines (power thresher: 819, pedal thresher: 584) are sufficient to achieve full threshing mechanization, with a mechanization degree of 168%.

3.6 Post-harvest Milling

In Bhutan, various types of power rice mills are used for rice milling operations. Lately, electrically operated compact rice mills have been gaining popularity due to their easy availability, efficiency, and affordability. Before this, the custom hired Engelberg screw type rice mills were in use.

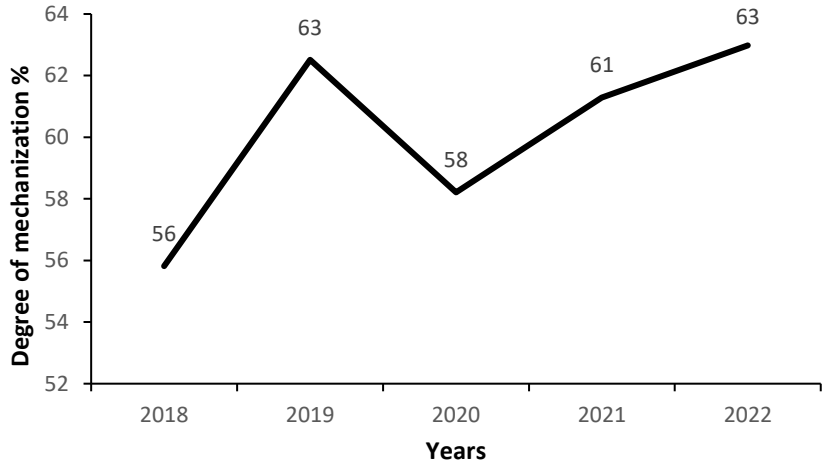

Figure 7. Degree of mechanization in milling for paddy cultivation

The advantages of using machines over traditional methods, such as mortar and pestle, are significantly higher in terms of capacity, labour reduction, total milling output, and decreased operational costs. Consequently, rice mills are becoming increasingly popular among farmers.

At the current stage of cultivation (24055 acre), existing machines are adequate, resulting in a mechanization level of 153%. If paddy cultivation covers the country's total wetland (58569.25 acre), the degree of mechanization in rice milling operations stands at 63% as shown in Figure 7.

4 Conclusion

Mechanization of paddy cultivation operations has been promoted for almost four decades since it was first introduced in the 1980s. This study delved into the implementation of mechanization in paddy farming in Bhutan, investigating the current degree of mechanization. Paddy is the only crop in the country where nearly all agricultural operations deploy machinery. Operations such as land preparation (67%), threshing (69%) and milling (63%) were more mechanized compared to reaping (19%), transplanting (6%) and weeding (0.05%). Similar observations were made in Asian countries like Sri Lanka and Philippines. Over the past five years, a noticeable and gradual increase in the degree of mechanization has been observed. This shift is attributed to the easy access and increased sales of machines like power tillers, power threshers, and rice mills.

Numerous private companies entered the market since 2018 to sell farm machinery. As of now, we have nine well-established private companies that are successfully running and providing quality farm machinery. In terms of operations with high potential for mechanization,

transplanting (6%), weeding (0.05%) and harvesting (19%) were the three next labour-intensive farm operations that are expected to be affected by the diminishing farm labour. Hence, intensive promotion of mechanization for these three operations is an urgent need to enhance the degree of mechanization, and to minimize farm labour shortages. The effort requires a strong collaboration between relevant agencies such as research and academic institutions, farm machinery manufacturers, dealers and related government agencies to create mechanization technologies from technical, economical, geographical, topographical and agronomic aspects.

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Evaluation of Commercial Sex Pheromone Lures for Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) Monitoring in Bhutan

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ABSTRACT

The fall armyworm has rapidly spread to 11 Dzongkhags in Bhutan by September 2023 since its first detection in 2019. This concerning spread highlights the critical need for comprehensive monitoring strategies. However, there is still a notable gap in understanding the seasonal behavior of fall armyworm in Bhutan, including its response to commercially available sex pheromone lures. Hence, the current study aimed to evaluate the effectiveness of seven commercially available sex pheromone lures (SPFR2111, SPFR2112, SPFR2113, SPFR2114, SPFR2115, PCI and Ecotech) in monitoring fall armyworm in maize fields in Sarpang, Punakha and Chukha Dzongkhags in 2023. The study employed a descriptive observational approach to monitor fall armyworm moth populations in maize fields. Phero T-traps (funnel traps) with specific lures were placed fifty meters apart in maize fields at a density of five traps per acre and positioned approximately 1.5 meters above ground level. The number of fall armyworm moths and non- target species captured by seven lures differed across various locations. Overall, SFPR2114, PCI, and Ecotech lures were more effective in trapping fall armyworm moths based on mean ranks. The lure SPFR2113 and SPFR2112 captured the lowest number of non-target species, while PCI captured the highest number. The peak of fall armyworm moth capture was in April in all the monitoring locations, signifying the need for timely monitoring and scouting during this vulnerable crop growth stages. The study's findings suggest the use of SPFR2114, SPFR2113, SPFR2112 and Ecotech lures for monitoring fall armyworm populations in Bhutan, particularly during the crucial period of April when there is a notable surge in moth captures for effective fall armyworm monitoring.

Keywords: *Maize; Monitoring; Pheromone lures; Population abundance; Spodoptera frugiperda*

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1 Introduction

The fall armyworm (FAW), *Spodoptera frugiperda* (Lepidoptera: Noctuidae) is a polyphagous pest that damages over 300 plants from 76 families (Montezano et al., 2018). Higher FAW damage is observed in maize, sorghum, rice, cotton, and pasture grasses (Montezano et al., 2018). It was first detected in Africa in 2016 and subsequently spread to Asia (Goergen, Kumar, Sankung, Togola, & Tamò, 2016; Sharanabasappa. et al., 2018; FAO, 2019). The rapid worldwide spread can be attributed to its robust flying ability (capable of covering over 100 km per night), high fecundity rate (with a single FAW female laying up to 1000 eggs), and broad host range (Murúa, Molina-Ochoa, & Coviella, 2006; Song et al., 2020). Furthermore, FAW do not diapause hence they can migrate to new places with suitable environmental conditions (Du Plessis, Schlemmer, & Van den Berg, 2020). Currently, two genetic strains of *S. frugiperda* i.e., corn strain and rice strain have been reported in Africa (Goergen et al., 2016). In Bhutan, FAW was first observed damaging maize in Dabchegang and Pepchu villages in Guma Gewog and Mendugang in Dzomi Gewog in Punakha in September 2019 (Mahat, Mitchell, & Zangpo, 2021). Currently, FAW has been detected damaging maize in 15 Dzongkhags (Chukha, Punakha, Paro, Thimphu, Mongar, Dagana, Wangdiphodrang, Lhuentse, Sarpang, Trashigang, Trashi Yangtse, Samdrup Jongkhar, Tsirang, Zhemgang and Trongsa).

FAW cause direct yield losses by feeding on the ears of the maize and cobs (Harrison, 1984) as well as indirect losses through defoliation (Day et al., 2017). Furthermore, FAW feeding on grains can attract saprotrophic and pathogenic fungi leading to mycotoxin contamination (Farias et al., 2014). Approximately 18 million tonnes/year of corn were lost to FAW damage in 12 African countries (Harrison et al., 2019), making up 21–53% of annual corn production (Montezano et al., 2018). Hence, it is crucial to develop sustainable monitoring strategies to manage FAW (Gebreziher & Gebreziher, 2020).

Pest monitoring is a crucial starting point in designing Integrated Pest Management (IPM) Programme (Prasad & Prabhakar, 2012). Pheromone based monitoring and surveillance are crucial for early detection of pests, aiding in forecasting their movement (Prasanna, Huesing, Eddy, & Preschke, 2018). Moreover, pheromone trapping saves time by reducing laborious sampling and unnecessary insecticide use (Cruz, Figueiredo, & Silva, 2010). Early detection and timely crop protection measures, facilitated by sex pheromone trapping, are pivotal for successful FAW management. The female FAW releases sex pheromones by exposing the last

abdominal segments (Cruz-Esteban, Rojas, & Malo, 2017), which triggers mating behaviour in males (Jacobson, Redfern, Jones, & Aldridge, 1970). This sexual communication between male and female moths is used in pest identification, mass trapping and mating disruption (Cardé & Minks, 1995; Witzgall, Kirsch, & Cork, 2010). Synthetic compounds emulating natural FAW pheromones (lure) in traps attract and trap male moths. Most of the commercial FAW lures contain three pheromone components: Z9-14: OAc; Z11-16: OAc; and Z7-12: OAc (Bratovich, Saluso, Murúa, & Guerenstein, 2019).

Currently, the FAW seasonal activity in Bhutan is still notably underexplored. Despite global attention to FAW management, there exists a significant gap in understanding its behaviour in Bhutan. This gap extends to investigating FAW's response to different commercially available sex pheromone lures. Hence, this research aimed to address the dual knowledge gaps by investigating into the uncharted territory of FAW's seasonal activity patterns in Bhutan using commercially available sex pheromone lures and simultaneously examining the potential of different lures as a mean of enhancing FAW monitoring strategies. Thus, this study aims to contribute not only to the local understanding of FAW dynamics but also to the broader global discourse on integrated pest management practices.

2 Materials and Methods

2.1 Study sites

The monitoring was conducted in 2023 in maize fields across multiple gewogs: Samphelling (Khempaithang and Sonamthang) in Chukha, Guma (Dapchagang) in Punakha, Gakiling (Rilanthang and Khopitar) and Singye (Shariphu and Yarpheling) in Sarpang Dzongkhag.

2.2 Pheromone traps and lures

Phero T-traps (Funnel trap) with specific lure were used for trapping male fall armyworm moths. A total of seven commercial pheromone lures manufactured by three companies were used in the study. These included the FAW Lure produced by Gaiagen Technologies Private Limited in India (PCI), Harmony Ecotech Private Limited (Ecotech) and the SPFR2111, SPFR2112, SPFR 2113, SPFR 2114, and SPFR2115 lures, all manufactured by Pherobank BV based in the Netherlands (Figure 1)**.**

Figure 9. Different lures used for monitoring

2.3 Traps and lures deployment in the field

This study employed a descriptive observational approach, focusing on monitoring fall armyworm captures with different pheromone lures in farmers' fields without altering any variables like maize varieties or fertilizer application. Phero T-traps (Funnel trap) with specific lure were placed 50-meter apart in the maize field and approximately 1.5 meters above ground level. Five pheromone traps per acre was used for trapping from seedling stage until crop maturity. The height of the pheromone traps was adjusted according to the growth stage of the maize plants, with the traps being raised as the maize plants matured. This was done so that the scent of the pheromone lure is carried across the tops of the maize plants by the wind. Pheromone lures were changed monthly using nitrile gloves to prevent contamination as well as lures losing strength over time generating misleading trap catches.

Table 1. Study sites and types of lures used

Dzongkhag	Gewog	Study site	Altitude	Types of lures used	Study period
Sarpang	Gakidling	Rilangthang	690 m	SPFR2111 and SPFR2112	March – June, 2023
Sarpang	Gakidling	Khopitar	752 m	SPFR2113, SPFR2114, SPFR2115, and PCI	March – June, 2023
Sarpang	Singye	Shariphu	326 m	SPFR2111, SPFR2112, SPFR2113, and PCI	March – June, 2023
Sarpang	Singye	Yarpheling	326 m	SPFR2114 and SPFR2115	March – June, 2023
Chukha	Samphelling	Khempaithang	305 m	'PCI' and Ecotech lures	February – June 2023
Chukha	Samphelling	Sonamthang	288 m	'PCI' and Ecotech lures	February – June, 2023

Punakha	Guma	Dapchagang	1350 m	SPFR2111, SPFR2112, SPFR2113, SPFR2114 and SPFR2115	March – June 2023

2.4 Data collection

All the male fall armyworm moths captured in the traps were emptied at fortnightly intervals and recorded. They were identified in the laboratory based on the morphological characteristics. Beneficial insects such as parasitoids, predators, and spiders trapped were collectively recorded as 'beneficial insect species'. All other captured pest's species such as *Spodoptera spp., Mythimna spp., Phragmites spp.* and *Helicoverpa* s*pp*., were recorded as "other pest species".

The categories 'beneficial insect species' and "other pest species" were merged to create a new category 'non-target species" to assess the species specificity of the different lures. To assess changes in FAW population and abundance, the sum of male moth captures from different traps in each village was calculated fortnightly. This was done for precise monitoring of population shifts during the study, irrespective of lure differences.

2.5 Statistical Analysis

JASP 0.18 was used for the analyses of the pheromone trap data. The analyses were performed for whole study period data for overall performance of the lures, and fortnightly analyses for differences in trap captures for all the study sites as site specific comparisons due to use of non-uniform treatments in different sites. The trap captures of different categories were subjected to Kruskal-Wallis H test (with Dunn's post hoc test if significance were observed) for Data from Dabchegang, Gakidling and Singye while data from Sampheling was subjected to Mann-Whitney U test (with post hoc-Wilcoxon signed-rank test if significance was observed) at 95% confidence. These tests were performed because data did not follow a normal distribution, even after applying transformations (log10(x+0.5), log10(x+0.05), and log(x+1)). The significant pairs of lures were further ranked after adjusting p-value (Bonferroni corrections).

3 Results and Discussion

3.1 Fall armyworm trap capture

The result presented in Table 2 shows variability in the trapping efficiency of the lures in different study sites. In Gakidling, SPFR2114 was preferable (Table 3). In Singye, the lure PCI

was preferable (Table 4). The lures from Harmony Ecotech showed similar efficiency to PCI for trapping fall armyworm in Sampheling (Table 5).

Table 2. Fall armyworm moth (number) captured by different lures in various locations

Gewog	Sex pheromone lures							
	SPFR2111	SPFR2112	SPFR2113	SPFR2114	SPFR2115	PCI	Ecotech	Total
Guma	46	17	12	64	95	x	x	234
Gakidling	4	18	21	64	20	25	x	152
Singye	9	38	21	30	17	62	x	177
Sampheling	x	x	x	x	x	1,130	639	1,769
Total	59	73	54	158	132	1,217	639	2,332

*Note: The symbol "x" is used to indicate where no specific lure was used.

The principle component of the female sex pheromone of *S. frugiperda* is (Z)-9-tetradecenyl acetate (Z9-14:Ac) and (Z)-7-dodecenyl acetate (Z7-12:Ac) (Tumlinson, Mitchell, Teal, Heath, & Mengelkoch, 1986). The variability in trapping outcome may have resulted from variations in pheromone composition of lures developed for FAW within a specific geographical regions (El-Sayed et al., 2003; Batista-Pereira et al., 2006). For example, sex pheromone lures manufactured in Central America were not effective in trapping in Brazil (Andrade et al., 2000) and Mexico (Malo et al., 2001). Weather factors such as temperature, evaporation and wind speed can also impact the trap catch by influencing the insect activity (Muthukumar & Kennedy, 2021). Furthermore, habitat composition such as different maize varieties and crops grown in the vicinity of pheromone trapping site could have influenced the response of the males to pheromone lures (Cruz-Esteban, Rojas, & Malo, 2020). The results of individual locations are highlighted below.

Dabchegang, Guma: The trap captures were not significantly [H = 2.143 (4, n = 125), p = 0.710] different amongst the different lures for the overall season.

Gakidling: The overall data comparisons showed significant differences [H17.358, (5, n=30), p = 0.004]. The Dunn's post hoc showed a significant difference between the pairs SPFR2111-SPFR2114 ($p < 0.001$, $p_{bonf} = 0.002$). From the post hoc comparisons, the lure SPFR2114 was preferable.

Table 3. Dunn's post hoc comparisons for means of male FAW moths captured by different lures in Gakidling

Comparison	Z	W_i	W_j	p_{bonf}
PCI - SPFR2111	1.091	125.956	112.678	1.000
PCI - SPFR2112	-1.641	125.956	145.933	1.000
PCI - SPFR2113	-0.732	125.956	134.867	1.000
PCI - SPFR2114	-2.734	125.956	159.233	0.094
PCI - SPFR2115	-0.688	125.956	134.333	1.000
SPFR2111 - SPFR2112	-2.732	112.678	145.933	0.094
SPFR2111 - SPFR2113	-1.823	112.678	134.867	1.000
SPFR2111 - SPFR2114	-3.825	112.678	159.233	0.002
SPFR2111 - SPFR2115	-1.779	112.678	134.333	1.000
SPFR2112 - SPFR2113	0.909	145.933	134.867	1.000
SPFR2112 - SPFR2114	-1.093	145.933	159.233	1.000
SPFR2112 - SPFR2115	0.953	145.933	134.333	1.000
SPFR2113 - SPFR2114	-2.002	134.867	159.233	0.680
SPFR2113 - SPFR2115	0.044	134.867	134.333	1.000
SPFR2114 - SPFR2115	2.046	159.233	134.333	0.612

Singye: Significant differences in overall trap captures were seen (H = 13.412, df = 5, = 270, p = 0.02), particularly in the PCI-SPFR2111 pair (p_bonf = 0.012).

Table 4. Dunn's post hoc comparisons for different lures in Singye gewog

Comparison	Z	W_i	W_j	p_{bonf}
PCI - SPFR2111	3.355	158.778	115.100	0.012
PCI - SPFR2112	1.048	158.778	145.133	1.000
PCI - SPFR2113	1.851	158.778	134.678	0.962
PCI - SPFR2114	2.016	158.778	132.533	0.657
PCI - SPFR2115	2.458	158.778	126.778	0.209
SPFR2111 - SPFR2112	-2.307	115.100	145.133	0.316
SPFR2111 - SPFR2113	-1.504	115.100	134.678	1.000
SPFR2111 - SPFR2114	-1.339	115.100	132.533	1.000
SPFR2111 - SPFR2115	-0.897	115.100	126.778	1.000

SPFR2112 - SPFR2113	0.803	145.133	134.678	1.000
SPFR2112 - SPFR2114	0.968	145.133	132.533	1.000
SPFR2112 - SPFR2115	1.410	145.133	126.778	1.000
SPFR2113 - SPFR2114	0.165	134.678	132.533	1.000
SPFR2113 - SPFR2115	0.607	134.678	126.778	1.000
SPFR2114 - SPFR2115	0.442	132.533	126.778	1.000

Sampheling: The overall FAW capture of the two lures was significantly different (p = 0.049, z = -1.98, Md Ecotech = 6, Md PCI = 15, n1 = n2 = 24).

Table 5. Wilcoxon test for comparison of means of male FAW moths captured at Sampheling

Measure 1	Measure 2	Test	Statistic	z	p	Effect Size	SE Effect Size
Ecotech	PCI	Wilcoxon	65.500	-1.980	0.049	-0.482	0.239

**Note.* For the Wilcoxon test, effect size is given by the matched rank biserial correlation.

3.2 Efficacy of the lures in relation to species specificity

Beneficial insects captured by different lures

The capture of beneficial insects varied across various locations, depending on the type of lure used (Table 6). PCI lure captured the highest number of beneficial insects (n=255). Numerous studies have demonstrated that FAW pheromone lures capture non-target insects such as beneficial species and other insect pests (Adams, Murray, & Los, 1989; Malo et al.,2001;Reyes-Prado, Segura, Martínez-Peralta, & Sosa, 2020). The sparse captures of beneficial insects might be attributed to a case of mistaken identity, where they could misinterpret the fall armyworm pheromone scent as their own, needing further investigation. Moreover, some beneficial insects are generalist predators or parasitoids that feed on various insects, including fall armyworm, and their attraction to pheromone lures may result from the presence of fall armyworm, also needing further investigation. The limited capture of beneficial insects further suggests that the use of lures may not adversely impact beneficial insect populations.

Table 6. Beneficial insects (number) captured by different lures in various locations

Location	Sex pheromone lures							
	SPFR2111	SPFR2112	SPFR2113	SPFR2114	SPFR2115	PCI	Ecotech	Total
Guma	0	1	0	0	0	x	x	1
Gakidling	29	58	35	24	27	208	x	381
Singye	57	29	42	43	30	23	x	224

Sampheling	x	x	x	x	x	24	65	89
Total	86	87	77	67	57	255	65	694

*Note: The symbol "x" is used to indicate where no specific lure was used.

The results of individual site are highlighted below.

Dabchegang: Only in one incidence was the capture of beneficial insect (*Chelonus spp.*) was seen for SPFR2112. No other lures captured the beneficial insects.

Gakidling: Beneficial (generalist natural enemy species) insects were caught by all the traps which had the lures for the study. There were no significant differences between the trapping of the beneficial insects [H= 66.813 (5, n = 30), p = 0.235].

Singye: Beneficial insects were also captured by all the lures used. There were no significant differences among the trap captures for beneficial insects [H = 4.067(5, n = 30), p = 0.54] for overall data.

Sampheling: The beneficial insects were also captured by the lures but no significant differences between the captures of the two lures [p = 0.89, z = 1.74, Md Ecotech = 1.5, Md PCI = 0, n1 = n2 = 24].

Other pest species captured by different lures

The lure SPFR2111 captured the highest number of other pest species followed by lure SPFR2115 and lure SPFR2112 (Table 7). The Harmony EcoTech and PCI lures captured fewer other moth species than others. The other pests' species trapped were *Phragmites spp., Spodoptera spp., Helicoverpa spp*., and *Mythimna spp*.

Table 7. Number of other pest species captured by the lures in various locations

Location	Sex pheromone lures							
	SPFR2111	SPFR2112	SPFR2113	SPFR2114	SPFR2115	PCI	Ecotech	Total
Guma	0	0	0	0	0	x	x	0
Gakidling	24	5	5	7	12	4	x	57
Singye	9	9	7	6	7	3	x	41
Sampheling	x	x	x	x	x	1	5	6
Total	33	14	12	13	19	8	5	137

*Note: The symbol "x" is used to indicate where no specific lure was used.

Dabchegang: No other pest species were captured during the study period.

Gakidling: Other pests' species such as *Mythimna spp.* and *Spodoptera spp.* were trapped. There was significant difference in the trap capture of other moth species [H = 11.185 (5, n = 30), p = 0.048] but post hoc comparisons with adjusted p-values showed no significant differences among the trap captures.

Singye: There were no significant differences in the trap capture of other moth species [H = 2.5 (5, n = 30), p = 0.775]. Other pest species captured belonged to *Phragmites spp., Mythimna spp.* and *Spodoptera spp.*

Sampheling: There was no significant differences in the trap capture of other pest species [p = 0.35, z = 1.095, Md Ecotec = Md PCI = 0, n1 = n2 = 24].

Non-target species captured by different lures

The result presented in Table 8 show the number of non-target species captured by seven lures in various location. The non-target species captured were beneficial insects like *Chelonus spp.* and other pests' species such as *Mythimna spp.* and *Spodoptera spp.*

Table 8. Non-target species captured by lures in various locations

Location	Sex pheromone lures							
	SPFR2111	SPFR2112	SPFR2113	SPFR2114	SPFR2115	PCI	Ecotech	Total
Guma	0	1	0	0	0	x	x	1
Gakidling	1007	295	172	448	605	1,380	x	3,907
Singye	534	247	132	587	408	1,005	x	2,913
Sampheling	x	x	x	x	x	45	78	123
Total	1,541	543	304	1,035	1,013	2,430	78	6,944

*Note: The symbol "x" is used to indicate where no specific lure was used.

Guma: The only incidence of non-target species trapped was seen for one trap with lure SPFR2112 where an adult *Chelonus spp.* was trapped.

Gakidling: The trap captures were significantly different [H = 23.032 (5, n = 30), p < 0.001] in the pairs PCI-SPFR2112 (p_{bonf} = 0.022), PCI-SPFR2113 (p_{bonf} < 0.001) and SPFR2111-SPFR2113 (p_{bonf} = 0.01) (Table 9). SPFR2113 and SPFR2112 lures caught the fewest non-target species on average, while PCI lure had the highest number of non-target species captures.

Table 9. Pairwise mean comparisons of the non-target species captured by different lures in Gakidling

Comparison	z	W_i	W_j	p_{bonf}
PCI - SPFR2112	3.180	26.500	8.800	0.022
PCI - SPFR2113	4.042	26.500	4.000	< .001
PCI - SPFR2114	2.246	26.500	14.000	0.371
SPFR2111 - SPFR2112	2.533	22.900	8.800	0.170
SPFR2111 - SPFR2113	3.395	22.900	4.000	0.010
SPFR2113 - SPFR2115	-2.299	4.000	16.800	0.322

Singye: There were significant differences [H = 25.986 (5, n = 30), p < 0.001] amongst the non-target species trap captures by different lures. The pairwise mean comparisons (Table 10) indicated the significant differences for the pairs PCI-SPFR2112 (p_{bonf} = 0.008), PCI-SPFR2113 (p_{bonf} < 0.001), and SPFR2113-SPFR2114 (p_{bonf} = 0.013). From the comparisons, SPFR2113 had the least mean trap capture of non-target insects while PCI had the largest mean trap capture.

Table 10. Pairwise mean comparisons for the non-target organisms captured by lures in Singye

Comparison	z	W_i	W_j	p_{bonf}
PCI - SPFR2112	3.448	27.600	8.400	0.008
PCI - SPFR2113	4.418	27.600	3.000	< .001
PCI - SPFR2115	2.479	27.600	13.800	0.198
SPFR2111 - SPFR2113	2.802	18.600	3.000	0.076
SPFR2112 - SPFR2114	-2.371	8.400	21.600	0.266
SPFR2113 - SPFR2114	-3.341	3.000	21.600	0.013

Sampheling: The trap captures of Harmony EcoTech and PCI were not significantly different (p = 0.215, z = 1.254, Md Harmony EcoTech = 2.5, Md PCI = 0.5, n1 = n2 = 24)

Seasonal dynamics of male fall armyworm moths

The seasonal population dynamics of the FAW population showed a consistent pattern across all the study sites, with peak trap capture observed around mid-April and then later declining towards May and June. The synchronized population rise in mid-April seems to be due to the availability of its primary host plant, young maize plants in all the monitoring sites. FAW damage was more severe at the young growing phase such as seedling and early whorl stages (Kareem, Anjorin, Odeyemi, & Akinbode, 2022). On contrary, their population declined during

the late spring and early summer suggested a potential effect of heavy downpours on fall armyworm. Rainfall traps moths and drown them in maize whorls and pupation tunnels such as soils (Sims, 2008).

Dabchegang, Guma, Punakha

The FAW population at peaked at around mid-April (about 400 male moths). However, the trap capture declined towards the latter half of April and further declining through May, and June (Figure 2).

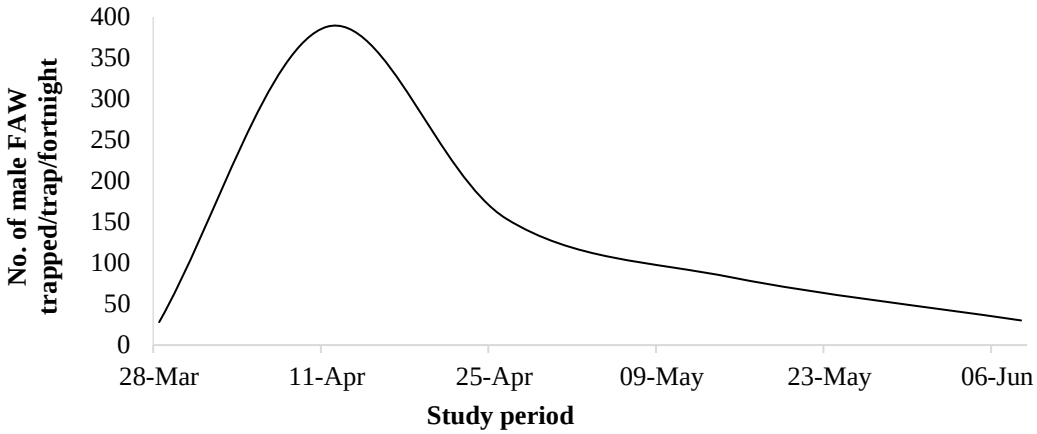

Figure 2. Population trend of male FAW moths at Dabchegang

Sampheling, Chukha

The trap capture of male FAW moths showed similar trend to that of Dabchegang, where the population showed peaked in the April and declined towards the end of the study period (Figure 3). The largest trap capture for Khempaithang was in later half of April (920 moths). The moth population declined towards June.

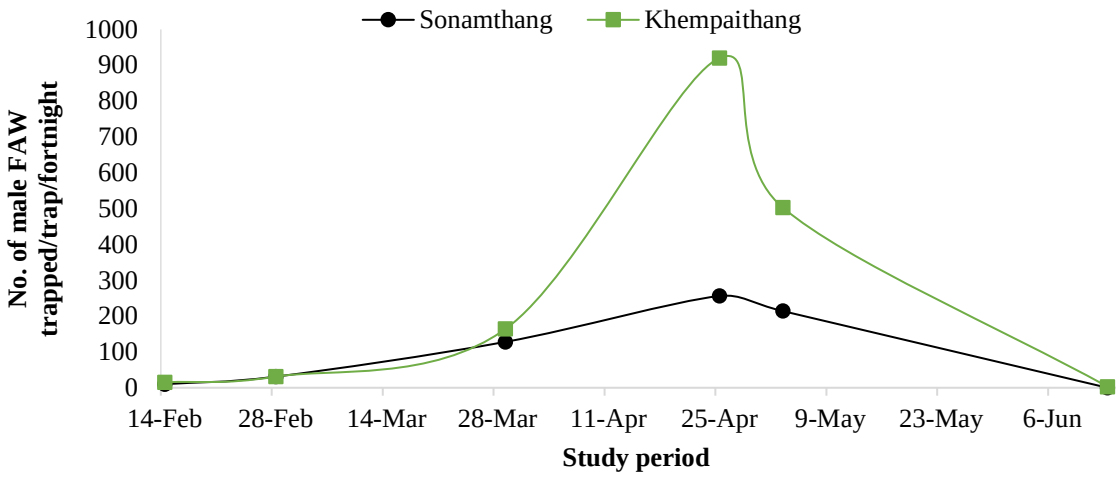

Figure 3. Population trend of male FAW moths at two villages of Sampheling, Chukha

Gakidling, Sarpang

The FAW moth population trend varied among the villages (Figure 4). At Rilangthang, the trap capture was highest (24 moths) towards the latter half of April and declined sharply towards June. At Khopitar, FAW population fluctuated throughout the study period. The peaks were seen in the first half of April (34 moths), first half of May (42 moths) and last half of May (23 moths).

Singye, Sarpang

The FAW population remained fairly minimal at Shariphu throughout the study period (Figure 4). The largest capture of FAW moths was seen in the first half of April (n=21 moths) and latter half of May (n=19 moths). For Yarpheling, the FAW population remained low in March and April but peaked in the latter half of May. The largest trap capture was 43 male FAW moths during the fourth week of May.

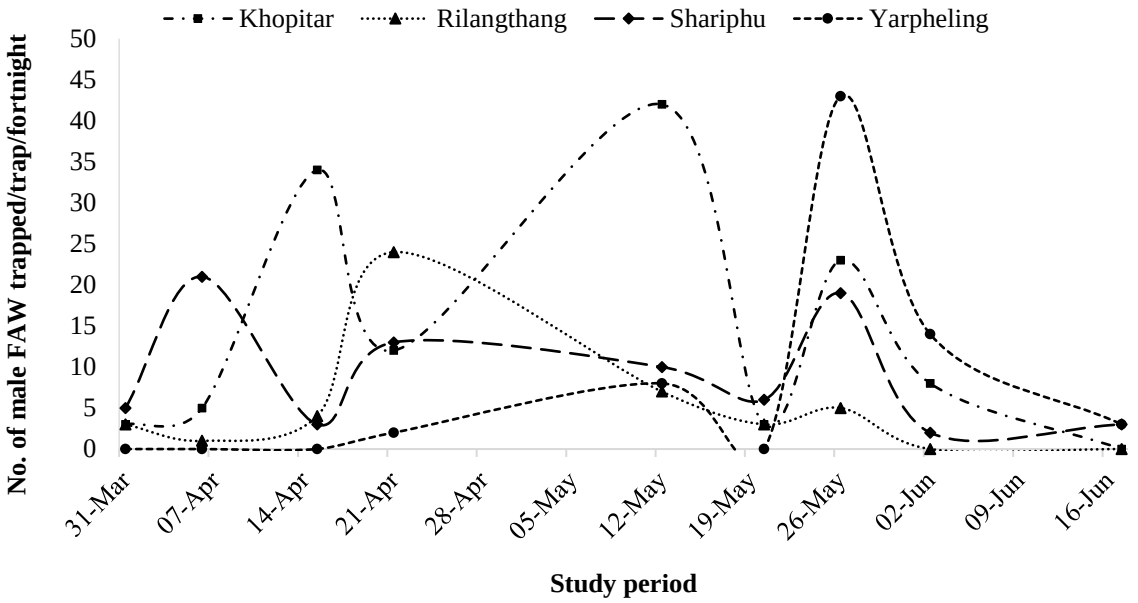

Figure 4. Population trend of male FAW moths in different villages of Gakidling and Singye, Sarpang

4 Conclusion

This study investigated the efficacy of seven pheromone lures in capturing fall armyworm moths in maize fields. Lure effectiveness varied across locations, but SFPR2114, PCI, and Ecotech lures caught the most fall armyworms. SPFR2113 and SPFR2112 caught the fewest non-target species, while PCI attracted the most. April saw peak moth captures in all locations, highlighting the need for monitoring and targeted control during this critical crop stage. Based on these findings, we recommend using SPFR2114, SPFR2113, SPFR2112, and Ecotech lures for fall armyworm monitoring in Bhutan, especially in April when captures spike. These lures can be valuable tools for early detection and studying population dynamics of fall armyworm. Their selectivity in attracting the target species while minimizing the capture of non-target beneficial insects makes them particularly suitable for precise monitoring. Understanding these population dynamics provides valuable insights for devising effective strategies to mitigate the impact of fall armyworm on maize during critical growth stages. Future studies should investigate factors impacting lure efficacy across various locations, explore integrating lures with other monitoring methods for holistic pest control, and evaluate the cost-effectiveness of lure-based strategies for smallholder farmers for sustainable crop protection.

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Screening for Heat and Rain Tolerant Cultivars of Cauliflower for Cultivation in Monsoon Season in the Subtropical Region of Bhutan

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ABSTRACT

There is a shortage of cauliflower in the domestic market during monsoon and early autumn seasons in Bhutan due to the absence of suitable cultivars for cultivation in subtropical region during these seasons. This study was conducted to assess the genotypic variability in yield of different cultivars of cauliflower under heat and rain (flood) stresses in the subtropical region. Four F1 hybrid varieties of cauliflower from the Takii Seeds, Japan (KSB-12.179, KSB-12.180, KSB-18.297 and KSB-20.320) and three F1 hybrid varieties from Syngenta Seeds, India (C-6099, CFL-1522 and Monsoon Queen) were evaluated in August 2022 in open field at ARDC Samtenling. The experiment was laid out in a RCDB design with three replications using Snow Mystique as the check variety. The objective of the study was to identify short duration, rain and heat tolerant varieties of cauliflower for cultivation in the monsoon season (July-August) in the subtropical region of Bhutan. In addition, all the cultivars were further assessed in September, and five cultivars that performed well in monsoon planting were evaluated in November 2022 as the second and third staggered planting trials to find out their performance in late monsoon and main seasons (September-November) respectively. The results from three staggered trials showed that Monsoon Queen matured in 53 days after transplanting (DAT), 56 DAT and 35 DAT in the first, second and third staggered planting trials with the mean head of 462 g, 376 g and 211 g respectively. In comparison, the check variety matured in 142 DAT, 114 DAT and 77 DAT in the first, second and third staggered planting trials with the mean head of 658 g, 403 g and 767 g, respectively. Monsoon Queen was the earliest maturing variety with good head weight and curd quality among the eight cauliflower varieties when transplanted in August 2022. However, both the head yield and curd quality of this cultivar declined in later plantings, indicating that this variety is not suitable for main season (autumn) planting. With the identification of Monsoon Queen as the heat and rain tolerant cultivar in this study, cauliflower can now be grown even in the monsoon season in the subtropical region of Bhutan.

Keywords: *Cauliflower; Heat tolerant; Rain tolerant; Variety; Short duration, Yield*

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1 Introduction

Cauliflower (*Brassica oleracea* var. *botrytis* L.) is one of the most important vegetable crops in Bhutan. Cauliflower, broccoli and cabbage are cole crops which are usually grown during the cool winter season. They prefer temperature of about 7 to 13^{o}C for optimal growth and development (AVRDC, 1990). In Bhutan, the area under cauliflower was 1,228 acres with the total production of 2,447.8 metric tons in 2021 (RSD, 2020). Curd is the edible part which is consumed as vegetables, eaten fresh as salad and also used in preparing pickles, fried snacks, burger and sandwich (Ashraf et al., 2017; Warland, McKeown, & McDonald, 2006). Cauliflower is rich source of vitamins and minerals like phosphorus, potash, calcium, sodium and iron which can protect from cancers, heart diseases and also help to maintain the cholesterol level and immune system of the body if consume regularly (Keck & Finley, 2004).

Cauliflowers varieties currently cultivated in Bhutan are mostly hybrids suitable for cultivation in autumn for harvest in winter, except for two hybrids namely Pragati 40 and White Express 50 which are recommended for spring season. In Bhutan, currently there are no suitable cauliflower varieties recommended for cultivation from July to September. Cauliflower is highly sensitive to climatic factors that influence the formation and growth of the curds. Based on temperature requirement, they are classified into early, mid and late season groups. Early varieties of cauliflower require higher temperature (20-25°C) for curd formation, while late varieties require lower temperature of 10-16°C (Chatterjee & Mahanta, 2013). The temperature above 25°C adversely affects the formation of curd that results in poor qualities or defective curds in the late varieties (Aleem et al., 2021; Swiader, Ware, & McCollum, 1992). Cool-season varieties of cauliflower cannot thrive under prolonged periods of warm weather, so there is no cauliflower production during the summer months in subtropical region of Bhutan. Thus, there is a good market opportunity for summer-grown cauliflower in this region of Bhutan if varieties tolerant to heat-induced disorders are identified. In cauliflower, the commonly observed high temperature induced disorders include bract development (development of small green leaves in the head), uneven head development, ricyness, bolting and brown/purple beads. However, the initiation of curds in cauliflower also depends on the genetic characteristics of the varieties (Saini, 1996).

Plant breeders have recently developed several new cauliflower varieties with improved heat tolerance over the more traditional varieties. According to Wang et al. (2011), the three main groups of cauliflower are:

a). European/temperate cauliflowers

i. Traditional cool-season varieties of cauliflower that perform well only in cold winter (temperature above 20°C adversely affects curd formation).
ii. Medium to late maturing varieties with curd head weight greater than 1.5 kg.
iii. Require lower temperature of 10-16°C for curd formation.
iv. If the temperature remains high, the plant will continue remain in vegetative phase without forming any curd.

b). Asian/Indian/tropical cauliflowers

i. Grow well in warm weather (heat tolerant).
ii. Early maturing cauliflowers which can harvested within 50-65 days.
iii. Require higher temperature (20-25°C) for curd formation.
iv. Usually small sized curd head (> 1 kg).

c). Semi-tropical cauliflowers

i. Intermediate between European and Asian cauliflowers in growth habit.
ii. Head weight ranges between 1.0 to 1.5 kg.

With the ban on import of green chillies, snap beans and cauliflowers to Bhutan from June 2016 due to a high residual content of pesticides, there is an urgent need to have early, heat and rain tolerant cauliflower cultivars in the country to make domestically grown cauliflower available in the market in late monsoon and early autumn seasons. All the existing cauliflower cultivars are of medium-late maturing varieties which perform well only during cool winter season. High temperature and waterlogging are the major abiotic stresses that hinder cauliflower cultivation during monsoon in the subtropical region of Bhutan. On the other hand, the heat tolerant cultivars of cauliflower can form heads at mean temperatures higher than 25°C (Collado-González, Piñero, Otálora, López-Marín, & Del Amor, 2020). Thus, early varieties of cauliflower that perform well in heat and rain for autumn harvest are needed to fill the gap in the domestic market. Over the past decade, there have been considerable increases in cauliflower production in the tropics and subtropics because of the availability of new, tropically adapted cultivars, resulting in increased farmer incomes (Lin, Chen, Li, & Lo, 2015).

The objective of this study was to introduce and identify heat and rain tolerant varieties of cauliflower that mature within two months for cultivation in monsoon season in the subtropical region of Bhutan for autumn harvest.

2 Materials and Methods

2.1 Cauliflower varieties and nursery management

Four F1 hybrid varieties of cauliflower introduced from the Takii Seeds, Japan and three F1 hybrid varieties from Syngenta Seeds, India were evaluated for their heat and rain tolerances at Agriculture Research and Development Centre (ARDC) Samtenling in RCDB design with three replications using the non-heat tolerant variety of cauliflower, Snow Mystique, as the check in open fields in August 2022 in the first staggered planting trial (Table 1). In addition, those cauliflower varieties that performed well and harvested within two months after transplanting in monsoon cultivation were further evaluated in the main season by transplanting in September (second staggered planting) and in November 2022 (third staggered planting) to assess their performance under autumn and winter plantings. The primary objective of second and third staggered planting trials was to find out the performance of the heat and rain tolerant genotypes of cauliflower that perform well in monsoon season when planted in autumn and winter seasons (September–November).

Table 1. Cauliflower varieties screened in three staggered planting trials in 2022 at ARDC Samtenling

Variety	Crop type	Seed source	Staggered planting trial
Snow Mystique (*)	F1 hybrid	Takii Seeds, Japan	1, 2 & 3
KSB-12.179	F1 hybrid	Takii Seeds, Japan	1 & 2
KSB-12.180	F1 hybrid	Takii Seeds, Japan	1 & 2
KSB-18.297	F1 hybrid	Takii Seeds, Japan	1, 2 & 3
KSB-20.320	F1 hybrid	Takii Seeds, Japan	1 & 2
C-6099	F1 hybrid	Syngenta seeds, India	1, 2 & 3
CFL-1522	F1 hybrid	Syngenta seeds, India	1, 2 & 3
Monsoon Queen (C-6105)	F1 hybrid	Syngenta seeds, India	1, 2 & 3

(*) Non-heat and rain tolerant (main season) check variety

Seeds of all cauliflower cultivars were sown in the plastic nursery plug trays (having 16 holes per tray) filled with FYM, topsoil and sand in 2:1:1 proportion in a greenhouse. The nursery was raised on 5 July, 15 August and 31 October 2022 for first staggered planting, second

staggered planting and third staggered planting, respectively at Agriculture Research and Development Centre (ARDC) Samtenling, Sarpang. Seedlings with four to six true leaves were transplanted in the trial fields on 18 August, 21 September and 30 November 2022 as the first staggered planting, second staggered planting and third staggered planting, respectively.

2.2 Experiment site, experiment design and data recording

Screening trial was conducted at the research farm (N $26^0$54'40", E 90°25'33"; elevation 375 m) of ARDC Samtenling. Seedlings of each cultivar with four to six true leaves were transplanted in the trial at a spacing of 60 x 45 cm (plant x row) in all three staggered trials. The treatments were arranged in a randomised complete block design (RCBD) and each treatment were replicated three times. Each plot was a raised bed of 25 cm high, measuring 2.25 m long by 1.0 m wide. The plots were separated by 50-cm-wide drains to facilitate drainage of rain run-off water. There were two rows in each plot, accommodating a total of 10 plants in each plot and five plants in each row. All the experimental plots were mulched with silver-coloured plastic mulch film before the planting of seedlings. The field trial had border rows on four sides, each border consisting of two rows of plants of Snow Mystique cultivar. The data were not collected from these border row plants. The standard cultural and management practices for cauliflower were followed. Briefly, 12.5 tonne/ha of well decomposed farm yard manure (FYM) was incorporated to the field at the time of field preparation. Fertilizer 50 kg N, 80 kg P_2O5 and 75 K_2O per hectare were applied before final land preparation. In addition, 50 kg urea was applied in two equal split doses at 30 and 45 days after transplanting. Irrigation was given immediately after planting and later as and when required. Weeds from the field were removed from the field by hands at 20, 35 and 45 days after transplanting (DAT).

2.3 Data collection

The data were collected from all 10 plants in each plot for all the parameters included in this study. Plant height was recorded just before the harvest by measuring the distance from the ground to the top (tallest leaf) of each plant. Days to harvest (maturity) and curd colour were also recorded at the time of harvest. Plants were harvested as and when they matured and were harvested at full maturity stage when the heads became smooth, firm and compact. The data on head (curd) weight per plant and yield per plot were recorded in each plot during harvest.

Yield per plot was converted to tonne per acre (t/acre). Incidence of major pests and diseases were also observed and recorded in all three staggered planting trials.

2.4 Data analysis

The data were subjected to analysis of variance (ANOVA) using the PROC MIXED procedure of the Statistical Analysis System (SAS) (version 9.4; SAS Institute, Cary, NC, USA). Multiple comparisons among the means were conducted using Fisher's protected least significant differences (LSD) test when effects were statistically significant ($p < 0.05$).

3 Results and Discussion

3.1 Major pests and diseases

The main pests and diseases observed in the trials were cabbage webworm (*Hellula undalis*), bacterial soft rot (*Pectobacterium carotovorum*, previously called *Erwinia carotovora* var. *carotovora*), black leg (*Phoma lingam*) and black rot (*Xanthomonas campestris)* (Table 2).

Table 2. Pests and diseases observed in three staggered planting trials of cauliflower

Variety	Pests and diseases incidences (%) in 3 staggering trials			
	Bacterial soft rot	Blackleg	Black rot	Cabbage webworm
Monsoon Queen	10 (1)	10 (1)	0	0
CFL-1522	10 (1)	10 (1)	10 (1)	10 (1)
C-6099	10 (1)	10 (1)	10 (1)	0
KSB-12.179	10 (1)	10 (1)	10 (1)	10 (1)
KSB-18.297	20 (1)	10 (1)	10 (1)	10 (1)
KSB-12.180	20 (1)	10 (1)	10 (1)	10 (1)
KSB-20.320	20 (1)	20 (1)	10 (1)	10 (1) & 15 (2)*
Snow Mystique	20 (1)	20 (1)	10 (1)	15 (1) & 10 (2)*

*****Number in parenthesis ( ) indicates the staggered planting trial

3.2 Yield and yield components

The data on plant height, maturity date, head weight and head yield of all seven varieties of cauliflower evaluated at ARDC Samtenling in three staggered planting trials are presented in Table 3, Table 4 and Table 5.

Table 3. Crop maturity duration and yield of cauliflower varieties in the first staggered planting trial (planted on 18 August 2022)

Variety	Maturity		Head wt. (g)	Yield/ plot (kg)	Yield/ acre (kg)	Plant height (cm)
	Date	DAT				
Monsoon Queen	10 Oct 2022	53 e	462 ab	3.903	6,581	41.7 e
CFL-1522	14 Oct 2022	57 e	441 ab	3.881	6,544	46.4 cde
C-6099	24 Oct 2022	67 d	475 ab	3.027	5,104	43.4 de
KSB-12.179	7 Nov 2022	81 c	538 ab	4.304	7,258	50.7 cb
KSB-18.297	4 Nov 2022	78 c	283 b	2.520	4,249	49.6 cde
KSB-12.180	22 Dec 2022	126 b	501 ab	2.829	4,770	61.9 b
KSB-20.320	27 Dec 2022	131 b	476 ab	3.559	6,001	51.6 c
Snow Mystique	7 Jan 2023	142 a	658 a	3.289	5,546	70.6 a
CV (%)	---	5.2	11.6	12.2	---	8.1
P-value	---	<0.0001	0.0140	0.4214	---	<0.0001

Table 4. Crop maturity duration and yield of cauliflower varieties in the second staggered planting (planted on 21 September 2022)

Variety	Maturity		Head wt. (g)	Yield/plot (kg)	Yield/ acre (kg)	Plant height (cm)
	Date	DAT				
Monsoon Queen	6 Nov 2022	46 b	376.4 ab	3.542 ab	5,973	45.3 bc
CFL-1522	25 Nov 2022	65 b	324.7 b	2.976 ab	5,018	46.1 bc
C-6099	26 Nov 2022	66 b	349.7 ab	3.497 ab	5,897	44.4 c
KSB-12.179	4 Dec 2022	74 b	374.2 ab	2.971 ab	5,010	49.0 abc
KSB-18.297	7 Dec 2022	77 b	335.8 b	2.468 b	4,162	52.0 ab
KSB-12.180	29 Dec 2022	99 a	530.9 a	4.247 a	7,162	49.5 abc
KSB-20.320	30 Dec 2022	100 a	533.2 a	3.905 ab	6,585	53.6 a
Snow Mystique	13 Jan 2023	114 a	403.2 ab	3.067 ab	5,172	54.7 a
CV (%)	---	10.6	12.5	11.7	---	7.4
P-value	---	0.0002	0.0087	0.0304	---	0.0235

Table 5. Crop maturity duration and yield of cauliflower varieties in the third staggered planting (planted on 30 November 2022)

Variety	Maturity		Head wt. (g)	Yield/plot (kg)	Yield/ acre (kg)	Plant height (cm)
	Date	**DAT**				
Monsoon Queen	4 Jan 2023	35 c	210.9 b	1.533 c	2,585	32.3 c
CFL-1522	23 Jan 2023	54 b	361.7 b	1.952 c	3,292	53.7 b
C-6099	4 Jan 2023	35 c	240.2 b	2.145 c	3,617	35.3 c

KSB-18.297	8 Feb 2023	70 a	621.9 a	5.241 b	8,838	59.4 b
Snow Mystique	15 Feb 2023	77 a	767.3 a	7.395 a	12,470	68.8 a
CV (%)	---	7.1	12.3	11.5	---	7.5
P-value	---	<0.0001	<0.0001	<0.0001	---	<0.0001

In the first staggered planting (18 August 2022), Monsoon Queen and CFL-1522 matured in 53 and 57 DAT respectively (Table 3). This maturity date of these two cultivars was statistically significant from other cauliflower cultivars. The mean head weight of Monsoon Queen and CFL-1522 were 462 g and 441 g respectively, but not statistically different from the highest weight (658 g) recorded in check cultivar (Snow Mystique). No severe pests and diseases in these two cauliflower cultivars. Their calculated productions per acre were 6,581 kg and 6,544 kg respectively. The check variety (Snow Mystique) took the maximum days after planting (142 DAT) for head maturity having the mean head weight of 658 g in the first staggered planting corresponding to the productivity of 5,546 kg per acre. The months of August and September were very hot with rain events occurring sporadically and sometimes heavy (data not shown) leading to increased levels of pest and disease incidences in non-heat and rain tolerant genotypes (Table 2). This high pest and disease and incidences coupled with hot growing conditions resulted in a low number of plant survival producing low head yield per plot by those cultivars. Consequently, Snow Mystique with highest mean head weight (658 g) did not produce the highest yield per plot in the first staggered planting trial.

In second staggering planting, the maturity ranged from 46 DAT to 114 DAT among cultivars, the earliest and the latest maturing cauliflower cultivars being Monsoon Queen and Snow Mystique, respectively (Table 4). The mean head weight of Monsoon Queen (376 g) was statistically not significant from other cultivars. Although the maturity of CFL-1522 not statistically significant from that of Monsoon Queen, it had lower head weight (325 g) that was significantly different from the KSB-20.320 that produced the highest head weight (533 g) in the second staggered trial. The days taken by KSB-12.180, KSB-20.320 and Snow Mystique for maturity were significantly different from the rest cauliflower cultivars in the second staggered planting trial.

The earliest maturing cultivar in the third staggered planting was Monsoon Queen with maturity duration of 35 DAT. However, some fuzziness and buttoning of curd were observed in this genotype (Figure 2c) but more of these physiological disorders recorded in CFL-1522,

thereby lowering the marketable yield of cauliflower head. As in the first and second staggered plantings, Snow Mystique took the maximum number of days (77 DAT) for head maturity (Table 5, Figure 1a).

All the cultivars matured earlier in the second and third staggered plantings than in the first staggered planting except CFL-1552 that took eight days more for maturity in the second staggered plantings (Figure 1a). Similarly, the head weights of all the cultivars were lower in the second staggered planting except three cultivars (KSB-18.297, KSB-12.180 and KSB-20.320) in comparison to that of the first staggered planting. There was increase in head weight only in KSB-18.297 (622 g) and Snow Mystique (767) in the third staggered planting compared to that in the first staggered planting (Figure 1b). The mean heads of Monsoon Queen in the second and third staggered planting trials were only 81% (376 g) and 46% (211 g) respectively in comparison to its first staggered planting (462 g). Similarly, the mean head weight of CFL-1522 was only 74% (325 g) and 82% (362 g) in the second and third staggered planting trials respectively in comparison to its first staggered planting (441 g).

The growth and development of cauliflower is classified into three stages: vegetative phase, curd initiation phase and curd development phase (Bhattarai, Pardhan, Chalise, & Piya, 2014). Cauliflower varieties or lines also generally differ in the requirement of temperature for curd initiation (Ara, Kaisar, Khalequzzaman, Kohinoor, & Ahamed, 2009). Temperature plays an important role in cauliflower influencing all these phases. Wurr, Fellows and Phelps (1996) suggested that the optimal temperature for curd initiation is lower in cauliflower types that mature in the summer than in those that mature in winter. The present study identified that the temperatures between 20℃ and 22℃ are good for curd formation for Monsoon Queen, the newly introduced heat and rain tolerant genotype of cauliflower. Further, this study found that only heat tolerant genotypes (Monsoon Queen and CFL-1552) were able to develop curd at high temperature, while the heat susceptible genotypes (Snow Mystique and KSB-18.297) were not able to develop curd at high temperature. Earliness in curd maturity is critical to marketability and profitability because less time from planting to harvest corresponds to reduced cost of production (mainly cost associated with pest control and weeding) and increased market value. In this study, the cultivars suitable for monsoon cultivation, Monsoon Queen and CFL-1552, expressed physiological disorders like buttoning and fuzziness of curd when planted in the main (winter) season.

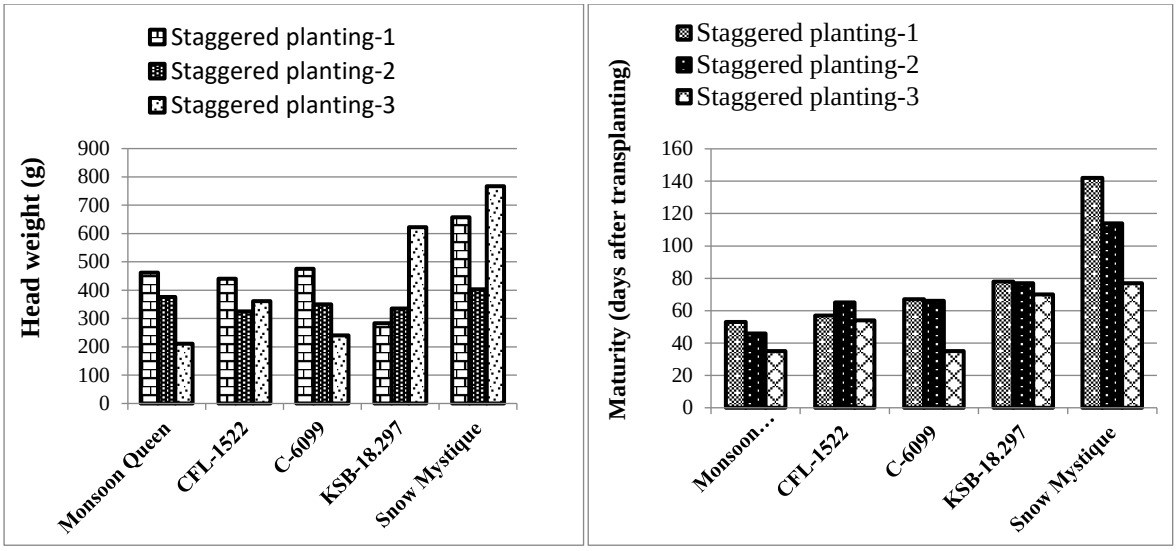

Figure 1. Curd head weight (left) and head maturity duration (right) of different cultivars of cauliflower in first, second and third staggered planting trials

With the development of tropical Indian hybrids cauliflowers, cultivation of cauliflower is possible throughout the year in India (Islam, Datta, & Chatterjee, 2016). The finding of this study is in line with that of Lin, Chen, Chen, Lee and Hsieh (2019) who reported that the cultivars of tropical cauliflower initiated curd development but with a different pattern from temperate cultivars when grown in cool season. Cebula Cebula, Kalisz and Kunicki (2005) suggested that the period before curd formation is shorter in early-maturity cultivars than in late-maturity cultivars in moderate climates. Another study reported that the number of leaves required to induce curd initiation was less than nine in tropical cauliflower at temperatures of 18 to 30℃ (Wurr, Fellows, & Fuller, 2004). For the conventional varieties of cauliflower, the optimum temperature for young seedlings is around 25℃ which at later growing stage drops to 20℃ for curd formation (Chatterjee & Mahanta, 2013; Kindo & Singh, 2018). However, if the temperature remains high (higher than required for curd formation), the plant will continue to remain in vegetative phase without forming any curd (Lin et al., 2019). In the present study, cauliflower cultivar Snow Mystique took 142 days for maturity after transplanting when planted on 18 August 2022 but it took only 77 days when transplanting was carried out on 30th November 2022.

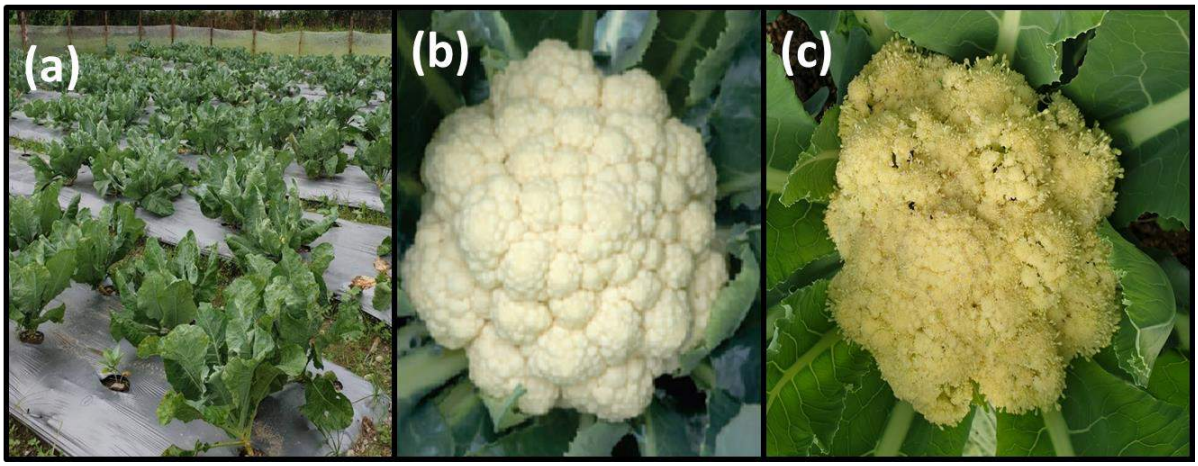

Figure 2. Plants (a) and curd head (b) of cauliflower cultivar Monsoon Queen in the first staggered trial and curd head (c) in the third staggered trial

In summary, the head weight and yield of heat tolerant genotypes of cauliflower, Monsoon Queen and CFL-1552 declined with each successive delay of transplanting date among the three transplanting dates (18th August, 21st September, and 30th November). Thus, the transplanting of Monsoon Queen variety between August and September is recommended for obtaining quality curd and maximum yield. Meanwhile, transplanting the cool season, cauliflower cultivar (Snow Mystique) in November matured early and produced the highest yield with lesser incidence of pests and diseases in this study. The findings of this study indicate that selection of varieties and optimum planting time are the key factors for high yield and quality curd production of cauliflower. The future study may focus on earlier transplanting dates (June-July) to see the curd quality and performance of Monsoon Queen for early monsoon cultivation in the subtropical region of Bhutan. In addition, economic analysis of cultivation of heat and rain tolerant genotypes of cauliflower during monsoon season is recommended.

4 Conclusion

The results from three staggered planting trials in different months confirmed that cauliflower cultivars Monsoon Queen and CFL-1552 were of shorter duration, tolerant to heat and rain stresses suitable for planting during monsoon season. These varieties produced good quality curd with marketable head weight and matured within 65 DAT when planted in August and September. However, the head weight of CFL-1552 was lower (325 g) than that of KSB-20.320 that produced the highest head weight (533 g) in the second staggered trial. On the other hand, the check cultivar, Snow Mystique which matured in 77 DAT in November

transplanting with the highest head weight among three staggered plantings was found indisputably suitable for autumn cultivation. Based on the results, Monsoon Queen was released in the 25th VRC of the Department of Agriculture, held in June 2023 in Thimphu. Release of this variety can extend cauliflower growing season in the subtropical region of Bhutan. With the identification of this early maturing, heat and rain tolerant cauliflower variety, maize-cauliflower-beans cropping system will likely emerge as the most economical cropping system in the dryland for southern foothill region of Bhutan as these three crops can be cultivated within a year in sequence. Further, this newly introduced cultivar of cauliflower could offer market opportunity in the region because of their good head size and excellent curd quality for monsoon cultivation.

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Evaluation of the off-season production of bulb onion (*Allium cepa* L.) in Mongar

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ABSTRACT

Bulb onion is one of the important commercial crops cultivated by the farmers in all the districts, and onion has been identified as one of the mandatory vegetable crops in Bhutan. The crop requires about five to six-month growing period from sowing till harvest. The harvest season coincides with the onset of the monsoon season and post-harvest losses due to high humidity and poor post-harvest management are high. With steady demand for the crop throughout the year and low domestic production, the current production cannot meet the market demand. Hence, substantial quantities of bulb onion are imported. Promotion of off-season bulb onion production with the harvest season during the dry season could minimize post-harvest losses and make it available in the market all year round. The objective of this experiment was to evaluate two bulb onion varieties, namely Pune Red and Pink onion 1358 for off-season production. The experiment was conducted at Lingmethang (600 masl) and Wengkhar (1650 masl) in the 2022 cropping season in a Randomized Complete Block Design (RCBD) with three replications and two treatments. The results indicate a significant difference ($P < 0.05$) in bulb height, weight, plant height, and neck diameter but no significant difference in bulb width. The maximum bulb weight 306.7 g was recorded at the Lingmethang station in the Pink 1358 variety. The yield obtained was 18.68 MT/acre for Pink 1358, 19.20 MT/acre for Pune Red at Lingmethang station, and 13.35 MT/acre for Pink 1358, 13.08 MT/acre for Pune Red at Wengkhar station. However, there was no significant difference ($P >0.05$) in yield in both stations. This study found that bulb onion production is feasible between August to March months in the mid-elevations upto 1650 masl. However, the best location for bulb onion production would be in the lower elevation where the yields are higher compared to the mid-elevation.

Keywords: *Bulb onion; Variety; Bulb characteristics; Yield*

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1 Introduction

Onion (*Allium cepa* L.) which is also called bulb onion belongs to the Amaryllidaceae family and most widely cultivated species of this genus. The crop is believed to have originated from Central Asia and it is a widely grown and consumed vegetable in the world (Saxena & Kumar, 2023). Bulb onions have gained importance due to its cash crop value and high export potential. Onion is mostly used as a spice during the preparation of different dishes such as meat, vegetables, and dal. It is also consumed as fresh salad and used in preparation of pickles. It is characterized by its distinctive flavour and pungency which is due to Allylpropyl disulphide, a sulphur-containing compound found in the scales of the bulb. And the outer skin colour which is red and yellow is due to the presence of anthocyanin and quercetin (Choudhary, 2018). It is also a good source of carbohydrates, fat, protein, vitamins, minerals, and high antioxidants that have several health benefits (Bhaskar, Tailor, Sharma, Singh, & Gupta, 2018).

Onion is a cool-season vegetable that requires and grows well under mild climates without extreme heat or cold or excessive rainfall. The optimum temperature for vegetative growth is 13°C to 24°C and bulb formation is 20°C to 25°C. For vegetative growth lower temperature combined with a short photoperiod is required whereas a relatively higher temperature along with a longer photoperiod is required for bulb development and maturity (Choudhary, 2018).

In Bhutan, bulb onion is one of the important commercial crops cultivated by the farmers in all the *Dzongkhags* (Districts). Bulb onion has been identified as one of the mandatory vegetable crops in the country and farmers are encouraged to take up cultivation on a large scale. The highest bulb onion production in a *Dzongkhag* in 2022 was Punakha with 28.03 MT, followed by Dagana with 27.56 and Tsirang with 27.01 MT. Overall production in 2022 in the country was 264.80 MT from 288.28 acres of harvested area (NSB, 2022).

With steady demand for the crop throughout the year and low domestic production, the crop cannot meet the domestic market demand. The domestic production yield per acre for the last three years was about 1067 kg/acre in 2020, 1008 kg/acre in 2021, and 920 kg/acre in 2022, and in the year 2022 bulb onion production was the lowest compared to other major vegetables (NSB, 2022). To meet the consumer demand, Bhutan imported about 6329.70 MT of onions and shallots in 2022 (DRC, 2022).

The Department of Agriculture thus far has released six bulb onion varieties for cultivation in the country (DoA, 2023). The most popular variety that has been cultivated by the farmers are

Bombay and Pune Red bulb onions and recently a new variety Pink 1358 has been released for cultivation.

Bulb onion production was encouraged after the cultivation of paddy in the paddy fields. The cultivation season begins from October to November for sowing, nursery raising, and harvesting in the May-June months (Phuntsho, Tshering, & Tamang, 2018; Tomiyasu et al., 2018). The crop requires about a five to six-month long growing period from sowing till harvest. The harvest season coincides with the onset of the monsoon season and post-harvest losses due to high humidity and poor post-harvest management are high. Post-harvest losses are due to rotting, sprouting, physiological loss in weight, and moisture evaporation from bulbs which results in serious losses with more than 50 percent of the harvest depending upon the variety and the storage conditions (Sharma & Chauhan, 2022).

To promote bulb onion in the country, promotion of off-season bulb onion production is encouraged as an alternative to have the crop for year-round available in the market. It also aims to harvest the bulbs during the dry season which could minimize post-harvest losses. In India, bulb onions are grown throughout the country in three seasons, *Kharif* (July-December), late *kharif* (October-March), and *rabi* (December-May) season but the major production is during the *rabi* season (Sable, Saras, & Patel, 2023). In our context, onion production is usually done once a year, where the nursery raising is carried out from October to November and harvested in the May to June months. To study and explore the feasibility of bulb onion production in other seasons of the year, this experiment was designed and planted in the off-season with the expected harvest during February and March months. Two existing onion varieties Pune Red and Pink onion 1358 was used in this experiment with the primary objective to evaluate the varieties for off-season production.

2 Materials and Method

The experiments were conducted at the Agriculture Research and Development Center, Wengkhar (27°16'12.42" N and 91°16'20.06" E) at 1650 meters above mean sea level (masl), and at the Agriculture Research and Development Sub-Center, Lingmethang (27° 15' 39.43" N and 91° 10' 46.13" E) at 650 masl. Two varieties of onion Pink 1358 and Pune Red were used for the experiment. Nursery at Lingmethang was raised on 2nd August 2022 and transplantation was carried out on 22nd September 2022. At Wengkhar the nursery was raised on 10th August 2022 and transplantation was carried out on 4th October 2022. The experiment was established in a Randomized Complete Block Design (RCBD) for two treatments (Treatment 1 Pink 1358

and Treatment 2 Pune Red) with three replications each in both stations. Each experimental plot was established measuring a plot size of 3 m² (3 m in length and 1 m in width) and 15 cm in bed height. About 30 kg of well-decomposed Farm Yard Manure (FYM) was applied to all the experiment plots and incorporated into the soil. The seedlings were transplanted at a distance of 20 cm row to row and 10 cm plant to plant after 52 days of sowing at Lingmethang and 70 days at Wengkhar. The seedlings were irrigated immediately after the transplanting and the crops were then irrigated when the soil moisture was dry. Standard crop management practices through nursery till harvest were followed in both stations. Data collection and monitoring of the crop were carried out timely. The crop was harvested on 27th February 2023 at Lingmethang and on 15th March 2023 at Wengkhar when more than 50% of bulb necks were fallen.

Data such as plant height, bulb height, bulb diameter, bulb weight, yield, pest, and diseases were collected from the experiment. Plant height was measured by a one-meter scale. Bulb weight and yield were measured using a digital weighing balance (Tanita KD-320) and bulb diameter and height were measured using a digital Vernier caliper (UYUSTOOLS, Stainless CLD 006). Pests and diseases were identified visually according to the manual. The data were statistically analyzed for both stations using the Statistical Tool for Agricultural Research (STAR) version 2.0.1. Analysis of variance (ANOVA) and Post Hoc test were carried out at a significance level of 0.05.

3 Results and Discussion

3.1 Bulb characteristics

The bulb characteristics as shown in Table 1, indicate a significant difference *($P < 0.05$)* in bulb height and weight but no significant difference in bulb width. The maximum bulb weight 306.70 g was recorded at the Lingmethang station in the Pink 1358 variety. Bulb height was also recorded highest in the Pink 1358 variety at Lingmethang station. Similar results were reported in the study conducted in Nepal, the interaction between the transplantation time and varieties showed no significant difference in the bulb diameter of the onion (Gautam, Khatri, & Paudel, 2006). However, the larger bulb onion plants produced larger bulbs, as the onion plant height, sheath diameter, and leaf number were positively correlated with average bulb weights (Nourbakhsh & Cramer, 2022).

Significant difference was observed in the plant height and bulb neck diameter *($P < 0.05$).* The variety Pink 1358 was taller in both stations. A thick bulb neck was also found in the Pink 1358

variety compared to the Pune Red in both stations. The thickness of the bulb onion neck is an important characteristic that needs to be considered for the bulb storage. Onions with a thin neck diameter store better than those with a thick diameter (Gautam et al., 2006), and for the longer duration storage Pune Red will have an advantage over Pink 1358 due to its thin neck compared to the Pink 1358. A thick bulb neck also takes a longer duration to dry the bulb after harvesting and has a high risk of infection during postharvest storage (Ratan, Gowda, & Pandey, 2017).

Table 1. Bulb onion characteristics

Station	Variety	Mean				
		Bulb Height (mm)	**Bulb Width (mm)**	**Bulb Weight (g)**	**Plant Height (cm)**	**Neck Diameter (cm)**
Lingmethang	Pink	90a	83.69	306.7a	51.1a	2.84a
	Pune	63.75b	78.02	179.9b	39.4b	2.16b
	CV %	6.17	13.25	32.64	14.27	11.53
Wengkhar	Pink	79.5	76.7a	164.57a	50.8a	2.75a
	Pune	53.2	68.2b	210.57b	39.7b	2.13b
	CV %	12.42	7.3	26.82	12.66	13.59

Means in the column with different letters are significantly different at (P <0.05)

3.2 Yield

The yield obtained indicates that there was no significant difference *(P >0.05)* in both stations as shown in Figure 1. The yield was higher at Lingmethang station which is 17.33 kg/3m² plot for Pink 1358 and 19.65 kg/3m² for Pune Red compared to Wengkhar which has 9.9 kg/3m² for Pink 1348 and 9.7 kg/3m² for Pune Red variety. This indicates that the bulb onion production from August to March month could be better in the lower elevations compared to mid-elevation at Wengkhar which has an altitude of 1650 masl. This could be because onions require higher temperatures during bulb formation while it prefers low temperatures at an early stage, and long days are favorable for production as they enhance leaf development and bulb formation which is directly related to bulb size (Khade, Thangasamy, & Gorrepati, 2019).

Although there was no significant difference *(P >0.05)* in yield in both stations, the Pink 1358 onion yield was lower compared to the Pune red at Lingmethang condition while there was no significant difference at Wengkhar condition. Similar results were also reported in the studies

carried out on bulb onion varieties during the summer season in India (Sharma & Chauhan, 2022).

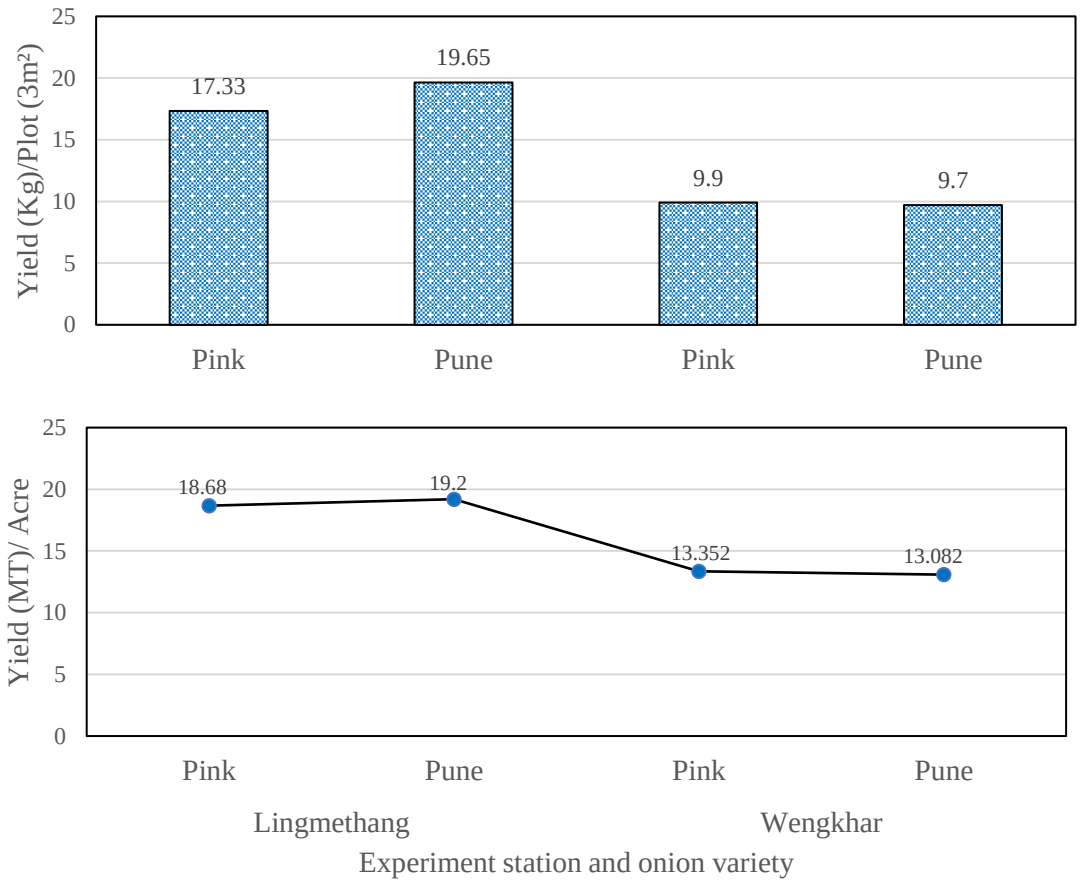

Figure 1. Statistical comparison of the yield of bulb onion across two stations

The mean yield at Lingmethang station ranged from 17.33 kg to 19.65 kg/ 3 m² equivalent to 18-19 MT/acre while at Wengkhar station the mean yield ranged from 9.7 kg to 9.9 kg/ 3 m² equivalent to 13 MT/acre. Similar results were also reported by Sable et al. (2023) in their study on the assessment of rabi onion varieties for the region of north Gujarat of five varieties of onion. The performance of the onion varieties was significantly influenced by the location, soil types, rainfall, and other climatic conditions (Tignegre et al., 2022). Practices of standard management during the bulb onion cultivation period contribute to the higher yield and increased bulb sizes and weight over the farmers' practices in the field (Srivastva, Meena, Tiwari, Singh, & Behera, 2022). The difference between the two bulb onion varieties in its bulb

characteristics and yield could be also due to the genetic makeup of the variety and suitability under different climatic and soil conditions (Gupta, Bhargav, & Dixit, 2020).

The mean yield comparison between the normal and off-season production showed that there was no significant difference *(P >0.05)* between the two seasons although the mean yield was slightly higher in the off-season production as shown in Table 2. This indicates that the off-season bulb onion production could be feasible and will have production comparable to the normal season production. If the recommended management practices are followed, the yields could be even higher than normal season. The normal bulb onion season production starts with planting during October-November and harvested during May-June. The off-season or summer production starts with nursery sowing and transplantation carried out in August, and harvested in early spring from February to March which similar to Indian bulb onion production seasonality (NHRDF, 2023).

Table 2. Bulb onion yield comparison

Season	**Mean Yield (MT/acre)**
Normal	12.2a
Off-season	13.22a

Means in the column with different letters are significantly different at (P <0.05)

4 Conclusion

Bulb onion is an important crop that is used as a spice for the preparation of different Bhutanese dishes and consumed daily by majority of the Bhutanese. To meet the demand there is a need increase the production by exploring other alternatives technologies and supplement the production from the normal season. This study found that bulb onion production is feasible between August to March months in the mid-elevations upto 1650 masl. In this study, the variety Pink 1358 produced 18.68 MT/acre and Pune Red 19.20 MT/acre at Lingmithang and Pink 1358 13.35 MT/acre and Pune Red 13.08 MT/acre at Wengkhar. The yields from the both the experimental sites were not statistically significant *(P >0.05)*. However, the best location for bulb onion production would be in the lower elevation where the yields are higher compared to the mid-elevation. The comparison of mean yield between the normal and off-season cultivation showed no significant difference between the two seasons although the mean yield was slightly higher in the off-season production (13.22 MT/acre). Encouraging the production of bulb onion in different seasons could ensure the availability all year round. Other than the production season, good storage structures and additional varieties need to be explored that are

suitable for both summer and winter productions which will give higher yield and has a good storage quality, so that the growers would have a choice of variety. Sharma & Chauhan, (2022) reported that the variety Agrifound Dark Red which is the popular and most cultivated variety in India is suitable for summer season production, and Khade, Gorrepati, & Thangasamy, (2017) reported that varieties such as Bhima Raj and Bhima Red can be grown in all the seasons. These varieties could be evaluated in the Bhutanese growing conditions to have a choice and suitable variety both for the summer and winter production of bulb onion in the country.

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Grafting of Tomato (*Solanum Lycopersicum* L.) onto Potato (*Solanum tuberosum* L.): Harvesting Double Crops from a Single Plant

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ABSTRACT

Rapid Urbanization and industrialization have been overtaking land for food production at the global level. Further, climate change has necessitated the modification of the existing food production system to adapt the changing environmental situations. Grafting is a rapid and economical solution to improving the yield in Solanaceous vegetables. In this study, the effects of grafting tomato (cv. Garv) on potato (cv. Desiree) rootstock were evaluated for yield of tomato and potato in comparison to non-grafted tomato and non-grafted potato plants. The results showed that the yield of tomato was significantly higher in non-grafted tomato (11.05 t/ha) and tomato grafted on potato with decapitation of potato shoots (4.07 t/ha) compared to that of tomato grafted on potato without decapitation of potato shoots (0.94 t/ha). On the other hand, the yields of non-grafted potato (1.44 t/ha) and tomato grafted on potato without decapitation of potato shoots (1.00 t/ha) were statistically higher than that of tomato grafted on potato with the decapitation of potato shoots. There were no statistical differences between the treatments for dry matter content and Total Soluble Solutes (TSS) of tomato and potato. The yield of tomato of the grafted pomato was negatively correlated to the yield of potato rootstock, but it was not statistically different. The data from this study suggest grafting of tomato on potato with decapitation of potato shoots is recommended for obtaining higher yield of grafted tomato and without decapitation of potato shoots for higher yield of potato from grafted plants.

Key words; *Pomato; Grafting; Tomato; Potato; Double Crop*

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1 Introduction

Globally, land for food production has been facing intense competition from urbanization and industrialization activities. Further, climate change has necessitated the modification of an existing food production system in order to adapt to changing environmental situations. Given the limited potential for horizontal expansion of agricultural land in Bhutan, the adoption of various forms of multiple cropping is considered a highly viable strategy for crop intensification (Katwal, 2013). Grafting is a promising technique, regarded as a rapid and economical solution to improving the yield in vegetable (Kumar & Sanket, 2017). The vegetable grafting began in Japan and Korea in the late 1920s by using resistant rootstock to control soil-borne diseases in cucurbits caused by *Fusarium oxysporum* and has since expanded to include vegetables such as eggplant, tomato, chili and several other solanaceous crops (Genova, Schreinemachers, & Afari-Sefa, 2013). The use of vegetable grafting was adopted by the World Vegetable Centre (AVRDC) and is now widespread across Asia, parts of Europe and the Middle East (Genova et al., 2013). Several studies have reported that vegetable grafting can increase resistance to abiotic stresses such as drought, salinity, heat and low soil temperatures and improve water use efficiency (Genova et al., 2013; Kumar & Sanket, 2017; Parthasarathi, Ephrath, & Lazarovitch, 2021).

In a vegetable graft, the above ground part (scion) is used to produce high nutritious yield while the below ground part (rootstock) is used to tolerate soil-borne stresses. Tomato and potato hetero-grafting combines two different species of vegetables for harvesting tomato fruits and potato tubers from scion and rootstock respectively avoiding many biotic stresses. This technique is an optimal agricultural production system for increasing crop yield and utilizing natural resources effectively (Parthasarathi et al., 2021). According to Mohammed, Humidan, Boras, & Abdalla (2009), tomato production improved significantly by 21%, and fruit total soluble solids content was also increased by grafting. The present study aimed to evaluate the effects of grafting tomato on potato rootstock, fruit characteristics, days to fruit maturity of tomato, tuber characteristics in potato, yield and post-harvest quality in both the crops.

2 Materials and Methods

2.1 Treatment and Experimental design

The study was conducted under a sub-tropical agroecological region at the Agriculture Research and Development Centre (ARDC) Samtenling (26^{o} 54' 17" N, 90^{o} 25' 51" E) located at 372 meters above mean sea level during the winter-spring cropping season (November-May) 2022-2023. The experiment was conducted using Randomized Complete Block Design (RCBD) with three replications and four treatments. The treatments consisted of potato and tomato grown normally without grafting and graft combination of tomato and potato with and without decapitating the potato shoots grown from the rootstock as detailed below:

1. Treatment 1: Tomato grafted on single potato shoot (rootstock) followed by decapitation of other shoots periodically after successful graft union.
2. Treatment 2: Tomato grafted on single potato shoot (rootstock) but all other shoots from rootstock were kept without decapitation.
3. Treatment 3: Non-grafted "Garv" tomato with single shoot.
4. Treatment 4: Non-grafted potato without decapitation of any shoots arising from the rootstock.

For this experiment, F1 hybrid tomato variety "Garv" (from Seminis Seeds, India) and potato variety "Desiree" were used for graft combination of pomato. The plot size of 2 m x1.2 m was used for each replication. Ten plants were grown with the recommended spacing of 40 x 60 cm in two rows per plot and total of 30 plants were grown for each treatment in three replications.

2.2 Planting materials

The seed tubers of potatoes having individual tuber weights of 30-40 gm were planted on 12th November 2022 in a well-prepared field. Farmyard manure (FYM) at the recommended rate of 5 t/ha was applied to all the plots uniformly during field preparation. The recommended dose of fertilizer NPK (70:40:30) kg/ha was applied as per the recommendation of the National Soil Service Centre (NSSC, 2009). The tomato seeds were sown in plug trays for nursery raising inside polyhouse using well-prepared soil medium one week after the date of planting potatoes.

2.3 Grafting of tomato over potato

One-month-old tomato seedlings were grafted using the cleft grafting method on the potato rootstock in the field on 12th December 2022 as per the method described by Kumar et al.,

(2016). The grafted tomato plants were maintained without flowers up to 45 days after grafting (DAG) since these can represent a competing nutrient sink for the potato tubers. After grafting, the pomato plants were covered with fifty percent shed nets for about a week to avoid desiccation of the grafted plants. The grafting success was recorded 3 weeks after grafting by counting the number of successful graft union formations in the field.

All the plants were stalked using bamboo stalks immediately after the grafting operation. All the plots were mulched using paddy straw and irrigated at weekly intervals. The earthing up of potatoes was carried out 2 months after the planting of potatoes and all other intercultural operations were carried out as required.

2.4 Soil characteristics of the experimental field

Composite soil samples at the depth of 0-20 cm were collected from the experimental site before and after conducting the experiment and were analyzed for the soil parameters namely pH, N, P, K & Mg, and soil texture was also examined. The NPK content of the soil was tested using the Reflectoquant Nitrate Test kits (3-90 mg/l NO_3-), Potassium test kit (Kalium test, 0.25-1.2 g/l k) & P- phosphate test kit (5-120 mg/lPO_4^{3-}, P- phosphate test).

2.5 Data collection

Data were collected from all the 10 plants from each plot. The observations recorded were average number of fruits per plant, average fruit weight (g), average fruit diameter (mm), plant height (cm), yield (t/ac), dry matter content (%) and Total Soluble Solids (TSS Brix◦) of tomato and tuber growth attributes including number of tubers per plant, single tuber weight (g), width of tuber (mm), number of shoots, dry matter content (%) and TSS (Brix◦). The tomato fruits were harvested at colour breaking stage while the potato tubers were harvested later after the haulm senescence and assessed for number of tubers per clump, tuber size, weight of tuber and the yield to analyze the correlation between the tomato and potato yield in pomato. To determine the dry matter content and the TSS of tomato and potato, three fruit or tuber samples per plot were randomly selected (second harvest in tomato). TSS and dry matter content were determined using a hand-held reflectometer (Vee Gee Scientific BTX-1) and oven (Memmert Universal Oven U) respectively following the guidelines developed by the Organization for Economic Co-operation and Development (OECD, 2005; DoA, 2018).

2.6 Organoleptic test

To determine the consumers' acceptability of potato tubers, the organoleptic test was carried out by 15 randomly selected panels. Potato tubers from each treatment were randomly selected immediately after harvesting and cooked without peeling. Each panelist was provided with 2-3 potato tubers of each sample. Potato tubers were assessed for their taste, aroma, texture, peeling easiness and softness using the nine-point Hedonic scale ranging from 1 = Dislike extremely and 9 = Like extremely (Singh-Ackbarali & Maharaj, 2014). The percentage of overall acceptability was calculated using the formula mentioned below (Jayasena & Cameron, 2008).

Equation 1:

$$Percentage\ of\ overall\ acceptibility = \frac{Number\ of\ Panelist\ rated > 5}{Total\ number\ of\ panelist} * 100$$

2.7 Data analysis

The collected data were firstly entered and processed in Microsoft Excel 2007 spreadsheet. Then it was analyzed using IBM SPSS Statistics Version 22.0.0. Both descriptive and inferential statistical analyses were done using the IBM SPSS Statistics software. One-way Analysis of Variance (ANOVA), and Tukey HSD post-hoc test was performed for pair-wise comparison and the Pearson correlation coefficient test was performed to analyze the correlation between different parameters at the significance level of p=0.05.

3 Result and Discussion

3.1 Growth characteristics & tomato fruit yield of Pomato plant

The results of this study clearly indicated that the pomato plant can be successfully developed by grafting tomato scion over potato rootstock. The grafting success between the tomato and potato was recorded at 95%. The first harvest of tomato was done on 09/03/2023 (81 DAT of tomato and 117 DAS of potato) and total of seven harvests were made at the interval of 7-10 days. No significant differences were observed in the yield of tomato from the grafted pomato plant with remaining potato shoots decapitated (4.07 t/ha) and the non-grafted tomato plant (11.05 t/ha) but the tomato yield of pomato plant with non-decapitated potato shoots from the rootstock (0.94 t/ha) was significantly lower (p=0.03) as compared to the two other treatments (T1 & T3) as shown in Table 1. The average number of fruits per plant was found to be significantly higher (p=0.01) in the non-grafted tomato plant (65.40) as compared to the two other grafted pomatoes (T1 & T2). The tomato fruit diameter was found to be significantly

higher in non-decapitated grafted pomato (T2=39.25) as compared to the non-grafted tomato (T3=27.04) but there were no significant differences in fruit diameter between the two grafted pomatoes. No significant differences were observed for average fruit weight, tomato plant height, dry matter content and TSS among the treatments.

Table 1. Growth and yield characteristics of grafted and non-grafted tomato plants

Treatment	No. of fruits per plant	Average fruit wt.(g)	Average fruit diameter (mm)	Ave plant height (cm)	Yield (t/ha)	Dry matter content (%)	TSS (Brix ◦)
T1: Tomato grafted on Potato (potato shoots decapitated).	23.23 *b*	42.27	36.68 *ab*	56.77 *b*	4.07 *ab*	5.72	6.46
T2: Tomato grafted on Potato (Potato Shoots Non decapitated).	6.13 *b*	35.58	39.25 *a*	21.43 *c*	0.94 *b*	4.83	5.40
T3: Non grafted Tomato (Garv)	65.40 *a*	38.20	27.04 *b*	79.57 *a*	11.05 *a*	6.45	5.77
p-Value =0.05	0.012	0.190	0.006	<0.001	0.030	0.506	0.181
CV (%)	95.23	11.57	17.94	48.56	100.91	27.61	12.01

3.2 Growth characteristics and fruit yield of potato plant

The potato was harvested on 28/03/2023 (136 DAS) after the haulm senescence. There was a significant effect of decapitating the remaining potato shoots after grafting on the potato tuber yield. The yield of potato was significantly lower (p=0.01) in grafted pomato with remaining potato shoots decapitated (T1: 0.74 t/ha) as compared to the non-grafted potato grown (T3=1.44 t/ha) as control (Table 2). However, the potato yield of non-decapitated grafted pomato (T2=1.00 t/ha) did not have any significant differences with the two other treatments.

Table 2. Plant growth characteristics and fruit yield of potato plant in grafted potato and non-grafted potato

Treatment	No. of potato tubers/ plant	Ave. wt. of potato tuber (g)	Potato yield (t/ha)	No of potato shoots/ clump	Width of potato (mm)	Potato dry matter content (%)	TSS (Brix ◦)
T1: Tomato grafted on potato (potato shoots decapitated).	4.97	39.87	0.74 *b*	1.00 *b*	47.16	14.33	5.43
T2: Tomato grafted on potato (potato shoots Non decapitated).	4.7	48.87	1.00 *ab*	1.33 *b*	48.91	21.90	5.19
T3: Non grafted Potato (Desiree)	8.13	50.74	1.44 *a*	2.37 *a*	50.92	19.76	5.52
p-Value =0.05	0.073	0.601	0.010	0.001	0.780	0.267	0.375
CV (%)	36.56	27.41	33.02	41.66	11.79	30.38	5.31

3.3 Correlation on growth and yield of tomato and potatoes in the grafted Pomato plant

Pearson correlation coefficient was conducted among quantitative parameters (Table 3). It was observed that there was a highly significant positive correlation (r=0.950, P=0.004) between the tomato plant height and number of tomato fruits per plant. This revealed that the number of fruits increased with the increase in plant height. The yield of tomato of the grafted pomato was negatively correlated (r= -468) to the yield of potato rootstock but statistically not significant (p=0.349).

Table 3. Correlation on growth and yield of tomato and potatoes in the grafted pomato plant

Characteristics	No of tomato fruit	Tomato fruit wt. (g)	Tomato yield (kg/ac)	Tomato fruit diameter (mm)	Tomato plant height (cm)	Tomato dry matter content (%)	Tomato TSS (Brix◦)	No of potato tubers/ clump	Ave wt. of potato tuber (g)	Potato yield (kg/ac)	No of potato shoots/ clump	Width of potato (mm)	Potato dry matter content (%)	Potato TSS (Brix◦)
No of Tomato fruit	1	.931**	.994**	-.175	.950**	.535	.474	.386	-.789	-.496	-.790	-.436	-.422	.376
Tomato fruit wt (gm)	.931**	1	.934**	.106	.853*	.469	.304	.140	-.913*	-.673	-.769	-.576	-.632	.432
Tomato yield (Kg/ac)	.994**	.934**	1	-.093	.910*	.552	.386	.401	-.801	-.468	-.744	-.448	-.379	.358
Tomato fruit diameter (mm)	-.175	.106	-.093	1	-.418	-.179	-.862*	-.305	-.338	-.183	.423	-.481	-.088	-.144
Tomato Plant Height (cm)	.950**	.853*	.910*	-.418	1	.497	.711	.344	-.671	-.503	-.877*	-.319	-.509	.436
Tomato Dry matter content (%)	.535	.469	.552	-.179	.497	1	.435	.644	-.104	.269	-.417	.379	-.330	.859*
Tomato TSS (Brix◦)	.474	.304	.386	-.862*	.711	.435	1	.290	-.015	-.104	-.714	.288	-.409	.527
No of potato tubers/ clump	.386	.140	.401	-.305	.344	.644	.290	1	.072	.557	.041	.250	.166	.360
Ave Wt. of potato tuber (gm)	-.789	-.913*	-.801	-.338	-.671	-.104	-.015	.072	1	.820*	.570	.855*	.529	-.096
Potato yield (Kg/ac)	-.496	-.673	-.468	-.183	-.503	.269	-.104	.557	.820*	1	.617	.784	.574	.083
No of potato shoots/clump	-.790	-.769	-.744	.423	-.877*	-.417	-.714	.041	.570	.617	1	.173	.558	-.438
Width of potato (mm)	-.436	-.576	-.448	-.481	-.319	.379	.288	.250	.855*	.784	.173	1	.289	.335
Potato Dry matter content (%)	-.422	-.632	-.379	-.088	-.509	-.330	-.409	.166	.529	.574	.558	.289	1	-.697
Potato TSS (Brix◦)	.376	.432	.358	-.144	.436	.859*	.527	.360	-.096	.083	-.438	.335	-.697	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2 tailed)

3.4 Sensory evaluation of Potato tuber

The sensory evaluation test results indicated that the average overall acceptability of all three different treatments ranged from 84% to 91% which indicated higher consumer acceptance (Table 3). Comparatively, Panelist preferred T1 (tomato grafted on potato with shoots decapitated) (Average overall acceptability=91%) over T3 (average overall acceptability= 85%) and T2 (average overall acceptability= 84%). The preference of consumers against each parameter is shown in Fig. 3. The overall consumer preferences of each parameters shows that T3 is more preferred for taste/flavor, T1 for aroma/smell, T1& T2 for texture/color, T1 for softness while there are no differences in preference with regards to peeling easiness.

Table 3. Sensory evaluation of Potato tubers from three different treatments

Test Parameters	Overall acceptability percentage		
	T1: Tomato grafted on Potato (Potato shoots Decapitated)	T2: Tomato grafted on Potato (Potato shoots non-Decapitated)	T3: Non grafted Potato
Taste/Flavour	73%	67%	80%
Aroma/Smell	93%	73%	73%
Texture/Colour	87%	87%	80%
Peeling Easiness	100%	100%	100%
Softness	100%	93%	93%
Average	91%	84%	85%

3.5 Soil characteristics and macro nutrient analysis

The soil texture of the experimental site was sandy clay loam both before and after the trial. However, soil pH was 5.17 before the experiment but became slightly alkaline after the experiment (pH=6.38). The value of all macronutrients content of the soil was lower after the experiment except that of Mg as shown in Table 5.

Table 5. Soil test results indicating the level of macronutrients, and other soil characteristics of the experimental site before and after the experiment

	Soil fertility parameters					
Soil sample	pH	Avail. N (%)	Avail. P (mg/l)	Avail. K (g/L)	Mg (mg/L)	Texture
Pre-trial	5.17	0.06	42.24	6.47	0.16	Sandy clay loam
Post-trial	6.38	0.0003	<5	<0.25	<0.5	Sandy clay loam

In this study both non grafted tomato and potato produced higher yield compared to the grafted ones. The Pearson correlation coefficient analysis showed that the yield of tomato of the grafted pomato was negatively correlated to the yield of potato rootstock though not significantly different statistically. This finding contradicts with the results of (Arefin et al., 2019; Singh et al., 2020) who reported that the grafted plants produced higher fruits due to the increase in plant height of the plants, leaf number, and branch number. Plant hormones play essential roles in fruit and tuber development (Aksenova et al., 2012). Specifically, the Gibberellins (GA) and Cytokinin (CK) are the key plant hormones playing pivotal roles in controlling different aspects of plant growth and development, influencing fruit set induction in tomatoes and tuber formation in potatoes (Wang et al., 2009; Matsuo et al., 2012). A high concentration of CK is a prerequisite for healthy tuber formation as well as cell division during tomato fruit development. Therefore, the pomato plant might have a big challenge in regulating Cytokinin for inducing fruiting and tuberization simultaneously (Fleishon et al., 2011). Understanding and manipulating the antagonistic relationship between Cytokinin and Gibberellin in grafted tomato plants can offer opportunities to optimize plant growth, enhance resistance to environmental stress, and improve overall yield and quality. (Fleishon et al., 2011; Schwarz et al., 2010).

From an agronomic point of view, grafting is important because it can combine the surface characteristics (fruit size) of scion plant with the underground characteristics (root system) of rootstock (Giosanu, Uleanu, Trãneci, & Vulpe, 2020). Due to the use of vigorous rootstock of potato, the root system of tomato becomes strong and the absorption of water and minerals increases compared to grafted tomato (Zeist et al., 2017). A good rootstock/scion combination usually guarantees a robust root system and the maintenance of good vegetative vigor and resistance to deal with abiotic and biotic stresses until the end of the farming cycle (Tomassoli, Ilardi, Barba, & Kaniewski, 1999). The low yield of the grafted tomato on potato with non-decapitation of shoots could be due to the partitioning of minerals and nutrients to different sinks namely underground potato tuber and above ground tomato fruits (Zhang & Guo, 2019). Although, this study did not look at the economic analysis of grafting tomato on potato rootstocks for commercial production of double crops on single plant, but grafting of tomato on potato rootstock indisputably reduces labor required for field preparations and enables the production of two different vegetables on a single plant thereby optimizing the utilization of limited land resources (Spanò, Ferrara, Gallitelli, & Mascia, 2020).

4 Conclusions

Grafting is an established technique to improve plant adaptation to various abiotic and biotic factors to increase plant yield and quality. This study showed that the tomato and potato plants belonging to the same Solanaceae family can be grafted successfully to produce double crops from a single plant. Decapitation and non-decapitation of remaining potato shoots was found to significantly affect the yield of tomato and potato as compared to the yield of non-grafted tomato and potato planted as checks. Decapitation of remaining potato shoots after grafting resulted in significantly lower potato yield as compared to the non-grafted potato. Similarly, the yield of tomato was significantly lower in non-decapitated pomato as compared to the non-grafted check tomato plants. Decapitated pomato plants produced higher tomato yields but lower potato yields. In non-decapitated pomato plants, the yield of tomato was recorded lower with higher yield of potato. However, there were no significant differences in yield of both tomato and potato between the decapitated and non-decapitated pomato plants. Hence, grafting of tomato on potato with decapitation of potato shoots is recommended for obtaining higher yield of grafted tomato and without decapitation of potato shoots for higher yield of potato from grafted plants. Although the hetero-grafting technology of pomato can increase food crop productivity for available limited land, it involves intense labor and requires practical grafting skills. Therefore, further economic analysis needs to be conducted to analyze the cost & benefit of the technology and study its potential utilization in enhancing the plant growth and performance under environmental stress. The future study may investigate the effect of potato rootstock on lycopene content of tomato and effect of tomato scion on carbohydrate content of potato. The research on potato rootstock for control of bacterial wilt of tomato is also suggested.

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Evaluation of Small Sized Watermelon Varieties for the Bhutanese Market

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Abstract

Watermelon is one of the important emerging cash crops in Bhutan contributing to the generation of farmer's income. However, a major challenge in watermelon farming in Bhutan is the lack of varieties with fruit sizes preferable to the consumers. Therefore, this research aimed to evaluate new hybrid watermelon varieties with smaller sized fruits for commercial cultivation in Bhutan. This study was conducted in four different locations in three research centres (ARDC Wengkhar, ARDC Bajo and ARDC Samteling). Six hybrid varieties namely, PPS 142, PPS 304, PPS 313, PPS 315, PPS 317 and Sugar Baby (check) were evaluated with two replications following completely randomized design. Fruit weight, diameter, height, Total Soluble Solids (TSS), fruit colour, flesh colour and yield per plot were recorded from the sample fruits. In addition, market and consumer preference surveys were conducted involving 11 vendors and 20 consumers in Mongar to evaluate the acceptability of varieties by vendors and consumers. The results showed that there was no significant difference in fruit weight, TSS, crop duration and yield among the six varieties. However, significant location-based variation was observed in the fruit weight and yield. All the varieties fell within the medium- sized category, commonly referred to as the "icebox" type in Lingmethang, Bajo and Panbang while it fell under "personal" type in Samtenling. The consumer and market preference survey indicated a preference for medium-sized, round fruits with a dark green colour, which aligns with the characteristics observed in the evaluated varieties. This result of this study provides varietal choices to farmers to produce and market suitable varieties and for consumers to obtain optimum fruit size varieties for consumption.

Keywords; *Watermelon; Weight; TSS; Yield; Consumer preference*

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1 Introduction

The global watermelon production has witnessed a remarkable growth, surging from 21.1 million tonnes in 1972 to 101 million tonnes in 2021, reflecting an average annual growth rate of 3.42% (FAO, 1972; FAO, 2021). Scientifically classified as *Citrullus lanatus*, and a member of the Cucurbitaceae family, watermelon is mostly consumed fresh and chilled, often served as a refreshing dessert. Additionally, its rind is occasionally processed into preserves and jam (Maynard, 2008). Distinguished by its high water content, which stands at 92%, watermelon is renowned for its juicy, sweet, and refreshing qualities, especially during hot weather (Leskovar et al., 2007; Romdhane et al., 2017). Consequently, it ranks as the second most widely grown fruits after banana in 2021 (FAO, 2021). Notably, watermelon boasts as a high lycopene containing fruit, with certain types containing more lycopene than tomatoes (Guner & Wehner, 2004). Furthermore, watermelon is rich in vitamins B, C, and E, as well as essential minerals like phosphorus, magnesium, calcium, and iron (Romdhane et al., 2017). It also provides valuable antioxidant compounds such as polyphenols, anthocyanins and flavonoids to the consumers (Jaskani et al., 2005; Kaur & Kapoor, 2008).

In Bhutan, watermelon is one of the important emerging cash crops which play a pivotal role in supplementing the income of numerous rural farmers' households (Kuensel, 2023). The country has witnessed swift increase in watermelon production, recording a total production of 156.02 metric tons in 2021 which is nearly a threefold increase compared to the preceding year as reported in Agriculture statistics (NSB, 2021; NSB, 2022). This fruit shows great promise due to its quick growth cycle and thus, there is an increasing popularity for large-scale cultivation in the country.

According to the existing literature, watermelon is categorized into three different types based on size: “personal” for the small size, weighing less than 2.6 kg; “icebox” for medium sized watermelons, ranging from 2.6 to 6.8 kg; and “picnic” for the large sized watermelons exceeding 6.8 kg (Miles et al., 2004). Large sized watermelons are often referred to as “picnic” type as they are commonly used to feed large gatherings during picnics, while the “personal” and “icebox” types are typically consumed within households (Klein, 2023).

In many countries, large sized watermelons are primarily sold as fresh cut fruit due to their challenging single serving consumption size (Mendoza-Enano et al., 2019). However, once

sliced, these watermelons are highly perishable owing to their high pH level (ranging from 5.2 to 6.7) and a water content ranging between 97 to 99%, which limits their shelf-life at the retail level (Cartaxo & Sargent, 1998; Lemos et al., 2017). Furthermore, fresh-cut watermelon is susceptible to off-odour development, discoloration, juice leakage, texture loss and microbial growth (Zhuang et al., 2011). Sliced watermelons also pose concerns related to heavy metal contamination and fungal and yeast growth, raising hygiene and consumer health issues (Aladesanmi, 2021). In contrast, small and medium sized watermelons are typically sold as whole fruits, ensuring freshness and hygiene. They are convenient for small households and easily fit into the refrigerator (Maynard, 2008). Moreover, they mature faster than the large sized varieties (Miles et al., 2004) allowing for immediate consumption without the need for refrigeration, which can otherwise compromise their sweetness, flavour and overall freshness (Gil et al., 2006). As a result, small and medium sized watermelons are convenient for self-consumption and contain more pulp due to thin rind when compared to larger sized watermelons (Maynard, 2008).

A notable challenge in watermelon farming in Bhutan is the lack of variety choices and manageable sizes of the fruit. The only existing small sized variety in the country is Sugar Baby while most of the varieties in the country are large in size with excessive weight which is inconvenient for household consumption. Therefore, this research aimed to evaluate new hybrid watermelon varieties with small sized fruits to provide choices for compact watermelon varieties for commercial cultivation in Bhutan. The primary objectives of this study were to assess the feasibility of the production of the compact watermelon varieties in Bhutan and to determine the yield of these varieties.

2 Materials and method

2.1 Study area

The research was carried out in 2023 in four different locations in three research centres across the country: Agriculture Research and Development Subcentre (ARDSC) Lingmethang (Altitude: 600 m, 27°15’38”N, 91°10’46”E) in the eastern region, Agriculture Research and Development Centre (ARDC) Bajo (Altitude:1200m, 27°29’25”N, 89°53’56”E) in the central region, ARDC Samteling (Altitude:375m, 26°91’01”N, 90°43’10”E) and ARDSC Panbang (Altitude:94m, 26°51’17.4”N, 90°57’50.2”E) in the southern region.

2.2 Research design

In this experimental trial, a Completely Randomized Design (CRD) was used, involving six different treatments, each replicated twice. These treatments consisted of six hybrid varieties, specifically PPS315, PPS313, PPS142, PPS304, PPS317, along with a check variety Sugar Baby. The hybrid seeds were procured from Pariposa Seeds, India in collaboration with National Seed Centre, Paro.

2.3 Methodology

The research was carried out in 2023 in all the four study sites. The nursery was raised in the end of January at ARDSC Lingmethang and in February in three other centres. Subsequently, in the second week of March, the seedlings were transplanted, and the harvesting period extended from late May to the final week of June in all the areas. The field was partitioned into 12 plots, each measuring 15 square meters, with a minimum of five plants in each plot, spaced 1 m by 3 m apart.

From each replication, three plants were selected at random and assigned labels. Various parameters including weight, diameter, height, Total Soluble Solids (TSS), fruit colour, flesh colour, yield per plot and number of fruits per plant, were recorded from two fruits each from the three selected plants. Fruit TSS was measured using the refractometer while the fruit height and diameter was measured using Vernier calliper.

Furthermore, a survey was conducted to understand the preference of consumers and vendors on small sized watermelons by randomly selecting 31 participants (11 vendors and 20 consumers) from Mongar. Semi structured questionnaires were used for collecting data from the participants.

The collected data was analysed using R software. Analysis of Variance (ANOVA) was used to compare the weight, height, diameter, TSS, and yield among the six different varieties while descriptive statistics was used for analysing survey data. Tukey's post hoc test was performed to compare multiple interactions among six different varieties. The decision was made at 95% confidence interval for statistical test.

3 Result and Discussion

3.1 Findings from the field experiment

3.1.1 Fruit quality parameters among different watermelon varieties at Lingmethang

The results indicated that there was no statistically significant difference in fruit weight, fruit diameter, total soluble solids (TSS), crop maturity, and yield among six different watermelon varieties. However, a notable distinction existed in fruit height within the Lingmethang region (Table 1). All the six varieties exhibited a mean weight between 3 kg and 7.7 kg, indicating that all these varieties belonged to "icebox" type watermelon. Sugar Baby demonstrated the largest fruit size at 7.7 kg, followed by PPS 142 at 6.0 kg and PPS 313 at 5.5 kg. Significantly, Sugar Baby and PPS 142 exhibited higher yields, suggesting a positive correlation between increased fruit weight and overall crop yield.

On the contrary, PPS 315 and PPS 317 displayed smaller fruits at 3.0 kg and 4.9 kg, respectively. Surprisingly, these varieties yielded higher production than PPS 313 and PPS 304 due to a greater number of bearing fruits compared to other varieties. Coming to the sweetness of the fruit, the TSS of all the varieties ranged between 10.5% and 12.5%. Notably, PPS 313 exhibited a higher TSS content at 13%, followed by PPS 317 at 12.5%, and PPS 315 at 12%, while PPS 304 exhibited the lowest TSS of 10.5%. All six varieties were harvested 80 days after transplanting (DAT). In the Lingmethang, PPS 315 and PPS 317 produced medium-sized fruits (< 5 kg) with higher yields. Thus, these two varieties can be recommended for commercial production of smaller sized watermelon.

Table 7. Fruit quality parameters among different watermelon varieties at Lingmethang

Treatments	Fruit weight (kg)	Fruit height (cm)	Fruit diameter (cm)	TSS (%)	Crop duration (DAT)	Yield (kg/plant)
PPS 142	6.0 (1.3)	28.5 (4.2)^{ab}	20.3 (0.4)	11.0 (0.0)	80.0 (0.0)	48.7 (0.5)
PPS304	5.0 (1.6)	21.5 (3.5)^{a}	20.5 (3.5)	10.5 (0.7)	80.0 (0.0)	32.4 (2.6)
PPS 313	5.5 (0.9)	31.8 (1.8)^{b}	19.0 (1.4)	13.0 (1.4)	80.0 (0.0)	37.9 (1.8)
PPS 315	3.0 (0.9)	20.3 (1.1)^{a}	17.5 (2.1)	12.0 (0.0)	80.0 (0.0)	45.0 (22.9)
PPS 317	4.9 (1.6)	29.0 (4.2)^{ab}	18.3 (2.4)	12.5 (0.7)	80.0 (0.0)	49.2 (6.8)
Sugar Baby	7.7 (1.3)	21.0 (0.0)^{a}	25.5 (2.1)	11.0 (1.4)	80.0 (0.0)	51.4 (24.6)
P-value	0.12	0.03	0.09	0.17	0.49	0.73

**Different lower-case letters in the superscript indicate statistically significant differences following the Tukey's HSD post hoc analysis at P<0.05; Values in parentheses indicate standard deviation of the mean*

3.1.2 Fruit quality parameters among different watermelon varieties at Bajo

The result showed that there was a significant difference in fruit weight, fruit height, fruit diameter and crop yield of six different varieties while there were no significant differences in TSS and crop duration (Table 2). The mean weight of the watermelon ranged from 1.7 kg to 6.2 kg, falling under "icebox" type. Out of six varieties, the highest fruit weight was observed in PPS 142 and PPS 315 with a mean weight of 6.2 kg and 4.5 kg while the lowest mean weight was recorded in PPS 304 and PPS 317 with 1.7 kg and 2.1 kg respectively. Likewise, PPS 142 and PPS 317 demonstrated the highest mean plant yields at 52.9 kg and 37 kg, suggesting a positive correlation between fruit weight and yield, particularly in the case of PPS 142 (Table 2). While the increased yield in PPS 317 is attributed to a greater number of bearing fruits, akin to the trend observed in Lingmethang.

Table 8. Fruit quality parameters among different watermelon varieties at Bajo

Treatments	Fruit weight (kg)	Fruit height (cm)	Fruit diameter (cm)	TSS (%)	Crop duration (DAT)	Yield (kg/plant)
PPS 142	6.2 (1.2)^{b}	27.9 (3.7)^{b}	14.2 (0.6)^{a}	10.5 (0.7)	82.0 (0.0)	52.9 (0.4)^{b}
PPS304	1.7 (0.6)^{a}	14.9 (2.0)^{a}	13.4 (1.8)^{a}	10.0 (1.4)	82.0 (0.0)	20.4 (1.8)^{a}
PPS 313	2.6 (0.4)^{a}	23.5 (1.1)^{ab}	17.2 (0.4)^{a}	12.5 (0.7)	82.0 (0.0)	23.0 (3.0)^{a}
PPS 315	4.5 (0.7)^{ab}	23.7 (2.0)^{ab}	14.8 (0.5)^{a}	12.0 (0.0)	82.0 (0.0)	21.9 (0.4)^{a}
PPS 317	2.1 (0.1)^{a}	22.5 (1.5)^{ab}	17.9 (1.1)^{a}	11.0 (1.4)	82.0 (0.0)	37.0 (2.3)^{ab}
Sugar Baby	3.3 (1.3)^{ab}	20.1 (3.7)^{ab}	19.4 (2.2)^{a}	11.5 (0.7)	82.0 (0.0)	25.5 (0.4)^{a}
P -value	0.01	0.03	0.01	0.22	0.49	0

**Different lower-case letters in the superscript indicate statistically significant differences following the Tukey's HSD post hoc analysis at P<0.05; Values in parentheses indicate standard deviation of the mean*

The TSS content of the fruits ranged from 10% to 12.5%, with PPS 313 and PPS 315 exhibiting the highest TSS levels at 12.5% and 12% respectively. Harvesting for all the varieties completed within 82 DAT. In Bajo, PPS 304, PPS 313 and PPS 317 displayed fruit weights below 3 kg, with PPS 317 achieving higher yield despite its smaller size (Table 2). Consequently, PPS 317 can be recommended for commercial cultivation, emphasizing its suitability for smaller sized watermelons with a concurrently higher yield.

3.1.3 Fruit quality parameters among different watermelon varieties at Samtenling and Panbang

The result showed that there was no significant difference in fruit weight, fruit height, fruit diameter, TSS, crop duration and yield among the six varieties in both Panbang and Samtenling region (Table 3). The mean weight of watermelon varieties ranged from 2.9 kg to 4.9 kg, falling under the "icebox" type watermelon. In contrast to the Lingmethang and Bajo regions, PPS

304 displayed the highest weight at 4.9 kg in Panbang and 1.3 kg in Samtenling, while the lowest weights were observed at 2.9 kg and 3.1 kg in Sugar Baby and PPS 317 in Panbang. In Samtenling, all varieties exhibited a mean weight less than 1.5 kg, falling under the "personal" type.

The variety PPS 142 produced the highest mean plant yield of 24 kg in Panbang while PPS 304 recorded the highest mean plant yield of 24.5 kg in Samtenling. The highest yield of PPS 142 obtained at Panbang corresponded to the yield recorded at Lingmethang and Bajo. In comparison to other regions, Samtenling displayed relatively smaller sized fruits across all varieties, potentially influenced by soil and microclimate.

The TSS level of the fruits ranged from 9.0% to 11.7% in Panbang and 8.3% to 10.9% in Samtenling. The highest TSS was observed in PPS 304 in Panbang and PPS 315 in Samtenling. Additionally, the crop duration was 82 days in Samtenling and varied from 92 days to 113 days in Panbang. Considering the small size and higher yield, PPS 317 is recommended for Panbang and PPS 304 for Samtenling.

Table 9. Fruit quality parameters among different watermelon varieties at Panbang and Samteling

Location	Treatments	Fruit weight (kg)	Fruit height (cm)	Fruit diameter (cm)	TSS (%)	Crop duration (DAT)	Yield (kg/plant)
Panbang	PPS 142	4.5 (0.5)	22.8 (2.1)	20.4 (1.7)	10.0 (2.1)	92.0 (7.8)	24.0 (2.8)
	PPS304	4.9 (1.5)	21.7 (2.9)	18.6 (3.5)	11.7 (1.4)	103.0 (0.0)	19.0 (7.4)
	PPS 313	3.4 (0.6)	23.1 (2.1)	15.9 (0.1)	10.8 (0.5)	103.0 (0.0)	15.0 (2.8)
	PPS 315	2.9 (0.2)	20.8 (0.4)	15.2 (0.7)	10.1 (0.7)	103.0 (7.8)	13.5 (3.1)
	PPS 317	3.1 (0.2)	23.0 (0.1)	16.4 (0.8)	11.3 (2.5)	92.0 (14.9)	16.0 (1.1)
	Sugar baby	2.9 (0.1)	18.5 (1.3)	17.9 (0.4)	9.0 (0.2)	113.0 (7.1)	14.0 (0.7)
	P -value	0.1	0.16	0.08	0.65	0.78	0.08
Samteling	PPS 142	1.0 (0.2)	15.8 (1.1)	65.4 (0.6)	8.3 (1.1)	82.0 (0.0)	21.5 (2.1)
	PPS304	1.3 (0.3)	12.8 (1.2)	13.0 (1.2)	8.8 (1.7)	82.0 (0.7)	24.5 (2.1)
	PPS 313	1.0 (0.1)	15.1 (1.1)	53.9 (1.8)	8.2 (2.8)	82.0 (0.0)	20.5 (0.7)
	PPS 315	1.0 (0.2)	14.4 (1.9)	10.8 (1.1)	10.4 (0.5)	82.0 (0.0)	20.5 (3.5)
	PPS 317	1.0 (0.2)	14.9 (0.5)	10.9 (0.4)	9.5 (0.0)	82.0 (0.0)	21.5 (3.5)
	Sugar baby	1.0 (0.0)	13.4 (1.3)	12.05 (0.2)	8.9 (0.5)	82.0 (0.0)	21.5 (0.7)
	P-value	0.46	0.29	0.69	0.67	0.49	0.62

** Values in parentheses indicate standard deviation of the mean*

3.1.4 Comparison of fruit quality parameters among different watermelon varieties in four study sites

The combined analysis of variance indicated that there was a significant difference in fruit yield among the four locations and treatments while there was no significant difference in yield by the interaction between location and treatments (L*T) as shown in the Table 4. This shows that the fruit yield is affected by locations and treatments alone and not by the interactions between them at predetermined level of significance (5%).

The data analysis revealed no significant differences in TSS levels among the six different varieties in all the study sites suggesting that all these varieties possess an equal degree of sweetness (Table 1, 2 and 3). Watermelon fruits with TSS content ranging from 10% to 12% are classified as having "very good" eating quality based on US grading standards, making them suitable for transportation (Yara, 2018). The minor variations in TSS levels observed within the varieties could potentially be attributed to soil variability in the growing locations and the maturation stages of the melons, as discussed by Ammawath et al. (2001). Furthermore, our findings aligned with the results reported by Davis et al. (2008), which indicated the presence of higher TSS levels in pigmented watermelons compared to non-pigmented varieties. The crop duration for these six varieties ranged from 80 to 113 DAT across the four growing locations, which is similar to the crop duration of icebox varieties of watermelon ranging between 70 to 120 DAT in Washington (Miles et al., 2004).

Table 10 Combined analysis of variance of yield for six watermelon genotypes evaluated at four environments

Source	**DF**	**Sum of squares (SS)**	**Mean sum of squares (MS)**	**Explained (%)**
Total	10	879	87.9	9.15
Replication	1	0	0.2	0
Location (L)	3	4955	1651.8	51.59
Treatments (T)	5	1775	177.5	18.48
L*T	15	672	67.2	7
Error	24	1323	55.1	13.78

When it comes to the shape of the fruits, this research observed two different fruit shapes namely, broad elliptical and round shape among six different varieties. The shapes of the fruits were identified using the cucurbit species descriptor (ECPGR, 2008). Broad elliptical shapes were found in four varieties viz, PPS 315, PPS 142, PPS 313 and PPS 317, while round shape was observed in sugar baby and PPS 304 (Figure 1).

Regarding fruit colour, all the varieties, except PPS 142, displayed a dark green colour. In contrast, PPS 142 had a light green colour with dark green stripes. Similarly, with regard to flesh colour, PPS 142 had light pink flesh while the remaining varieties had dark red flesh indicating that all the varieties are pigmented type (Figure 1). Red fleshed watermelons are a rich source of phytochemical lycopene which acts as an antioxidant and protects from cancers (Perkins-Veazie et al, 2004). None of the varieties had yellow flesh.

Figure 10. Images of six different varieties (Right from top: Sugar baby, PPS 313, PPS 317; Left from top: PPS 142, PPS 304, PPS 315

3.2 Findings from the market and consumer preference survey

3.2.1 Shape, size and colour

In order to gain valuable insights into market demand and consumer preferences regarding watermelons, we conducted interviews with a total of 11 vendors and 20 consumers. The results of our market and consumer preference survey revealed a strong inclination towards medium sized watermelons characterized by a dark green colour and moderate level of sweetness. A significant majority of respondents, comprising 64% of vendors and 85% of consumers, expressed a distinct preference for medium-sized watermelons over the smaller and larger watermelons (Table 5 and Table 6). This preference is primarily attributed to the convenience

of medium-sized fruits, which can be easily consumed in one sitting, conveniently stored in refrigerators, and are generally more affordable compared to larger varieties. Respondents also indicated that smaller-sized watermelons tend to have less pulp, making them less desirable. Correspondingly, our findings align with a similar study conducted in Nigeria, where a preference for medium-sized watermelons was attributed to their affordability and reduced postharvest loss (Adeoye & Balogun, 2012). Given that all six varieties under consideration bear fruits weighing less than 6 kg, all the six varieties can be recommended for medium-sized fruits.

Table 11. Consumer preference on watermelon characteristics

Category	Consumer (No)	Percentage (%)
a. Gender		
Male	6	30
Female	14	70
b. Size		
Medium	17	85
large	2	10
Small	1	5
c. Shape		
Oblong	1	5
Round	11	55
Elliptical	6	30
Flattened	1	5
Don’t know	1	5
d. Colour		
Dark green	17	85
Stripped	2	10
Medium green	1	5
e. Rind thickness		
Thick	1	5
Thin	17	85
Don’t know	1	5
Both	1	5
f. Flesh colour		
Red fleshed	20	20
Yellow fleshed	0	0
g. Sweetness		
High	8	40
medium	12	60
Low	0	0
h. Seed content		

Fewer seed	18	90
Medium seed	1	5
Don’t know	1	5

When it comes to the shape of watermelons, our survey revealed that 55% of consumers favoured round fruits, while 30% preferred broad elliptical ones (Table 5). Consumers tend to favour round watermelons for their sweetness, whereas elliptical varieties are perceived to be waterier with less flavour, as indicated by Yazawa (2023). In contrast, 73% of vendors reported a higher demand for broad elliptical watermelons, with round fruits accounting for only 18% of their preference (Table 6). Consequently, for round watermelons, varieties such as "Sugar Baby" and "PPS 304" are recommended, while for broad elliptical fruits, the remaining varieties including "PPS 313," "PPS 315," "PPS 317," and "PPS 142" are suitable choices.

In terms of colour, a significant majority of both vendors (85%) and consumers (80%) preferred dark green watermelons. Moreover, all consumers unanimously favoured red-fleshed watermelons, believing them to be sweeter than the striped and light green fruits. For watermelons with dark green skin and red flesh, five varieties, namely "PPS 304," "PPS 315," "PPS 317," "PPS 313," and "Sugar Baby," are recommended. Additionally, for those seeking stripe watermelons, "PPS 142" is a suitable option.

Table 12. Market preference on watermelon characteristics

Category	Vendors (no)	Percentage
a. Gender		
Male	10	90.9
Female	1	9.1
b. Market demand		
Yes	6	54.5
No	5	45.5
c. Size		
Medium	7	63.6
Small	4	36.4
Large	0	0
d. Shape		
Broad elliptical	8	72.7
Round	2	18.2
Don’t know	1	9.1
e. Colour		
Stripped	2	18.2
Dark green	8	72.7
Don’t know	1	9.1

3.2.2 TSS, rind thickness and seed content

In our survey, it was found that 60% of consumers prefer fruits with a moderate level of sweetness, while the remaining 40% prefer fruits with a high level of sweetness (Table 5). Yara (2018) reported that fruits with medium sweetness typically have a Total Soluble Solids (TSS) content ranging between 10-12%, a characteristic that is exhibited by all six varieties examined in this study.

Furthermore, a significant majority of consumers, specifically 85%, expressed a preference for fruits with thin rinds (Table 5). Thin-rinded fruits are favoured because they tend to have a higher pulp content. In contrast, a small minority, constituting 5% of consumers, favoured fruits with thicker rinds, citing their convenience and suitability for transportation. Regarding seed content, a substantial 90% of the consumers indicated a preference for fruits with fewer seeds (Table 5). However, this study has failed to record the rind thickness and seed count of each variety which may be included in the future studies.

4 Conclusions

This study found that all the six watermelon varieties evaluated fall under the classification of medium sized watermelons, often referred to as "icebox" types except for Samtenling where it falls under “personal” types. Overall, there were no significant differences for various parameters, including weight, height, diameter, TSS, crop duration, and yield indicating that all six varieties demonstrated consistent performance in terms of yield and size in all the study sites. All the six varieties can be promoted for commercial production of small sized watermelon production. However, considering location effect on yield and size, this research recommends PPS 315 and PPS 317 for Lingmethang, PPS 317 for Bajo and Panbang and PPS 304 for Samtenling for commercial production. Both fruit vendors and consumers demonstrated a preference for medium-sized watermelons characterized by moderate TSS content and a dark green colour. Thus, this study shows the potential of small sized watermelon for commercial production. Since the present study’s finding is based on the experiment conducted in the research centres, this study recommends future study on the comparison of fruit quality parameters in farmer’s field to validate the findings.

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