Volume 8 Issue 1 June 2025 ISSN 2616-3926

Royal Government of Bhutan

BHUTANESE JOURNAL OF AGRICULTURE

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

Editorial

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Publisher

Agriculture Research and Innovation Division, Department of Agriculture
Ministry of Agriculture and Livestock, Thimphu, Bhutan
Post Box 113, Postal Code 11001
Contact no. +975-2-322228/331316

ISSN 2616-3926 (Print)
ISSN 2707-9821 (Online)

Volume 8, Issue 1 June 2025 ISSN 2616-3926

BHUTANESE JOURNAL OF AGRICULTURE

BJA

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The Bhutanese Journal of Agriculture is registered with the ISSN International Centre,
Located in Paris 75003 (France), 45 rue de Turbigo.

FOREWORD

The Department of Agriculture is delighted to publish the 8th Volume of the Bhutanese Journal of Agriculture (BJA). The BJA continues to be a vital platform for sharing scientific findings, innovations, and practical knowledge among researchers, extension agents, and policymakers within the agriculture sector.

BJA was established with the vision of fostering a strong research culture and improving evidence-based decision-making in agriculture. Each edition of the journal reflects the dedication of our national research community, and this volume is no exception. The articles featured here represent diverse studies and experiments that address both emerging and persistent challenges in our farming systems.

We are proud of the increasing standards of the BJA, which are a direct result of the committed efforts of our editorial team, comprised of professionals from the Department of Agriculture and the College of Natural Resources.

I extend my sincere appreciation to all the authors for their valuable contributions, the peer reviewers for their critical evaluations, and the BJA editorial board for their unwavering commitment. I encourage all professionals to seriously pursue scientific writing and consider peer-reviewed publications an integral part of their research journey and professional growth.

We hope you find this volume insightful and resourceful.

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 works undertaken by the Bhutanese scientist. The publication aims to generate scientific knowledge, information and technologies that contribute to the development of agriculture sector which ultimately benefits the Bhutanese farming communities. The peer reviewed research papers published in the BJA provide the scientific basis for making critical decisions in agriculture. Although small in size, Bhutan has a diverse agro-ecology that is influenced by the mountainous terrain. Adaptive research is thus very essential for adaptation of specific technologies, skills, information, and knowledge to make agriculture sector more resilient and sustainable. The BJA serves a very good platform for the Bhutanese agriculture professionals to publish, present and share their outputs with the global agriculture professionals.

This edition Volume 8 of the BJA received more than 15 manuscripts which were reviewed by 10 experienced experts. The review reports were deliberated by a panel of reviewers in a three-day technical workshop. The review workshop is a special feature of the BJA as it ensures that the 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 were accepted for publication 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.

I wish you an intuitive reading.

(Tirtha Bdr. Katwal)
Editor-In-Chief

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Climate Variability and Its Influence on Maize (*Zea mays* L.) Production Decline in Eastern Bhutan

Kinzang Thinley[a], Thinley Gyeltshen[a], Dorji Wangchuk[b], Kinley Sithup[a], Tenzin Rabgay[a], Tshering Choden[a], Tshering Pem[a], Sonam Deki[c]

ABSTRACT

Maize is a staple food crop in eastern Bhutan, but its production has significantly declined in recent years, potentially due to the effects of climate change. Despite this, there has been limited research on the impact of climate variability on maize yield in the region. This study aims to assess climate variability trends and their effects on maize yields from 2006 to 2023. Using the Mann–Kendall trend test and Sen's slope estimation, the temperature and rainfall trends were analysed, while Pearson correlation and multiple linear regression were applied to examine the relationship between climate variables and maize yields. Minimum and maximum temperatures showed an upward trend increasing by 0.03°C and 0.06°C, respectively. In contrast, rainfall exhibited no clear trend but displayed significant year-to-year variability. While rainfall and minimum temperature had a weak influence on maize production and yield, maximum temperature had a significant positive impact, explaining 29% of the variation in production and 37% of the variation in yield. The remaining unexplained (71% for production and 63% for yield) suggest the importance of non-climatic factors and localized microclimatic conditions. This research emphasis the focus on non-climatic and microclimatic factors to fully understand the causes behind the declining maize production in the region. To enhance climate monitoring and develop more effective adaptation strategies for agricultural crops, it is recommended to establish additional weather stations beyond those currently operated by the National Centre for Hydrology and Meteorology (NCHM).

Keywords *Maize; Production; Rainfall; Temperature; Yield*

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1 Introduction

The agricultural sector employs 41.7% of the Bhutan's population and contributes 14.96 % to the GDP with 6.57 % from crops alone (National Statistic Bureau [NSB], 2024a; NSB, 2024b). Maize, the second most important cereal, is cultivated by 64% of rural households (Katwal & Bazile, 2020), and constitutes 62% of annual production in the eastern districts (National Statistic Bureau, 2023), serving as the staple food for this region. It plays a crucial role in food and nutritional security, accounting for 44% of the national food composition (Wangmo, 2019), with a per capita consumption of 109.6 g d^{-1} (Department of Agriculture [DoA], 2021).

Despites its importance, maize production has declined, with an average yield stagnating at 3.6 t ha^{-1} (NSB, 2022) and showing high year-to-year variability (Wangmo, 2024). Maize self-sufficiency has dropped from 99.2% in 2006 to 72.3% in 2019 (DoA, 2021). Factors such as climate variability, labor shortages, human-wildlife conflicts, and a shift to cash crops contributes to reduced maize cultivation. Most notably, changes in temperature and precipitation pose significant threats (Waiba & Sangay, 2024), necessitating an urgent study to assess their impacts on maize production.

Climate variability, including deviations in temperature and rainfall, is a key factor of agricultural performance (Abegaz & Kebede, 2022; Arunrat *et al.*, 2022; Thornton *et al.*, 2014). It leads to extreme weather events, which disrupts ecosystems and livelihoods (Kyaw *et al.*, 2023; Wheeler & Von Braun, 2013). A global trend toward warmer condition is driven by shifts in climate variability (Field *et al.*, 2018). Projections indicate that temperatures in South Asia could rise over by 2°C by the mid-21st century, with increases of 3-6° C at higher altitudes by the late 21st century (Intergovernmental Panel on Climate Change [IPCC], 2014). Temperature and rainfall variability account for 30–50% of annual cereal yield fluctuations globally (Holleman *et al.*, 2020).

Eastern Bhutan's agriculture, situated on diverse terrains, is highly exposed to climate changes. Historical data (2005-2014) reveal rising summer temperatures and declining winter temperatures, coupled with asymmetrical decreases in annual rainfall, leading to prolonged dry spells during critical crop growth periods (Lhamo *et al.*, 2023; MoAF, 2016; Tenzin *et al.*, 2019). Furthermore, simulation models have revealed notable abnormalities in the distribution and pattern of rain across the country (National Environment Commission [NEC], 2011).

Extreme weather events, including flash floods, windstorm, hailstorm, pest outbreaks, and soil erosion, have significantly impacted Bhutanese farmers (Chhogyel *et al.*, 2020; Katwal *et al.*, 2015; Tenzin *et al.*, 2019; Waiba & Sangay, 2024). For instance, cyclone Aila in 2009 caused extensive damage to crops and infrastructure, while landslides and floods in 2010 affected over 2000 acres of farmland (Tenzin *et al.*, 2019). Soil erosion during the rainy seasons results in the loss of 8.6 tons of soil per hectare annually (DoA, 2011). Prolonged dry spells have also led to crop failures and disrupted planting schedule (Tenzin *et al.*, 2019). Windstorm have caused damage, especially in the pre-monsoon season, affecting over 5000 acres of agricultural crops (maize, rice, potato, chili and buckwheat) in 2010 (DoA, 2010). Warming trend have exacerbated pest and diseases outbreak in maize field (Katwal 2013), contributing to a projected 10.3% decline in maize yields by 2050 under rainfed conditions (International Center for Tropical Agriculture [ICTA], 2017).

Given maize's vulnerability to climate variability, understanding its interactions with climatic factors is crucial. Despites increasing extreme weather events, localized studies on maize production remain limited, leaving the specific impacts unclear. Hence, this study examines time-series data (2006-2023) on precipitation, temperature, and maize yields in eastern Bhutan, using regression models to explore the relationship between climate and crop yield anomalies. Insights from this research will inform strategies to enhance resilience and productivity in maize cultivation.

2 Materials and Method

2.1 Study area

The eastern Bhutan (Lhuentse, Mongar, Tashigang, Tashiyangtse, Pemagatshel and Samdrup Jongkhar) spans 12,942 square kilometres and is home to population of 1.73 million, with a total of 39,938 landholders involved in agriculture (Bureau, 2017). The area experiences diverse climatic conditions, ranging from warm temperate climate in the north to a subtropical climate in the south (Yangdon *et al.*, 2022). Owing to its varied topography, the altitude in the region ranges from 300 to 4000 meter above sea level (masl), with temperature ranging from 15.3^{o} C to 24.6^{o} C and an average annual rainfall of about 1,262 mm (National Center for Hydrology and Meteorology, 2023). Additionally, the region is divided into several agro-ecological zones primarily, subtropical, temperate, and highland, with maize being the predominant crop cultivated at altitudes ranging from 300-3000 masl (Katwal *et al.*, 2015).

Various maize varieties, including open–pollinated and hybrid varieties, are grown in the east, covering approximately 11994 acres of land (NSB, 2022). However, the improved maize variety "Yangtsipa" is the most widely grown due to farmers' preferences and its adaptability (Wangmo, 2018).

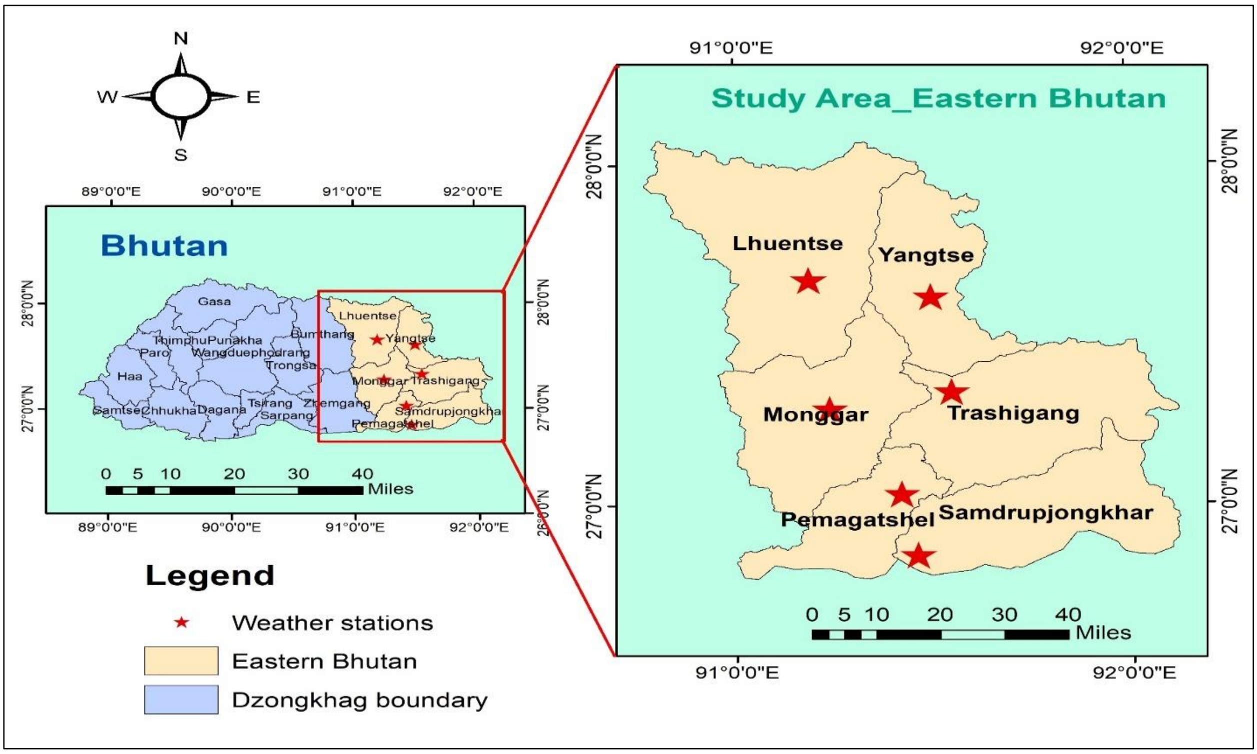

Figure 1. Study area

2.2 Climate and maize anomalies datasets

The research relies mainly on datasets acquired from various government departments and local agencies. Specifically, the time series meteorological data from 2006 to 2023, including precipitation, minimum temperature (T_{min}) and maximum temperature (T_{max}) was acquired from National Centre for Hydrology and Meteorology of the Royal Government of Bhutan. Likewise, the secondary dataset on cultivated area, production, and yield of maize from 2006 to 2023 was obtained from the National Statistics Bureau and the Agriculture Statistics of Department of Agriculture.

2.3 Analysis of Long-term Climate Variability and Trends

The maize growing season in the region spans from March to September and is often considered synonymous with the annual crop cycle. Hence, annual trends for the following climate variables were analysed:

- Temperature (annual maximum and minimum at weather stations of six eastern Districts)
- Precipitation (annual accumulated quantities at weather stations of six eastern districts)
- Area, production and yield of maize annually

The methods used in the paper, including the Mann-Kendall trend test, Sen's slope estimation, Pearson correlation, and multiple linear regression, are appropriate for the study's objectives (Gadedjisso-Tossou *et al.*, 2021; Mann, 1945). The Mann-Kendall test evaluates the presence of trends in a dataset, with the null hypothesis (H_0) stating that no trend exists in the population and the alternate hypothesis (H_1) suggesting the presence of a trend. The null hypothesis is rejected if $p < 0.1$ (Poudel & Shaw, 2016). These statistical methods are widely used in climate variability and agricultural studies to analyse trends and relationships between climate variables and crop production (Yue & Wang, 2004). The computation of the Mann-Kendall test involves specific equations to detect the presence of upward or downward trends in time-series data (Pohlert, 2016), as illustrated below:

$$sgn\ (xi - xj) = \begin{cases} 1, & xi - xj > 0 \\ 0, & xi - xj = 0 \\ -1, & xi - xj < 0 \end{cases} \tag{1}$$

$$E[S] = \sum_{1=1}^{n=1} \sum_{j=i+1}^{n} sgn(xi - xj) \tag{2}$$

$$VAR\ (S) = \frac{1}{18}\{n(n-1)(2n+5) - \sum_{j=1}^{p} tj(tj-1)(2tj+5)\} \tag{3}$$

$$Z = \begin{cases} \frac{E[S]-1}{var\ (s)} & S > 0 \\ 0 & if\ S\ = 0 \\ \frac{E[S]+1}{var\ (s)} & S < 0 \end{cases} \tag{4}$$

In Equations (1) and (2), x_i and x_j represent the value of the time series at a particular position, i and j. S in Equation (2) represents the sum of the signs of the differences between pairs of observations. *"n"* represents the total number of observations in the time series, and t represents the Kendall rank correlation coefficient, which measures the strength and direction of the monotonic trend in the time series.

Similarly, Sen's slope estimator is used to quantify the trend of time series datasets, and it finds application in diverse fields such as hydrology, climatology, and environmental sciences (Meena, 2020; Pohlert, 2016). Sen's slope, developed by Sen in 1968, is a nonparametric procedure used as an index for quantifying trends (Sen, 1968). The slope is calculated using the following equation;

$$\beta = Median\left(\frac{xj-xi}{j-i}\right), j > i \tag{5}$$

β represents Sen's estimated slope, $\beta > 0$ means an upward trend, and $\beta < 0$ is a downward trend in a time series. Additionally, *xi* and *xj* are the values of the time series at positions *i* and *j*, respectively, and (*j* - *i*) is the time interval between the two observations.

2.4 Climate-maize anomalies relationship

The Pearson's correlation analysis was performed to measure the strengthen and direction of linear relationship between maize yield and climate variability using following equation;

$$r = \frac{\Sigma((xi - x)(yi - y))}{(\sqrt{(\Sigma((yi - \mathrm{y})^2)})(\sqrt{(\Sigma((yi - \mathrm{y})^2)})} \tag{6}$$

Where, *xi* and *yi* in the equation represent the individual values of the two variables, while *x* and *y* represent the means of the two variables, respectively. The correlation coefficient *(r)* is calculated to assess the statistical significance of the correlation, which can be determined by examining the confidence interval (*p*-value). The range of correlation coefficients is -1 to +1, represents the complete independency of the variables (Poudel & Shaw, 2016). The statistical significance is kept at 95% confidence level. ($p > 0.05$).

Furthermore, to examine causality, a multiple regression analysis was conducted to determine if there is statistically significant difference between independent (rainfall, T_{min}, T_{max}) with dependent variables (maize area, production, yield) as explained by a linear model in the following equations;

$$Y = a + b1\,x1 + b2\,x2 + \cdots bn\,xn \tag{7}$$

Where Y is the dependent variable; *a* is the constant; $b_1, b_2, \ldots, b_n$ are the beta coefficients for independent variables; and $x_1, x_2, \ldots, x_n$ are the independent variables. In these studies, the multivariate regression analysis was carried out separately for maize area, production and yield with precipitation, minimum temperature and maximum temperature as to indicate how climates variables influence the maize attributes.

2.5 Statistical analysis

The descriptive and inferential statistic was performed using statistical software such as R version 4.3.2 and Statistical Tool for Agriculture Research (STAR). For analysing trend of climate and maize anomalies, Mann-Kendall and Sen's slope was used and performed in XLSTAT in Microsoft excel. The significant level in variation of climate trend is considered at $p < 0.05$.

3 Results and discussion

3.1 Descriptive statistics on maize attributes and climate variability

The average area under maize cultivation was 23,894.9 acres, with a deviation of 8,313.3 acres over the years. The lowest area under maize cultivation was recorded at 9,751.2 acres, while the highest was 35,491 acres, suggesting significant year-to-year fluctuations, possibly due to various influential factors. Similarly, the average maize production was 33,868.6 MT, with a standard deviation of 11,438.8 MT, signifying substantial annual variability. The lowest production was 15,415.6 MT, while the highest was 52,950 MT, showing a difference of 37,534.4 MT. Additionally, the average maize yield was 1.5 MT per acre, displaying a moderate fluctuation. The lowest yield recorded was 0.97 MT per acre, while the highest was 1.95 MT per acre, exhibiting a range of 0.98 MT per acre between the best and worst production years, potentially due to growing conditions and management practices (Table 1).

Throughout the study period, the mean temperature was 19.7°C, with fluctuations of approximately 0.5°C (Table 1). The lowest temperature observed was 14.2°C, while the highest reached 25.7°C. The region experiences moderate seasonal or daily temperature changes of around 11.5°C (Table 1). With respect to rainfall, an average of 1418.6 mm was recorded, with deviations of up to 207 mm (Table 1). The highest recorded rainfall was 1841 mm, indicating the occurrence of intense downpours in the region.

Table 1. Descriptive analysis of maize attributes and climate variability

Variables ➛	Maize anomalies			Climate variables			
Descriptive statistic ➘	Area (Field *et al.*)	Production (MT)	Yield (MT ac^{-1})	Rainfall (mm)	Tmin (° C)	Tmax (° C)	Ave temperature (° C)
Min	9751.2	15415.6	0.9	1025.0	14.2	22.9	18.6
Max	35491.0	52950.0	1.9	1841.8	15.7	25.7	20.3
Mean	23894.9	33868.6	1.5	1418.6	14.8	24.5	19.7
StdDev	8313.4	11438.8	0.2	207.1	0.4	0.8	0.5
SE_Mean	1959.5	2696.5	0.1	48.8	0.1	0.2	0.1
CV (%)	34.8	33.77	18.08	14.6	3.0	3.56	2.8

Min = minimum; Max = Maximum; StdDev = Standard deviation; SE_Mean = Standard error of mean; CV = Coefficient of variance

3.2 Trend of Climate Variability in Eastern Bhutan (between 2006 and 2023)

There was no significant increase for both T_{max} (Kendall's tau = 0.206, p = 0.26, Sen's slope = 0.06) and T_{min} (Kendall's tau = 0.309, p = 0.09, and Sen's slope = 0.03°C/ year) during the last 18 years (2006-2023). However, T_{max} increased by 0.06°C per year, while T_{min} saw an increment of 0.03° C per year (Fig. 2a). The rate of increase in T_{max} was found to be twice as fast as that of T_{min} (Figure 2a). These findings are consistent with studies of Rinzin *et al.* (2024), which also reported an annual increase in T_{max} ranging from 0.01°C to 0.06° C per year during the season. On the other hand, T_{min} has been steadily rising over time, particularly in 2006, 2011, 2016, 2021, 2022, and 2023 (Figure 2a). The steady increase in both T_{max} and T_{min} is likely attributed to the increase in emission scenario (Rinzin *et al.*, 2024). Additionally, NCHM (2019) has also projected a temperature increase of 0.8- 3.2° C CMIP5 under the RCP 8.5 scenario.

The analysis of annual rainfall trend showed relatively stable throughout the same period, with significant year-to-year variation (Kendall's tau = 0.00, p>0.96, Sen's slope = -5.73 mm per year). Notable fluctuation in rainfall were observed in 2007, 2012, 2019, 2020, and 2022, while decrease was noted in 2006, 2011,2018 and 2021, suggesting that annual rainfall amounts varied without a notable increase or decrease trend in Eastern Bhutan (Figure 2b). This variability may be tributed to interaction of heterogeneous topography (Shrestha *et al.*, 1999) and influence to latitudinal variation (Dorji *et al.*, 2021). Similar finding was reported by Dorji *et al.* (2021), indicating statistically insignificant trends in rainfall for all season. Shahnawaz and Strobl (2015) also observed high variability in monthly precipitation during the rainy season in Bhutan, without a discernible trend in any specific direction of change. Additionally, our results align with those of NCHM (2019), demonstrating significant year-to-year variation in rainfall without any significant increasing or decreasing trend at any weather stations.

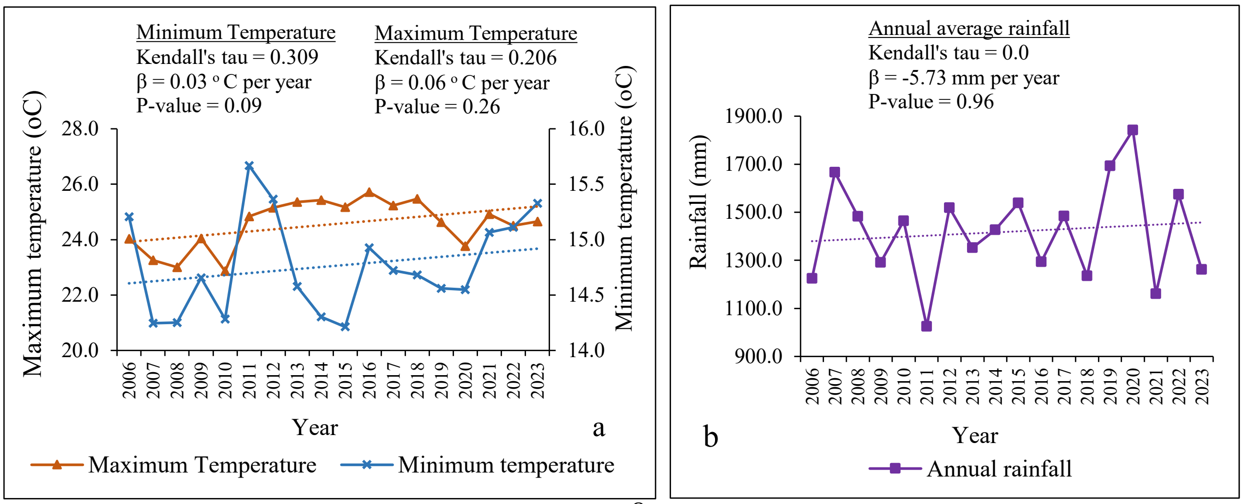

Figure 2. Trend of T_{min} and T_{max} (left) and rainfall (right)

3.3 Trend of Maize area, Production and Yield

A significant decrease in maize area was observed (Kendal's tau = -0.441, β = -1283.5 acres per year, p = 0.013) between 2006 and 2023 as shown in Figure 3. Sen's slope analysis also confirms a yearly decrease of -1,283.5 acres of maize area in the east. The area saw a fluctuation until 2017, however it sharply declined after 2018 (Figure 3). This decline may be ascribed to the reduced number of maize growers, dropping from 38,397 holders in 2021 to 37,707 holders in 2022, representing a 2% decrease (NSB, 2022). There might be several factors behind, however a diagnostic survey could identify factors contributing to the decline in maize area in the east that will aid in revitalizing maize growers.

Likewise, maize production showed a substantial but not statistically significant decline over time (Kendall's tau = -0.206, β = -1043.09 MT per year, p = 0.27) (Figure 3). The Sen's slope estimator confirms a yearly decrease of -1043.09 MT in maize production. This decrease could be associated to crop damage during plant development caused by strong winds, prolonged dry spells, heat waves, damage by wild animals and outbreak of pest and diseases, resulting in significant production losses (NSB, 2022). Further studies are required to quantify these effects.

In contrast, the increase in maize yield was statistically significant (p <0.0001) and displayed a positive trend with a Kendall's tau value of at 0.77, suggesting 77% relationship. According to the Sen's slope estimator, maize yield showed an increase of 0.051 metric tons per year, accounting for a 28% increase from 2006 to 2023 (Figure 3). Despites a decrease in maize cultivation area, the increase in annual temperature may have contributed to the rise in maize yield, enabling maize production in higher altitudes. Our findings are consistent with those of Poudel & Shaw (2016), who noted that higher temperatures during the growing season had a positive impact on maize yield in Lamjung District, Nepal. Apart from climate factors, it is possible that agronomic factors, such as access to high-quality seeds, played a role, as 24-50% of maize seed were replaced with seeds of assure high quality through community-based seed production groups (Katwal *et al.*, 2015). As observed, the trend of annual rainfall in the east exhibited a high year-to-year variation but remained relatively stable over the period without significant increase or decrease. Thus, the implementation of dryland irrigation schemes with the support of water reservoirs, sprinklers, drip sets, rainwater harvesting, and the renovation of irrigation schemes (Commercialization Agriculture Resilient Livelihood Enhancement

Program [CARLEP], 2024) may have contributed to the increase in maize yield. Besides, as reported by Poudel & Shaw (2016), the use of new seeds and agricultural technology, improved irrigation, and better crop management practices are also likely to have attributed for the increased crop yield alongside the effect of climate change.

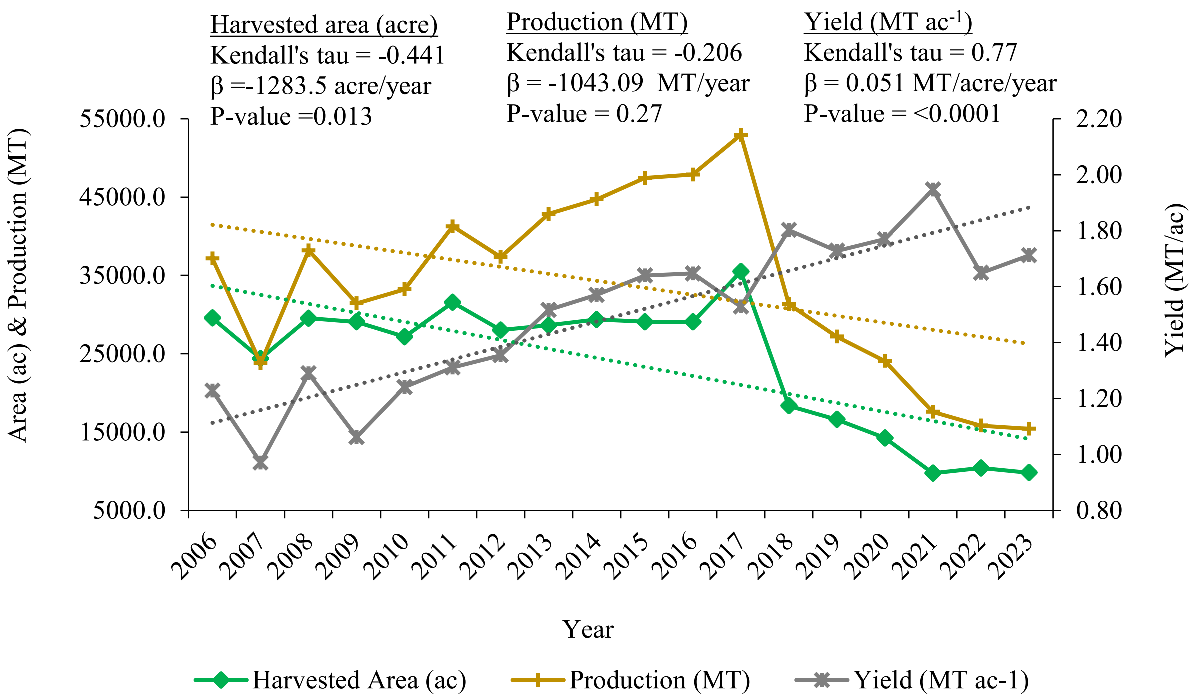

Figure 3. Trend analysis of area, production and yield of maize in Eastern Bhutan

3.4 Correlation between Climate variability (Rainfall and Temperature) and Maize Yield

A weak and negative correlation between rainfall and area (R = -0.15) and production (R = -0.14) was observed, indicating that as rainfall increases, maize production decreases (Table 2). This finding is consistent with the negative correlation between rainfall and rainfed maize in Ethiopia (Moges & Bhat, 2021) and the US Midwest (Liu & Basso, 2020), as well as the result reported in Ghana by Ndamani and Watanabe (2014). However, there was little or no relationship between rainfall and maize yield (p = 0.97; R = -0.009), which aligns with the findings of Poudel & Shaw (2016) regarding the lack of significant effect of rainfall on millet yield in Nepal.

A weak and negative correlation with no significant relationship was found between T_{min}, and maize area (R = -0.19) and production (R = -0.19) (Table 2). Similarly, the association between maize yield and T_{min} was not statistically significant (p = 0.6), although it showed a positive relationship (R = 0.12), implying that maize yield increases with increasing T_{min} (Table 2)

The correlation coefficient between maize production and T_{max} is 0.37, indicating a positive relationship, which suggests that higher T_{max} may be associated with increased maize production (Table 2). However, this correlation is not statistically significant ($p = 0.12$), implying that rising T_{max} does not significantly affect maize production but rather induces the outbreak of pests and diseases, leading to production decline (Escalada *et al.*, 2015). This is supported by incidences such as the fall armyworm outbreak in maize field (Mahat *et al.*, 2021); (Ie *et al.*) and the occurrence of outbreak of turcicum leaf blight, and grey leaf spots, which damaged 70 to 80% maize crop in eastern Bhutan (Katwal *et al.*, 2013). These findings are consistent with studies in Nepal, where the emergence of new pests and diseases has negatively affected crop production over the past 20 years (Maharjan *et al.*, 2009).

Conversely, there was a significant effect of T_{max} ($p = 0.01$) on maize yield, with a coefficient of $R = 0.56$, suggesting a moderate positive relationship between T_{max} and maize yield. This signifies that as T_{max} increases, maize yield tends to increase, and this trend is not correlated with rainfall pattern and T_{min}, but rather with T_{max} (Table 2). The maximum temperature during the study period was approximately 26°C, which is considered optimal for maize growth and development, potentially explaining the observed yield increase over the period. However, if T_{max} continues to rise beyond this range, it could negatively impact maize production, leading to a decline in yields. Developing and adopting heat-tolerant maize varieties could help mitigate the adverse effects of rising temperatures and sustain production levels. These results align with finding indicating increased maize yield being positively associated with higher temperatures in Thailand (Kyaw *et al.*, 2023) and with wheat in Ethiopia (Abegaz & Kebede, 2022). Similar findings also reported in Nepal with positive relationship between T_{max} and wheat yield (Poudel & Shaw, 2016). The increase in maize yield in the eastern region coinciding with rising temperature may be due to non-climatic factors such as agronomic aspects including planting calendar, adoption of improved cultivar fertilizer application, use of certified seeds, and extension services (Atiah *et al.*, 2022; Kyaw *et al.*, 2023; Oluoch *et al.*, 2022).

Table 2. Correlation between climate variables and maize attributes

Climate variables	Coefficient	Area (acre)	Production (MT)	Yield (MT ac^{-1})
Rainfall	R	-0.15	-0.14	-0.009
	p-value	0.53	0.57	0.97
T_{min}	R	-0.19	-0.19	0.12
	p-value	0.43	0.43	0.6

T_{max}	R	0.04	**0.37**	**0.56**
	p-value	0.85	0.12	**0.01**

MT = Metric ton; Tmin = Minimum temperature; Tmax = Maximum temperature

3.5 Changes in maize attributes (area, production and yield) due to climate trend

3.5.1 Climate impact on maize area

The model 1 (Rain only) explained a mere 3% of the variation (R-squared = 0.03) and had an adjusted R-squared of -0.04, signifying poor model fit. The coefficient for rain (-6.29, p = 0.53) was not statistically significant, suggesting a weak or no association between rainfall and maize area (Table 3). The model 2 (Rain and T_{min}) slightly increased the R-squared to 0.14, explaining 14% of the variation in maize area. Nonetheless, the adjusted R-squared remained low (0.03), with neither rain (-15.53, p = 0.21) nor T_{min} (-7691.54, p = 0.17) demonstrating statistical significance (Table 3). In addition, model 3 (Rain, T_{min}, T_{max}) also accounted for 14% of the variation (R-squared = 0.14), but the adjusted R-squared decreased to -0.04. None of the variables, rain (-14.98, p = 0.26), T_{min} (-7933.31, p = 0.18), or T_{max} (585.00, p = 0.73), were statistically significant, suggesting that these climatic factors do not significantly elucidate changes in maize cultivation area (Table 3). Other non-climatic factors, such as farm labor shortages, human-wildlife conflicts, and the replacement of maize cultivation with commercial cash crops, may have contributed to the decline in maize cultivation area.

3.5.2 Climate impact on maize production

Rainfall alone (Model 1) accounts for only 2% of the variation in maize production, and its impact is not statistically significant (p = 0.15). Similarly, the combination of rain and T_{min} in Model 2 explains 13% of the variation, but neither rainfall nor T_{min} shows statistical significance ($p > 0.05$). In contrast, incorporating rain, T_{min}, and T_{max} in Model 3 explains the highest variation, at 29% (Table 3). Notably, T_{max} has a significant positive impact on maize production (p = 0.03), while rain and T_{min} remain insignificant. This indicates that T_{max} is a key climatic factor influencing maize production, whereas rain and T_{min} have minimal direct effects. The remaining variability (71%) is likely attributable to non-climatic factors, such as the use of high-quality seeds and improved crop management practices.

3.5.3 Climate impact on maize yield

Rain (Model 1) had no significant effect on maize yield (p = 0.98) (Table 3). Although the influence of rain and T_{min} (Model 2) on maize yield was not significant, however they accounted for 3% of the variation (Table 3). The inclusion of rain, T_{min}, and T_{max} (Model 3) provided the best fit, explaining 37% of the variability in maize yield (R-squared = 0.37) (Table

3). T_{max} exhibited a significant positive impact on maize yield (0.19, p = 0.02), whereas rain (0.0003, p = 0.34) and T_{min} (0.04, p = 0.82) showed no significant effects (Table 3). Although T_{max} accounted 37% of the variation in maize yield, 63% of yield changes were still explained by other influential factors. These factors could be the use of quality seeds, better crop management practices and introduction of new agro-technology (Poudel & Shaw, 2016). Similar studies also suggested that types of agronomic practices will have a significant influence on maize yield rather than climate variabilities (Kyaw et al., 2023).

Therefore, T_{max} is the most significant factor, particularly in maize production and yield. Rain and T_{min} exhibited a much weaker influence and did not significantly predict maize outcomes in this study. Any variation or fluctuation in T_{max} will have adverse impact on overall maize production and yield in the region. This result indicates that maize production is highly susceptible to the rising of temperature and there are chances of new pest and diseases outbreak and prolonged dry spell. Thus, the strategies such as introduction of climate resilient varieties need to explored for adapting with the climate change.

Table 3. Impact of different climate predictors on area, production, and yield of maize

Attribute	Model	Predictors	R-squared	Adjusted R-squared	Coefficient of Rain	Coefficient of T_{min}	Coefficient of T_{max}
Area	Model 1	Rain	0.03	-0.04	-6.29 (ns)	-	-
	Model 2	Rain and T_{min}	0.14	0.03	-15.53 (ns)	-7691.54 (ns)	-
	Model 3	Rain, T_{min} and T_{max}	0.14	-0.04	-14.98 (ns)	-7933.31 (ns)	585.00 (ns)
Production	Model 1	Rain	0.02	-0.04	-7.90 (ns)	-	-
	Model 2	Rain and T_{min}	0.13	0.01	-20.28 (ns)	-10310.46 (ns)	-
	Model 3	Rain, T_{min} and T_{max}	0.29	0.15	-14.8 (ns)	-12701.1 (ns)	5784.4 (*)
Yield	Model 1	Rain	0.00006	-0.06	0.0001 (ns)	-	-
	Model 2	Rain and T_{min}	0.03	-0.1	0.0002 (ns)	0.12 (ns)	-
	Model 3	Rain, T_{min} and T_{max}	0.37	0.23	0.0003 (ns)	0.04 (ns)	0.19 (*)

*The p-values are shown in parenthesis; ns = not significant; * = p-value less than 0.05; ** = p-value less than 0.01; *** = p-value less than 0.001; T_{min} = minimum temperature; T_{max} = maximum temperature*

4 Conclusion

The study concludes that rainfall pattern in eastern Bhutan has remained relatively consistent over the study period, with high year-to-year variations. In contrast, neither T_{min} nor T_{max}

demonstrated a significant increase, although rate of T_{max} was observed to be twice as fast as that of T_{min} at 0.06° C per year. Maize, a staple food in the east, experienced a significant decrease in cultivation area and production, as previously discussed. Conversely, maize yield saw a substantial increase of 0.05 metric ton per year, making a 28% increase from 2006 to 2023. Notably, neither rainfall nor T_{min} seemed to have an impact on the area and production of maize in eastern Bhutan, suggesting the presence of other non-climatic factors. However, T_{max} emerged as the influential factor among all climate variables, explaining 29% and 37% variation in production and yield, respectively. Any fluctuation in T_{max} is likely to have a detrimental effect on overall maize production and yield in the region.

Therefore, the study recommends the development of a strategy to mitigate the adverse impact of rising temperatures on maize yield. Furthermore, the declining production cannot be solely attributed to climate variables (rainfall, T_{min}, and T_{max}), indicating the possible influence of other non-climatic factors that should be studied to maximize maize production in the country.

5 Author's contribution statement

Kinzang Thinley and Thinley Gyeltshen were involved in conceptualizing and designing the research protocols, analysing the data, interpreting the results, and drafting the manuscript. Dorji Wangchuk reviewed the manuscript and offered recommendations for further enhancements, while Tshering Pem and Tenzin Rabgay were involved in the formatting and validation of the manuscript. Kinley Sithup, Sonam Deki, and Tshering Choden contributed to sourcing secondary climate data from NHCM, as well as sorting, organizing, and validating the data in an Excel spreadsheet.

6 Acknowledgement

The authors are highly indebted to the management of the National Centre for Hydrology and Meteorology, Thimphu, for providing times series dataset on climate variable from 2006 to 2023. Meanwhile, cooperation of the co-authors is also acknowledged for their role in making this research article possible.

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Determination of the Shelf Life of Chili (*Capsicum annuum* L.) in Cold Store and Ambient Room Temperature Conditions Harvested at Different Maturity Stages

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Abstract

In Bhutan, different varieties of chili (Capsicum annuum L.) are grown in all the twenty Dzongkhags. Chili being a warm-season crop is produced in the summer but during the winter months, the plant growth is retarded due to low temperatures. During the chili season, there are huge supply in the market but a deficit during the winter months while the demand from the consumers is constant. Storing the last harvest of the summer chili production for the winter months in the cold store could be one possible way to make domestic chilies available during the winter months. This study was conducted to determine the storage shelf life of chili of different maturity stages in ambient room and cold store conditions at the National Post Harvest Sub-centre, Lingmethang. The experiment design was a factorial arrangement with a complete randomized design with two treatments, ambient room temperature and cold storage conditions with five replications. Under each treatment, three maturity stages such as red, light, and dark green chilies were studied. Physiological weight loss, shrinkage, decay, and shelf life data were recorded at weekly intervals. The results indicate dark green chilies could be stored for eight weeks, light green chilies for six weeks, and red chilies for five weeks in the cold store at 8 to 10°C in 90-95% relative humidity. While in the ambient conditions, chilies could be stored for two weeks. Significant physiological weight losses ($p<0.05$) were observed across different chili maturity stages in the cold storage. The dark green maturity stage can be stored for the longest duration. Storing fresh green chilies from the last harvest of the local Bhutanese chili in the cold store could make chilies available during the winter months, when there is a scarcity of local Bhutanese chili in the market.

Keywords: *Physiological weight loss; Shrinkage; Decay; Shelf life*

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1 Introduction

Chilli (*Capsicum annuum* L) is commonly known as pepper, chili, and chile depending on its location. It is an important crop that is cultivated throughout the globe both for consumption and for commercial use. The major producers are India, China, Thailand, Ethiopia, and Indonesia (Agricultural Market Intelligence Centre, 2021). The crop belongs to the Solanaceae family and it is most commonly consumed in horticultural crops in its fresh form. It is cultivated in tropical, sub-tropical, and temperate regions (Kapoor, Sidhu, Tandon, Jindal, & Mahajan, 2022). It is most commonly used as spices, vegetables, ornamental, and medicinal purposes as it contains vitamin B, vitamin C, carotene, antioxidants, and flavonoids (Villa-Rivera & Ochoa-Alejo, 2021). It is also one of the fundamental ingredients in many cuisines, adding spice and flavor to dishes. It is consumed fresh, dried, powder, pickles, sauces, and as a paste.

Five species of chili such as *Capsicum annuum* L., *Capsicum frutescens* L., *Capsicum baccatum* L., *Capsicum pubescens* Ruiz and Pav, and *Capsicum chinense* Jacq., are cultivated under the genus Capsicum (Bosland & Votava, 2000). The most popular and cultivated is the *Capsicum annuum* L. In Bhutan, chili is grown in all the twenty *Dzongkhags*. Different varieties of chilies are cultivated such as *Sha Ema, Baegap Ema, Nubi Ema*, Super Solo, Indian chili IR-8, and hybrid varieties HPH 1069, Sitara Gold, SHP 4884, and SV 2319 (Department of Agriculture [DoA], 2024). The Department of Agriculture under the Ministry of Agriculture and Livestock, so far released about eight varieties of chili and one variety of sweet peppers for cultivation (DoA, 2024). In the year 2023, Bhutan produced about 4848.12 MT of chilies from an area of about 2888.53 acres with an average yield of 1678 kg/acre. Paro Dzongkhag was the highest producer with 1005.07 MT, followed by Wangduephodrang with 467.59 MT and Punakha Dzongkhag with 434.95 MT (National Statistics Bureau [NSB], 2024). Chili is one of the main cash crops of the farmers which provides higher returns with a season and with the higher returns, farmers in the western part of the country have started to cultivate on a large scale (National Biodiversity Centre [NBC], 2015). However, chili being a warm-season crop it is produced only in the summer season and during the winter months the plant growth is retarded due to low temperatures. During the chili season, there are huge supply in the market but a deficit during the winter months while the demand from the consumers remains constant.

According to Poudel, et al., (2021), the demand for this fresh chili is year-round but due to being perishable in nature, it can only be stored for 4-7 days at ambient conditions. It is important to study the storage shelf life of chili to determine the causal factor and provide the ways and means to reduce the losses, suitable postharvest handling technology development in chili is necessary to fetch a good market price after certain weeks or months of storage when there is lean period of its availability in the market. There are great roles of the harvesting technique, pre-cooling, sorting, packaging, and storage facilities in the quality maintenance of chili for a longer period.

In Bhutan, post-harvest losses of chili hinder the income of the farmers. On the contrary, the domestic production of chili is very low during the winter months due to unfavorable climatic conditions for production. Storing the last harvest of the summer chili production for the winter months in the cold store could be one possible way to make domestic chilies available during the winter months. A study on post-harvest losses of chilies in Bhutan found that 84% of chili farmers avoided storing chili produce for more than a night, as storage for multiple days resulted in increased post-harvest losses due to decay, wilting, and discoloration (Wangmo & Dendup, 2021). The storage practices were usually in the farmhouses without temperature, moisture, or ventilation control.

However, with Bhutan's progress in storage practices by introducing cold storage facilities in various strategic regions of the country by the Food Corporation of Bhutan (Food Corporation of Bhutan Limited [FCBL], 2025), the storage losses in the nearby location could be minimized. The cold store facilities were established to store perishable commodities such as fruits, vegetables, and livestock products to ensure a longer shelf life and maintain their quality thereby reducing postharvest losses. This advanced technology will prove to be an advantage over the ambient stores that the farmers practice at the household level. However, there is still a lack of research on prolonging the shelf life of perishable commodities, such as chili in improving its shelf life in cold store facilities. Previous studies in other parts of the world have shown that different maturity stages of crops can significantly impact their shelf life (Guijarro-Real, et al., 2023; Tolasa et al., 2021 and Tsegay et al., 2013), and to validate these results this study was conducted with the objective to determine the storage shelf life of chili of different maturity stages in ambient room conditions and cold store.

2 Materials and method

2.1 Sample Collection Area

The different maturity stages of chilies (local big chili) varieties were harvested and collected from Wama village located at 1724 masl 27°07'56.74" N and 91°02'42.16" E under Silambi

Geog, Mongar *Dzongkhag*. The chilies were transported to the National Post Harvest Sub-centre, Lingmethang on the same day. The village produces a variety of vegetables and supplies to the nearby schools and markets. In the Silambi *Geog*, Wama village produces maximum chilies till the end of November month. The chilies for the study were collected from the last harvest from the Wama village on November 4, 2023.

2.2 Study Area

The study on the determination of the shelf life of chili in cold store and ambient conditions was conducted at the cold store facilities of National Post Harvest Sub-centre, Lingmethang from November 5, 2023, to January 5, 2024. The chilies were sorted and graded based on their size, shape, and color quality, and at different maturity stages. The damaged, bruised, punctured, rotten, and pest damage were removed.

2.3 Experiment design

Factorial arrangement with a Complete Randomized Design (CRD) with two treatments, treatment 1 (T_1) ambient room temperature storage and treatment 2 (T_2) under cold storage conditions. Under each treatment, three factors were studied. Factor one chilies that had turned to dark green colour, factor two light green colour chilies, and factor three chilies that had turned red.

The fresh chilies were sorted into red chili, light green chili, and dark green chili and were further divided into two treatments. For each treatment, there were five replications. In each replication, 15 kg of chilies were weighed. A total of 450 kg of chilies (150 kg of red chili, 150 kg of light green, and 150 kg of dark green chili) were stored. The chilies were stored using the plastic crates.

The cold store temperature was set to 8°C to 10° C and 90-95% humidity (Walker, 2010). A data logger was placed for ambient room conditions to record the room temperature and humidity. The data on physiological weight loss, chili shrinkage, and decay were recorded every one-week interval.

2.4 Physiological weight loss

The weight of the chilies was measured before the storage and at every weekly interval using a high-precision electronic digital weighing balance (Blue Star). The recorded weight was then calculated in percentage. The physiological weight loss was measured using a standard precision weighing scale and recorded the data. The physiological weight loss was expressed in percentage using the following equation (Tsegay, Tesfaye, Mohammed, Yirga, & Bayleyegn, 2013) and mean in different maturity stages of stored chili.

$$Physiological\ weight\ loss\ (\%) = \frac{Initial\ weight - Final\ weight}{Initial\ weight} X\ 100$$

2.5 Decay

A random sample of 100 numbers of chilies from each storage crate was taken and the number of chilies decayed was recorded. The decayed chilies quantity was then determined in percentage from the number of samples collected randomly. The decayed chilies were assessed visually based on the symptoms of decay developed on the chili fruits at the different storage intervals (Tsegay, Tesfaye, Mohammed, Yirga, & Bayleyegn, 2013).

2.6 Shrinkage

The number of chili shrinkage was assessed visually at weekly intervals. Randomly 100 chilies were selected from the crates and then the number of chilies that had shrinkage was recorded based on the surface depression development on the chili fruits (Lowands, Banaras, & Bosland, 1994). The shrinkage of chili in different maturity stages was then determined in percentage from the 100 chilies selected from the lot.

2.7 Shelf life

The shelf life of fruits was decided based on the appearance and spoilage of fruits. When 50% of chili showed symptoms of shrinkage, decay, or spoilage due to pathogens and chilling injury, a lot of chilies were considered to have reached the end of shelf life (Rao, Gol, & Shah, 2011). The shelf life was evaluated based on the number of days at the storage.

2.8 Data analysis

The data collected during the experiment were processed in Microsoft Excel 2013 spreadsheet. It was analyzed using Statistical Tool for Agricultural Research (STAR) version 2.0.1. Both descriptive and inferential analysis were done using the software. Analysis of variance (ANOVA) and Post Hoc test were carried out at a significance level of 0.05.

3 Result and Discussion

3.1 Physiological weight loss of chilies

The results from the experiment showed that the chilies in the ambient room temperature condition could be stored for two weeks. A significant difference *(P-value < 0.05)* was observed among the different maturity stages, dark green, light green, and red chilies which could be stored for two weeks irrespective of the maturity stages. In the first week of the storage experiment, the maximum weight loss was observed in red chili with a mean weight of 8.58 kg from 14 kg of initial weight, and in the second week, it was 4.20 kg as shown in Table 1. The lowest was in dark green chili with a mean weight of 10.22 kg from 14 kg in the first week and 5.54 kg in the second week of storage in the ambient room temperature condition (Table 1). The chilies in all the stages have shrinkage due to high temperatures of 26^0C to 28^0C and low relative humidity of 40-50% in ambient room conditions and could not be marketed at the end of the two-week storage period. The physiological weight loss of the stored chilies was mostly due to decay and shrinkage.

Table 1. Mean weight of chili stored at an ambient room temperature condition

	Mean weight of chili (Kg) stored at an ambient room temperature condition		
Treatment	Week 0	Week 1	Week 2
Dark green	14	10.22a	5.54a
Light Green	14	9.60b	5.06b
Red	14	8.58c	4.20c
Mean	14	9.47	4.93
CV (%)		3.07	3.33
P-value		0	0

**Means with the same letter in the column are not significantly different at P-value < 0.05*

The chilies in the cold store could be stored for a maximum of two months period. During the storage period a significant difference *(P-value < 0.05)* was observed among the different maturity stages of fresh chilies stored in the cold store conditions. Red chilies could be stored for five weeks while the dark green chilies could be stored for eight weeks in the cold store. The mean weight recorded was 13.76 kg dark green, 13.63 kg light green, and 13.23 kg red chilies in the first week of storage and 5.33 kg for dark green chilies at the end of eight weeks of storage period.

Loss in the weight of chilies gradually increased every week with the rapid weight loss was observed in red and the lowest in dark green chilies during the eight weeks of storage period as shown in Table 2. More than 50% of weight loss was observed from the fifth week in red chilies and from the sixth week onwards in dark green and light green chilies.

Table 2. Mean weight of chili stored in the cold store condition

	Mean weight of chili (Kg) stored in cold store condition								
Treatment	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Dark Green	14	13.76a	13.31a	12.75a	11.86a	11.40a	8.17a	7.19	5.33
Light Green	14	13.63a	13.14a	12.64a	10.18b	9.01b	5.04b		

Red	14	13.23b	12.64b	11.39b	9.38c	5.28c	
Mean	14	13.54	13.03	12.26	10.48	8.57	6.61
CV (%)		1.39	2.31	1.17	1.76	1.15	2.4
P-value		0	0.01	0	0	0	0

**Means with the same letter in the column are not significantly different at P-value < 0.05*

A cold store could have a significant difference in storing fresh chilies compared to the ambient room temperature conditions which could offer for consumption over a longer period (Hameed, et al., 2013). In line with the study by Hameed et al., (2013), chilies stored at 15°C experience maximum quality weight loss, and decay during storing compared to those stored at or below 10°C as more ethylene production and respiration higher at higher temperatures. The weight loss of sweet pepper fruits harvested at fully ripened and full green fruit were significantly higher than fruits harvested at intermediated stages. The physiological weight loss in the ripened fruits could be due to changes in the permeability of cell membranes causing them sensitive to water losses, which is in line with the study conducted by Tsegay, Tesfaye, Mohammed, Yirga, & Bayleyegn, (2013) on the effects of harvesting stage and storage duration on postharvest quality and shelf life of sweet bell pepper. The study also reported that completely ripened and full green chili stages have significantly higher weight loss than the intermediate stages.

3.2 Shrinkage

The number of chili shrinkages was recorded in every hundred chili randomly selected from the stored crate. The shrinkage in red chili was 97%, followed by light green 88% and dark green 70% at the end of two weeks storage in ambient room temperature conditions as shown in Figure 1a. In cold store conditions, red chili has 38% at the end of five-week storage, light green 47% at the end of six-week storage, and 40% dark green at the end of the eight-week storage period as indicated in Figure 1b. Rapid development of shrinkage in the chilies was observed in the red chilies followed by light green and dark green chilies.

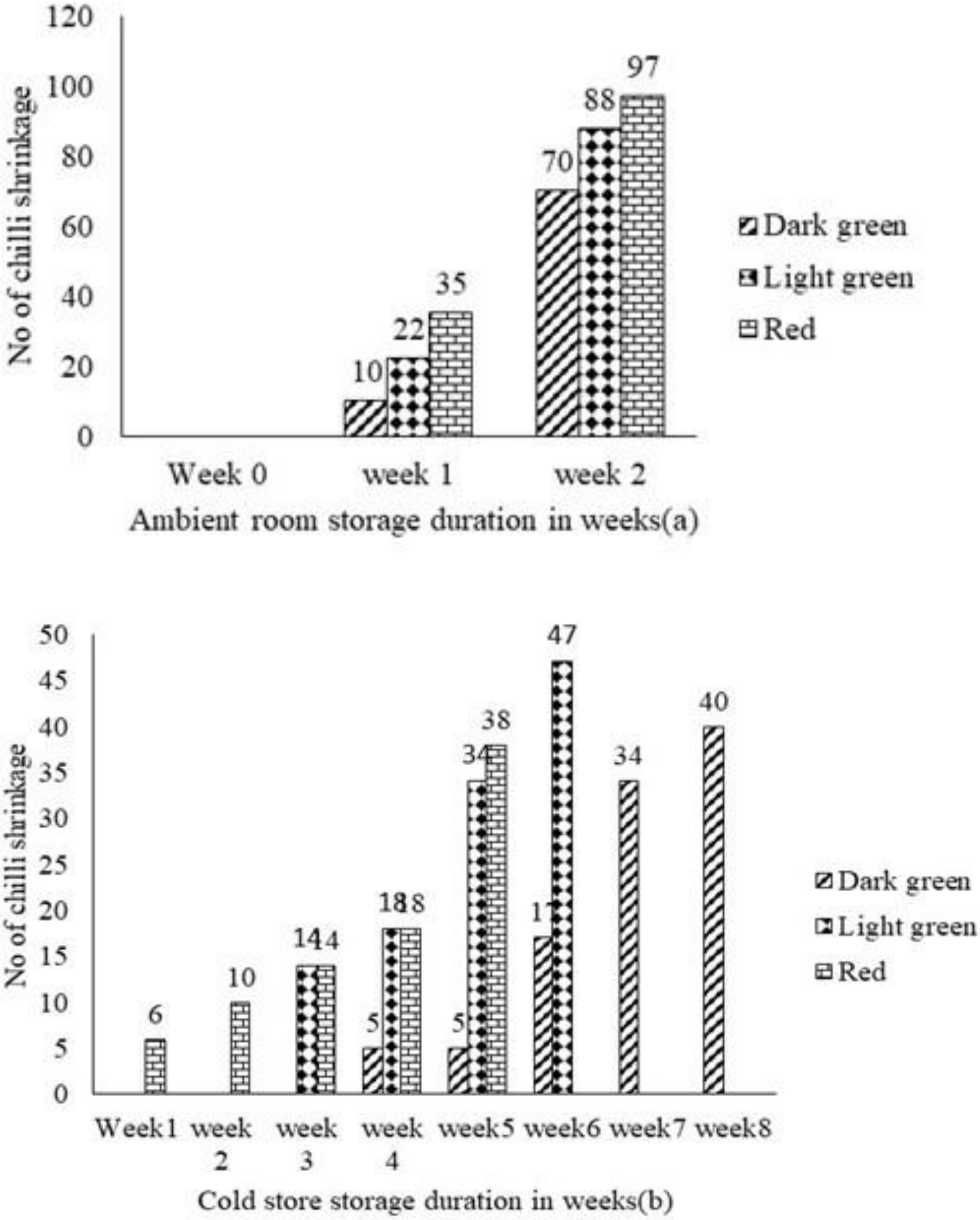
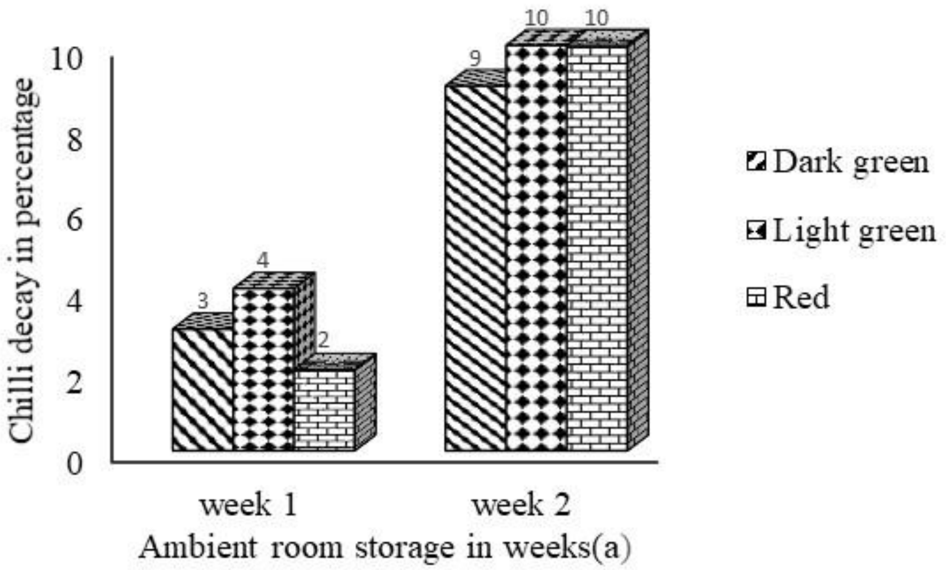


Figure 4. Chilli shrinkage in ambient (a) and cold store (b) during storage

3.3 Decay

The decay of chili fruits at ambient room temperature conditions for the red and light green chilies was 10% each and 9% in dark green chilies at the end of two weeks of storage as shown in Figure 2a. In the cold store conditions in red chilies, there was 25% decay, 15% decay in light green chilies at five-week and six-week storage respectively, and 14% for dark green chilies at the end of eight-week storage in cold store conditions (Figure 2b).

In ripe fruits and vegetables ethylene production continues to increase and increasing ethylene production can result in loss of chlorophyll and decay which in turn decreases the shelf-life and storability capacity of the produce (Watkins & Nock, 2012 and Mope, Adegoroye, Oluwalade, & Adeyelu, 2024).



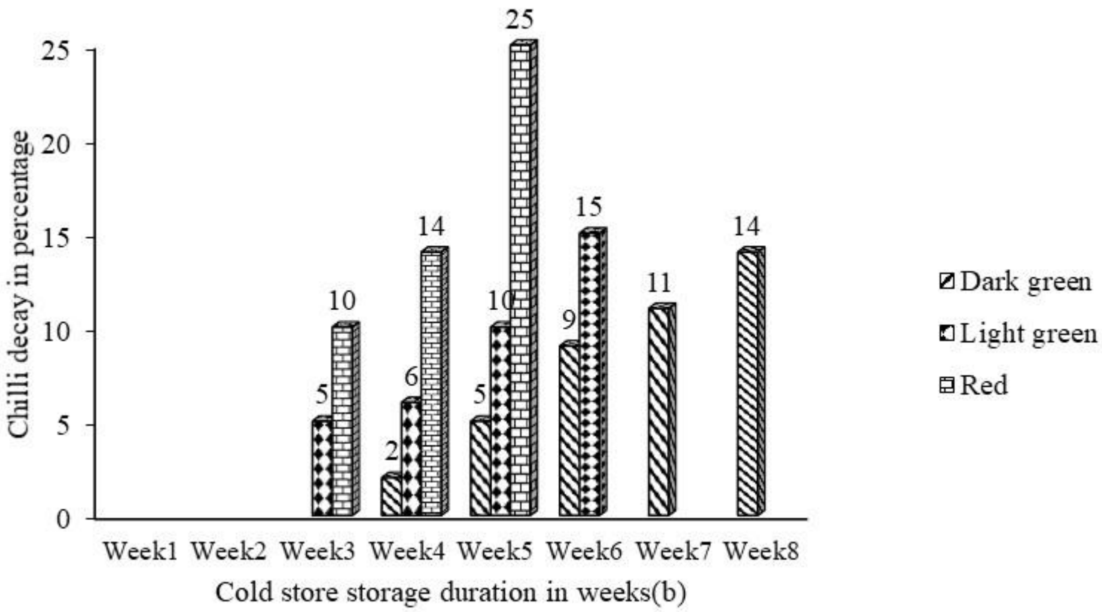


Figure 5. Chilli decay percentage in ambient room (a) and cold store (b)

3.4 Shelf life

Red chilies can be stored for five weeks, light green chilies for six weeks, and dark green chilies for eight weeks in the cold store conditions while in the ambient room temperature conditions, the chilies could be stored for two weeks as quality that are marketable.

The red colour indicates the chilies fruits are ripe and the ripe chilies could be stored for five weeks in the cold store. The maturity stage of chili during storage significantly affects post-harvest quality and shelf life. A study on fruits indicated that as the fruit ripens, it becomes sweeter but exhibits decay rates, highlighting a trade-off between sweetness and shelf life (Rahman et al., 2016). In addition, the research revealed that the type of pepper and its ripening stage greatly affect sugar and capsaicinoid levels, with sugars increasing significantly as the peppers ripen, enhancing flavor but also decreasing shelf life (Guijarro-Real et al., 2023). In line with the study by Tsegay, Tesfaye, Mohammed, Yirga, & Bayleyegn (2013), states the sweet peppers showed that increasing harvest maturity and storage duration improved total soluble solids but reduced fruit firmness.

4 Conclusion

The determination of the shelf life of chili in cold storage and ambient room temperature conditions was conducted at the National Post Harvest Sub-centre Lingmethang for the fiscal year 2023-2024 to determine the storage shelf life of chili of different maturity stages in ambient room temperature conditions and cold store. The results indicate that the chilies could be stored in the cold store for about two months after the harvest at 8°C to 10°C. While at ambient room temperature conditions, the chilies could be stored for only two weeks. This could have advantages in storing the fresh green chilies during the surplus chili production periods. The last harvest of the local Bhutanese chili could be harvested in mid-November months, stored in the cold stores, and then marketed during the winter months when local Bhutanese chili supply is scarce in the market. This will also support utilization of the facilities such as cold storage infrastructure currently established by the Food Corporation of Bhutan at various locations of the country for the storage of perishable fruits, vegetables, and other farm products.

This study on chili storage in ambient room temperature and cold store conditions of different maturity stages also showed that the red and light green chili qualities deteriorated faster than the dark green chilies during the storage period. The weight loss, shrinkage, and decay in chili were rapid in red followed by light green and dark green chilies. Sorting of the deteriorated chili needs to be carried out at frequent intervals to prevent further quality losses in the stored chili. However, the nutrient content changes during the chili storage period need to be studied in future research of the chili storage.

5 Acknowledgment

The authors would like to thank Officiating Chief Post Production Officer, National Post Harvest Centre for encouragement and support for this research work. The authors would like to extend sincere appreciation and acknowledgment to Dorji Phuntsho and Sonam Tobgay of National Post Harvest Sub-centre, Lingmethang, and all others involved for assisting in setting up the trial and data collection during the whole research period. And lastly to the Royal Government of Bhutan for the fund support for this research.

6 Authors' contribution statement

Kinley Wangmo developed the study conception and design, implementation of the research, data collection, data analysis, interpretation of results, and draft manuscript preparation. Pema Chophel contributed to the development of the study conception and design, as well as the implementation of the research and data collection. Thinley Wangdi carried out the literature review, data analysis, interpretation of results, and draft manuscript preparation.

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Adoption of Improved Rice Varieties in Sarpang District of Bhutan

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ABSTRACT

The adoption of improved rice varieties (IRVs) is imperative for ensuring smallholder farmers' food security as well as their collective contribution to national food security. It is important to comprehend the adoption rate of IRVs and determine what influences their adoption. This study employed a farmer-oriented approach to understand the current adoption status of IRVs and the factors affecting their adoption in Sarpang district of Bhutan. A total of 264 rice growing households selected through a multi-stage sampling technique were interviewed using structured and semi-structured questionnaires. A binary logistic regression was employed to analyse the data, and the adoption of IRVs was defined from the perspective of whether farmers grow any of the IRVs or not. The result showed that the household-level adoption rate of IRVs was 60.61%, which translated into a coverage of 47.25% of the total cultivated wetland in the district. A total of 18 rice varieties were recorded in the study site with five IRVs; three of which were released officially and two were sourced by farmers through informal channels from India. The IRVs in the area showed a 39.71% yield advantage over the traditional varieties (p < .001). The empirical results showed that family size had a significantly positive influence (p = .023) on the probability of adoption of IRVs, suggesting that bigger families were more likely to adopt IRVs due to increased labour availability for agricultural tasks. Conversely, total wetlands under cultivation had a significantly negative influence (p = .01) on the probability of the adoption of the IRVs. This indicates that farmers who cultivated smaller wetland areas were more likely to adopt IRVs, due to the higher productivity of IRVs meeting their household's food needs.

Keywords: *Adoption; Binary logistic regression; Factors; Improved rice varieties; Varietal diversity*

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1 Introduction

Rice (*Oryza sativa* L) is consumed by more than half of the global population, which is produced in more than 100 countries, with Asia accounting for 90% of global production (Fukagawa & Ziska, 2019). In Bhutan, rice is grown by 21,891 households in an area of 22,985 acres (National Statistics Bureau [NSB], 2023) with a total production of 40,563 MT (Department of Agriculture [DoA], 2020). Despite this limited land area, rice holds a pivotal role in Bhutanese agriculture. It is not only a staple food for the Bhutanese but also a significant crop that supports the livelihoods of many farmers across the country. It is cultivated in all 20 districts of Bhutan, at altitudes ranging from 150 meters in the south to 2,600 meters in the north (Chhogyel & Bajgai, 2016). The importance of rice in Bhutan extends beyond sustenance, influencing cultural practices and agricultural strategies within the nation.

The Department of Agriculture is emphasizing self-sufficiency in rice production; however, Bhutan's rice production has been plagued by several setbacks (Chhogyel & Bajgai, 2016). Bhutan is currently 25% self-sufficient in rice production and consumption (13th Five Year Plan, 2024), and the government aims to raise the sufficiency level to 30% within the next five years. India is the main supplier of rice imports, and the country imports an average of around 80,000 MT annually, hence the need to put in more effort to attain a higher level of self-sufficiency in rice.

Bhutan's agricultural sector has undergone a remarkable transformation during the past 112 years, evolving from shifting cultivation-Tseri to sedentary, modern, and increasingly profitable farming, with the transition marked by three distinct phases i.e., subsistence farming (1907–1970), self-subsistence to part commercial (1970–1990), and integrated and semi-commercial farming (1990–2020) (Gurung, 2012). Rice is considered one of the key cereal crops that contribute to the nation's GDP, and since the 1960s, systematic planning, the establishment of legal and policy frameworks, as well as modern technology and machinery, have all helped to boost crop productivity (Ministry of Agriculture and Forests [MoAF], 2021). The MoAF has established systematic plans in every Five-Year Plans for the agricultural sector to meet the requirement and development in particular areas generally to boost the country's GDP. From the start of the planned development in 1961, the RNR sector progressively contributed to the nation's GDP (Economic and Social Commission for Asia and the Pacific, 1961) and to meet rice self-sufficiency. According to Shrestha (2004), the study provided significant insights into the program's impact on Bhutan's agricultural sector and overall economy. This study used rigorous economic assessment approaches such as cost-benefit analysis and impact evaluation, sheds light on the program's success in improving rice production, improving farmer lives, and encouraging sustainable agricultural growth in the country.

The southern foothill of Bhutan, ranging in elevation from 200 to 3,600 meters above sea level (masl), has a subtropical climate with distant wet and dry seasons that support extensive subsistence agriculture via various forms of multiple cropping, with rice serving as the primary summer crop (Dendup et al., 2021). This region accounts for 35% of national rice acreage including the districts of Samdrup-jongkhar, Samtse, and Sarpang (Chhogyel & Dendup, 2020). In Bhutan, 27 modern rice varieties have been released, five of which were released by ARDC-Samtenling for the wet-subtropical zone of Bhutan, namely Bhur Rey Kaap-1, Bhur Rey Kaap-2, Bhur Khambja-1, Bhur Khambja-2, and Sokha Rey-1 (DoA, 2020). According to Dendup et al. (2021), adopting improved cultivars favourably influences productivity and total rice production.

The adoption of improved rice varieties (IRVs) is important for ensuring food security and boosting livelihoods; nevertheless, IRV adoption has remained relatively low in underdeveloped countries (Checco et al., 2023). According to Saka et al. (2005), farmers have responded positively to intervention programs that encourage the use of IRVs, with a 68.7% adoption rate and then a mean yield of IRVs that is significantly higher than the yield of local varieties, with a yield advantage of 38.7%. Thus, one of the important interventions to increase rice production and improve national food security is the promotion of IRVs (Dendup et al., 2021). According to Chhogyel & Bajgai (2016), 68% of farming households in Wangdue and 62% in Punakha districts have adopted IRVs.

The development and acceptance of IRVs and technologies are critical for ensuring contribution to national food security and income security. Furthermore, in order to build policies and programs to assist rice sector growth and boost rice production and efficiency, it is necessary to identify the rate of adoption and factors influencing the limited adoption of IRVs. Thus, the DoA under the Ministry of Agriculture and Forests, haven been initiating technical interventions in major rice-growing districts to boost rice yield and production from 2008 to 2009 (Chhogyel et al., 2015). However, limited empirical research has been undertaken so far to examine the factors influencing IRVs adoption and their adoption rate in the wet subtropical zone of Sarpang district. Therefore, this study attempts to determine the adoption rate as well as key factors affecting the adoption of IRVs by the farmers of Sarpang district.

2 Materials and Method

2.1 Study site

Sarpang is one of the major rice-growing districts of southern Bhutan. The district's elevation ranges from 200 to 3,600 meters above sea level (masl). This region experiences a subtropical climate with distant wet and dry seasons. During the monsoon season (June to September), it receives significant rainfall ranging from 1,500 mm to 2,500 mm on average, contributing to the fertility of the soil and supports agricultural productivity including rice cultivation.

Farmers are engaged in both rainfed and irrigated rice farming depending on the availability of water resources. A questionnaire-based survey was conducted in five major rice-growing gewogs namely Dekling, Gelephu, Samtenling, Sherzong, and Umling (Figure 1).

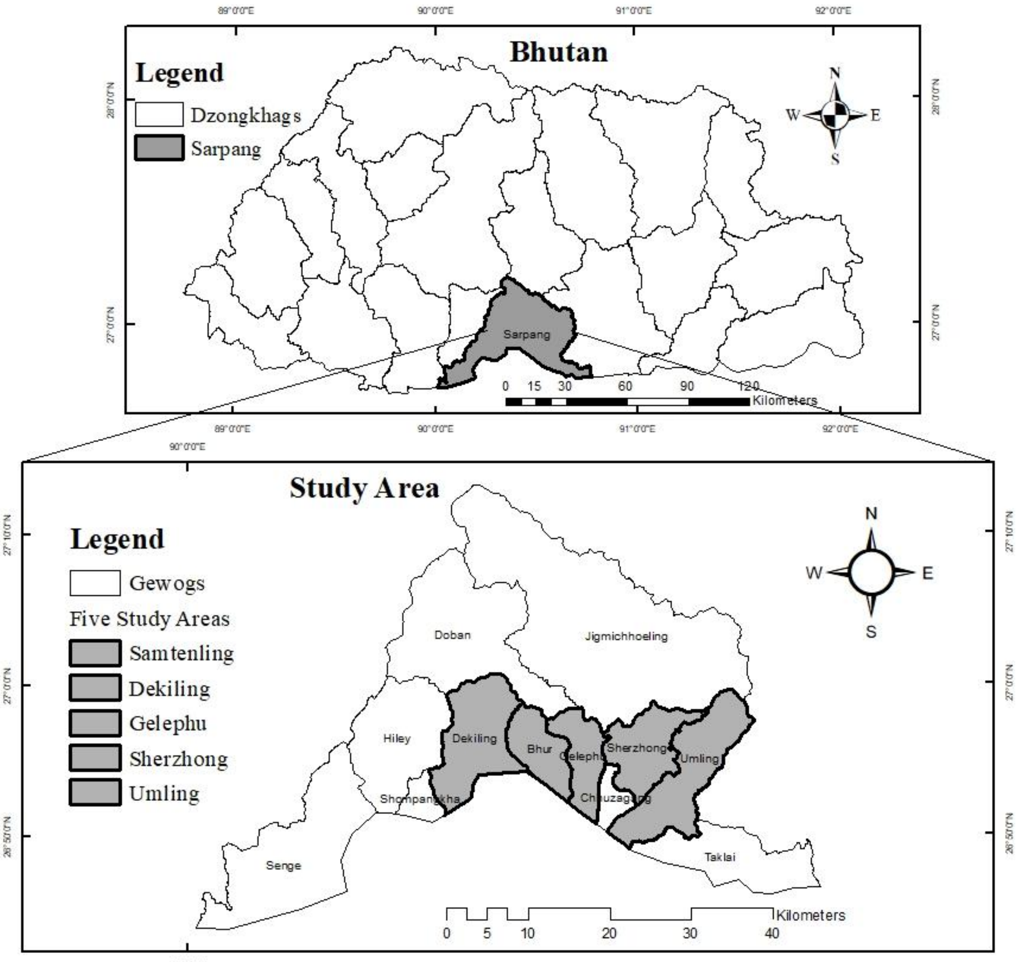

Figure 1. Study Area- Sarpang, Bhutan

2.2 Sampling technique

A multi-stage random sampling method was employed to select rice-growing households. In the first stage, five gewogs were selected purposively based on the total number of rice growing households in each gewog as well as the intensity of rice production and accessibility of agriculture technology. In the second stage, three chiwogs from each gewog were selected through the Probability Proportional to Size random sampling method, and only two chiwogs for Gelephu due to the lack of rice cultivators in the other chiwogs. In the final stage, rice-growing households from each gewog were selected randomly. The Raosoft Sample Size Calculator (online software) was used for generating the sample size from the given population with the margin of error (5%), confidence interval (95%), and response distribution (50%) taking into consideration (Raosoft, 2004). Considering the number of households in the selected rice growing areas which was statistically perceived as population (N), the sample size (n) of 264 households was derived from $N = 317$ (Table 1).

Table 1. Distribution of sample size across the study area

Study Area	Chiwogs	No. of HHs	Total HHs	Proportion (%)
Umling	Dangling	10	61	23.1
	Rejoog	11		
	Gaden	40		
Sherzhong	Barshong	13	43	16.3
	Tashiphu	16		
	Pemayoedling	14		
Dekiling	Chokorling	31	74	28
	Jigmeling	27		
	Nubgang	16		
Gelephu	Pelrithang Khoted	16	27	10.2
	Pelrithang Khamaed	11		
Samtenling	Samtenling	48	59	22.3
	Samtenthang	7		
	Khemapang	4		
Total			264	100

2.3 Data collection

Between January 10th and February 30th, 2024, primary data was collected from five rice-growing gewogs within the Sarpang district. The data for the study was gathered for the 2023 rice growing season, with the exception of Gaden chiwog, which is situated within the Umling gewog. For Gaden chiwog, data on paddy cultivation was collected from the previous year, 2022. This exception was because of a halt in paddy cultivation due to the reconstruction of their irrigation channel. Data collection involved employing both structured and semi-structured questionnaires. These questionnaires encompassed inquiries regarding respondent demographics, land-holding classifications, the prevalence of farmers cultivating IRVs versus traditional varieties, and factors influencing the adoption of IRVs. The aim was to highlight the adoption rates, traits, yields, and the factors affecting the adoption of IRVs across different regions.

2.4 Data analysis

Data were analysed using Jeffrey's Amazing Statistics Program (version 0.18.3, JASP Team, 2024). The analytical techniques that were used in this study comprised simple descriptive statistics and binary logistic regression analysis. Descriptive statistics includes frequency distribution, means, and percentages. Statistical differences in selected variables between adopters and non-adopters were determined using the Chi-square test for categorical or dummy variables and independent t-test/ Mann-Whitney U test for continuous variables. Normality and homogeneity of variance of the data were tested prior to conducting an independent t-test. One-way ANOVA of yield values given by the farmers for traditional, IRVs (Indian), and IRVs (Bhutanese) was performed in order to determine the significant difference in the yield of different rice varieties. The yield data was first log(x) transformed to fulfill the assumption of equal variance. Bonferroni post-hoc test was performed, after the ANOVA result showed significant treatment difference, to determine the difference between each treatment.

Binary logistic regression analysis was performed to determine the influence of socio-demographic variables on the probability of adoption of IRVs in this study, and previous studies (Chukwu et al., 2016). According to Hosmer and Lemeshow (2000), logistic regression is a statistical method used to predict the relationship between one or more explanatory variables (independent variables) and the response variable (dependent variable), which consists of two or more categories, on a category or interval scale. The response variable comprises dichotomous qualitative data, denoted by a value of 1 (one) representing the occurrence of an event, and a value of 0 (zero) indicating the non-occurrence of the event (Rusliyadi et al., 2022). The logit model is specified as follows:

$$\text{Log } Li = \text{Log } (P_i / [1 - Pi]) = \beta_o + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki} + \mu_i \quad (1)$$

Where Log Li is the log of odds ratio for farm i, is called the logit or logit model. It gives the odds ratio of the probability of occurrence of events. X_i is a vector of independent variables; β_o is the intercept and β_i, i=1…k are the coefficients of the independent variables to be estimated, and μ_i is the error term. The explanatory variables included in the model are listed in Table 2 together with their hypothesized effect on the adoption of improved rice varieties. To assess multicollinearity among the predictors, a Variance Inflation Factor (VIF) test was performed and tolerance values were calculated. The VIF values for all predictors ranged between 1 and 2, and the tolerance values were between 0.5 and 0.9. These results indicate no serious multicollinearity in the model, allowing all factors to be included. All the figures were made using the R statistical software version 4.3.0 (R-Core-Team, 2023) with attached packages: ggplot2, gridExtra, and patchwork.

Table 2. Description of the variables specified in the logistic regression model

Variable	Meaning	Description	Expected sign
Dependent variable			
Adopt IRVS	Whether a farmer grows IRVs or not	Dummy (grows = 1, 0 otherwise)	
Independent variables			
Gender	Gender of the household head	Dummy (Female = 0, Male = 1	+ -
Age	Age of the household head	Continuous (years)	-
Education	If the household head had any formal education	Dummy (yes = 1, 0 otherwise)	+
Household size	Number of people in the household	Continuous (number)	+
Wetland size	Total cultivable wetland (owned + leased)	Continuous (acre)	+
Family labour	Number of active individuals helping in farming	Continuous (number)	+
Extension visit frequency	Number of extensions visits in a year	Continuous (number)	+
Farm machinery ownership	If the household owns any type of farm machinery	Dummy (yes = 1, 0 otherwise)	+
Farming experience	Numbers of years farming	Continuous (years)	
Source of irrigation	Source of irrigation during the rice growing season	Dummy (river/canal water = 0, Rainfed = 1)	+
Marketing	If the households sell their produce after harvest or not	Dummy (yes = 1, 0 otherwise)	+

3 Results and Discussion

3.1 Socio-demographic features of the surveyed rice farmers

The descriptive statistics of the farmers separated by adoption status and socio-demographic characteristics for the 264 surveyed rice farmers (186 male ad 78 female) from five gewogs of Sarpang district are presented in Table 3. The average age of the household head was 52 and each household had almost 6 individuals on average. However, the active family members i.e., the family members above the age of 15 actively contributing to rice cultivation, were only half of the total individuals in the household on average. The study area had an average wetland size of 2.15 acres. The majority (70.45%) of the respondents were male and formed 42.05% of the adopters in total. This dominance of male leadership within a family could be attributed to the cultural norms of the people where male descendants are often favoured to inherit land and properties, especially in the local communities. Almost 97% of the surveyed individuals had farming as their main occupation and 91% had more than 10 years of farming experience. Just 28.8% of the household heads had a formal education, and only 18.6% of the households owned farm machinery (of any kind). On average, the farmers reported having met the extension agent of the gewog only two times annually. The majority (95.8%) of the households utilized river/canal water for irrigating their paddy field.

The result of the differences in the means of characteristics between the adopters and non-adopters showed a significant difference in the average household size ($U = 5756$, $p < .001$), active family members ($U = 6227$, $p < .001$), and the wetland size ($U = 9971$, $p < .006$, Table 4.1). Specifically, the adopters showed higher means in the household size and number of active family members compared with their non-adopter counterparts. Whereas, the adopters of IRVs had lower area of land compared to the non-adopters of IRVs. These results suggest possible differences between adopters and non-adopters in terms of household structure and family involvement in farming activities.

Other characteristics such as age of the household head, gender of the household head, average contact with an extension agent, occupation of the household head, farming experience of the household head, education level of the household head, farm machinery ownership, source of irrigation, and proportion of males and females, did not differ between the adopters and the non-adopters.

Table 3. Descriptive summary of socio-demographic characteristics of rice farmers by adoption status

Characteristics	Categories	Pooled data	Adopters	Non-adopters	*p*-value
Age of household head (years)		52	52.1	51.8	0.84
Household size (numbers)		5.8	6.1	5.48	< .001*
Family labour (numbers)		3.41	3.5	3.2	< .001*
Wetland size (area)		2.15	1.96	2.32	0.006
Extension contacts (Frequency)		2.1	2.1	2.2	0.55
Gender (%)	Male	70.45	42.05	28.41	0.63
	Female	29.55	18.56	10.98	
Occupation (%)	Farmer	96.6	58.7	37.9	0.22
	Government/Civil service	1.9	0.7	1.2	
	Self-employed	1.5	1.1	0.4	
Farming experience (%)	>10 years	90.9	55.7	35.2	0.09
	6-10 years	6.1	4.2	1.9	
	1-5 years	3	0.7	2.2	
Education (%)	Formal education	28.8	15.5	13.3	0.15
	No formal education	71.2	45.1	26.1	
Farm machinery Ownership (%)	Yes	18.6	10.3	8.3	0.38
	No	81.4	50.4	31	
Source of irrigation (%)	River/canal water	95.8	57.2	38.6	0.14
	Rainfed	4.2	3.4	0.8	

Note: *significant at $p < .001$

3.2 Awareness on improved rice varieties

The results of the study revealed a remarkable level of awareness regarding IRVs, with an impressive 99.24% of the surveyed households demonstrating familiarity with the IRVs (Table 4). This significant percentage underscores a widespread understanding and recognition of the benefits associated with IRVs among the surveyed population.

Further analysis was performed to shed light on the sources contributing to this heightened awareness. Among the surveyed individuals, it was found that 40.84% of the population gained knowledge about IRVs through interactions with fellow farmers. This peer-to-peer exchange underscores the importance of farmer networks in disseminating information and knowledge about agricultural innovations. Similar findings were documented by Lwoga et al., (2011) in Tanzania and Adetimehin et al., (2018) in Nigeria, who attributed these results to the consistent availability, accessibility, credibility, and reliability of information shared within farmer networks, which are deeply trusted by rural communities.

Additionally, the Gewog Agriculture Centre and agriculture extension agent emerged as significant contributors, accounting for a combined total of 59.39% of the population's awareness about IRVs. Also reported by Lwoga et al., (2011), these institutions play a crucial role in delivering agricultural education, training, and support services to rural communities, thereby serving as key conduits for knowledge transfer and technology adoption. However, the lowest number of farmers gained knowledge from the Agriculture Research and Development Centre (ARDCs) which could be due to the functioning of the research centre as it is mainly instituted to conduct research rather than information dissemination. Additionally, a weak linkage between researchers and extension services may have contributed to this gap, suggesting a need for stronger collaboration to enhance outreach and knowledge-sharing.

Overall, the data underscores the diverse pathways through which awareness about IRVs is generated, ranging from informal farmer networks to formal agricultural extension services and research institutions. By understanding these sources of awareness, policymakers, and agricultural organizations can tailor their outreach efforts to effectively reach and educate diverse agricultural communities, ultimately facilitating the widespread promotion and adoption of IRVs and contributing to sustainable agricultural development.

Table 4. Awareness level of the respondents and source of information about IRVs for the respondents in Sarpang district

Details	Frequency	Percentage
Aware of IRVs		
Yes	262	99.24
No	2	0.76
Total	264	
*Source of Information**		
Other Farmers	107	40.84
Gewog Agriculture Centre	97	37.02
Agriculture Extension Agent	56	21.37
ARDC-Samtenling	2	0.76
Total	262	

Source: Field Survey, 2024

* Source of information is only for the 262 respondents that were aware of IRVs

3.3 Household-Level adoption rate

In this study, a household was considered an adopter if they grew any of the IRVs in any area of land. As observed, regardless of the varieties of IRVs, 60.61% of the sampled households cultivated improved varieties (Table 5). However, the adoption rate of IRVs varied greatly between the study sites with Gelephu having the lowest adoption rate (44.4%) and Umling having the highest adoption rate (68.9%). Further analysis of the households cultivating IRVs revealed that out of the 60.61% of households cultivating IRVs, 72% of the households cultivated IRVs which were released officially in Bhutan while the remaining 27% of the households cultivated Indian IRVs sourced from informal channels (Table 6).

The differences in the adoption rates reported among the study sites show farmers' preferences of specific variety to specific needs and social settings, as seen in Wangdue-Punakha Valley by Chhogyel & Bajgai (2016). They also mentioned that the disparity in adoption rates could also be linked to variations in the levels of support provided by DoA across different gewogs and districts.

The prevalence of Bhutanese IRVs in a significant portion of households indicates the significance of governmental support, research, and development efforts in promoting the adoption of IRVs. The presence of Indian IRVs highlights the impact of farmer-to-farmer knowledge transfer on adoption trends. Farmer networks might have played a key role in this dynamic process, which might have led Bhutanese farmers to seek out Indian IRVs. This could be because they recognized the perceived benefits of Indian IRVs in terms of specific features or qualities offered by these varieties. The presence of Indian IRVs which are not officially released in our country also highlights the diverse sources of IRVs being cultivated and suggests the importance of considering both formal and informal channels in assessing adoption rates and understanding farmers' preferences.

The overall adoption rate of 60.61% for IRVs in this study site was slightly lower than the adoption rate of 65% for Wangdue-Punakha Valley as reported by Chhogyel & Bajgai (2016). This slightly lower rate of adoption in the district suggests the need for more effort to promote the adoption of IRVs, especially considering Sarpang as one of the major rice-producing districts.

However, the adoption rate of IRVs in this region has significantly improved, with the current rate of 60.61% marking a twofold increase compared to the 32% household adoption rate reported in low-altitude zones in 2002 (Shrestha, 2004). This increase in the adoption rate of IRVs underscores the success of the efforts by the MoAL to promote the adoption of IRVs.

Table 5. Household-level rice variety adoption rates in five gewogs of Sarpang district for the 2023 rice growing season

Gewogs	Number of sampled households		Total
	Adopters	Non-adopters	
Dekiling	45 (60.8)	29 (39.2)	74
Gelephu	12 (44.4)	15 (55.6)	27

Samtenling	39 (66.1)	20 (33.9)	59
Sherzhong	22 (51.2)	21 (48.8)	43
Umling	42 (68.9)	19 (31.1)	61
Total	160 (60.61)	104 (39.39)	264 (100)

Source: Field survey, 2024
Note: The values in the parenthesis indicate the percentage of rice growers

Table 6. Adoption rate of Bhutanese and Indian IRVs in terms of the number of households and area under cultivation

Varieties	No. of adopters	Area (acres)
Bhutanese	126 (72)	161.12 (64.2)
Indian	49 (28)	90 (35.8)
Total	175	251.12

Source: Field Survey, 2024 Note: values in the parenthesis indicate the percent of farmers and area under IRVs cultivation

3.4 Cultivated area under IRVs

Table 7 shows the total area of wetland, the total cultivated land for the study sites, and the land allocation by adopters and non-adopters. On average, each household in the study site possessed 2.15 acres of wetland, with rice cultivation covering approximately 2 acres of this land, representing 92.3% of the total wetland area. This indicates a high utilization of wetlands for rice cultivation among the surveyed households.

The percent area grown with IRVs was 47.25%, equivalent to 251.12 acres, compared to the total cultivated wetland (566.7 acres) in the surveyed gewogs. Notably, Dekiling, Samtenling, and Umling gewogs had a higher percentage of wetland areas under IRVs compared to areas under traditional varieties. Conversely, in Sherzong and Gelephu gewogs, traditional varieties accounted for 67.5% to 73% of the total cultivated wetland area. This was primarily due to the presence of better-performing local varieties, such as Mama rice in Gelephu and Sipsoo rice in Sherzong, which are well-adapted to the local conditions (Figure 2). Further analysis revealed that out of the 47.25% of land cultivated with IRVs, 64.2% of the wetland was cultivated with IRVs officially released in our country while the remaining 35.8% was covered by Indian IRVs, which were not officially released (Table 6).

The percentage of wetlands cultivated with IRVs in this study area was lower, standing at 47.25%, compared to the findings of Chhogyel and Bajgai (2016) for Punakha (56.7%) and Wangdue (54.5%) district. The area under IRVs in this study represents a significant increase compared to historical adoption rates in the region. For instance, compared to the 17% of the wetland cultivated with IRVs reported by Shrestha (2004) in 2002 in the low-altitude region, the current area under IRVs reflects a substantial improvement of IRV adoption over time.

However, there appears to be no significant change in the total wetland cultivated with IRVs compared to 2011, as noted by Ghimiray et al. (2013) in the same agroecological region. Despite this, the sustained high percentage of area under IRVs observed in this study indicates the continued success of efforts to promote IRVs and enhance farming practices in the region.

Table 7. Land allocation in rice production and the area under IRVs across the study area

Gewogs	*N*	Total wetland (acres)	Area cultivated to rice (acres)			Average area grown with rice per household (acres)
			IRVs	Traditional varieties	Total	
Dekiling	74	118.9	63.35 (56.4)	48.91 (43.6)	112.26	1.5
Gelephu	27	64.7	15.16 (27)	40.9 (73)	56.06	2.1
Samtenling	59	105.2	55.7 (54)	47.57 (46)	103.27	1.7
Sherzong	43	110.3	34.06 (32.5)	70.85 (67.5)	104.91	2.4
Umling	61	167.7	82.85 (53.5)	72.06 (46.5)	154.91	2.5
Total	264	566.7	251.12 (47.25)	280.29 (52.75)	531.41	2

Source: Field survey, 2024

Note: The values in the parenthesis indicate the percentage of land cultivated with rice

3.5 Rice varieties grown by farmers

The study found 18 different rice varieties under cultivation in the Sarpang district during the 2023 growing season. A total of five IRVs and 13 traditional varieties were grown by the respondents in an area of 531.41 acres (Table 8). Agriculture Research and Development Center-Samtenling has released six IRVs to date, however, farmers only grew three IRVs (Bhur Khambja-1, Bhur Khambja-2, and Samtenling Rey Kaap-3). Farmers also grew two IRVs (Ranjit and Badhur) from India released by the Assam Agricultural University in 1990 (Dutta et al., 2023). Despite not being formally released in the district, the open border between Bhutan and India allowed the farmers to adopt two enhanced Indian cultivars through informal channels (farmer-to-farmer interaction). Umling and Sherzong gewogs were among those cultivating Indian IRVs.

Bhur Khambja-1 was the most widely cultivated IRV in terms of both the number of cultivators and the area cultivated (Table 8). This variety, characterized as a medium-maturity main-season variety is widely adopted for upland and rainfed ecologies in Bhutan (Chhogyel et al., 2016; Dendup & Chhogyel, 2018; Dendup et al., 2021). This variety was originally bred in

IRRI using IR12979-24-1 and UPL RI 5 as parents and released for the uplands of the Philippines as APO (Ghimiray & Vernooy, 2017).

The high adoption rate of Bhur Khambja-1 was also reported in previous studies, including in Singey gewog by Dendup et al. (2021). Furthermore, compared to the 4% adoption rate for the low altitude zone in 2011 (Ghimiray et al., 2013), Bhur Khambja-1 cultivation has significantly increased, covering an area of 25%. However, its adoption in gewogs like Gelephu and Umling remained very minimal due to the presence of better-performing varieties such as Mama in Gelephu and Ranjit in Umling (Figure 2).

Currently, only the farmers from Samtenling and Dekiling gewogs grew the newly released variety - Samtenling Rey Kaap-3, which is an introduced variety from Lao PDR with an unknown pedigree (Figure 2). This variety was recently released in 2022 by ARDC-Samtenling and to date, 7.6% of the surveyed population grew the variety in a total area of 22.29 acres which corresponds to 4.2% of the total rice area.

Among the 13 traditional varieties, Khamtey was the most popular variety among the surveyed households in the study area. Approximately 27.6% of farmers cultivated Khamtey, covering 127.67 acres of wetland. The popularity of Khamtey can be attributed to the variety's preferred taste and good market price, particularly in Sherzong, Samtenling, and Umling gewogs.

Table 8. The adoption rate of IRVs and traditional rice varieties based on the number of households and areas under cultivation for the 2023 rice growing season

Varieties	Number of adopters	Total area cultivated (acres)
Improved Rice Varieties		
Bhur Khambja-1	101 (38.2)	132.7 (25)
Ranjit	38 (14.4)	69.2 (13)
Samtenling Rey Kaap-3	20 (7.6)	22.3 (4.2)
Badhur	11 (4.2)	20.8 (4)
Bhur Khambja-2	5 (1.9)	6.1 (1.1)
Total	175	251.1 (47.25)
Traditional Rice Varieties		
Khamtey	73 (27.6)	127.6 (24)
Champa	30 (11.3)	38 (7.2)
Mama	17 (6.4)	32.9 (6.2)
Masinu	14 (5.3)	19.7 (3.7)
Sipsoo	14 (5.3)	20.7 (4)
Manjana	9 (3.4)	14.1 (2.6)
Mouli	6 (2.3)	8.3 (1.6)
Poudhey	5 (0.7)	7.5 (1.4)

Mosuli	4 (1.5)	4.6 (0.8)
Tsirang Zam	2 (0.7)	1.9 (0.3)
Apa bara	1 (0.4)	3.6 (0.7)
Ausaley	1 (0.4)	1.1 (0.2)
Cerki	1 (0.4)	0.2 (0.05)
Total	177	280.29

Source: Field Survey, 2024

Note: Values in the parenthesis indicate the percentage of farmers for the first column and the percentage of total land for the second column

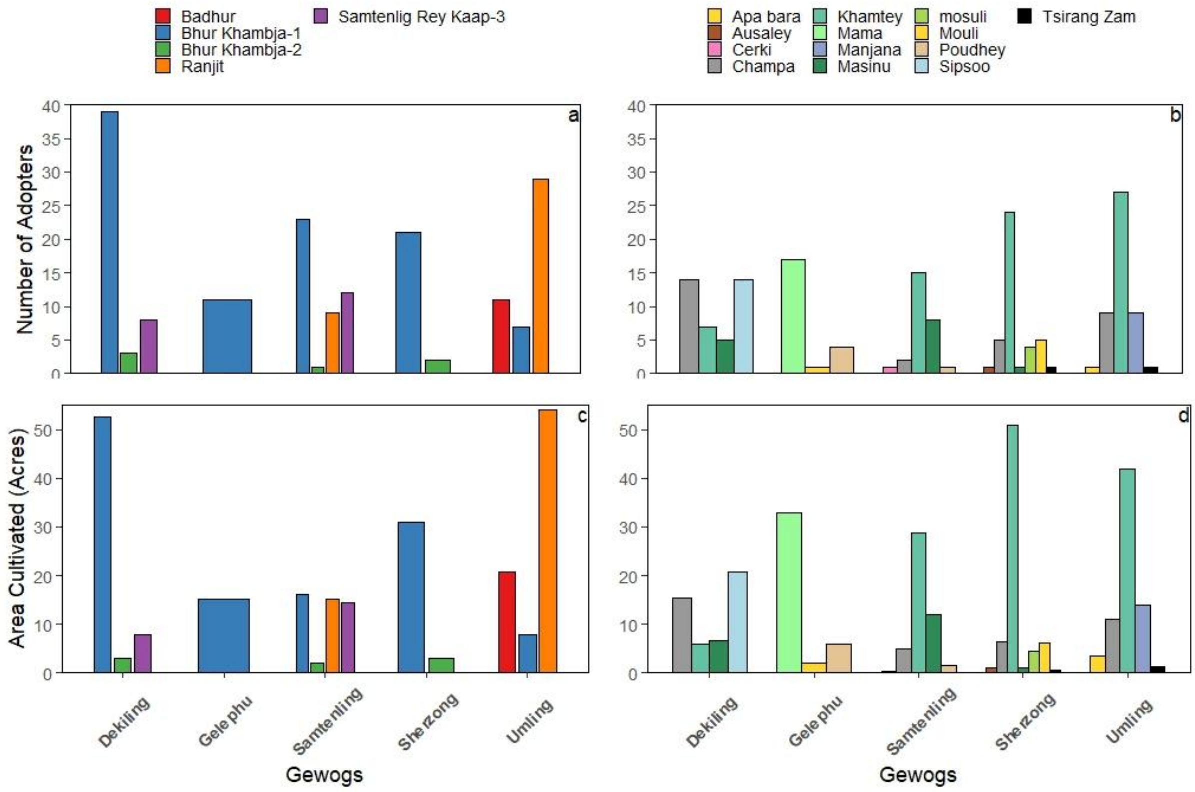

Figure 2. a. Number of households from each gewog adopting IRVs. b. Number of households from each gewog adopting traditional varieties. c. Wetland areas under different gewogs cultivated with IRVs. d. Wetland areas under different gewogs cultivated with traditional varieties

3.6 **Rice varietal diversity**

The findings from the study provided interesting insights about the farmers' diversity of rice varieties. The data showed that a significant portion of the farmers (68.5%) grew only one variety of rice. Upon further disaggregation of the data in this subgroup, 51.9% of them grew IRVs and 48.1% of them grew traditional varieties (Table 9). Moreover, 29.5% of the surveyed households grew a combination of two different rice varieties. Among these households, the majority (62.8%) cultivated a combination of IRVs and Traditional variety. Some households (20.5%) grew a combination of two different traditional varieties, while others (16.7%)

cultivated two different IRVs. A very small proportion of the population (1.9%) grew three different rice varieties. Primarily, they grew one IRV along with two traditional varieties, showcasing a diverse approach to rice cultivation practices.

Farmers claimed that their desire to make use of each type's distinct traits and advantages is what motivates them to plant a diversity of rice varieties. While IRVs are favoured for their higher yield potential, which guarantees enough output till the following harvest, traditional varieties are preferred for their culinary qualities. In order to increase total production, farmers also combine two different IRVs, including both the Bhutanese and Indian varieties because they believe them to be locally adapted. Furthermore, the inclusion of several Bhutanese IRVs, for example, Samtenling Rey Kaap-3 in conjunction with Bhur Khambja-1 and 2, allows performance assessment and testing. As seen in this study and reported by other studies (Chhogyel & Bajgai, 2016; Dendup et al., 2021), rice variety diversification is a common technique in developing nations, especially among subsistence farmers. Farmers may satisfy their household demands through this variety diversification technique while also reducing the chance of crop failures (Almekinders et al., 1994; Gauchan et al., 2005).

Table 9. Varietal diversity of rice in the study area for 2023 rice growing season

Variety composition	Frequency	Percentage
Single	181	68.5
Only Improved	94	51.9
Only Traditional	87	48.1
Double	78	29.5
Improved and Traditional	49	62.8
Traditional and Traditional	16	20.5
Improved and Improved	13	16.7
Triple	5	1.9
1 Improved and 2 Traditional	4	80
2 Improved and 1 Traditional	1	20
Total	264	100

Source: Field Survey, 2024

3.7 **Yield differential among rice varieties**

The yield data from farmers were collected in terms of their local unit called Muri (which is equivalent to 40 kg) and converted to kg $acre^{-1}$ (Dendup et al., 2021). The study found significant differences ($F(2, 349) = 48.972$, $p < .001$) in the mean yield of different rice varieties. Both the Indian and Bhutanese IRVs had higher yields compared to the traditional varieties (Table 10). On average, IRVs demonstrated a remarkable yield advantage of 39.71% over traditional varieties. This finding underscores the genetic superiority of IRVs and highlights their potential to enhance agricultural productivity and food security.

Interestingly, the analysis showed just a little yield disparity of 43 kg acre^{-1} between Indian and Bhutanese IRVs. This suggests that both Bhutanese and Indian IRVs perform comparably well in terms of yield in the proposed study site. Samtenling Rey Kaap-3 was the best-performing IRV, with the highest yield per acre (993.21 kg acre-1, Figure 3). Badhur, Bhur Khambja-1, Ranjit, and Bhur Khambja-2 came next, demonstrating the wide range of high-yielding choices for the farmers. When compared among traditional types, some of the varieties—namely, Sipsoo, Champa, Cerki, and Mosuli—showed higher yields. This demonstrates how important traditional varieties are to preserving agricultural diversity and satisfying specialized consumer wants or preferences.

The yield advantage of IRVs in this study area was similar to what was reported by Dendup et al. (2021) in the neighbouring area of Singey gewog (37.9%). Punakha (33%) and Wangdue (25%) districts in central Bhutan also reported similar findings of yield advantage of IRVs (Chhogyel & Bajgai, 2016). Similar findings were also reported internationally by Tsinigo et al, (2017) in Ghana, Bello et al. (2020) in Nigeria, and Hossain et al. (2006) in Bangladesh. This indicates that IRVs are a promising strategy for raising agricultural productivity and tackling global food security issues because they are consistently effective in increasing rice yields.

Overall, these results highlight how critical it is to encourage the use of IRVs to increase rice yield and support food security. Furthermore, identifying the performance of certain varieties, both traditional and IRVs can help guide focused initiatives meant to improved rice growing techniques and maximize yields for Bhutanese farmers.

Table 10. Mean yield difference between the Bhutanese IRVs, Indian IRVs, and the traditional varieties grown by the farmers

Type of variety	Mean yield (kg acre^{-1})
Improve Rice Varieties (Bhutanese)	919.6 ± 25.02 a[1]
Improve Rice Varieties (Indian)	876.8 ± 40.51 a
Traditional Varieties	642.8 ± 24.81 b

[1] Means followed by the same lowercase letters within a column indicate no significant difference between treatments ($p < .05$) as established by the Bonferroni post-hoc test. Values are means ± standard deviation.

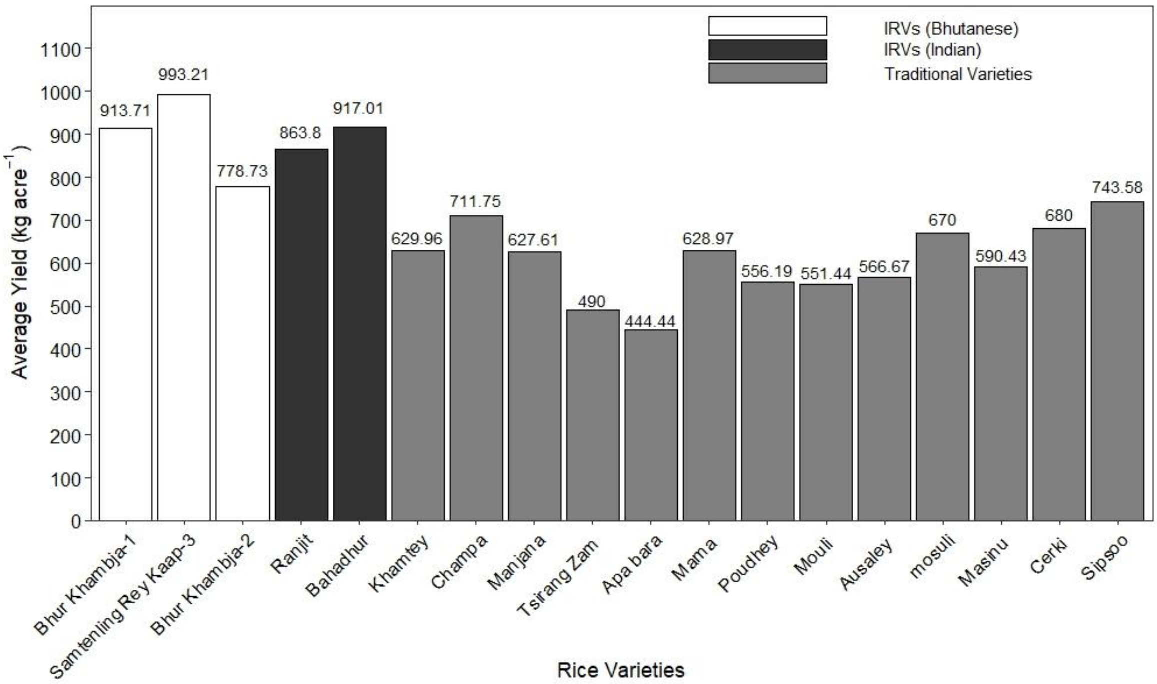

Figure 3. Average yield of Bhutanese IRVs, Indian IRVs, and traditional varieties recorded in the Sarpang district

3.8 **Source of paddy seeds**

The study showed that the seed sources differed among the varieties. The Bhutanese IRVs were mostly distributed from the Gewog Agriculture Centre which is free of cost (Figure 4). Also, the ARDC-Samtenling was one major seed source for the newly developed rice variety (Samtenling Rey Kaap-3). The 14% of the farmers sourcing seeds from ARDC were mainly those who were selected as a trial for the variety Samtenling Rey Kaap-3. As for the Indian IRVs, some farmers sourced it from the Indian farmers and most of them availed it from their fellow farmers. The traditional varieties were all sourced from informal channels including fellow farmers and self-saved seeds.

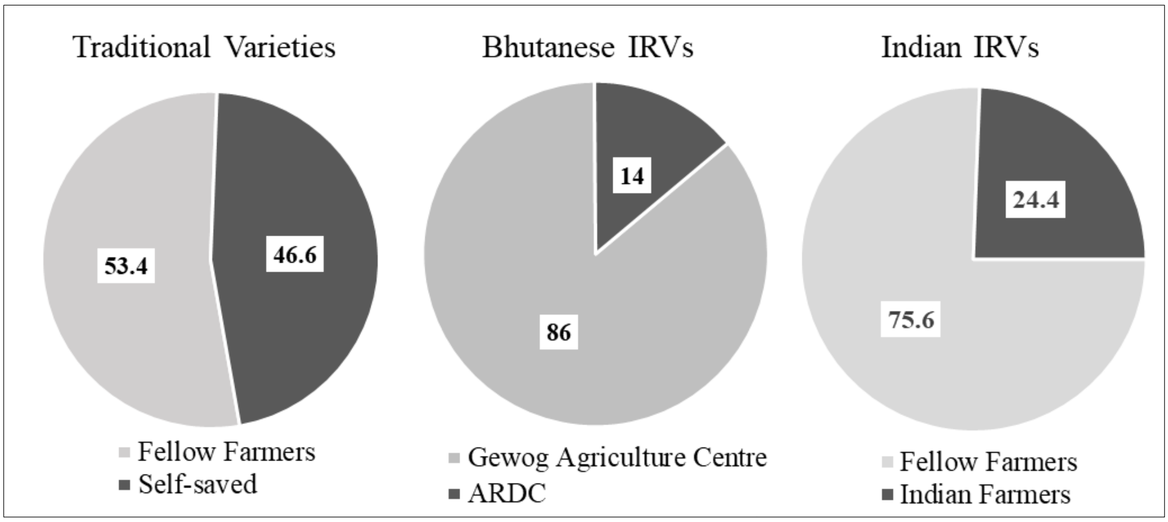

Figure 4. Sources of Bhutanese IRVs, Indian IRVs, and traditional varieties

3.9 **Positive and negative traits of IRVs**

The adopters of IRVs highlighted a range of benefits compared to traditional varieties (Figure 5 (a). Foremost among these advantages was the capacity of IRVs to yield significantly higher quantities of rice, a factor that resonated strongly with respondents. Additionally, a notable proportion of adopters acknowledged IRVs for their enhanced resistance to lodging, mitigating the risk of crop damage and yield loss. Furthermore, some adopters appreciated the early maturity of IRVs, facilitating timely harvesting and potentially reducing susceptibility to adverse weather conditions. While a minority of respondents noted IRVs' improved traits such as drought resistance, preferred taste, resistance to pests and diseases, and uniform maturity compared to traditional varieties, these attributes still contributed to the overall appeal and adoption of IRVs among farmers seeking improved agricultural outcomes.

The surveyed individuals predominantly identified poor taste as the primary negative traits associated with IRVs (Figure 5 (b). This finding indicates that despite the numerous advantages of IRVs, concerns regarding sensory qualities persist among a significant portion of adopters. Additionally, a minority of respondents expressed concerns over other negative traits, including low market price, early maturity, and an increased incidence of pests and diseases. The problem with early maturity was that the paddy would mature before the monsoon season ends hence complicating the process of drying and storage. Also, an increased incidence of bird attacks was noted as IRVs mature first compared to the traditional varieties. These concerns highlight various challenges faced by adopters of IRVs, ranging from economic considerations to environmental vulnerabilities and pest management issues. Understanding and addressing these negative traits are crucial for the continued adoption and sustainable cultivation of IRVs in agricultural practices. Researchers must prioritize these issues as part of the variety development process, ensuring that future IRVs are not only high-yielding but also resilient to local challenges and well-suited to farmers' needs. By incorporating feedback from farmers and addressing specific shortcomings, researchers can enhance the overall acceptance and long-term viability of IRVs in diverse agricultural settings.

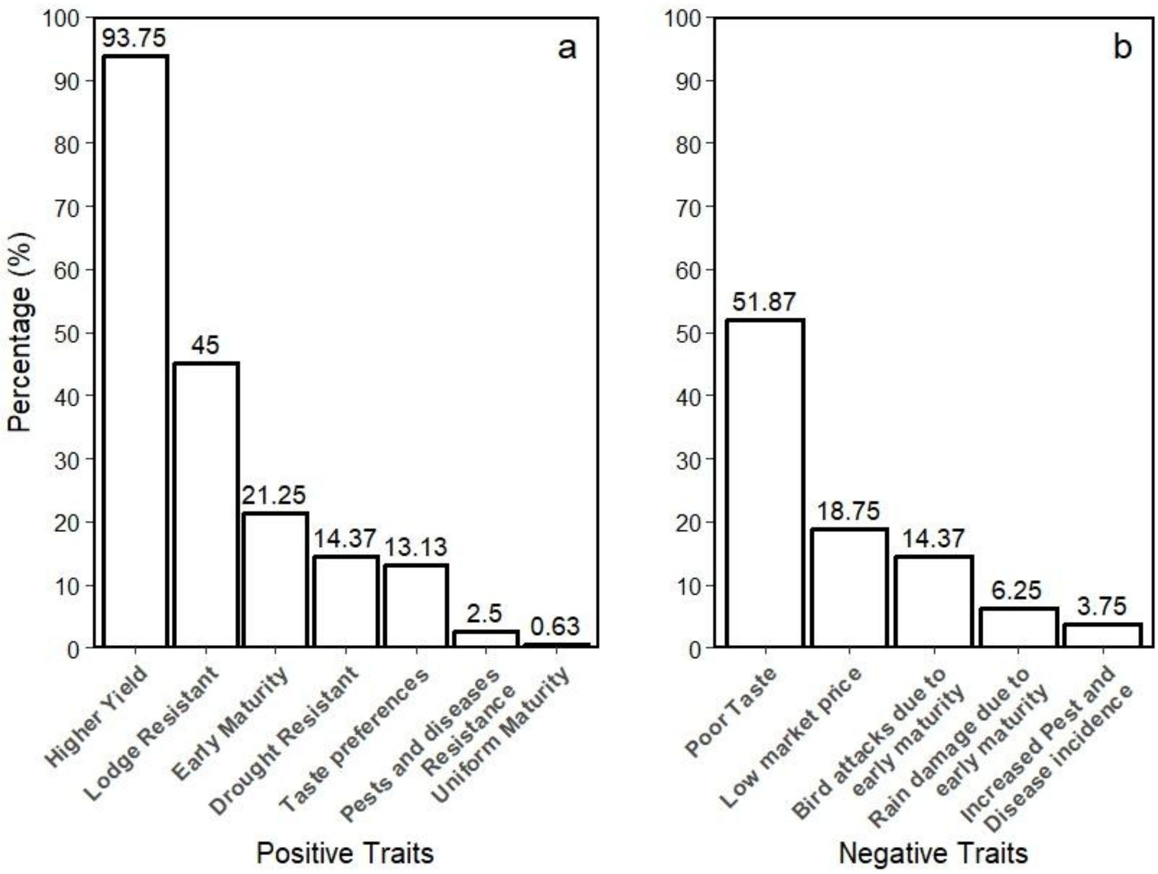

Figure 5. (a) Positive and (b) negative traits of IRVs according to the IRV adopters (n = 160)

3.10 **Factors affecting the adoption of IRVs**

The surveyed data were analysed using the maximum likelihood estimation of a logistic regression model to assess the factors affecting the adoption of IRVs in the wet subtropical zone of Bhutan. The factors that influence the adoption of IRVs are presented in Table 4.8. The model had a correct prediction rate of 67.045%. Given that the model's primary goal was to determine the main factors that influence the adoption of IRVs, its -2 Log Likelihood and substantial model chi-square (p <.001) support its suitability for the purpose (Table 11).

The results indicated that the family size and total wetland (owned + leased) were the

Table 11. Logit estimates of coefficients of various determinants affecting the adoption of improved rice varieties in Sarpang district, Bhutan, 2023

Variables	Coefficient estimate (β)	Standard error	Odds ratio	*p*-value
Constant	-1.609	1.149	0.200	.162
Age	-0.002	0.013	0.998	.895
Family Size	0.212	0.098	1.237	.023 *
Total Wetland	-0.325	0.125	0.723	.010 *
Extension visit frequency	0.007	0.177	1.007	.970
Gender (male)	-0.188	0.312	0.828	.547
Education (yes)	-0.272	0.313	0.762	.385
Total Family labour	0.143	0.127	1.154	.259
Farm machine ownership (yes)	-0.208	0.353	0.812	.556
Farming experience (6-10 years)	1.455	1.032	4.283	.158
Farming experience (More than 10 years)	1.385	0.856	3.996	.106
Source of Irrigation (Rainfed)	0.966	0.855	2.629	.258
Marketing (Yes)	0.222	0.480	1.248	.664
Model χ^2		34.409		< .001***
-2 Log likelihood		319.603		
Overall cases correctly predicted (%)		67.045		
Sample size		264		

Note: * significant at $p < .05$, *** significant at $p < .001$

significant factors that influenced the adoption of IRVs. However, the variables such as the age of the household head, extension visit frequency, gender of the household head, education of the household head, farm machinery ownership, farming experience, source of irrigation, marketing their produce, and total family labour did not have any significant effect in their influence on the adoption of the IRVs.

3.10.1 The influence of family size

The model's results showed that family size significantly increased the likelihood of adopting IRVs. More specifically, the positive coefficient estimate showed that families with greater family sizes were more likely to adopt IRVs than families with fewer members. This result is consistent with previous research (Ruzzante et al., 2021; Garba et al., 2019; Chukwu et al., 2016), which frequently uses family size as a proxy for labour availability in agricultural contexts. The greater labour availability for farming tasks in bigger families might be the reason for the positive correlation seen between family size and IRV adoption. There is more ability to do rice cultivation activities, such as planting, weeding, and harvesting, when there are more family members available to help in agriculture.

According to the findings of Bahiru et al. (2023), there is a negative relationship between household food security and family size, meaning that larger families are more likely to experience food insecurity. Considering that larger households typically have higher food requirements, this correlation is very noteworthy. Households may utilize IRVs as a practical solution in response. According to research done by Hossain et al. (2006); Chhogyel & Bajgai (2016); Tsinigo et al, (2017); Bello et al. (2020); Dendup et al. (2021); Osei et al. (2022); and also seen in this study, IRVs usually yield more than traditional types. Households can increase rice production using IRVs and better match it to the nutritional needs of families.

3.10.2 The influence of total wetland

To assess the effect of farm size on the probability of adoption of IRVs, the total wetland cultivated by the household was included in the model. The results of the analysis showed that the probability of adopting IRVs was negatively and significantly impacted by the total wetland area. This implies that compared to families with lower wetland areas, those with bigger wetland areas were less likely to adopt IRVs. This negative effect of land size was contrasting to what was proposed. The result of this study also contrasted with the following studies: Oyekale and Idjesa, (2009); Ghimire et al. (2015); Chukwu et al. (2016); Chandio and Yuansheng, (2018); Rahaman et al. (2020); Loko et al. (2022). They reasoned that since they have the means and space to test and apply new methods on their farms, farmers with greater land holdings are more likely to embrace improved rice production technology.

Households with smaller wetland sizes showed a higher probability of adoption of IRVs in this study. The trend might be probably caused by the IRVs' higher yielding potential than traditional varieties, which allow farmers with smaller areas of land to produce more food. This result is consistent with that of Bahiru et al. (2023), who observed a positive relationship between land size and household food security. They emphasised that in order to meet yearly food and nutritional needs, higher agricultural output is required because smaller landholdings are more vulnerable to food insecurity. Furthermore, the fact that smaller landholders choose IRVs emphasizes how crucial technology is to promote sustainable farming practices.

4 Conclusion

This study assessed the awareness, adoption rate, yield difference, and factors affecting the adoption of IRVs in the Sarpang district. A remarkably high level of awareness regarding IRVs was recorded in the study area. A majority (60.61%) of the farmers adopted IRVs which included both the Bhutanese and Indian IRVs, reflecting a positive trend towards embracing these varieties. However, the area cultivated with IRVs remained relatively low compared to the traditional varieties. The Gewog Agriculture Centres and fellow farmers were the most prominent sources of Bhutanese and Indian IRVs, respectively. A diverse range of rice varieties was recorded, with Bhur Khambja-1 emerging as the most widely cultivated IRV and Khamtey as the most cultivated traditional variety in terms of both the number of cultivators and the area cultivated. Importantly, IRVs in the study area demonstrated a significant (39.71%) yield advantage over traditional varieties. The most acknowledged positive characteristic of IRVs was their higher productivity, whereas their poor cooking quality was recognized as a negative attribute. The empirical results on factors affecting the adoption of IRVs showed that family size had a significant positive influence on the probability of adoption of IRVs, whereas, the total wetland had a significant negative influence on the probability of adoption of IRVs. This study recommends that Bhutanese rice researchers need to consider the farmers' preferences for rice varieties and specific traits, their socio-demographic characteristics such as family size and land size, while considering the development and release of IRVs in the region, in order to enhance and promote the adoption of the IRVs. Further studies should be taken up to better understand the factors other than those included in this study, affecting the adoption of IRVs in multiple locations.

5 Acknowledgment

We extend our heartfelt gratitude to Dr. Tusli Gurung, gewog Agriculture Extension Officers, and Tshogpas for their invaluable guidance, support, and assistance. We deeply appreciate their patience, insightful feedback, and constant motivation, which significantly enhanced the quality and depth of my research.

6 Authors' contribution statement

The research work was in partial fulfilment of the BSc Organic Agriculture programme of Ms. Yangchen Ghishing, which was supervised by Dr. Mahesh Ghimiray, Faculty of Agriculture at CNR. The study was conceptualized and designed jointly by the two authors, with ideas and relevant literature provided to the supervisee. The proposal was then vetted by a committee within the faculty and suggestions for improvement were incorporated. The supervisee was responsible for implementing field work including data collection, validation, analysis, and interpretation with intermittent guidance and supervision. Mr. Pema Tamang helped with field data collection, data analysis, and provided constructive feedback. Ms. Yangchen Ghishing drafted the manuscript and Dr. Mahesh Ghimiray provided critical comments and feedback for improvement.

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Use of Information Communication Technology for Agriculture Extension Services in the Western Dzongkhags of Bhutan

Chimi Rinzin[h], Thubten Sonam[i], Tirtha Bdr Katwal[h]

ABSTRACT

This study examines the Information and Communication Technology (ICT) in the extension services in Bhutan. Using survey data from Agriculture and Livestock Extension Supervisors across four Dzongkhags, the research explores ICT access, utilization, and competency levels. While most respondents had access to mobile internet (84.2%) and used platforms like WhatsApp (89.5%), the study found gaps in proficiency with advanced tools, such as GIS and data analysis software. Only 18.4% of participants reported receiving ICT training, highlighting a critical need for capacity building. Challenges such as slow internet, insufficient equipment, and limited technical support were identified as barriers to ICT integration. The findings emphasize the need for strategic investments in ICT infrastructure, skills training, and resource availability to empower extension workers and improve agricultural outreach. This research underscores the transformative potential of ICT in bridging information gaps and fostering sustainable agricultural practices in Bhutan.

Keywords: *ICT in Agriculture Extension; Extension Worker Capacity Building; Social Media for Agricultural Services*

1 Introduction

Agriculture contributes 14.96 % of Bhutan's GDP and supports 41.7% of the population (National Statistic Bureau [NSB], 2024a; NSB, 2024b). The Ministry of Agriculture and Livestock (MoAL), through its decentralized extension network in the Dzongkhags, delivers technologies, information, and development services to farming communities. Represented by agriculture and livestock extension officials at Dzongkhag and Gewog levels, MoAL ensures technical coordination, backstopping, and farmer skill development through outreach, training,

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and field visits. However, challenges such as scattered settlements, poor infrastructure, and monsoon conditions hinder timely service delivery (DoA, 2020).

The rugged terrain of Bhutan exacerbates delays, complicating the extension workers' ability to address diverse farmer needs. Studies highlight the potential of Information and Communication Technology (ICT) in improving service efficiency. ICT fosters market activities, facilitates information exchange, and promotes economic growth (Saidu et al., 2017).

Shruti and Rao (2023) emphasize that ICT transforms extension systems by accelerating and enhancing service delivery. Similarly, a study in Ethiopia found that video-mediated communication led to higher adoption rates of recommended technologies compared to conventional methods (Abate et al., 2023). In Nigeria, ICT improved outreach, provided market prices, addressed farm issues, and delivered weather forecasts (Okeke et al., 2015). In India, ICT increased awareness and encouraged modern farming practices (Fu & Akter, 2017).

MoAL has introduced several ICT initiatives in Bhutan. These include the e-RNR Crop Advisory system, e-Pest Surveillance system, Marketing and Cooperative Information System, Interactive Voice Response (IVR) system, Virtual Extension & Communication Network System (VERCON), Food and Agriculture Statistical Information System, and Transboundary Animal Disease Information System (GIS-based) (Tshering, 2019).

The Marketing and Cooperatives Information System (www.agrimarket.gov.bt), developed by the Department of Agriculture Marketing and Cooperatives (DAMC), supports cooperatives and farmer groups. In 2009, DAMC launched the IVR system to provide farmers with updated market prices from auction yards. Additionally, the Food and Agriculture Organization (FAO) established the Virtual Extension and Research Communication Network (VERCON) to improve communication between policy, research, and extension actors. Veterinary epidemiology and animal disease surveillance also benefit from ICT, as demonstrated by the FAO's Transboundary Animal Disease Information System (TAD info). This software helps veterinarians manage real-life issues effectively (Tshering, 2019). The Agriculture Extension Strategies 2019–2028 recommends using print media, radio, ICT, and television for mass communication to reach farmers. However, the documentation of ICT usage in these efforts is limited (DoA, 2020).

Despite prioritizing ICT in agriculture, gaps in adoption, benefits, ICT skills of the agriculture and livestock extension officials and challenges remain unassessed. This study focuses on understanding the status of ICT use, adoption, aptitude, and challenges faced by extension workers in Bhutan's western Dzongkhags, aiming to bridge these gaps and enhance service delivery.

2 Materials And Method

2.1 Study site

The study was carried out in the West Central Region of Bhutan, which includes the Dzongkhags (Districts) of Thimphu, Paro, Haa and Chuukha as presented in Figure 1. These districts benefit from their proximity to the capital city and their location along the main highway connecting western and central Bhutan, improving connectivity and access to ICT facilities. Approximately 29,951 farmers reside in this region, with Thimphu having the least (3180) (DoA, 2017). The region comprises of 34 gewogs, and agricultural and livestock research outreach, and extension services are delivered by the Agriculture and Livestock Extension Supervisor in each gewog.

2.2 Sampling method and sample size

There are 34 Gewogs in the west region with a total of 56 Extension Workers for agriculture and livestock services. The sample size was calculated using Yamane's formula, resulting in a selection of 38 extension workers from the total population of 56 using random sampling method. The primary data was collected using a semi-structured questionnaire via an online survey.

2.3 Data analysis

The data was cleaned, coded, and ranked using Microsoft Excel 360. R-Statistics was used for major statistical analysis, including testing assumptions and hypotheses. Descriptive statistics such as central tendency, frequency and variance were employed to study the features of various nominal and categorical data, while inferential tests such as correlation and Chi-square were used to assess associations between variables.

3 Results And Discussion

3.1 Demographic characteristics

The respondents were predominantly male (65.8%) and mainly represented Chhukha Dzongkhag (36.8%). Most were aged 30-40 (44.7%), held diploma qualifications, and had 10-20 years of service (63.2%). The group comprised Agriculture (52.6%) and Livestock Extension Supervisors (47.4%) as in Table 1.

Table 2. Demographic variables

		Count	Count %
Dzongkhags	Chhukha Dzongkhag	14	36.8
	Haa Dzongkhag	8	21.1
	Thimphu Dzongkhag	7	18.4
	Paro Dzongkhag	9	23.7
Gender	Male	25	65.8
	Female	13	34.2
Qualification	Certificate	1	
	Diploma	25	
	Bachelors	12	
Age	20-30	4	
	30-40	17	
	40-50	15	
	50-60	2	
Designation	Agriculture Extension Supervisor	20	52.6
	Livestock Extension Supervisor	18	47.4
Service Years	01-Oct	7	18.4
	Oct-20	24	63.2
	20-30	6	15.8
	30-40	1	2.6

3.2 ICT Resources and Tools available to Extension Workers

3.2.1 Radio, TV, Mobile internet and Broadband Internet

The accessibility of ICT resources varies significantly among respondents (Table 2). Most of the respondents rated access to digital learning resources, access to computers and radio as neither good nor poor. However, access to television and mobile internet is being rated as good by most of the respondents.

Table 3. Access to ICT resources by respondents

ICT resources	**Accessibility (%)**				
	Very Poor	**Poor**	**Neither good nor poor**	**Good**	**Very Good**
Access to digital learning resources (Online courses, YouTube, Udemy and etc).	2.6	21.1	50	21.1	5.3
Access to the computer internet	7.9	15.8	50	21.1	5.3
Access to Television	5.3	13.2	26.3	39.5	15.8
Access to Radio	15.8	26.3	34.2	21.1	2.6
Access to Mobile Internet	0	13.2	31.6	34.2	21.1

A study has reported that 19 of the 20 Dzongkhags have fully operational cable TV services, which are fully operational, offering about 40 channels, with only two in Dzongkha channel (T & T, 2015). The Bhutanese newspaper also reported that mobile phones are a common ICT among Bhutanese people. Almost all residents (98%) have a mobile phone which is around 2.7 mobile phones for a household (Choki, 2023). The Bhutan Information and Media study (2013) noted that radio remains popular in rural population. These findings further indicates that Bhutanese have good access to ICT resources. Therefore, extension workers can leverage these tools - mobile internet, mobile phones, TV and Radio to share information on new technologies, crop management, pest control, market prices, and agromet advisory services.

3.2.2 Access to computers and other ICT tools

The study found varying levels of access to ICT tools among respondents. Specifically, only 2.63% reported having access to a digital camera, while 60.53% had access to Wi-Fi, 21.05% to tablets, 10.53% to fixed-line phones, 5.27% to microphones and speakers, 18.42% to data cards, and 18.42% to projectors (Figure 1).

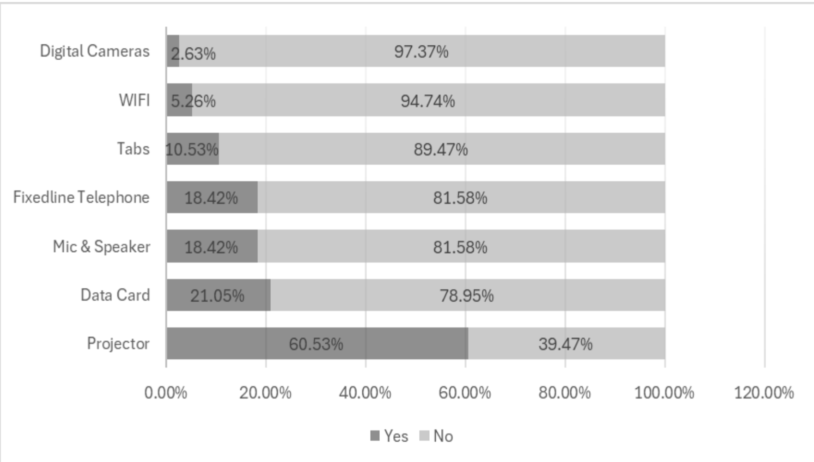

Figure 1: Access to different ICT facilities

These findings indicate significant gaps in the availability of critical ICT tools, particularly digital cameras, microphones, and fixed-line phones, which are essential for effective communication and data collection in extension services. According to Verma (2009), such tools are use for the transfer of agriculture technologies. For instance, personal digital entertainment devices such as camers, projectors and tablets are used for streaming media, podcasts, vodcasts, blogs and operating social media sites enabling the transfer of the techonolgy and informations. Further, it is observed that the use of radio, public phone, telephone, television shorth messages service and computer in the extension services can be considered as an innovation. This would benefit in interacting and reaching out more to the farmers (OLUYOMI, nd). In light of these findings, it is recommended that targeted interventions prioritize improving access to underutilized tools like digital cameras, microphones, and fixed-line phones, as well as increasing the availability of tablets and projectors

Further, as presented in table 3, the majority (97.4%) of the respondents had access to a computer while only 2.6% did not have. Among those who had access to a computer, 15.8% have a computer with i3 specifications, 39.5% have a computer with i5 specifications, and 21.1% have a computer with i7 specifications while 23.7% could not recall the specifications of their computers.

Table 4: Specification, age, and computer of the respondents

Access to Computer	**Yes**	**No**		
Response (%)	97.4	2.6		
Computer Specification	**i3**	**i5**	**i7**	**I don’t know the specification**
Response (%)	15.8	39.5	21.1	23.7
Computer Age (years)	**1 to 5**	**5 to 10**	**10 to 15**	
Response (%)	73.7	18.4	7.9	

These findings suggest that while access to computers is widespread, a significant proportion of respondents either have outdated hardware or lack awareness of their device's capabilities, which could impact their ability to perform advanced tasks effectively.

3.3 Use of ICT in extension services

3.3.1 Use of social media in the extension services

Social media use in the extension system varies as presented in Figure 2, 47.4% of respondents use Facebook, 84.2% use WeChat and Telegram, and 89.5%, use WhatsApp. This finding highlights the dominant use of social media by the extension officials in western Dzongkhags. Similarly, a study also found Facebook to be most widely used platform in Bhutan, (77%), followed by WeChat (72%) and YouTube (58.4%) (BMF, 2021). According to a study on the role of social media in extension, it is found that farmers use various social media platforms to share knowledge and innovation, and to solve problems (Ankita, Verma, & Rani, 2023). Accordingly, the extensions could utilize this platform to share knowledge, innovations, and solve problems collaboratively.

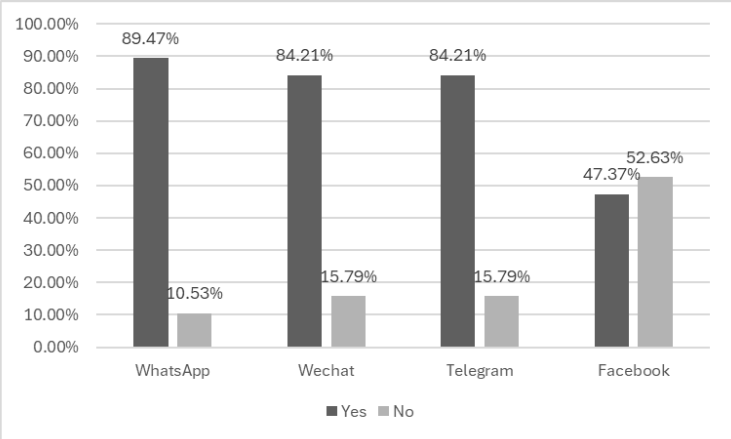

Figure 2: Use of social media in Extension Services

3.3.2 Application of ICT in the Extension services

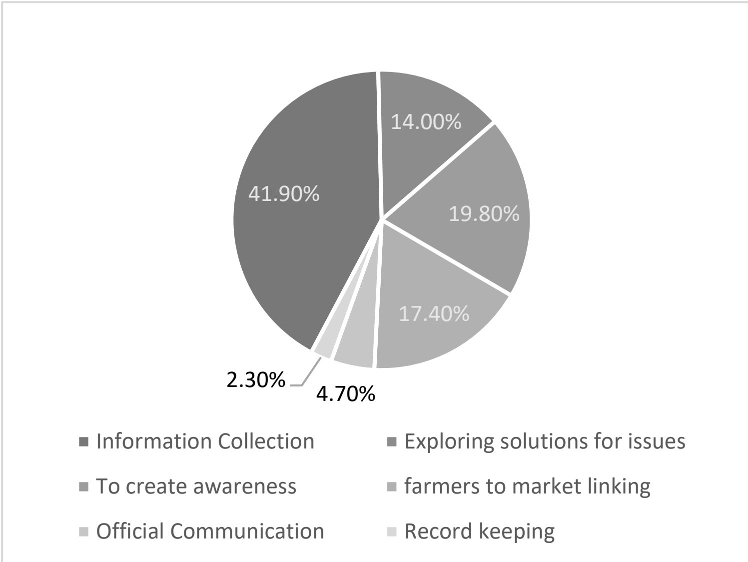

Figure 3: Application of ICT across different fields

As shown in figure 3, the primary use of ICT by extension officials is for information collection (41.9%). This is followed by using ICT in creating awareness programs (19.8%). Linking farmers to markets is another significant use, representing 17.4%, while exploring solutions for issues makes up 14%. However, ICT is used less frequently for official communication (4.7%) and record keeping (2.3%). These findings highlight that ICT tools are primarily utilized for gathering and disseminating information, while their application in administrative tasks like communication and record-keeping remains limited. A study resported that ICT can transform agricultural extension by improving efficiency, effectiveness, and reach. It provides farmers with real-time information on weather, market prices, and crop management, as well as access to financial services and value-added services (Samadder & Rao, 2023). Another study concluded that the use of ICT in the service delivery system has not only achieved the greater awareness and knowledge, but it has also enhanced the farmers attitudes towards trying new technology and new way of life positively (Fu & Akter, 2017). It is also found out that the ICT aids provide up-to-date information on commodity market prices, input costs, and consumer patterns, which can help farmers in having a better position in negotiations and livelihood development (Rohila, Yadav, & Ghanghas, 2017). This suggests potential areas for improvement in integrating ICT into broader extension services.

3.4 Proficiency level in ICT skills

3.4.1 ICT Capacity Development in Extension Services

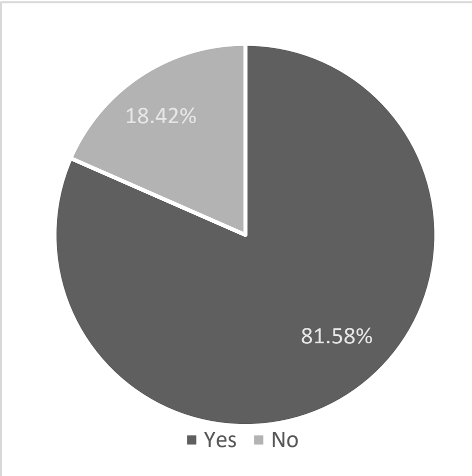

Figure 4: ICT training attended

Of all the respondents, 18.4% received ICT training, while the remaining 81.6% did not receive any training on ICT as presented in figure 4. A study by Nyarko (2021). observed a perfect positive relationship between the ICT training and ICT tools used for communicating agriculture and extension services. The training of Extension Workers on the use of ICT tools is likely to further enable them to make efficient use of ICT for extension services.

3.4.2 Basic proficiency in resolving computer issues

As presented in table 4, most of the respondents indicated either good, poor or very poor skills in Basic computer troubleshooting skills. A report highlighted that basic software management and system maintenance improves reliability and stability, performance of the computer and reduces downtime and disruption (Davidson, 2023). These indicate an opportunity for targeted interventions, such as tailored educational programs or workshops, aimed at improving the understanding and practical execution of software management and system maintenance.

Table 5. Basic computer troubleshooting skills of respondents

	Very poor %	Poor %	Good %	Very good %	Excellent %
Software installation and uninstallation	23.70%	31.60%	23.70%	18.40%	2.60%
Cleaning computers	21.10%	31.60%	36.80%	7.90%	2.60%
Computer set up	18.40%	26.30%	42.10%	10.50%	2.60%

3.4.3 Competency in Microsoft Office applications

Table 5 presents the competency in Microsoft office applications. Most of the respondents rated their skills to be good. However, there is also a presence of respondents with very poor or poor skills. These results suggest that the respondents generally had moderate skills in using the Microsoft office application. To improve overall proficiency in the use of productivity software, targeted training programs should be prioritized, focusing on advanced features and practical applications to address gaps in skills, particularly for those who rated themselves as "Poor." Efforts should aim to elevate moderate skill levels to "Excellent" by teaching advanced functionalities, creative techniques, and effective use of collaborative tools.

Table 6. Rating of Skills in utilizing the Microsoft Office

Microsoft office	Very poor %	Poor %	Good %	Very good %	Excellent %
Word processing	2.6	13.2	47.4	34.2	2.6
PowerPoint Production	2.6	23.7	50	21.1	2.6
Excel usage	2.6	23.7	42.1	31.6	0

3.4.4 Proficiency in creating information and communication packages

As observed in Table 6, the respondent’s ability to produce effective communication and information materials were rated either poor or very poor by most of the respondents. The skills in production of information and communication packages are critical for effective extension services as it can achieve the desired impact and promote sustainable practices. Further, the ability to produce quality communication materials ensures that the information is effectively conveyed and understood by the target audience. A video- mediated agriculture extension services in Ethiopia pointed out that this method reaches wider audience, and it also leads to the higher understanding in farmers (Abate, 2019). The Agriculture Extension Strategies highlights that the use of print media, radio, ICT and Television to support the farmers (DoA, 2020). Therefore, to improve proficiency, targeted training programs may be prioritized, focusing on the audio-visual training courses for the extension officials.

Table 7. Ability to produce effective communication and information materials by respondents

	Very poor %	Poor %	Good %	Very good %	Excellent %
Skills on Video Production	23.7	44.7	26.3	2.6	2.6
Skills on Audio information Production	26.3	47.4	23.7	0	2.6
Skills on production of pamphlets	26.3	42.1	26.3	2.6	2.6

3.4.5 Skills in data management and record keeping

The skills in data management and record keeping (Table 7) have the highest level of proficiency in using Google Applications and Microsoft Excel, with 44.7% rating their skills as "good". In using MS Access Database, the highest proportion rated their skills as "poor" (44.7%), with only 7.9% rating their skills as "very good". Effective data management and record-keeping are essential for all Extension Workers as it enables them to professionally collect, store, analyze, and use data to make informed decisions. Further, it is reported that extensions are supposed to maintain consistent and reliable data for agriculture importance (DoA, 2020). Therefore, regular training in data management and record keeping may be conducted to improve the skills further. On the other hand, the online data storing and collection can be encouraged to promote the continuous use of google applications and Microsoft Excel.

Table 8. Rating of Skills on data management and record keeping

	Very poor %	Poor %	Good %	Very good %	Excellent %
Google Applications	7.9	28.9	44.7	15.8	2.6
Excel	5.3	26.3	44.7	23.7	0
MS Access Database	15.8	44.7	31.6	7.9	0

3.4.6 Skills in the use of analytical and decision-making tools

The skills of the respondents on the use of analytical and decision-making tools are presented in Table 8. Most of the respondents rated their skills as either poor or very poor, and only a few rated their skills as good. These skills help develop cost-effective solutions, analyze data, and use trends for planning. Tools like SPSS, R-statistics, and GIS are valuable for data analysis and spatial planning. GIS aids in feasibility studies, mapping, and network analysis for agricultural activities. Studies suggest that Big Data and GIS in agriculture can optimize production, predict yields, and support precision farming, adding value to the extension services (Kosior, 2017). Further, the study also shows that the simple application of GIS in the sampling of sites, mapping plots in field and examining the soil types leads to the improvement of production and yields. To address significant skill gaps in SPSS, R-Statistics, Python, and GIS, prioritize foundational and advanced training programs, focusing on practical, hands-on learning. Encourage mentorship, use of online resources, and self-paced learning platforms to build proficiency.

Table 9. Skills of respondents on the use of Analytical Software

Software	Very poor %	Poor %	Good %	Very good %	Excellent %
SPSS	36.8	47.4	15.8	0	0
R-Statistics	57.9	26.3	15.8	0	0
Python	71.1	26.3	2.6	0	0
GIS	44.7	31.6	23.7	0	0.00%

3.5 Challenges of ICT development in Extension Services

ICT development in Bhutan's extension services faces challenges such as infrastructure limitations, limited ICT skills, and resource constraints as presented in the table 9. Similarly, a report highlights that the low adoption of ICT programs in Bhutan is often attributed to budget and human resource limitations (MOIC, 2015). Addressing these obstacles will require investment in infrastructure, training, and support for extension agents to effectively use ICT tools

Table 10. Challenges of ICT development in extension field as per the respondents

Challenges	Strongly disagree (%)	Disagree (%)	Agree nor disagree (%)	Agree (%)	Strongly agree (%)
Slow internet	5.3	5.3	39.5	31.6	18.4
No internet	21.1	23.7	26.3	15.8	13.2
Insufficient high-end computers	0	13.2	39.5	21.1	26.3
Issues with the maintenance of	2.6	10.5	39.5	26.3	21.1
Lack of equipment's					
Or software	5.3	10.5	42.1	28.9	13.2
Weak ICT skills	2.6	13.2	31.6	26.3	26.3
Weak ICT technical support	2.6	18.4	36.8	31.6	10.5
Not enough ICT capacity building	2.6	13.2	18.4	28.9	36.8
No budget for ICT facilities	5.3	5.3	21.1	36.8	31.6
Weak policy support	2.6	7.9	44.7	34.2	10.5

4 Conclusions

The study reveals that ICT resources, tools, and skills among extension workers in Bhutan are moderately accessible but limited in scope, particularly in areas like advanced analytical tools, multimedia production, and data management. While access to mobile internet, social media platforms, and computers is widespread, gaps in training, outdated equipment, and limited proficiency in essential software hinder the full utilization of ICT in extension services. The findings emphasize the need for targeted interventions to address skill deficiencies and improve access to critical tools like digital cameras, projectors, and advanced software.

Addressing these challenges will require a multi-pronged approach, including investment in infrastructure, regular ICT capacity-building programs, and the integration of advanced tools into extension services. Leveraging ICT for knowledge dissemination, market linkages, and decision-making can transform Bhutan's agricultural extension system, ensuring more effective service delivery and empowering farmers with timely and actionable information.

5 Limitation of the Study

This study's findings are based on self-reported data from extension workers, which may be subject to biases such as social desirability or recall inaccuracies. Additionally, the sample size and scope are limited to certain regions or Dzongkhags, which may not fully represent the diversity of ICT access and usage patterns across Bhutan. The study also does not account for the impact of contextual factors, such as geographic remoteness or socio-economic status, which could influence the accessibility and effectiveness of ICT resources. Furthermore, while the paper discusses the challenges faced by extension workers, it does not explore in-depth the perspectives of farmers or other stakeholders involved in the extension process. Future studies could benefit from a more comprehensive, multi-stakeholder approach to capture a fuller picture of ICT's role in agricultural extension.

6 Acknowledgement

The authors would also like to acknowledge the support provided by the Dzongkhag Agriculture Officers and Dzongkhag Livestock Officers of the Paro, Haa, Chhukha, and Thimphu Dzongkhag during the fieldwork phase of this study. The National Centre for Organic Agriculture deserves special thanks for their consistent support throughout the entire research process.

7 Authors' contribution statement

Mr. Chimi Rinzin, Corresponding Author, lead for conceptualizing the research, developing the survey questionnaire, coordinating the survey and lead data analysis. Mr. Thubten Sonam is the research advisor and supervisor. Mr. Tirtha Bdr Katwal, lead for the development of the conceptual framework for designing this research and article, writing and overall guidance for this research.

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Comparative Assessment of Drying Technologies to Minimize Postharvest Losses in Turmeric

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ABSTRACT

Turmeric, a valuable spice with high medicinal value, is highly perishable due to its high moisture content (70-80%), necessitating the need for efficient postharvest technologies to minimize losses. Drying is a proven method to extend shelf life and reduce losses, but no comprehensive studies on turmeric drying have been conducted in Bhutan. This study, conducted at the Agriculture Research and Development Centre, Wengkhar, evaluated three drying methods; Open Sun Drying (control), a Fabricated Electric Dryer, and a Solar Dryer integrated with IoT technology, to determine their efficacy in reducing turmeric postharvest losses. Using stratified and random sampling, 450 turmeric rhizomes were sliced and dried across treatments. Significant differences were observed in weight loss and water activity between the methods at a 5% significance level. Although, the Electric Dryer had the shortest drying duration (7.76 hours), it retained higher water activity (58.05), increasing the risk of microorganism growth. In contrast, the IoT-based Solar Dryer required the longest drying time (71.05 hours) but achieved the lowest water activity (39.7) and superior product quality in texture and color. Therefore, given its ability to handle larger volumes, the IoT-based Solar Dryer is recommended for commercial operations. Future research should focus on biochemical composition, particularly curcumin content, and the economic viability of different drying methods.

Keywords: *Drying technologies; Dry weight; Post harvest loss; Turmeric; Water Activity*

1 Introduction

Turmeric (*Curcuma longa*) has been recognized as a valued medicinal herb throughout history (Malik & Kumar, 2022). Its medicinal use is so well-established that the European Medicines

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Agency (EMA) approved turmeric-based products, including herbal teas, in 2019 for addressing mild digestive disorders such as flatulence and indigestion (EMA, 2019). In Bhutan, Turmeric is widely used for the treatment of Diabetes Mellitus (Choden & Erdene, 2014). The primary bioactive component of turmeric, curcumin, has been extensively studied for its wide range of therapeutic effects. These include anti-inflammatory, antioxidant, anti-cancer, anti-mutagenic, and anticoagulant properties, as well as its ability to regulate fertility and blood sugar levels (Krishi et al., 2018).

Besides its medicinal significance, turmeric holds substantial economic importance in the economy of India, which remains the world's leading producer and exporter of turmeric, accounting for over 46% of the global market (Mirjanaik & Vishwanath, 2020). In Bhutan, turmeric has emerged as a prominent spice crop alongside cardamom, ginger, and garlic. According to the (National Statistis Bureau, 2023), around 143.1 acres of land were used for turmeric cultivation in Bhutan, yielding approximately 134.7 metric tons annually. However, Bhutan recorded a negative trade balance in turmeric during 2022 and 2023, with imports valued at Nu 10.8 million and Nu 9.7 million respectively, while exports were limited to Nu 1.4 million and Nu 0.99 million (Department of Revenue Customs, 2023). This trade imbalance underscores a significant potential for enhancing domestic turmeric production, presenting a promising opportunity for Bhutanese farmers to reduce import dependency and improve income generation.

Similar to other agricultural commodities, turmeric requires proper post-harvest technologies to minimize economic losses. Due to its inherently high moisture content of 70-80%, turmeric is highly perishable (Prasad et al., 2006). In the northeast hill regions, post-harvest losses of fresh turmeric range between 535 kg and 1,480 kg, resulting to an estimated 10.5% loss of the total production, emphasizing the need for improved preservation techniques (Singh et al., 2020). Drying is a common method used globally to extend the shelf life of turmeric, reducing moisture content below critical levels to prevent spoilage (Prasad et al., 2006). While traditional sun drying techniques are still commonly used, advanced drying technologies is increasingly promoted to reduce post-harvest losses and enhance the quality of the product. These modern techniques aim to minimize moisture content while preserving curcumin levels, which is essential for maintaining the medicinal and economic value of turmeric (Damale & Patil, 2018).

Several studies have explored the effectiveness of different drying techniques for turmeric. For instance, Kumar et al. (2016) has examined the performance of solar dryers for various agricultural products, while Borah et al. (2015) evaluated the solar conduction dryers for both sliced and whole turmeric rhizomes. However, these studies focused only on one type of drying technology, and the evaluation was limited to the chemical composition of the final product. There is a notable gap in comprehensive research on turmeric drying methods in Bhutan. Hence, the study was undertaken to assess different drying methods with the objective of identifying and promoting appropriate technologies that can effectively minimize post-harvest losses in turmeric production.

The study assessed three different drying methods: open sun drying (control), electric drying using a locally fabricated dryer, and solar drying method integrated with Internet of Things (IoT) automation within a greenhouse. The methods were evaluated based on drying time, weight loss, water activity, and colour changes of the product. The study aimed to reduce post-harvest loss of turmeric and improve the quality through appropriate and efficient drying technology.

2 Materials and Method

2.1 Study area

The study was carried out in 2023 at the Agriculture Research and Development Centre, Wengkhar, in Mongar Dzongkhag (Figure 1), situated at an altitude of 1720 meters above sea level. During the study period, the area received an annual rainfall of 695.3 mm and recorded maximum and minimum temperatures of 22.3°C and 13.8°C, respectively (National Center for Hydrology and Meterology, 2023).

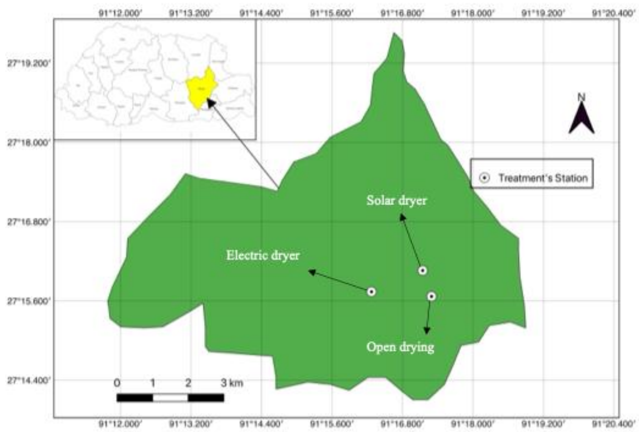

Figure 6: Study Location at ARDC-Wengkhar

2.2 Treatments

The study incorporated three treatments for drying turmeric: T1- Open Sun Drying (Control), T2- Electric Dryer, and T3- Solar Dryer. The electric dryer, developed by the National Post-Harvest Center (NPHC), Paro, is fabricated using locally available materials such as plywood and bamboo. The dryer measures 2 x 1 m and is equipped with four bamboo trays to accommodate the turmeric samples. A heater installed at the base generates hot air, while an exhaust fan positioned at the top ensures uniform air circulation throughout the drying chamber. The internal drying temperature was consistently maintained at 35°C to ensure controlled and standardized drying conditions.

The solar dryer used in the study is a fabricated greenhouse structure measuring 10 x 5 m. Within the structure, two rows of wooden shelve, each measuring 8 × 4 meters, were installed to hold the turmeric. The internal environment is regulated through IoT-based automation system consisting of temperature and humidity sensors to maintain a constant temperature of 35°C and a relative humidity of 50%. It has four exhaust fans positioned at both the front and rear of the greenhouse, programmed to activate automatically when humidity levels exceed the set threshold of 50%. Additionally, two electric fans were installed to ensure uniform air circulation which automatically activates when temperatures rise above 35°C.

The Open Sun Drying method followed the conventional approach of drying turmeric in open areas without any protective enclosure, subjecting the product to ambient environmental conditions.

The drying temperatures in both T2 (Electric Dryer) and T3 (Solar Dryer) were standardized at 35°C to ensure uniformity across treatments and to avoid skewness in data collection.

2.3 Sampling Method

A two-stage sampling method was applied. In the first stage, stratified sampling was used to classify the turmeric samples into three different size categories; Large, Medium, and Small. In the second stage, simple random sampling was employed to select 50 samples from each category, resulting in 150 rhizomes per treatment and a total sample size of 450 fresh turmeric rhizomes.

2.4 Data Collection

Each selected turmeric rhizome was initially weighed to record the fresh weight in grams and its initial water activity (aw) was measured after peeling. The rhizomes were then uniformly sliced using a mechanical slicer to ensure consistency in slice thickness and uniform drying across all treatments. The prepared slices were arranged on drying trays corresponding to their respective drying methods. The drying process was continuously monitored, and the final drying time was determined when the turmeric slices reached a water activity level of 6%. A digital weighing balance was used to measure the fresh and dry weights of turmeric, while a Pawkit water activity meter was employed to determine its water activity. Following the completion of the drying process, the final weight of each sample was recorded to determine weight loss, which was calculated using the following formula:

Weight loss = Fresh weight- dry weight

The quality of the dried turmeric was assessed based on colour, texture, and odour. All data were recorded and organized using MS Excel for further analysis.

2.5 **Data Analysis**

Data analysis was performed using R software (version 4.3.2) and STAR software. The descriptive statistics including mean, minimum, maximum, and standard deviation were also computed. For inferential analysis, a two-way Analysis of Variance (ANOVA) was conducted to evaluate the significance of differences among treatments at a 95% confidence level. Post-hoc analysis was conducted using the Tukey HSD test to evaluate pairwise differences between treatments. In addition, a correlation test was also performed to assess the relationship between drying time and weight loss among the different treatments.

Prior to conducting ANOVA, the normality of the data was confirmed through visual inspection using histograms and boxplots.

3 Results and Discussion

3.1 Descriptive statistics of variables of interest

The descriptive analysis of drying time, weight loss, and post-drying water activity (aw) revealed notable trends across the three drying methods. The electric dryer demonstrated the shortest average drying time, with a mean duration of 7.76 hours, while the IoT-based solar dryer exhibited the longest, averaging 71.05 hours. In terms of weight loss, the electric dryer resulted in the highest mean weight loss of 58.05 grams, while the open sun drying method showed the lowest mean weight loss of 36.45 grams (Table 1).

The variation in drying time was most pronounced in the electric dryer, as reflected by its highest standard deviation of 1.59 hours, suggesting inconsistent drying performance. In contrast, both the IoT-based solar dryer and the open sun drying method showed no variation in drying time, with standard deviations of 0, indicating consistent drying durations (Table 1).

Regarding weight loss, standard deviations were relatively uniform across treatments, showing minimal variability. However, the standard deviation for water activity post-drying was highest in the electric dryer (0.12), compared to the solar dryer, which had the lowest variability of 0.06 (Table 1).

The notable differences in drying time variation for the electric dryer suggest the need for continuous monitoring once the turmeric is placed inside the chamber. The high variability likely indicates uneven air circulation, as the exhaust fan may not uniformly distribute warm air within the dryer. This observation highlights the potential for further optimization of the electric dryer. Future modifications could include improving air circulation or avoiding the placement of products on shelves close to the heater, particularly if continuous monitoring is not feasible.

Table 11. Descriptive statistics of Fresh and Drying weight, Drying time, Weight loss, and Water activity after drying across different treatments.

Treatment	Variable	Minimum	Maximum	Mean	SD
	Fresh weight (g)	48	170	105.9	33.6
	Dry weight (g)	10	31	17.7	6.14
Electric Dryer	Drying time (hrs)	6.49	10.28	7.76	1.59
	Weight loss (g)	27	89	58.05	16.42
	Water activity after drying (%)	0.31	0.53	0.4	0.12
	Fresh weight (g)	34	142	74.05	27.43
	Dry weight (g)	4	21	10.05	4.32
Solar Dryer	Drying time (hrs)	71.05	71.05	71.05	0
	Weight loss (g)	20	75	39.7	16.4
	Water activity after drying (%)	0.44	0.56	0.49	0.06
	Fresh weight (g)	33	128	67.25	27.59
	Dry weight (g)	3	14	7.35	3.92
Control (Open)	Drying time (hrs)	27.46	27.46	27.46	0
	Weight loss (g)	15	68	36.45	16.15
	Water activity after drying (%)	0.42	0.55	0.47	0.07

3.2 **Assessment of Weight Loss of Turmeric**

The two-way ANOVA revealed a statistically significant difference in the weight loss of dried turmeric across the treatment groups, leading to the rejection of the null hypothesis at the 0.05 significance level (Table 2). A Tukey HSD post-hoc analysis further indicated significant differences between the Open Sun Drying and Electric Dryers as well as between Solar and

Electric Dryers at the 5% confidence level. However, no significant difference was observed between the Solar and Open Dryers within the 95% confidence interval (Table 2).

Table 12. Two-way ANOVA output of weight loss between the treatments

	Degree of Freedom	Sum of squared	Mean of squared	F value	P Value
Treatment	2	5426	2712.8	10.18	0.000***
Residuals	57	15192	266.5		

*Notes: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05*

In both significant comparisons, the weight loss was higher in the Electric Dryer relative to the other treatments. Specifically, the Electric Dryer resulted in an average additional weight loss of 21.6 grams when compared to the Open Sun Drying method. Likewise, in comparison to the Solar Dryer, the Electric Dryer exhibited an increased mean weight loss of 18.35 grams (Table 3).

Table 13. Significant differences between treatments with Tukey HSD post-hoc test

Treatment	Difference	Lower	Upper	P value
Open-Electric Dryer	-21.6	-34.02	-9.18	0.000***
Solar-Electric Dryer	-18.35	-30.77	-5.93	0.002***
Solar - Open Dryer	3.25	-9.17	15.67	0.81

*Notes: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05*

Based on these findings, the Electric Dryer was the most effective in reducing turmeric weight during the drying process. However, from a practical perspective for commercial-scale operations, the Solar Dryer is recommended due to its substantially larger volume capacity, accommodating approximately ten times the capacity of the Electric Dryer. Additionally, the Solar Dryer yielded superior quality in terms of texture and colour. These findings align with the study by Mirjanaik & Vishwanath (2020), who reported that solar tunnel drying was more efficient than open sun drying, preserving higher levels of curcumin (5.83%), volatile oils (4.74%), and oleoresin (12.4%), while also reducing drying time. However, unlike their study, which utilized a solar tunnel dryer, the present research employed a protected greenhouse solar dryer with IoT-based automation, offering a more advanced and modern technological solution.

However, due to the absence of data on curcumin content and other biochemical quality parameters in the current study, future research should include these critical assessments to enhance the robustness of findings and support evidence-based recommendations for optimal turmeric drying technologies. Such comprehensive evaluations will be essential for promoting the broader adoption of efficient and high-quality post-harvest drying practices.

3.3 **Assessment of Water activity and Duration of drying time**

Water activity and drying time are crucial parameters when determining the most suitable drying technology for turmeric. Roos 2002 defined water activity as, “an equilibrium property of water in foods and other materials”. Water activity measures the availability of water for biological reactions and is a key factor in determining the potential for microorganism growth (Canovas et al., 2020).

A two-way ANOVA was performed to assess the significant differences among the drying technologies. The analysis revealed statistically significant differences between the Electric Dryer and Open Sun Dryer, as well as between the Electric Dryer and Solar Dryer for water activity, but no significant differences were observed between the Open Sun Dryer and Solar Dryer at the 0.05 significance level. The electric dryer recorded the highest water activity, 58.05%, compared to the open sun dryer and the solar dryer (Table 4). These results suggest that the Electric Dryer maybe associated with increased postharvest losses, as the higher water activity indicates an increased potential for microorganism growth. Similar findings were reported by the Borah et al. (2015); Chumroenphat et al. (2021); Huang et al. (2021); and Singh et al. (2020). However, Bourdoux et al. (2016); and, Pittia & Antonello (2016) contested the direct correlation between higher water activity (a_w) and postharvest losses emphasizing that susceptibility to losses is more dependent on the intrinsic characteristics of the agricultural product. For instance, starch-rich foods are highly prone to microbial growth regardless of the water activity level in dried products. The ideal water activity for spice crops such as turmeric, garlic, and ginger must be maintained at 20-30% to inhibit microbial growth (Canovas et al., 2020).

Regarding drying time, the null hypothesis was rejected at the 5% significance level, indicating statistically significant differences among all three treatments. The Electric Dryer demonstrated the shortest drying time, completing the process in 7.76 hours, whereas the Solar Dryer took the longest at 71.05 hours. The Electric Dryer was 63.29 hours faster than the Solar Dryer and 19.7 hours faster than the Open Sun Dryer (Table 4). These findings suggest that, based on drying time alone, the Electric Dryer is the most efficient technology. The substantial variation in drying time across treatments raises concerns regarding the lack of environmental control mechanisms specifically, the inability to regulate ambient air movement, temperature, and relative humidity in both the Solar Dryer and Open Sun drying conditions. This limitation may have contributed to extended drying durations in these treatments due to less stable microclimatic conditions.

Table 14. ANOVA output of duration of drying time and water activity between the treatments

Treatment	Water Activity (%)	Duration of Drying time (hrs)
Electric Dryer	58.05^{a}	7.76^{c}
Open	36.45^{b}	27.46^{b}
Solar	39.7^{b}	71.05^{a}
P value	0.000^{***}	0.000^{***}

*Notes: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05*

Although the Electric Dryer demonstrated the fastest drying, it was associated with higher water activity, indicating a higher potential for microorganism growth. Moreover, its limited capacity makes it inefficient for handling large scale turmeric processing as repeated drying cycles would substantially increase labour and energy costs. In contrast, the Open Sun Dryer depends on optimal sunlight conditions, making it unreliable during periods of poor weather. Furthermore, the open exposure of turmeric during this method increases the risk of contamination from dust and other environmental pollutants, adversely affecting product quality and hygiene.

In comparison, the Solar Dryer emerged as the most effective drying method, producing turmeric with lower water activity levels, although requiring a longer drying duration. These findings are consistent with previous studies; for instance, Borah et al. (2015) reported that the Solar Conduction Dryer (SCD) reduced the moisture content of sliced turmeric samples from 78.65% to 5.5% within 12 hours, whereas Open Sun drying required 25.5 hours to achieve comparable results. The SCD was also noted for its effectiveness in minimizing mould growth, particularly under humid conditions, due to its ability to dry wet samples more rapidly. Although the SCD utilized stainless steel components and was designed for small-scale operations, the present study's Solar Dryer features a larger structure, offering improved economies of scale. Similarly, Kumar et al. (2016) it the suitability of Solar Dryers as the most efficient and cost-effective drying solution, especially in developing countries, where affordability and performance are critical factors for processing agricultural commodities.

3.4 Association between weight loss and duration of drying time among the treatments

The relationship between weight loss and drying time for the various treatments was analyzed using a Pearson correlation test, a statistical method used to determine the strength and direction of the linear relationship between two continuous variables. The findings revealed a negative correlation coefficient of -0.4, indicating a moderately weak inverse relationship between drying time and the weight loss experienced by turmeric.

This outcome signifies that as the drying time increases, the weight loss of turmeric tends to decrease. This trend can be observed in Figure 1. The implications of these results are significant, leading to the conclusion that drying methods requiring extended durations, such as solar drying technology, maybe the most effective. After a certain point in the drying process, the weight loss of turmeric reaches a plateau, suggesting that prolonged drying times do not yield further reductions in weight loss. Therefore, these findings highlight the need to evaluate more efficient drying techniques that optimize weight loss within an appropriate time frame.

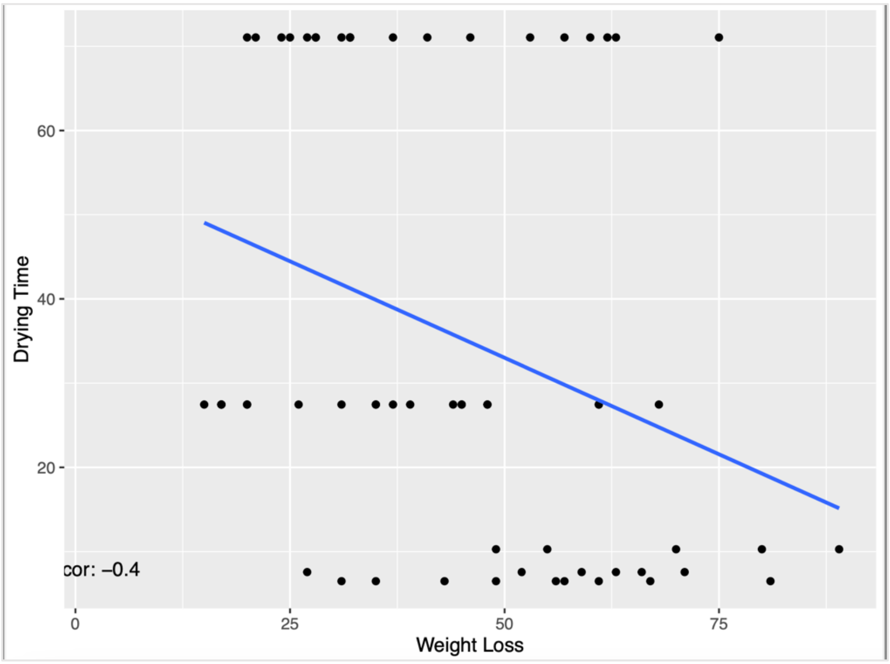

Figure 7: Correlation between weight loss and drying time

4 Conclusion

In conclusion, this study highlights the significant influence of various drying methods on the physical attributes, rehydration capacity, sensory quality, bioactive composition including the antioxidant characteristics of turmeric. Among the methods tested, turmeric dried using the

Solar Dryer integrated with IoT-based climate control technology exhibited superior physical qualities, including vibrant color, minimal shrinkage, and reduced hardness. However, this method required the longest drying duration.

In contrast, the Electric Dryer achieved the highest weight loss, and the shortest drying time compared to Open Sun Drying and Solar Drying. Despite its efficiency, the Electric Dryer has limitations, including high water activity, limited capacity, increased labor demands, and high energy consumption, making it less suitable for commercial-scale operations.

Considering scalability and product quality, the IoT-enabled Solar Dryer is recommended due to its larger operational capacity and ability to retain desirable physical quality parameters such as color and texture. To encourage broader adoption of Solar Drying technology, future research should focus on evaluating its impact on the chemical composition of turmeric, particularly curcumin, which is vital for its medicinal and therapeutic properties. Additionally, further studies are needed to examine the effect of drying temperature on drying duration and economic analysis of Solar Dryer technology to optimize their performance and application for commercial uses.

5 Acknowledgment

The authors gratefully acknowledge the valuable support provided by the Elementary Support Personnel (ESP) and the Program Director of the Centre for their contributions to the successful execution of this research. Sincere appreciation is also extended to the staff of the Agriculture Research and Development Centre (ARDC), Wengkhar, for their technical guidance and constructive feedback throughout the study.

6 Authors' contribution statement

Thinley Gyeltshen, Tenzin Rabgay, Tshering Penjor, and Domang- Study conception and design; Implementation of research, data analysis and interpretation of result and drafting of manuscript**.** Pema Yangdon, Tshering Pem, Kinzang Thinley, Kinley Sithup and Kinley Wangmo- Implementation of research and data collection; data cleaning; and data analysis and interpretation of result.

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Assessment of Walnut Grafting Success under Locally Fabricated Hot Callusing Technology with IoT based Environmental Control

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ABSTRACT

Walnut grafting under open conditions often achieves a relatively low success rate of 0-20%, primarily due to difficulties in maintaining optimal environmental conditions. Grafting is typically carried out in February and March when the plants are dormant, during which the temperatures fall below 15°C. However, successful walnut grafting requires an optimal temperature of 27°C and a relative humidity of 90%, conditions that are difficult to maintain in an open environment. Hot callusing technology presents a solution to achieve and sustain these optimal conditions. This study, conducted at the Agriculture Research and Development Centre (ARDC) Wengkhar and Drepong village, Mongar Dzongkhag, aimed to develop an effective and sustainable hot callusing technology. The system was developed using locally available materials integrated with IoT (internet of things) technology to automate and monitor environmental conditions. The efficacy of locally fabricated hot callusing systems on the success rate of walnut grafting was evaluated both on-station and on-farm. The study initiated on-station in 2023 with 180 seedlings achieved a graft success rate of 78%. The second study conducted on-farm in 2024 with 1,170 grafted seedlings, achieved a 76% success rate. For both the sites, the grafting was done in February month when the plants were still at dormancy stage. Unlike the past studies, this study made use of vertical space and IoT for automation and monitoring. Further, investment analysis demonstrated a positive Net Present Value (NPV) and a high Internal Rate of Return (IRR), confirming the economic viability of this technology for walnut nursery enterprise development. The findings indicate that the locally fabricated hot callusing system, coupled with IoT technology, provides a sustainable and profitable solution for walnut grafting in Bhutan, with the potential for broader applications in agricultural enterprise development.

Keywords: *Walnut grafting; Success rate; Hot callusing technology; Temperature; Humidity; Internet of Things (IoT)*

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1 Introduction

Walnut is one of the potential cash crops in Bhutan with good domestic and export market opportunities. In 2021, the country produced approximately 129.31 metric tonnes of nuts from 8911 bearing trees, contributing to 0.30% of the total fruit production (National Statistics Bureau, 2024). However, most of the walnut orchards in Bhutan consist of seedling-origin trees, which take a longer time to bear fruits and exhibit yield variability (RNR-RC Yusipang, 2003).

Recognizing the importance of walnuts as a high-value crop, the Million Fruit Tree Plantation Project (MFTP) has identified walnuts as one of the priority commodities for promotion. In 2024, as part of the MFTP Phase III, 33,817 walnut seedlings were distributed nationwide for plantation of which 91% of the total walnut seedlings were imported from the neighbouring countries, while only 9% were produced domestically (National Seed Centre, 2024b). This significant gap underscores the high demand for walnut seedlings within Bhutan. Further, grafted walnut seedlings fetch higher prices in the market ranging from Nu 175 to 205 per seedling (National Seed Centre, 2024a).

However, walnut trees are among the most challenging fruit crops to graft with a low graft success rate ranging from 0-20% when grafted under open conditions (Avanzato & Atefi, 1995; Gandev, 2015; Lagerstedt, 1983). A critical factor for successful grafting is the formation of callus tissue, which facilitates the union between grafted parts (scion and the rootstock plant). The rapid formation of callus tissue is essential and is influenced by several factors including temperature, light, pressure, moisture, and chemical growth regulators (Lagerstedt, 1983). Among these factors, temperature and humidity are the main factors affecting the callus formation in walnuts (Rongting & Pinghai, 1991). It requires an optimum temperature of 27°C and a Relative Humidity (RH) of 90-95% at the graft union for three weeks for successful callus formation (Avanzato & Tamponi, 1987; Karadeniz, 2005). Several studies have reported that walnuts do not form callus tissue when the temperature falls below 20°C (Hassan et al., 2019; Reil et al., 1998). Generally, grafting is performed in February and March when the buds are dormant. However, during this period, the temperature is below 20ºC and RH is below 70% , making it difficult to achieve the required conditions for successful grafting in open environments (National Center for Hydrology and Meteorology, 2023).

To address this, Hot Callusing Technology (HCT) offers a solution by selectively heating the graft union to promote callus formation while keeping the rest of the plant unheated (Avanzato & Atefi, 1995; Gandev, 2017; Lagerstedt, 1983). Hot callusing is the method of heating the graft union of the plants to accelerate the callus formation while leaving other plant parts unheated (Lagerstedt, 1983). This technology, first developed by Lagerstedt Harry B in 1981, has been widely studied and has demonstrated a graft success rate of 80-85% in various trials (Avanzato & Atefi, 1995; Erdogan, 2004; Gandev, 2017; Vanzyl, 2009). In 1997, the National Centre for Organic Agriculture (NCOA), the then Renewable Natural Resources Research Centre (RNR-RC) Yusipang, Thimphu carried out a trial on walnut grafting by developing the HCT (RNR-RC Yusipang, 2003). The study found it very promising for commercial production of grafted walnut seedlings in the country. However, the technology was not widely adopted due to challenges such as interrupted power supply, difficulty in monitoring and maintaining the required callusing temperature by analogue thermostats, and the nonavailability of other essential spare parts of the HCT in Bhutan (RNR-RC Yusipang, 2003). Therefore, this study aimed to redesign and develop an enhanced hot callusing system with the following objectives:

i. Develop an efficient and sustainable hot callusing system with locally and readily available materials.
ii. Integrate IoT technology for precision control and monitoring of callusing parameters (temperature, humidity) and other automation processes to reduce labour costs.
iii. Evaluate the effectiveness of the prototype for potential enterprise development.

2 Materials and Method

2.1 Study area

The first trial was initiated on-station at Wengkhar in 2023 to test the prototype. A total of 180 seedlings were grafted and placed in a hot callusing tube in a 4 x 4.5 m net house. After the successful testing of the prototype on-station, the second trial was initiated on-farm at Drepong village under Mongar Dzongkhag in 2024 in one of the private nurseries in a 5 x 10 m net house. A total of 1170 grafted seedlings were placed in the hot callusing tube in a 5 x 10 m net house.

2.2 Seedlings Propagation

a. *Propagation of rootstocks:* Seedlings of 1-2 years old attaining pencil size were used as rootstocks.
b. *Scion Collection*: Prior to grafting, scion woods were collected in December from the healthy and productive matured softshell walnut trees. Scion woods with 2-3 buds were cut and waxed to prevent moisture loss during storage until they were used for grafting in February.
c. *Grafting:* Grafting was done in February when the plants were in their dormant stage. To reduce contamination, all grafting knives were cleaned with ethanol before any cuts were made. Rootstocks were carefully selected so that the scion and rootstock diameters match at the graft union. Bench graft with side veneer grafting technique was used to graft the seedlings. All the grafted seedlings were then placed in the hot callus chamber.

2.3 Design and fabrication of hot-callusing apparatus

The hot-callusing apparatus that we designed was mainly based on the design described by (Lagerstedt, 1983) with some modifications using locally available materials. The fabricated hot-callusing apparatus provides heat only to the graft union area to accelerate callusing while the other parts of the plant (scion and root) remain unheated. The fabricated apparatus comprises of the following parts:

a. *Semi-permanent structure*: A 10 x 5 m size greenhouse tubular frame was used to construct a shade house with 70% shading to in-house all the hot-callusing related equipment. The main purpose of the structure was to protect delicate grafted walnut seedlings, IoT devices, and sensors from direct exposure to sunlight and rain. Generally, a total of 54 callusing tubes can be fitted in a 10 x 5 m structure. However, in our study, we installed only 39 callusing tubes in the structure.

b. *Hot-callusing tube:* A 75 mm diameter PVC pipe, commonly available at local hardware stores was used as the primary material for the hot-callusing tube (Figure 1). On one side of the PVC pipe, 30 callusing chambers were cut to enclose the graft union area. Inside each pipe, 6 mm thick plastic foam was lined as a heat insulator and an 8 mm copper tube was inserted to circulate hot water. This hot water circulation maintained the necessary temperature for hot-callusing. Some of the hot-callusing tubes were equipped with temperature sensors to monitor the callusing temperature. Each callusing tube accommodated 30 grafted plants by maintaining 10 cm between two plants. With 39 hot-callusing tubes in a structure, it accommodated about 1170 grafted seedlings. Following this design, the final production of the hot-callusing tubes was outsourced to a local private firm.

Figure 8. 75 mm diameter PVC pipe as hot-callusing tube and 110 mm PVC roof gutter as root holder pipe

c. *Root Holder PVC*: PVC roof gutter pipe of 110 mm diameter was used as a platform to hold the root system of the grafted walnut seedlings (Figure 1). The root holder pipe was filled with soil mixed with mosses and fitted with an automated drip irrigation system *d.* *Boiler Tank*: A 200 L plastic barrel was used as the main water reservoir and heating unit for the hot-callusing system (Figure 2). A water level sensor was fitted inside a barrel to enable automatic refilling when the water level dropped. A barrel was also fitted with a 2500-watt electric water heater to heat the circulating water and a temperature sensor to monitor the water temperature. To minimize heat loss to the surrounding environment, the barrel was insulated by wrapping black plastic foam. The water temperature within the tank was consistently maintained between 50-55 °C.

Figure 9. 200 L plastic barrel insulated with black foam to retain water temperature

e. *Water Circulation Pump:* To circulate the hot water from the reservoir tank to the hot-callusing tubes, we used a regular household water pump with 1 HP capacity which was connected to a 240 V AC power supply through pump relay switch. The pump relay switch was then connected to the IoT based controller which will switch ON and OFF the pump based on the temperature setpoints detected by the temperature sensor fitted inside the hot-callusing tube.

2.4 IoT based control and monitoring system

The successful formation of graft union in walnut seedlings placed inside the hot-callusing tube requires precision maintenance of a temperature (26-27°C) at the graft union (Lagerstedt, 1983). To accomplish this we used microcontrollers, sensors, and cloud IoT service for remote monitoring and control systems. The basic working principle of the system is as follows (Figure 3).

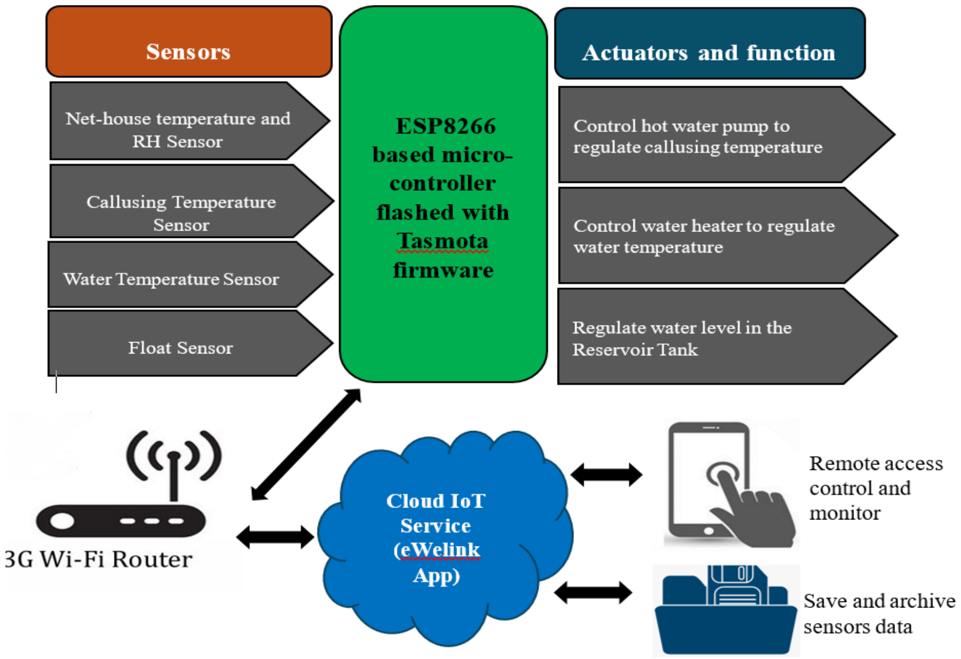

Figure 10. Basic architecture of Hot callusing IoT based climate control and monitoring system

a. Microcontroller: We used a NodeMCU Microcontroller which is a low-cost, open-source development board based on the ESP8266 Wi-Fi chip (NodeMCU Documentation, 2023). It was designed for IoT applications and is highly popular for creating connected devices and automation systems. The NodeMCU is then uploaded with the latest version of Tasmota firmware. Tasmota is an open-source firmware designed to provide firmware for ESP8266 and ESP32 based Microcontroller (Tasmota, 2023). It is popular due to its ability to transform various devices into locally controlled, MQTT integration and support for a wide range of sensors and actuators. The microcontroller was then connected to the sensors, actuators, Wi-Fi and configured as main controller for automation

b. Sensors: Sensors are fundamental components in any automation systems, providing the data needed for machines and devices to make autonomous decisions. Sensors measure various physical parameters such as temperature, humidity, light, pressure, motion, and gas concentrations, ensuring that automated processes respond effectively to changing conditions (Thompson, 2015). In this study, we used three types of sensors for measuring temperature, humidity and water level in the system as follows:

i) DS18B20 temperature Sensor: It was used to measure the temperature of the hot-callusing tube and the temperature of water in the boiler tank. The DS18B20 is a digital temperature sensor widely used in various electronics and automation projects due to its accuracy, simplicity, and versatility. It communicates over a 1-Wire bus, which allows multiple sensors to be connected to a single data pin. The DS18B20 can measure temperatures ranging from -55°C to +125°C with an accuracy of ±0.5°C in the range of -10°C to +85°C (Maxim Integrated, 2020). Temperature data from these sensors regulates the temperature of hot-callusing tubes and water temperature of the boiler tank.

ii) HTU21D temperature and humidity sensor: It was used to measure temperature and humidity inside the net-house. The HTU21D is a digital humidity and temperature sensor known for its high accuracy, compact size, and low power consumption. It measures relative humidity from 0% to 100% with an accuracy of ±2% and temperature from -40°C to +125°C with an accuracy of ±0.3°C (TE Connectivity, 2017).

iii) Magnetic water level sensor: It is a device used to detect the water level in a tank or reservoir. It operates based on the principle of magnetic float switches, where a buoyant float rises and falls with the water level. As the float moves, it activates a reed switch inside the sensor, which can either open or close an electrical circuit, signaling the water level status to the microcontroller.

a. Actuators: Actuators are devices responsible for converting electrical, hydraulic, or pneumatic energy into mechanical motion. They enable automated systems to perform physical tasks, such as opening valves, moving robotic arms, or adjusting the position of machinery etc. In this system we used two actuators that is, I HP water pump to circulate hot water in the hot-callusing tubes and 2500 Watts electric heater to heat water in the boiler tank

b. 3G Wi-Fi router: To connect our microcontroller to the internet we used 3G Wi-Fi router which provides internet access using a 3G mobile network. It connects to the internet by receiving a 3G signal from a SIM card provided by a B-mobile operator and then broadcasts a Wi-Fi signal.

c. IoT Cloud Service (eWeLink App): We used eWeLink Cloud Service as a main IoT platform. It allows users to control and monitor IoT devices remotely through smartphones or tablets. The app communicates with connected devices via cloud servers, enabling users to turn devices on or off, set schedules, or check device status from anywhere with an internet connection (eWeLink, 2023). The app is designed for ease of use, with drag-and-drop functions for automating tasks, creating schedules, and setting up scenes. It also provides space to store and retrieve sensor data for one hour interval for the total duration of 6 months.

d. Setup and configuration of eWeLink App:

- App download and registration: The first step in setting up the eWeLink app was to download it from the Google Play Store (for Android devices) or the Apple App Store (for iOS devices). After installing, we opened the app and created an account using email address or phone number. Then received a verification code and completed the registration process.
- Adding Devices: Second step was to add our microcontroller devices by powering on and tapping the “+” button on the App home screen. The app typically connects via Wi-Fi and requires the input of our 3G Wi-Fi network credentials (SSID and password).
- Device configuration and automation scenes: Once our devices were connected, we configured various settings, such as renaming the device and creating schedules for automated operation. We have created three automation scenes for controlling the hot-callusing system as follows:
- Automation Scene 1: If the temperature inside the hot-callusing tube drops below 26 ^{o}C the water Pump will start and circulate the hot water in the hot-callusing pipe networks. If the temperature inside the hot-callusing tube rises above 27 ^{o}C the pump stops to circulate the hot water
- Automation Scene 2: If the temperature of water in the boiler tank drops below 50 ^{o}C the device will switch ON the water heater. If the water temperature rises above 55 ^{o}C it will switch OFF the water heater.
- Automation Scene 3: If the water level sensor detects a LOW signal the device will activate the electric valve and allow the water to flow in the boiler tank. If the level sensor detects HIGH signal the device will deactivate the electric valve.

2.5 Vertical stacking design of hot-callusing tubes

In this study we developed a vertical stacking design to accommodate more grafted walnut seedlings by utilizing the vertical space and optimizing horizontal space (Figure 4). The structure was divided into 3 rows with 1.4 m distance between each row. In each row, a total of 18 callusing pipes were installed vertically by maintaining a distance of 0.6 m. With this design, a total of 54 callusing tubes can be fitted in a 5x10 m structure. However, in this study, a total of 39 callusing tubes were installed. Each callusing tube accommodated 30 grafted plants with a total of 1170 grafted seedlings in 39 callusing tubes.

Figure 11. Vertical stacking design of hot callusing tubes

2.6 Irrigation layout

Drip irrigation was installed in the root zone along the gutter using Jain Drip and the irrigation was scheduled twice for 30 minutes in a day (Figure 1).

2.7 Sensitivity analysis

A sensitivity analysis was conducted to evaluate the profitability of the technology under different market conditions, considering five distinct scenarios. As the model is particularly sensitive to changes in the price of walnut seedlings, scenarios involving a 10% increase and a 10% decrease in annual revenue were considered. Additionally, since variations in the discount rate also influence the model's outcomes, changes of ±2% in the discount rate were incorporated into the analysis. The following scenarios reflect these adjustments;

a. Normal: Based on current market conditions.
b. Optimistic: Assuming a 10% increase in annual revenue and a 5% decrease in annual variable costs.
c. Pessimistic: Assuming a 10% decrease in annual revenue and a 5% increase in annual variable costs.
d. Higher Discount Rate: Assuming a 2% increase in the discount rate.
e. Lower Discount Rate: Assuming a 2% decrease in the discount rate.

3 Results and Discussion

3.1 IoT-based monitoring and automation

An IoT-based control and monitoring system was set up and tested one day prior to the start of the walnut grafting process. Then the system has been kept operating continuously for over 30 days, with sensor data including callusing temperature, boiler water temperature, outside temperature, and humidity logged to the eWeLink cloud server at hourly intervals. The recorded data was later downloaded from the eWeLink server for further analysis and visualization. The IoT system effectively controlled and maintained the temperatures of both the hot-callusing chamber and the boiler tank within the specified range. However, there was a sudden temperature drop in both the hot-callusing chamber and boiler tank on the fifth day of the experiment (Figure 5). This occurred due to a breakdown of the boiler tank's water heater, which was later replaced with a new unit. Additionally, it indicated that walnut grafting in open air would be challenging during the experiment period due to the relatively low outside temperature. A more efficient way to maintain the temperature of the hot-callusing chamber was observed by increasing the temperature of the circulating water from the boiler. However, when the water temperature exceeded 60°C, the LDP pipe network became difficult to maintain, as the pipes began to break down and leak due to the high heat.

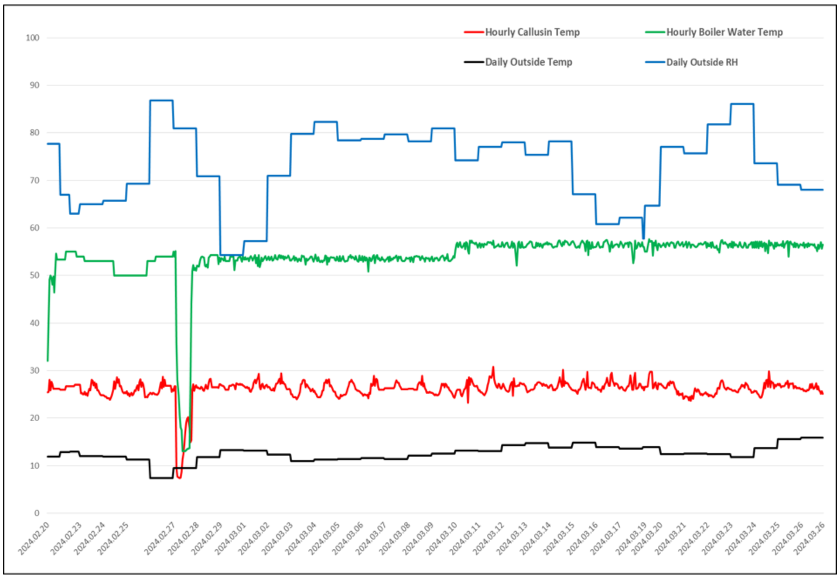

Figure 12. Record of daily callusing temperature, outside temperature, boiler water temperature and outside relative humidity for a month from an eWeLink server

3.2 Callus formation and Graft success

The grafted seedlings were immediately placed in a hot-callusing chamber, where the temperature at the graft union was maintained between 26-27°C for 30 days. The heat from the chamber accelerated the natural wound response in the plant. As a result, both the rootstock and scion began producing callus tissue at the cut edges. Callus is a mass of undifferentiated cells that forms as the plant's healing mechanism. The callus tissue bridges the gap between the rootstock and scion, promoting cell differentiation and vascular tissue connection over time. This connection is vital for water and nutrient transport between the two parts (Hartmann & Kester, 1959). Callus formation was visually inspected on a weekly basis. It was observed that the grafted seedlings began forming callus within 21 days of being placed in the hot-callusing chamber (Figure 6).

Figure 13. Callus formation at the graft union of walnut seedling

The on-station trial showed 78% graft success where 140 seedlings out of 180 formed a successful graft union. Similarly, the on-farm trial at Drepong also showed 76% graft success with 889 seedlings out of 1170 forming successful graft unions. The success rate of 76% on-farm and 78% on-station is relatively higher compared to the graft success rate in the open condition which has a maximum success rate of 30% at Wengkhar condition. The higher success rate in the HCT would be a result of localized heating of graft union while leaving other plant parts unheated due to which, buds remain dormant during grafting time and start growing at the end of uniting process (Lagerstedt, 1983; Soleimani et al., 2010).

The previous study also recorded graft success between 75-80% in the hot callusing system at Yusipang (RNR-RC Yusipang, 2003). They also indicated that the higher success rate was attributed to the absence of moisture and nutrient translocation to the scion until the callus bridge between the scion and rootstock had formed, due to the focused heating of the graft union area (Lagerstedt, 1983). In this study, an optimal temperature of 25-27°C was maintained at the walnut graft union for four weeks. Research has shown that walnut seedlings when exposed to this temperature range form callus tissue at the graft union within 21-28 days of grafting, which is essential for the union between the scion and rootstock (Gandev, 2015; Lagerstedt, 1983; RNR-RC Yusipang, 2003).

3.3 Vertical space utilization

Most hot-callusing setups described in the literature did not incorporate vertical stacking designs (Gandev et al., 2018; Lagerstedt, 1983; RNR-RC Yusipang, 2003). In contrast, this study innovatively utilized the vertical space within the greenhouse, greatly improving its overall efficiency. Without vertical stacking, a 5 x 10 m greenhouse would have been limited to accommodating only 500 seedlings. However, by taking advantage of the available vertical height, the same greenhouse was able to house 1,170 grafted seedlings, which is more than doubling its original capacity. This design not only expanded the capacity for seedlings but also enhanced operational efficiency, resulting in more streamlined management and care processes.

The results of this study highlight the potential of vertical farming technology as a practical solution, especially in urban and peri-urban settings where land availability is constrained. The use of vertical space optimizes land use, enabling higher crop density in limited areas, which is crucial for addressing the growing demand for agricultural productivity in space-limited environments. Furthermore, the vertical stacking design promotes better airflow and light distribution, further supporting seedling health and growth.

3.4 Investment analysis

To evaluate the profitability of the technology, an investment analysis was conducted, considering the costs incurred for setting up HCT and the production of walnut seedlings over ten years. The initial investments for experiment setup and material costs amounted to Nu 244646, with a 5% increase in variable cost annually over the following ten years. Using a discount rate of 12% which is the standard benchmark for economic analyses in developing countries, the analysis revealed that the entrepreneur could achieve the break-even point by the second year, with an Internal Rate of Return (IRR) of 61% exceeding the discount rate and a positive Net Present Value (NPV) of Nu 534358.677 (Table 1). Similar findings were also reported by RNR-RC Yusipang (2003) where they reported a positive NPV and a higher IRR for walnut grafting using HCT. The benefit calculations were based on a graft success rate of 77%, representing the average success rate achieved across both on-station and on-farm conditions. To account for potential uncertainties and market fluctuations, a sensitivity analysis was conducted across five different scenarios: normal, optimistic, pessimistic, higher discount rate, and lower discount rate. The results showed there was no major changes in the investment model though there are slight changes in the NPV and IRR value, indicating that the technology remains stable and profitable under varying conditions (Table 2). The detailed costing and the sensitivity analysis for different scenarios are given in Annexure 1 and 2.

Table 1. Investment analysis of hot callusing technology for walnut seedling propagation

Year	Cost (C)	Benefit (B)	Net Benefit (NB)	DF $(1+r)^{-t}$	Net DF (NBxDF)	ANDF
0	244646	0	-244646	1.0000	-244646	-244646.0
1	22359	184684.5	162325.5	0.8929	144933.482	-99712.5
2	23609	184684.5	161075.5	0.7972	128408.402	28695.9
3	28440	184684.5	156244.5	0.7118	111211.749	139907.6
4	43109	184684.5	141575.5	0.6355	89973.7897	229881.4
5	92759	184684.5	91925.5	0.5674	52160.9974	282042.4
6	111640	184684.5	73044.5	0.5066	37006.6169	319049.0
7	25165	184684.5	159519.5	0.4523	72158.5207	391207.6
8	43109	184684.5	141575.5	0.4039	57179.9699	448387.5
9	27240	184684.5	157444.5	0.3606	56776.0651	505163.6
10	94009	184684.5	90675.5	0.3220	29195.0842	534358.7
			61%	**NPV**	**534358.677**	

Table 2. Sensitivity analysis of the hot callusing technology under different scenarios

SN	**Scenario**	**Variable Change**	**NPV (Nu)**	**IRR %)**	**Break-even**
1	Normal	Without any changes	534358.677	61	2nd Year

2	Optimistic	Annual revenue increase by 10%, Annual variable cost decrease by 5%	664167.036	74	2nd Year
3	Pessimistic	Annual revenue decrease by 10%, Annual variable cost increase by 5%	404550.319	49	3rd Year
4	Discount rate	Increase by 2%	478248.229	61	2nd Year
5	Discount rate	Decrease by 2%	598075.79	61	2nd Year

4 Conclusion and Recommendations

The study demonstrated that the Hot Callusing Technology (HCT) achieved a graft success rate of 76-78% in walnuts, significantly improving grafting outcomes compared to conventional methods. Another innovation in this technology is the efficient use of vertical space, which maximizes greenhouse capacity and production efficiency. Additionally, the integration of IoT systems for monitoring and controlling environmental conditions makes the technology not only adaptable but also scalable, providing opportunity for youth entrepreneurs to adopt it as a viable business enterprise.

The investment analysis further indicated the economic feasibility of HCT with a higher Internal Rate of Return (IRR), a positive Net Present Value (NPV), and a breakeven point by the second year of operation. Moreover, the sensitivity analysis revealed that the breakeven point remained consistent across five different scenarios, indicating that the technology is resilient, profitable, and adaptable to various economic conditions.

Given these findings, HCT is highly recommended for adoption by the National Seed Centre (NSC), private nursery operators, and young entrepreneurs for commercial production of grafted walnut seedlings. The combination of high success rates, efficient use of space, integration with IoT systems, and strong financial returns makes it a promising technology for scaling up walnut production on commercial scale.

5 Acknowledgment

We would like to thank CARLEP-IFAD for the financial support and the operators of the centre, Drepong Agriculture Extension Agent, for supporting us in setting up an on-farm trial at Drepong village under Mongar Dzongkhag.

6 Authors' contribution statement

Pema Yangdon contributed to the implementation of research, data collection, result interpretation, and drafting of the manuscript. Dr. Tshering Penjor played a key role in the study's conception and design, overseeing the research process and contributing to manuscript preparation. Thinley Gyeltshen was responsible for data analysis and result interpretation. Lungki, Mandira Acharya, Tshewang Dorji, Tshering Pem, and Dema Yangzom supported the research through their involvement in data collection and implementation. Domang provided valuable input in study conception and design, while Sangay Dendup played a critical role in reviewing and editing the manuscript draft.

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Annexure 1 Net Present Value Model for Hot Callusing Technology

Si No	Particular	Unit	Quantity (No)	Rate (Nu)	Amount (Nu)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Fixed Cost															
1	Greenhouse	No	1	43500	43500										
2	Latching Solenoid	No	1	4500	4500					4500					4500
3	Smart Irrigation Controller	No	1	7500	7500					7500					7500
4	Water Pump	No	1	9500							7500				
5	Power Relay Switch	No	1	4500	4500				4500				4500		
6	Temperature and Humidity Thermostat	No	2	6500	13000					13000					13000
7	Router	No	1	4250	4250						4250				
8	Hot Callusing Pipe	No	40	1680	67200						67200				
9	PVC Gutter Pipe	No	40	1030	41200					41200					41200
10	HDPE Pipe	Meter	100	28.06	2806							2806			
11	CPVC Tank Nipple	No	2	72	144			144			144			144	
12	CPVC Ball Valve	No	1	187	187			187			187			187	
13	Greenshed Net	Roll	1	3200	3200			3200			3200			3200	
14	Grafting Knife	No	6	1000	6000				6000				6000		
15	Secateur	No	6	1500	9000				9000				9000		
16	250litres barrel	No	1	2500	2500										
17	Water Heating Rod	No	1	1350	1350			1350			1350			1350	
Total A					**210837**			**4881**	**19500**	**66200**	**83831**	**2806**	**19500**	**4881**	**66200**
Variable Cost															
1	Scionwood	No	1170	4	4680	4680	4680	4680	4680	4680	4680	4680	4680	4680	4680
2	Grafting Tape	No	5	250	1250		1250		1250		1250		1250		1250

3	Rootstock	No	1170	9	10530	10530	10530	10530	10530	10530	10530	10530	10530	10530	10530
4	WiFi Bill	Monthly	1	99	99	99	99	99	99	99	99	99	99	99	99
5	Electricity Bill	Monthly	1	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Total B					**18059**	**16809**	**18059**	**16809**	**18059**	**16809**	**18059**	**16809**	**18059**	**16809**	**18059**
Labor Cost															
1	Ground Preparation	No	6	600	3600										
2	Greenhouse Installation	No	4	600	2400										
3	Callus Pipe Installation	No	5	600	3000					3000	3000				3000
4	Automation Setup	No	2	600	1200			1200		1200	1200				1200
5	Grafting	No	5	600	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
6	Monitoring	Hours/week	2	75	150	150	150	150	150	150	150	150	150	150	150
7	Setting Up Grafted Plants in Callusing Pipe	No	2	600	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
8	Setting up rooting media for the grafted plants	No	2	600	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Total C					**15750**	**5550**	**5550**	**6750**	**5550**	**9750**	**9750**	**5550**	**5550**	**5550**	**9750**
Grand Total (A+B+C)					244646	22359	23609	28440	43109	92759	111640	25165	43109	27240	94009
With 5% increase in cost					256878.3	23476.95	24789.45	29862	45264.45	97396.95	117222	26423.25	45264.45	28602	98709.45
With 5% decreases in cost					232413.7	21241.1	22428.6	27018.0	40953.6	88121.1	106058.0	23906.8	40953.6	25878.0	89308.6
Revenue															
	Total Grafted plants	1170		77											
	Market price	205		901	184684.5	184684.5	184684.5	184684.5	184684.5	184684.5	184684.5	184684.5	184684.5	184684.5	184684.5
	With 10% increase in revenue				**203152.95**	**203152.95**	**203152.95**	**203152.95**	**203152.95**	**203152.95**	**203152.95**	**203152.95**	**203152.95**	**203152.95**	**203152.95**
	With 10% decrease in revenue				**166216.05**	**166216.05**	**166216.05**	**166216.05**	**166216.05**	**166216.05**	**166216.05**	**166216.05**	**166216.05**	**166216.05**	**166216.05**

Annexure 2 Sensitivity Analysis of hot callusing technology under different scenarios

Scenaro 1: Without changing anything

Discount rate 0.12

Year	Cost (C)	Benefit (B)	Net Benefit (NB)	DF (1+r)-t	Net DF (NBxDF)	ANDF	
0	244646	0	-244646	1.0000	-244646	-244646.0	
1	22359	184684.5	162325.5	0.8929	144933.482	-99712.5	
2	23609	184684.5	161075.5	0.7972	128408.402	28695.9	***Break-even***
3	28440	184684.5	156244.5	0.7118	111211.749	139907.6	
4	43109	184684.5	141575.5	0.6355	89973.7897	229881.4	
5	92759	184684.5	91925.5	0.5674	52160.9974	282042.4	
6	111640	184684.5	73044.5	0.5066	37006.6169	319049.0	
7	25165	184684.5	159519.5	0.4523	72158.5207	391207.6	
8	43109	184684.5	141575.5	0.4039	57179.9699	448387.5	
9	27240	184684.5	157444.5	0.3606	56776.0651	505163.6	
10	94009	184684.5	90675.5	0.3220	29195.0842	534358.7	
			61%	**NPV**	**534358.677**		

Scenaro 2: Revenue increases by 10% and cost decreases by 5%

Discount rate 0.12

Year	Cost (C)	Benefit (B)	Net Benefit (NB)	DF (1+r)-t	Net DF (NBxDF)	ANDF	
0	232413.7	0	-232413.7	1.0000	-232413.7	-232413.7	
1	21241.05	203152.95	181911.9	0.8929	162421.339	-69992.4	
2	22428.55	203152.95	180724.4	0.7972	144072.385	74080.0	***Break-even***
3	27018	203152.95	176134.95	0.7118	125369.378	199449.4	
4	40953.55	203152.95	162199.4	0.6355	103080.651	302530.1	
5	88121.05	203152.95	115031.9	0.5674	65272.1893	367802.2	

6	106058	203152.95	97094.95	0.5066	49191.3234	416993.6
7	23906.75	203152.95	179246.2	0.4523	81081.8779	498075.4
8	40953.55	203152.95	162199.4	0.4039	65509.6172	563585.1
9	25878	203152.95	177274.95	0.3606	63927.1241	627512.2
10	89308.55	203152.95	113844.4	0.3220	36654.8499	664167.0
			74%	**NPV**	**664167.036**	

Scenaro 3: Revenue decreases by 10% and cost increases by 5%

Discount rate 0.12

Year	Cost (C)	Benefit (B)	Net Benefit (NB)	DF (1+r)-t	Net DF (NBxDF)	ANDF	
0	256878.3	0	-256878.3	1.0000	-256878.3	-256878.3	
1	23476.95	166216.05	142739.1	0.8929	127445.625	-129432.7	
2	24789.45	166216.05	141426.6	0.7972	112744.42	-16688.3	
3	29862	166216.05	136354.05	0.7118	97054.1195	80365.9	***Break-even***
4	45264.45	166216.05	120951.6	0.6355	76866.9284	157232.8	
5	97396.95	166216.05	68819.1	0.5674	39049.8055	196282.6	
6	117222	166216.05	48994.05	0.5066	24821.9105	221104.5	
7	26423.25	166216.05	139792.8	0.4523	63235.1634	284339.7	
8	45264.45	166216.05	120951.6	0.4039	48850.3226	333190.0	
9	28602	166216.05	137614.05	0.3606	49625.006	382815.0	
10	98709.45	166216.05	67506.6	0.3220	21735.3185	404550.3	
			49%	**NPV**	**404550.319**		

Scenaro 4: Discount rate increases by 2%

Discount rate 0.14

Year	Cost (C)	Benefit (B)	Net Benefit (NB)	DF (1+r)-t	Net DF (NBxDF)	ANDF	
0	244646	0	-244646	1.0000	-244646	-244646.0	
1	22359	184684.5	162325.5	0.8772	142390.789	-102255.2	
2	23609	184684.5	161075.5	0.7695	123942.367	21687.2	***Break-even***

3	28440	184684.5	156244.5	0.6750	105460.587	127147.7
4	43109	184684.5	141575.5	0.5921	83824.0613	210971.8
5	92759	184684.5	91925.5	0.5194	47743.2242	258715.0
6	111640	184684.5	73044.5	0.4556	33278.0916	291993.1
7	25165	184684.5	159519.5	0.3996	63749.9459	355743.1
8	43109	184684.5	141575.5	0.3506	49630.5735	405373.6
9	27240	184684.5	157444.5	0.3075	48415.4343	453789.1
10	94009	184684.5	90675.5	0.2697	24459.1548	478248.2
			61%	**NPV**	**478248.229**	

Scenaro 5: Discount rate decreases by 2%

Discount rate 0.1

Year	Cost (C)	Benefit (B)	Net Benefit (NB)	DF (1+r)-t	Net DF (NBxDF)	ANDF	
0	244646	0	-244646	1.0000	-244646	-244646.0	
1	22359	184684.5	162325.5	0.9091	147568.636	-97077.4	
2	23609	184684.5	161075.5	0.8264	133120.248	36042.9	***Break-even***
3	28440	184684.5	156244.5	0.7513	117388.805	153431.7	
4	43109	184684.5	141575.5	0.6830	96697.9715	250129.7	
5	92759	184684.5	91925.5	0.6209	57078.5031	307208.2	
6	111640	184684.5	73044.5	0.5645	41231.716	348439.9	
7	25165	184684.5	159519.5	0.5132	81858.7264	430298.6	
8	43109	184684.5	141575.5	0.4665	66046.0156	496344.6	
9	27240	184684.5	157444.5	0.4241	66771.8375	563116.5	
10	94009	184684.5	90675.5	0.3855	34959.3305	598075.8	
			61%	**NPV**	**598075.79**		

Bhutanese Farmers Perspectives on Climate Events and Agrometeorological Advisory Services

Chimi Rinzin[n], Tirtha Bdr Katwal[n], Tshering Wangchen[o] and Ngawang[o]

ABSTRACT

Bhutan's agriculture sector is predominantly subsistence-based and highly vulnerable to extreme weather and climate events. As a result, Agrometeorological Advisory Services (AAS) have become increasingly important for helping farmers adapt to these challenges. In recognition of this, the 13th Five Year Plan of the Department of Agriculture prioritizes the development and delivery of effective AAS to build resilience among smallholder farmers. To assess the reliability, usefulness, and accessibility of AAS, a national survey was conducted. The findings show that while 48.1% of respondents were aware of AAS, only 45.7% of them actively used the information for making farming decisions. Awareness varied across Dzongkhags, with Punakha showing the highest awareness (90.6%), and 48.3% of those aware reported using the service. Farmers reported seven types of extreme climate events affecting their agriculture, with pests and diseases being the most common, mentioned by 77.6% of respondents. These events led to the highest reported crop loss of 204,966 kilograms. Cold waves and frost were the next most reported issues (18.7%). Awareness of AAS was highest among poultry farmers, and the service was rated as the most useful for cereal, vegetable, and fruit production. The most common sources of AAS were Bhutan Broadcasting Service (48.8%) and social media (23.4%). Among the services provided, the 24-hour and 3-day weather forecasts were considered the most useful, showing a strong demand for short-term forecasts. These findings will help guide the improvement and expansion of AAS to better support Bhutanese farmers in adapting to climate risks.

Keywords: *Agrometeorological Advisory Services, climate change adaptation, extreme weather events, smallholder farmers, agricultural resilience, Bhutan agriculture, weather forecast utilization.*

1 Introduction

The vulnerability and risks of the agricultural sector to weather and climate induced extreme events is well established. The increased frequency of extreme climate events which are driven by climate change increases the risk of food insecurity and adaptation needs of the agriculture sector (Hasegawa et al, 2021). Further, climate change induced weather patterns and disasters makes the agriculture sector highly vulnerable, threatening crop productivity and the overall

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sustainability of the sector (Zambrano-Medina et al. 2024). As the first strategy to minimize and protect agricultural communities against the wrath of extreme climate events through early warnings, the World Meteorological Organization (WMO) supports its members to develop and promote national agrometeorological and climatological services to help develop sustainable and economically viable agricultural systems (https://wmo.int/activities/agricultural-meteorology-and-food-security, nd). According to the WMO, agrometeorological advisory services help and prepare farmers to make informed decisions on different farming operations which can save them from inevitable losses. Walker (2024) has defined agrometeorological (agromet) service as the service that climate experts, using long term climate data and satellite images, provide advance information about the ensuing weather and climate to all stakeholders of the agricultural sector for making sensible farming decisions to avoid or reduce losses from weather and climate induced extreme events. Agrometeorology science can significantly support the adaptation of the agriculture sector to climate variability and climate change events (Salinger, Stigter & Das, 2000). Agrometeorology as a tool is now more robust, dynamic in responding to diverse needs, and reliable with the use of satellite-based weather and climate data monitoring systems and advancement of Information and Communication Technology (ICT) that supports rapid and concise data processing. Chattopadhyay (2018) has defined AAS as the agrometeorological and agroclimatology information which can be used by the farming communities to enhance and safeguard their agriculture-based livelihoods from the menace of weather and climate. For this study we have adopted this definition of AAS broadly referring to all the weather and climate related information and other crop advisory services disseminated to the farming communities as coping strategies to enhance their resilience to climate change impacts.

Bhutan's geographical location coupled with a mountainous topography exposes the country to frequent weather and climate hazards such as flash floods, Glacial Lake Outburst Flood (GLOF), landslides, cyclone induced storms and erratic rainfall affecting the lives and livelihoods of the people (NCHM, 2023). The Bhutanese agriculture is largely a unique smallholder mountain agricultural farming systems (Katwal and Bazille, 2020) that is highly dependent on the seasonal monsoon and the bear the brunt of fickle weather events (Katwal et al, 2015; Chogyal, Kumar and Bajgai, 2020). With only about 29% of the total agricultural land under the assured irrigation schemes (MoAL, 2023), both the small seasonal variations and extreme events can cause severe impacts to the farming communities. Further, Bhutan's economy hinges on climate-sensitive sectors like agriculture, livestock and forestry contributing 14.67% and hydropower making another 13.40% of the GDP (NSB, 2023). The agriculture sector comprising livestock, fishery and forestry continues to remain an important source of revenues and employs 43% of the population (LFS, 2022). Recognizing the need for robust AAS, weather forecast services were started in 2007 under the then Ministry of Agriculture and Forest which is now further strengthened and upgraded to a more reliable satellite-based forecast. The agromet services is led and coordinated by the National Centre for Hydrology and Meteorology (NCHM), an autonomous agency of the Royal Government of Bhutan (Wangchuk et al, 2023).

The AAS plays a vital role as an early warning system for the smallholder farming communities precautioning them to make informed on-farm decisions against resulting inclement weather and extreme climate incidents. The Department of Agriculture (DoA) has prioritized the development and provision of robust AAS as one of its key priority areas to support climate smart agriculture and build resilience of the farmers in the current 13th Five Year Plan (FYP). The agromet services are in its formative stages as well as the awareness and utilization of the existing services by the target stakeholders are quite limited. To deepen the understanding of the status of agromet services and the perspectives of the farming communities who are the end users, a national study was undertaken with three main objectives. First to document the Bhutanese farmers perspective on climate events and its impact on the farming community; second to understand the status of the AAS, extent of use and usefulness of current AAs; and thirdly to draw lessons from farmers perspectives and experiences to further improve and strengthen the AAS. This research was implemented by the Agriculture Research and Innovation Division (ARID), DoA with fund support from World Bank (WB) as a part of the enhancement of Agro-Met Decision Support System (ADSS) for the DoA.

2 Materials and Method

The key methodology for this study was a national survey of farming households from five representative sample *Dzongkhags* (districts). A three-day training workshop was conducted to develop, pre-test, and finalize the data collection questionnaire, train and equip survey enumerators with the necessary skills for quality data collection, and identify representative Dzongkhags while determining the sample size. Furthermore, the workshop delved into sampling methods and designs, offering hands-on training to enhance participants' understanding in selecting representative samples. This component was seen to be very crucial for ensuring the validity and reliability of the data. The survey was conducted using a semi-structured questionnaire developed in the Kobo toolbox application. It consisted of 12 modules designed to explore various aspects of Bhutanese farmers' perceptions, perspectives and experiences regarding climate events and other AAS. Data collection was carried out by enumerators using the Kobo collect application.

The survey covered five (25%) *Dzongkhags* namely Paro, Punakha, Wangduephodrang (Wangdue), Sarpang and Mongar and 11 (5%) *Gewogs* (blocks) from these *Dzongkhags* with a total respondent of 690 individuals. These locations were meticulously selected, ensuring a comprehensive representation of the agriculturally vibrant landscape and diverse agro-ecological zones (AEZ) of the country. The enumerators for this survey were Agriculture Extension Officers of the DoA posted in the *Gewogs*. The total sample size was 690 respondents from five *Dzongkhags* and 11 *Gewogs*. The AEZ size, *Dzongkhags*, *Gewogs* and number of respondents and other details are presented in Table 1.

Table 15:AEZ, Dzongkhags, Gewogs and details of respondents covered in the study

AEZ	**Dzongkhag**	**Gewogs**	**No of respondents**		
			Male	**Female**	**Total**
Warm Temperate (1200-1800 m asl)/Cool Temperate (2600 -3600 m asl)	Paro	Dopshari	14	44	58
		Loongnyi	21	36	57
		Sharpa	19	65	84
		Tsento	63	21	84
Warm temperate/Dry subtropical (1200-1800 m asl)	Punakha	Barp	13	19	32
Warm temperate/Dry subtropical (1200-1800 m asl)	Wangdue	Thedtsho	5	23	28
Wet subtropical (150-600 m asl)	Sarpang	Dekiling	52	35	87
		Gakidling	24	59	83
		Samtenling	44	20	64
	Total		320	370	690

3 Results and Discussion

The results and findings from this study are sequenced according to the three objectives of the study. The results are then used to infer the critical gaps in the current AAS as the end users' perspectives to further improve and strengthen the agromet services. There were 690 respondents of which 320 were male and 370 female (Table 1) to ensure an equal representation of gender-based perspective on climate events and agromet services.

3.1 Land Use information

Land holding size is an important factor that influences farmers' decisions on farming practices, crop selection and adoption of other farming operations. In Table 2 we present the distribution of land holdings across five sample *Dzongkhags* of Paro, Punakha, Wangdue, Sarpang, and Mongar. Across all the five Dzongkhags, the percentage of residents with large land holdings of 5 acres or more is few, with most residents falling into the land holding category of 0-2 or 2-5 acres. The national average land holding size is 2.22 acres (MoH, 2021). The size of holding reiterates that Bhutanese farmers qualify as smallholders who can be significantly affected by even small disruptions in their source of livelihoods. A high percentage of respondents fall under the category of having no land which can be explained by the fact that the respondents normally report as not having land if they have no legally registered land in their own name as the land is normally registered in the name of the head of the family (*Thram* holder). Alternatively, some respondents may possess only one category of land use. Most households in Pato fall into the category of land holding size of 0-2 acres with 71% possessing dryland and 61% wetland. In Punakha almost half of the respondents reported having no land which can be explained by the fact that the respondents were from Barp *Gewog* which is a peri-urban area with a high percentage of temporary residents who may not possess registered farmland in that *Gewog*. In Mongar, 77% of respondents own orchards followed by Sarpang with about 20%.

Table 2. Agriculture land information of the study sites

Dzongkhags	Category of Land Holdings	Dry Land (%)	Wet Land (%)	Orchard (%)
Paro (n=283)	No land	12	33	94
	0-2 acres	71	61	6
	2-5 acres	14	7	0
	5-10 acres	3	0	0
Punakha(n=32)	No land	47	34	94
	0-2 acres	53	53	6
	2-5 acres	0	13	0
	5-10 acres	0	0	0
Wangdue (n=28)	No land	18	0	100
	0-2 acres	82	64	0
	2-5 acres	0	29	0
	5-10 acres	0	0	0
	10 acres and above	1	0	0
Sarpang (n=234)	No land	0	50	79
	0-2 acres	66	40	18
	2-5 acres	30	9	2
	5-10 acres	4	1	1

	10 acres and above	0	0	0
Mongar (n=113)	10 acres and above	0	7	0
	0-2 acres	40	57	77
	2-5 acres	51	1	0
	5-10 acres	8	0	0

3.2 Crops and livestock farming in the study sites

The identification of prevalent crops and livestock was necessary to understand the use and effectiveness of AAS in relation to land use types, crops, livestock and other farming practices. While most farmers may not be formally educated, they are very intelligent and take prudent farming decisions. Through an extensive review of literature (Dessart, Barreiro-Hurlé, and Van Bavel, 2019), we have found that a careful understanding of the farmers' behavior which influences farmers decision making can lead to the development of more realistic and effective farming policies and interventions. In this study, we considered the farmers' choice of crops as an important indicator to understand the influence of climate events and its correlation to choice of crops and farming practices. In all the five *Dzongkhags,* cereals, vegetables and fruits were the most dominant crops in agriculture-based system. In the livestock-based system, cattle farming is the most prevalent in all the *Dzongkhags* (Table 3). The choice of diverse farming practices by farmers are the indicators of their strategic decision for a sustainable, integrated and climate resilient farming system. Obviously, climatic factors, land suitability, market and household needs would have significantly influenced the choice of these crops and livestock farming which is further examined in other sections.

Table 3. Dzongkhags, crops and livestock farming in the study area

Crops/Livestock	**Dzongkhag and Percentage of respondents by farming practices**				
	Paro	Punakha	Wangdue	Sarpang	Mongar
Cereals	22.90	33.80	23.50	19.10	21.20
Vegetables	24.80	27.50	24.30	24.70	21.40
Fruits	21.40	17.50	15.70	23.70	18.80
Poultry	0.60	1.30	0.90	7.00	6.30
Cattle	16.30	20.00	18.30	17.70	22.20
Piggery	0.20	NA*	NA	3.00	0.20
Forestry	0.1	NA	NA	0.40	0.20

3.3 Crops and land use types

Dryland agriculture and terraced wetland are the two dominant agriculture land uses system in Bhutan. Data was collected to know the popular crops cultivated by farmers according to the land use types.

3.3.1 Major crops cultivated in the dryland

The crops cultivated in the drylands included five cereals, 10 vegetables and one plantation crop (Table 4). In Paro the primary crops include chili, potato, green leaves, and Cole crops whereas in Punakha key crops were cole crops, chili, and maize. In Wangdue green leaves, chili, and Cole crops are dominant vegetables with maize and wheat as the two main cereals. Among all the *Dzongkhags* Sarpang has the maximum diversity as influenced by the favorable AEZ and growing season with the cultivation of a wide variety of cereals, vegetables and plantation crops. In Mongar maize, potato, chilli and green leaves are reported to be the major crops.

Table 4. Dzongkhag, crops and percentage of respondents growing crops in dryland

Crops	**Dzongkhag and Percentage of respondents cultivating the crops**				
	Paro	Punakha	Wangdue	Sarpang	Mongar
Paddy	0.60	NA	3.10	3.20	0.20
Maize	1.80	17.90	3.10	15.90	22.20
Wheat	8.40	NA	6.30	NA	6.40
Upland paddy	NA	NA	NA	NA	NA
Millet	0.70	NA	NA	3.30	NA
Potato	16.50	NA	NA	5.20	21.60
Winter Potato	NA	NA	NA	9.00	3.00
Chilli	19.40	28.20	31.30	15.70	18.20
Asparagus	5.20	2.60	NA	0.40	0.40
Carrot	7.80	NA	NA	0.60	0.80
Green Leaves	11.10	15.40	46.90	13.70	18.00
Cole Crops	10.40	35.90	9.40	14.00	9.00
Peas	4.00	NA	NA	2.30	0.20
Turnip	8.10	NA	NA	0.20	NA
Beetroot	5.80	NA	NA	NA	NA
Arecanut	0.10	NA	NA	16.40	NA

3.3.2 Major crops cultivated in the wetland

Under the wetland production systems, it is rational to find paddy as the dominant crop in all the Dzongkhags except for Sarpang which has 20.90% arecanut. Among the cereals maize and wheat are popular as they fit well in sequence after rice. Besides cereals, potatoes and different types of vegetables are also cultivated in the wetland (Table 5).

Table 5. Dzongkhag, crops and percentage of respondents growing crops in wetland

Crops	Dzongkhag and Percentage of respondents cultivating the crops				
	Paro	Punakha	Wangdue	Sarpang	Mongar
Paddy	53.10	56.00	42.90	16.70	88.50
Maize	0.50	6.00	1.60	16.10	1.90
Wheat	12.60	22.00	14.30	NA	NA
Millet	NA	NA	NA	1.50	NA
Potato	6.70	NA	1.60	4.50	3.80
Winter Potato	NA	NA	NA	7.90	NA
Chilli	14.60	NA	9.50	11.80	1.90
Asparagus	1.20	NA	NA	o.30	NA
Carrot	1.20	NA	4.80	0.60	NA
Green Leaves	3.00	2.00	19.00	6.70	1.90
Cole Crops	1.70	14.00	6.30	11.20	1.90
Peas	4.40	NA	NA	1.50	NA
Turnip	0.50	NA	NA	0.30	NA
Beetroot	0.50	NA	NA	NA	NA
Arecanut	NA	NA	NA	20.90	NA

3.3.3 Climate and its related events observed

The respondents reported seven different types of extreme climate events which have affected their crops and other agricultural enterprises. Among the seven different climate and its related events most respondents reported the occurrence of pests and disease followed by drought (Figure.1). The least observed climate events were cyclones and flood. In 2023, based on the frequency of occurrence, 77.6% of respondents said pests and disease while 18.7% mentioned cold wave and frost (Table 6). In general, Bhutanese agriculture sector is proven to be highly exposed to the impact of climate change triggering natural calamities including the emergence of new pests and diseases (MoAL, 2023). These observations are also in line with the findings reported by Chogyel, Kumar & Bajgai (2020) who investigated the potential ramifications of extreme climate and weather events in Paro, Punakha, Wangdue and Sarpang *Dzongkhags* where farmers reported erratic monsoon rains, droughts and windstorms as the most common extreme events causing crop losses. In the Chitwan district of Nepal which has a similar socio-economic landscape like Bhutan, a study Bajracharya et al, (2023) have also recorded drought, flood, erratic rainfall, and hailstorms as the most commonly occurring extreme events perceived by farmers. Furthermore, the population dynamics of agricultural insect pest and diseases are influenced by climatic factors mainly temperature, rainfall and humidity and extreme climate events can enhance the incidence of pest and disease-causing significant production losses (Subedi, Poudel & Aryal, 2023). The emergence of new pests and diseases like Fall Armyworm in maize, incessant rainfall during rice harvest season in 2021 affecting 2500 acres of rice amounting to a production loss of 2,400 Mt and the outbreak of 13 different animal diseases at an epidemic scale are associated with climate change (MoAL, 2023). The findings and records from such studies further corroborate the farmers' observation of pests and diseases as an emerging extreme event triggered by climate change.

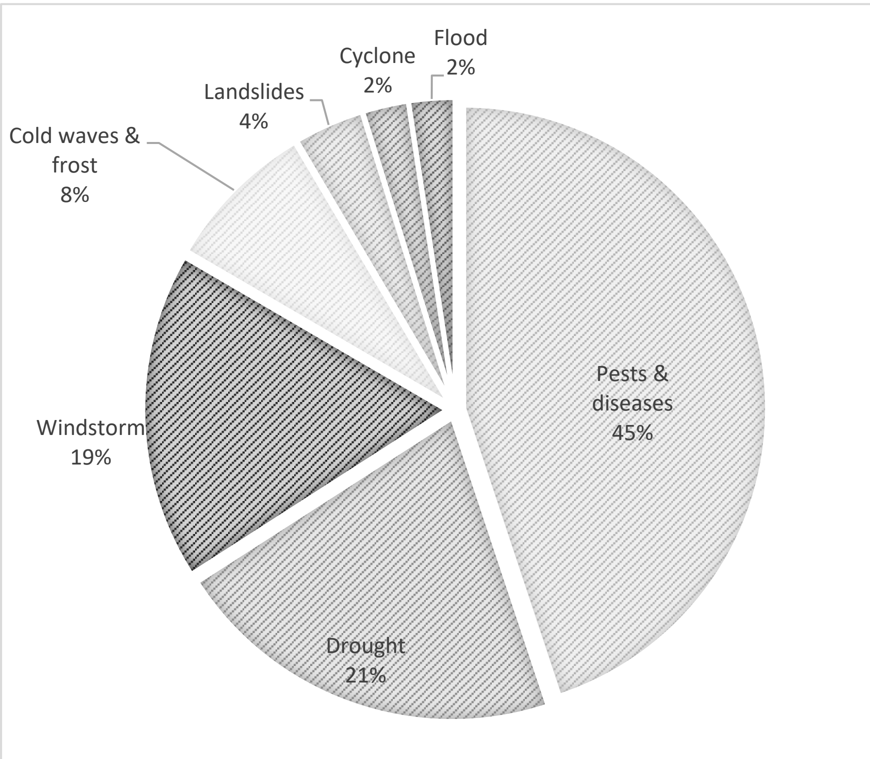

Figure 14: Climate/weather and related events experienced till 2022 by the respondents

Table 6. Frequency of pests & diseases, and cold wave & frost observed in 2023

Frequency of occurrence	Pests & diseases (%)	Cold wave & frost (%)
1-2 times in a year	77.6	18.7
3-4 times in a year	6.9	0.7
5-6 times in a year	1.3	0.1
More than 6 times in a year	0.3	0.6
Never	13.9	79.9

To estimate the crop losses respondents were first asked to recollect the extreme weather events that occurred in 2023 and provide their estimate of crop losses caused by the events. The respondents reported seven different weather and related events, namely pests and diseases, droughts, storms, landslides, floods and cyclones. Among these events, 55% of the respondents reported pests and diseases as the most frequent event causing the highest total production loss of 204,966 Kgs in all four categories of crops (Table 7). Drought was the second most observed event while cyclone was reported as the least observed event in 2023. Of the four types of crops, maximum loss was estimated for vegetables followed by fruits, cereals and spices (Table 7). This data indicates that a careful choice of the types of crops is an important coping strategy to reduce the impact of extreme events. The extreme weather events recorded by the meteorological stations of the NCHM in the five surveyed Dzongkhags further confirm the incidences of extreme events in the form of 24-hour rainfall, maximum temperature and minimum temperature (NCHM, 2024).

Table 7. Crops and estimated production loss due to climate/weather and related events in 2023

Climate Events	Respondent who reported the events (%)	Crops & Estimated Production lost (Kg)				
		Cereals	Vegetables	Fruits	Spices	Total (Kg)
Pest & Diseases	55	15708	30447	47421	490	94066
Droughts	23	22856	67476	3530	0	93862
Storms	15	2985	205	5870	0	9060
Landslides	5	80	500	2600	80	3260
Floods	1	3180	618	200	0	3998
Cyclones	1	100	620	0	0	720
Total	100	44909	99866	59621	570	204966

3.3.4 Agrometeorology Advisory Services (AAS)

The NCHM and DoA are striving to provide reliable real time agromet and crop advisory services to the farmers through national broadcasting and social media platforms. Farmers comprise the last mile end users and the most vulnerable in the agricultural value chain. Vedeld et al, (2020) who compared weather and climate services in Norway and India have concluded that reliable and efficient AAS is essential to adapt and avert risks in agriculture sector. Such services which are targeted for the farming communities can be made more efficient, usable and integrated with local farming practices by leveraging the application of social media tools. Further, to facilitate Climate Smart Agriculture in India, the India Meteorological Department (IMO) disseminate the crop AAS and alerts through print, visual, radio and other IT based media tools such as short message service (SMS) and Interactive Voice Response Service (IVRS) to help farmers to take quick farming decisions that can prevent crop losses (Amith et al, 2022). To continuously improve and ensure that AAS is useful to the end users it is important to know their level of awareness. The awareness of the farmers on AAS varied significantly (Table 8). Overall, 48.1% of respondents were aware of the AAS but only 45.7% of them genuinely used it to make farming decisions. Punakha had the highest awareness at 90.6%, with 48.3% of those aware using the information. In contrast, Mongar had the lowest awareness at 13.3% and only 33.7% of those aware utilized the AAS. Farmers' feedback on the AAS should be taken as benchmark by the service providers to further improve and strengthen the AAS.

Table 8. Awareness and adoption of AAS

Dzongkhags	**Awareness Level (%)**		**Respondent who are aware and use the services (%)**	
	Yes	**No**	**Yes**	**No**
Punakha	90.6% (29)	9.4% (3)	48.3% (14)	51.7(15)
Wangdue	82.1% (23)	17.9% (5)	69.6% (16)	30.4% (7)
Paro	78.8% (223)	21.2% (60)	39% (87)	61% (136)
Sarpang	17.9% (42)	82.1% (192)	71.4% (30)	28.6% (12)
Mongar	13.3% (15)	86.7% (98)	33.7% (5)	66.7% (10)
Total	48.1% (332)	51.9% (358)	45.7% (152)	54.2% (180)

A binary logistic regression analysis (Table 9) was conducted to examine the factors influencing awareness of Agrometeorology Advisory Services. The results indicated that location and literacy were significant predictors. Individuals from Paro ($B = 3.246$, $p < 0.001$), Punakha ($B = 4.353$, $p < 0.001$), and Wangdue Phodrang ($B = 3.608$, $p < 0.001$) exhibited significantly higher levels of awareness compared to those from Mongar. Additionally, individuals who could read and write ($B = 0.784$, $p < 0.001$) were more than twice as likely to be aware of the services ($Exp(B) = 2.191$) compared to those who could not. However, gender

(B = -0.155, p = 0.5) and head of the family (B = 0.176, p = 0.412) did not significantly impact awareness levels. These findings suggest that geographic location and literacy are the primary factors influencing variations in awareness of Agrometeorology Advisory Services. Dzongkhags such as Paro, Punakha, and Wangdue Phodrang are relatively more developed, with better road connectivity, greater media reach, and early adoption of agrometeorological services. Consequently, differences in accessibility, outreach activities, and development infrastructure likely contribute to the disparity in awareness across regions. Interestingly, despite high awareness in Paro, Punakha and Wangdue, actual usage of the services tends to be lower. This may be attributed to a cultural tendency among farmers in these regions to rely heavily on peer practices, observing and emulating what fellow farmers do. This pattern aligns well with findings from the study conducted in the southern India where the farmers' initial exposure to agro-meteorological advisories often occurs through fellow farmers, underscoring the centrality of word-of-mouth dissemination (Venkatasubramanian, Tall, Hansen, & Aggarwal, 2014).

Table 9. Factors influencing awareness of Agrometeorology Advisory Services

Variables in the Equation		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1a	Monggar			205.109	4	0	
	Paro	3.246	0.323	101.121	1	0	25.692
	Punakha	4.353	0.676	41.443	1	0	77.692
	Sarpang	0.22	0.337	0.426	1	0.514	1.246
	Wangdue Phodrang	3.608	0.579	38.886	1	0	36.89
	Gender	-0.155	0.229	0.454	1	0.5	0.857
	head_family	0.176	0.215	0.674	1	0.412	1.193
	Write and read	0.784	0.22	12.729	1	0	2.191
	Constant	-2.121	0.516	16.89	1	0	0.12

A Variable(s) entered step 1: dzongkhag, Gender, head family, Write and Read.

3.3.5 Sources for AAS

Rural communities require and rely on the most convenient source for their AAS needs. We investigated the popularity of the different sources that relay AAS to the farming communities in the five *Dzongkhags*. In all the five *Dzongkhags,* the Bhutan Broadcasting Service (BBS) television was identified as the most used source for AAS by 48.80% of respondents followed by social media (23.40%) (Figure. 2). This can be explained by the fact that BBS television broadcasts in the national language. With the wide use of mobile phones by rural communities, social media platforms through interactive voice messages are gaining popularity. The NCHM website apparently was the least used source because most of the rural communities are not literate to access websites.

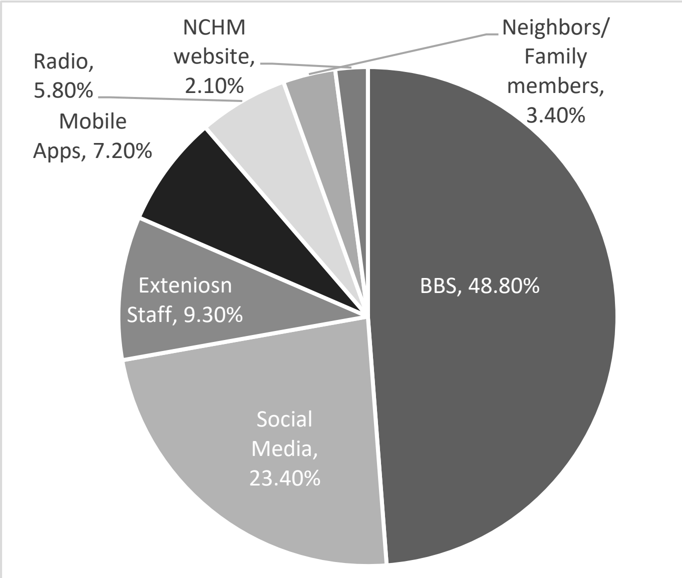

Figure 15: Sources of AAS

When the data on the different sources was disaggregated by Dzongkhags, BBS was still ranked as the most popular source except in Wangdue which ranked social media as the most popular (Table 11). After BBS and social media forums, *Gewog* Agriculture staff served as the next important source of AAS. In Mongar, neighbors and family members (45.5%) served as an important source for agromet information which could perhaps be facilitated by social media forums. It is very encouraging to note that there were no respondents in all five *Dzongkhags* who responded that they had no idea on the AAS. This is a very positive indicator of the usefulness, need and source of AAS. The least source was the NCHM website, which is understandable as our clients are the rural population.

Table 11: Dzongkhags and various sources of AAS

Dzongkhags	**Categories of Source and Respondents (%)**								
	Newspapers	**BBS**	**Social media**	**Extension staff**	**Radio**	**NCHM websites**	**Neighbors & family**	**Weather Apps**	**No idea**
Paro	0	62.8	27.7	4.4	0	2.2	1.5	1.5	0
Punakha	0	46.4	28.6	17.9	7.1	0	0	0	0
Wangdue	0	33.3	56.3	16.7	13.9	0	5.6	5.6	0
Sarpang	0	32.9	15.2	12.7	12.7	3.8	1.3	21.5	0
Mongar	0	45.5	9.1	0	0	0	45.5	0	0

3.3.6 Farmers' perception of the usability of AAS

One of the important AAS services is the weather forecasting for farmers to know in advance the ensuing weather conditions. Any weather forecast is perceived as the best if it is accurate and reliable which translates to the usability of the forecast. Respondents were asked to rate the four different frequencies of forecast currently provided through the AAS into four categories namely very useful, useful, not useful or neutral. The percentage of respondents rating the 24-Hour Forecast and Three day forecast as either very useful or useful was the highest (Figure.3). The rating trend of very useful or useful decreased as the frequency of forecast increased. There was a high percentage of respondents who remained neutral for three days, 10 days and monthly seasonal forecast indicating that these forecasts were not very effective as compared to 24 Hour forecast which had less than 8% respondents under the neutral category.

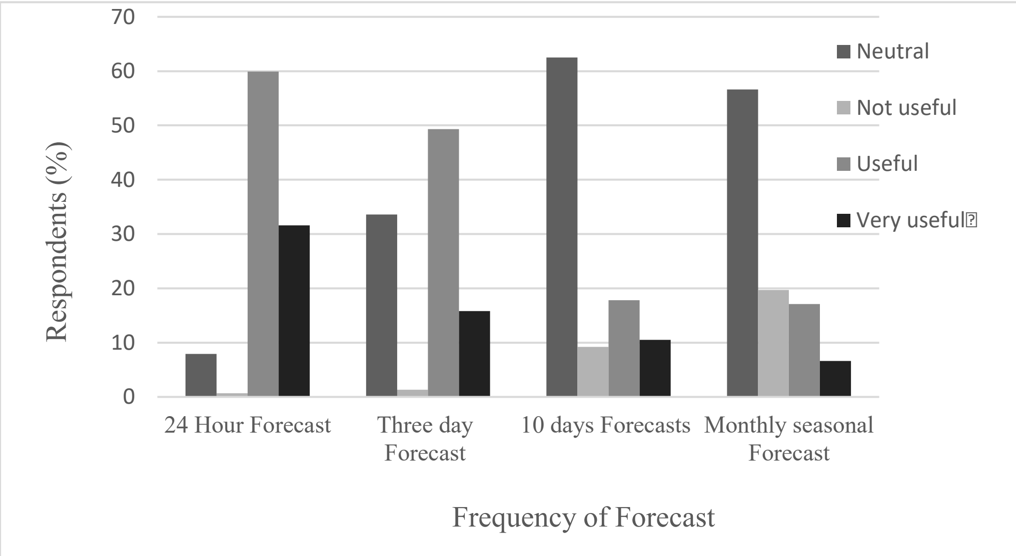

Figure 16. Rating of the usability of forecasting service by frequency of forecast

3.3.7 AAS use based on crops and farming steps

The most logical and widespread coping strategies adopted by subsistence farmers to avert risk from crop failures is the cultivation of diverse crops. Farmers use their experience and indigenous knowledge to select the crops. AAS requirements for crops vary depending on their agronomic needs and crop husbandry practices. We assessed the usefulness of AAS by categories of crops grown by the respondents. Most of the respondents perceived that AAS is useful in cereals (57.9%), vegetables (37.5%) and fruits (24.3%) (Figure. 4). The use of AAS was rated the least for spices and Medicinal and Aromatic Plants (MAPs) due to the versatile nature and ability of these crops to tolerate climate extremes.

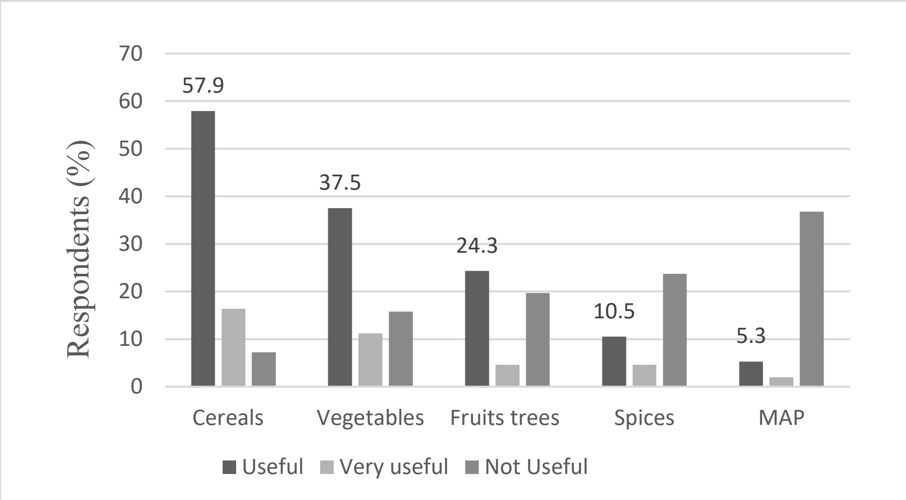

Figure 17: AAS use by crops

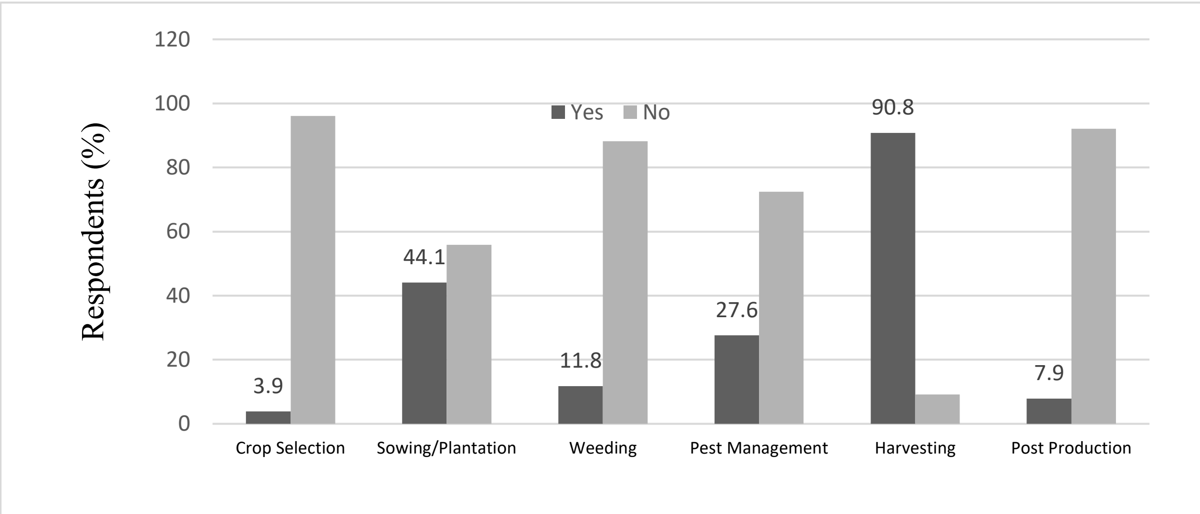

Figure 18. AAS use based on farming steps

The survey found that the use varied depending on the farming stages. According to the respondents AAS is predominantly used for decision making during harvesting (90.8%) followed by the sowing/plantation (44.1%). Farmers consider harvesting and sowing/plantation as the most critical farming steps where AAS can benefit them. At present AAS is the least used by farmers for crop selection (3.9%).

3.3.8 Suggestions to improve the AAS

The direct and most important beneficiaries of AAS are rural communities. To improve and strengthen these services, respondents were asked to provide suggestions based on their perceptions. The majority (43.5%) recommended enhancing the quality and accuracy of AAS. Additionally, 16.5% called for more detailed information, 14.3% suggested simplifying the content, 7% requested sector-specific advisories, and 18.7% had no specific suggestions (Figure. 6).

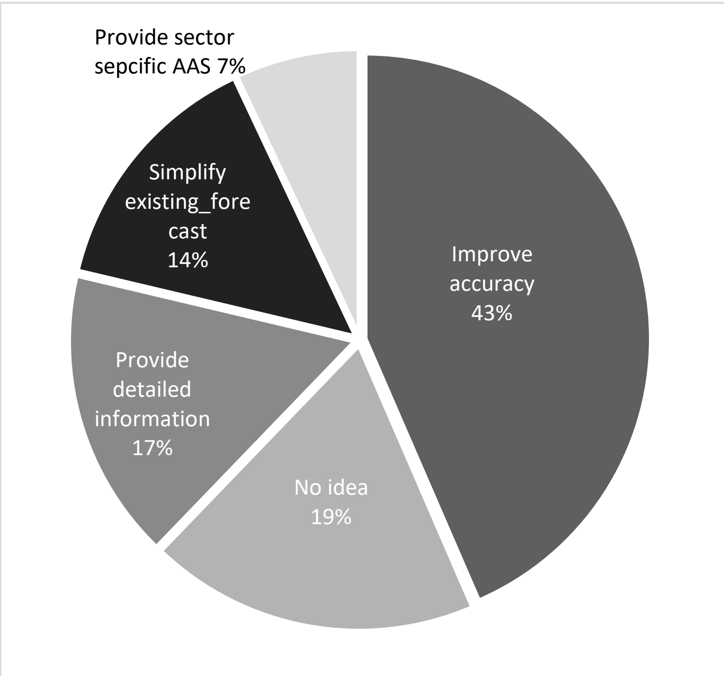

Figure 19: Suggestions for improving AAS

Findings from the binary logistic regression further highlight the importance of tailoring AAS delivery to specific user contexts. Awareness of AAS was significantly higher in Dzongkhags such as Paro, Punakha, and Wangdue Phodrang, likely due to better access to infrastructure, media, and extension services. Similarly, literacy was found to be a strong predictor of awareness, indicating that individuals who can read and write are more likely to understand and utilize the advisories.

According to WMO (2024), AAS can only achieve their intended positive impacts when they are delivered on time, in easily understandable language and format, and are specific to the local context. Therefore, improving AAS requires not only technical enhancements such as greater accuracy and detail, but also a focus on localized outreach strategies, simplified communication for low-literacy users, and increased coverage in underserved Dzongkhags to ensure equitable access and adoption across rural Bhutan.

4 Conclusion

Bhutan’s mountainous terrain and fragile Himalayan landscape make it highly susceptible to extreme weather and climate events such as droughts, hailstorms, frost, flash floods, cyclones, and outbreaks of new pests and diseases affecting both crops and livestock. These events, regardless of their scale, have a disproportionate impact on smallholder subsistence farmers who have limited financial resources and adaptive capacity, making them especially vulnerable to climate shocks.

The country's complex topography creates diverse microenvironments even within short distances, which poses additional challenges in developing and disseminating uniform, timely, and reliable Agrometeorology Advisory Services (AAS). Despite these challenges, current initiatives by the National Center for Hydrology and Meteorology (NCHM) and the Department of Agriculture (DoA) to deliver AAS to last-mile users are showing promise. The study revealed that 48.1% of farmers were aware of the AAS, and 45.7% of them actively used it in their farming decisions—an encouraging indication of its relevance and potential.

However, the findings also expose significant gaps in awareness, access, and utilization of AAS across different Dzongkhags. Geographic disparities and literacy levels emerged as major factors influencing awareness, while gender and family roles had little effect. Moreover, the study underscores the need for short-term, localized forecasts that are more relevant to farmers' immediate decisions—particularly for harvesting and sowing—rather than generalized long-term advisories.

Farmers’ feedback calls for improved accuracy, simplified content, and more detailed, sector-specific advisories. As Bhutan's information and communication landscape evolves, there is a timely opportunity to leverage digital platforms and localized delivery mechanisms to enhance AAS outreach.

5 Acknowledgements

The author of this research acknowledges the funding support provided by the World Bank and the technical support provided by the Department of Agriculture. The extension officers of the 11 gewogs from Paro, Punakha, Sarpang, Wangdue and Monger are also acknowledged for the surveying. Special thanks to the National Centre for Organic Agriculture for providing administration and facility support.

6 Authors' contribution statement

Mr. Chimi Rinzin led the conceptualization of the research, developed the survey questionnaire, coordinated the field survey, and led the data analysis. Mr. Tirtha Bdr Katwal provided leadership in developing the conceptual framework, contributed significantly to the writing of the manuscript, and offered overall guidance throughout the research process. Mr. Tshering Wangchen, as the focal person for the Agrometeorology Project under the Department of Agriculture, played a key role in securing research funding, coordinating on-ground implementation, and contributing to research design and conceptualization. Mr. Ngawang supported the development of the survey questionnaire, assisted in coordinating the field survey, and contributed to the data analysis.

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Monitoring Population Dynamics of Leafhoppers and Planthoppers in Paddy Fields in the Subtropical Region of Bhutan Using Light Trap

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ABSTRACT

Rice is an important cereal crop for food security in Bhutan, but its production is threatened by many insect pests including planthoppers and leafhoppers. This study monitored and analyzed the population dynamics of green leafhopper, brown planthopper, white-backed planthopper, and zigzag leafhopper using commercial light traps in two Gewogs of Sarpang Dzongkhag: Chuzergang Gewog (Dawathang in 2018, 2020, and 2021; Karbithang in 2018) and in Samtenling Gewog (ARDC Samtenling in 2020, 2021, and 2022; farmer's field in Samtenling in 2022. The results showed variation in hopper populations between monitoring sites and time period. Green leafhopper was consistently the most abundant species across all sites and years, with mean trap counts ranging from 182 to 1,736 individuals per trap. In contrast, brown planthopper showed fluctuating trends, peaking at 608 per trap in some sites and declining to below 100 in others. White backed planthopper and zigzag leafhopper remained relatively low, with trap means ranging from near zero to 331 and 258, respectively. Relative abundance data showed these similar patterns, with green leaf hopper dominating the hopper composition, comprising 52.7%–69.1% of populations across sites. In contrast, white backed planthopper and zigzag leafhopper represented the least abundant species. Across rice growth stages at four monitoring sites, mean hopper counts were lowest during tillering, increased significantly during booting, and peaked at grain-filling. The highest pest pressure occurred during grain-filling, with green leafhopper and brown planthopper being the most abundant. Populations declined at maturity. These findings underscore the importance of monitoring hopper populations across different sites and time periods to better understand their dynamics. Additionally, it is important to implement targeted pest management strategies during critical growth stages, particularly booting and grain-filling, to effectively mitigate hopper pressure and reduce crop losses.

Keywords: *Rice; Planthoppers; Leafhoppers; Population Dynamics; Monitoring*

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1 Introduction

Rice (*Oryza sativa* L.) is an important food source and a key component of global food security, as it sustains over half of the world's population (Maurya, Dwivedi, Khan, Giri, & Dixit, 2022). This staple food crop is integral to the diets of billions of people, particularly in Asia where it is a primary source of carbohydrates and nutrition. In 2022, global rice production reached approximately 780 million tonnes, making it the fourth-most-produced cereal, following maize, wheat, and barley (Food & Agriculture Organisation [FAO], 2023). This huge production capacity reflects rice's important role in meeting the dietary needs of a rapidly growing global population. In Bhutan, rice is the most widely grown cereal, with 40,563 metric tons (mt) of irrigated paddy and 241 mt of upland paddy harvested in 2023, highlighting its vital role in the nation's food production (National Statistics Bureau [NSB], 2023). Despite its relatively small scale compared to global production, Bhutan's focus on rice underscores its importance in maintaining local food supply.

Insect pest attacks significantly limit rice yields, causing annual losses of up to 20-30% (Haider, Akhtar, Noman, & Qasim, 2021). Major insect pests include stem borers like the yellow stem borer in the Philippines (Bandong & Litsinger, 2005), and leaf folder in Pakistan (Haider, Akhter, & Sabir, 2014). Sucking pests, such as planthopper and leafhopper, cause severe damage to paddy, resulting in reduced yields and poor grain quality. Rice planthoppers are especially destructive, damaging about 20 million hectares annually (Hu et al., 2014). The common leaf and plant hopper in the rice ecosystem is the rice green leafhopper, brown plant hopper, and white-backed plant hopper (Deshwal et al., 2019; Kumar et al., 2023). Adults and nymphs of these pests cause 'hopper-burn' by sucking sap from tillers, leading to chlorosis, wilting, and yield losses of 10 to 70% (Dey, Das, & De, 2024)

Hopper burn has led to significant yield and economic losses globally (Horgan et al., 2018; Quayum, Hossain, & Sharmin, 2023). In addition to physical damage, hoppers are vectors for viral diseases like rice tungro virus, rice ragged stunt, rice grassy stunt viruses, and southern rice black-streaked dwarf virus, causing stunted growth, yellowing, and reduced grain yield (Lu, Zhang, He, & Zhou, 2016). Hoppers can migrate long distances, leading to outbreaks in rice-growing areas (Hereward et al., 2020; Huang et al., 2022), such as the migration of brown plant hoppers and white-backed planthoppers from northern Vietnam to southern China in the spring (Otuka, Matsumura, Watanabe, & Van Dinh, 2008).

Early detection and effective monitoring are crucial to mitigate the impact of insect pest infestations. Light traps have gained attention as a promising tool for monitoring seasonal fluctuations of insect pests (Abbas et al., 2019). These traps, which attract nocturnal insects using light sources, offer a non-invasive and environmentally friendly means of tracking pests (Rashid, Ridoy, Rahman, Rahman, & Mondal, 2022). Light trap catch data can show peak insect activity periods (Dadmal & Khadakkar, 2014), enabling precise timing of control measures, and early detection of outbreaks. Additionally, light traps can directly reduce populations by capturing significant numbers of pests (Patidar, Vaishampayan, Band, & Sahu, 2019). Ali et al. (2020) reported that light traps captured approximately 94% more insects compared to field sampling, demonstrating their higher effectiveness.

In Bhutan, research on planthoppers and leafhoppers is limited, particularly regarding the identification, abundance, and population dynamics in the paddy ecosystem. This study aimed to fill this research gap by conducting a systematic investigation into the diversity, abundance, and population dynamics of hopper species in paddy fields using a light trap. Such findings will not only enhance the understanding of hopper ecology in the subtropical region but also support the development of precise and sustainable pest management strategies tailored to local conditions. The study is expected to have practical implications for local farmers, extension agents, and policymakers. The data presented here can support tailored integrated pest management programs, potentially improving rice production practices and mitigating crop losses due to hopper infestations.

2 Materials and Methods

2.1 Monitoring sites and period

The study was conducted across multiple years in two Gewogs of Sarpang Dzongkhag. In Chuzergang Gewog, monitoring was carried out at Dawathang (26.8631°N, 90.5275°E; 245 m asl) during 2018, 2020, and 2021, and at Karbithang (26.8662°N, 90.5104°E; 227 m asl) in 2018. In Samtenling Gewog, monitoring was conducted at ARDC Samtenling (26.9047°N, 90.4309°E; 381 m asl) in 2020, 2021, and 2022, and at a farmer's field in Samtenling (26.9081°N, 90.4267°E; 389 m asl) in 2022.

2.2 Light trap

A commercial insect light trap manufactured by Physilab and marketed by S.K. Appliances, Ambala, Haryana, India, was used in the study. The trap was made of mild steel and a 100 W incandescent bulb was used (Figure 1). It contains a box at the bottom measuring 40 cm (length)

× 40 cm (breadth) × 25 cm (height) for placing an insect collection tray and a funnel (30 cm in length, 5 cm diameter at the tail end) that directs trapped insects into the collection tray. The trap is equipped with a roof covering the entire setup. The trap was placed in the center of the paddy field, with a shelter to protect it from rain. The traps were raised 2 meters above the ground. They were turned on at 6:30 AM and turned off at 6:30 PM.

Figure 20. Light trap installed in a paddy field for hopper monitoring

2.3 Data collection

Hopper counting commenced at the tillering stage, approximately one month after transplanting, and continued weekly until the paddy reached maturity. The number of adult green leaf hoppers, brown plant hoppers, white-backed plant hoppers, and zigzag plant hoppers were collected weekly from August to November. Segregation of the light trap catches was done in the laboratory, as the traps contained many non-target species. In the laboratory, the hoppers were morphologically identified based on key characteristics described by Wilson & Claridge (1991).

2.4 Data analyses

Data visualization and exploratory summaries were performed using RStudio version 4.4.2 (2024-10-31 ucrt). Yearly and site-specific trends in hopper populations were analyzed by calculating the mean counts of each species per year and per monitoring site, respectively, to show temporal and spatial variations. To ensure the accuracy and reliability of the results, any data points from years with missing or incomplete records were excluded from the analysis.

Relative abundance by monitoring year and site was calculated by first summing the total counts of all hopper species for each year and site to obtain the total abundance. For each year and site, the abundance of each species was then summed individually. The relative abundance of each species was calculated by dividing its abundance by the total abundance for that year or site and multiplying by 100 to express it as a percentage. Relative abundance is important for the comparison of species populations across different years and sites, providing insights into their ecological roles and variations in distribution.

To analyze mean hopper counts by paddy stage, the data were categorized into Tillering (hopper catches in August), Booting (hopper catches in September), Grain Filling (hopper catches in October), and Maturity (hopper catches in November). For each paddy stage, the counts of green leafhopper (GLH), brown planthopper (BPH), white-backed planthopper (WBPH), and zigzag leafhopper (ZZLH) were summed across years and monitoring sites. The mean count for each hopper type was then calculated by dividing the total counts by the number of observations for each respective stage.

3 Results and Discussion

3.1 Population Trend by Year and Monitoring Sites

The four hopper species trapped were GLH, BPH, WBPH, and ZZLH (Figure 2). The mean number of different hopper species trapped per trap showed prominent year-to-year variation. In 2020, the GLH had the highest mean count of 245 individuals per trap, followed by the BPH at 134.5. WBPH and ZZLH were comparatively lower, averaging 87.2 and 18.6 respectively. The trend continued in subsequent years, with GLH consistently dominating, though its numbers slightly declined over time from 245.3 in 2020 to 173.6 in 2022 before increasing again to 214.8 in 2023. Meanwhile, BPH fluctuated, peaking again in 2023 at 112.1 per trap. WBPH and ZZLH followed similar fluctuations but remained the least abundant overall (Figure 3). A summary of total counts and means by year and site is provided in Table 1 and Table 2.

Figure 21. Four types of hoppers trapped in the light trap. From left to right: White-backed plant hopper, Zigzag leafhopper, Brown planthopper and Green leafhopper

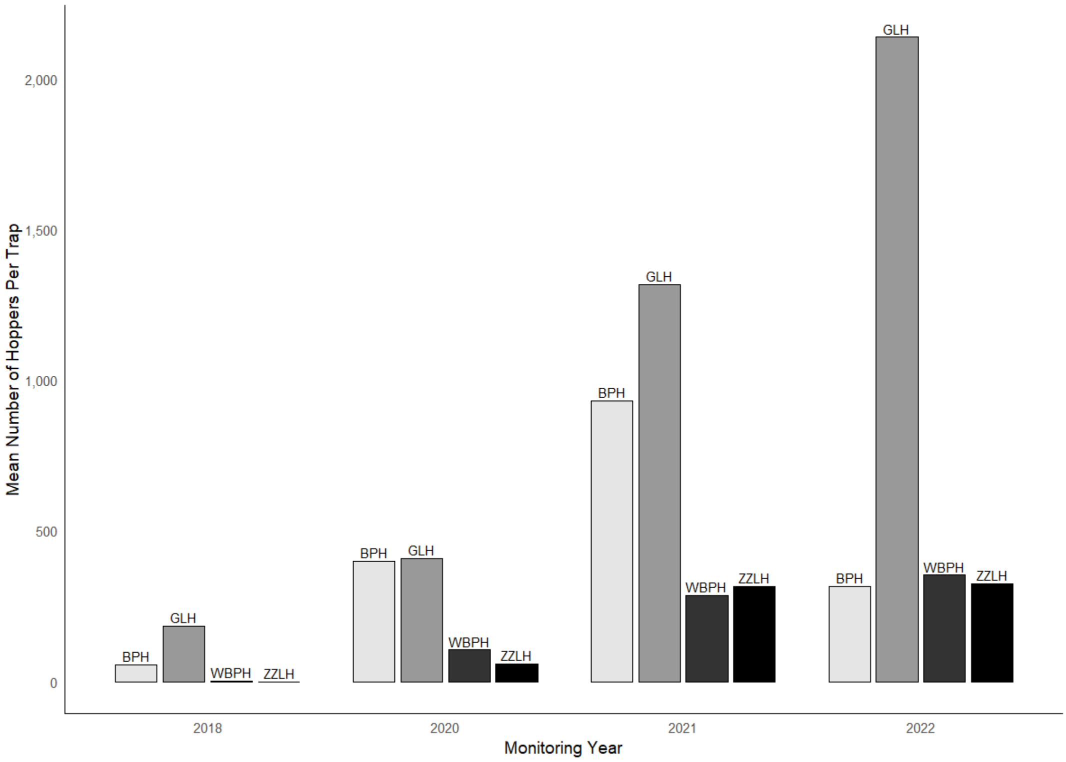

Figure 22. Mean number of hoppers per trap by year for BPH, WBPH, GLH, and ZZLH, showing yearly variation in species abundance.

Temperature strongly affects insect abundance, development rate, and number of generations (Haider et al., 2021). The surge in population may be attributed to favourable weather conditions, such as higher temperatures. Laszlo, Janos, & Marta (2012) found that light trap catches increased with rising temperatures. Conversely, the decline in hopper numbers could reflect adverse environmental conditions, such as excessive rainfall. Rainfall reduces the insect population by damaging their wings and dislodging from the plants (Karthik, Reddy, & Yashaswini, 2022). Madhuri, Dash, & Rout (2017) found that rainfall reduced the GLH population.

The mean number of different hopper species trapped per site showed prominent variation across locations. GLH had the highest mean counts, ranging from 182 individuals per trap at Karbithang to 1,736 at the farmer field in Samtenling. BPH counts varied between 76.9 and 608, while WBPH and ZZLH were comparatively lower, with WBPH averaging from 4.17 at Karbithang to 331 at ARDC Samtenling, and ZZLH ranging from 0 to 258 individuals per trap. This pattern indicates that GLH consistently dominates the hopper population across sites, whereas WBPH and ZZLH remain the least abundant overall (Figure 4).

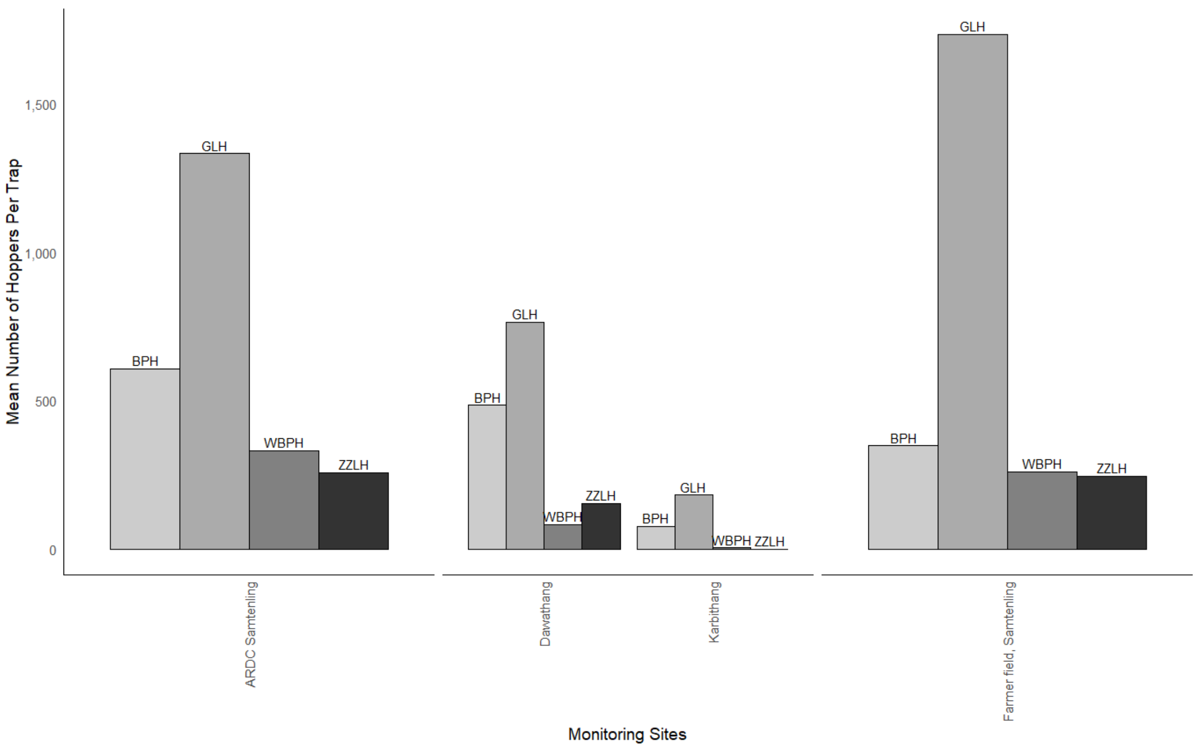

Figure 23. Mean number of hoppers per trap by year for BPH, WBPH, GLH, and ZZLH, showing yearly variation in species abundance. The data presented for ARDC Samtenling represent the total counts collected over three years (2020, 2021, and 2022), whereas the data for Farmer field, Samtenling correspond to only one year (2022).

Table 16. Hopper population counts by species and year from two monitoring sites in Samtenling Gewog.

Hopper species	ARDC Samtenling						Farmer field, Samtenlling					
	2018	2020	2021	2022	Total	Mean	2018	2020	2021	2022	Total	Mean
GLH	-	5851	18,070	25,407	49,328	16443	-	-	-	17357	17357	17357
BPH	-	5491	14,136	2867	22,494	7498	-	-	-	3479	3479	3479
WBPH	-	1699	6072	4472	12,243	4081	-	-	-	2606	2606	2606
ZZPH	-	949	4554	4051	9554	3185	-	-	-	2452	2452	2452
Total	-	13990	42,832	36,797	93,619	31206	-	-	-	25894	25894	25894
Mean	-	3498	10,708	9199	23,405	7802	-	-	-	6474	6474	6474

Table 17. Hopper population counts by species and year from two monitoring sites in Chuzergang Gewog.

Hopper species	Dawathang						Karbithang					
	2018	2020	2021	2022	Total	Mean	2018	2020	2021	2022	Total	Mean
GLH	2242	1506	21485	-	25233	8411	2173	-	-	-	2173	2173
BPH	443	1699	13829	-	15971	5324	923	-	-	-	923	923
WBPH	0	201	2511	-	2712	904	50	-	-	-	50	50
ZZPH	0	124	4949	-	5073	1691	0	-	-	-	0	0
Total	2685	3530	42774	-	48989	16330	3151	-	-	-	3153	3153
Mean	671	883	10694	-	12247	4083	788	-	-	-	788	788

* The dash (-) indicates that monitoring was not conducted during those periods.

3.2 Relative Abundance by Monitoring Sites

The relative abundance of hopper species showed significant variation across the monitored sites. At ARDC Samtenling, GLH constituted the majority of the hopper population, accounting for 52.7%, followed by BPH at 24.0%. The population of WBPH and ZZLH were comparatively lower, representing 13.1% and 10.2%, respectively. In Dawathang, GLH remained the dominant species with a relative abundance of 51.5%, while BPH comprised 32.6% of the population. The proportions of WBPH and ZZLH were 5.5% and 10.4%, respectively. At the Farmer Field site in Samtenling, GLH was prevalent, constituting 67.0% of the hopper population. BPH accounted for 13.4%, whereas WBPH and ZZLH comprised

10.1% and 9.5%, respectively. In Karbithang, GLH was dominant population at 69.1%, with BPH contributing 29.3%. The presence of WBPH was minimal (1.6%), and ZZLH was nearly absent. Overall, GLH consistently exhibited the highest relative abundance across all monitoring sites, followed by BPH (Figure 5).

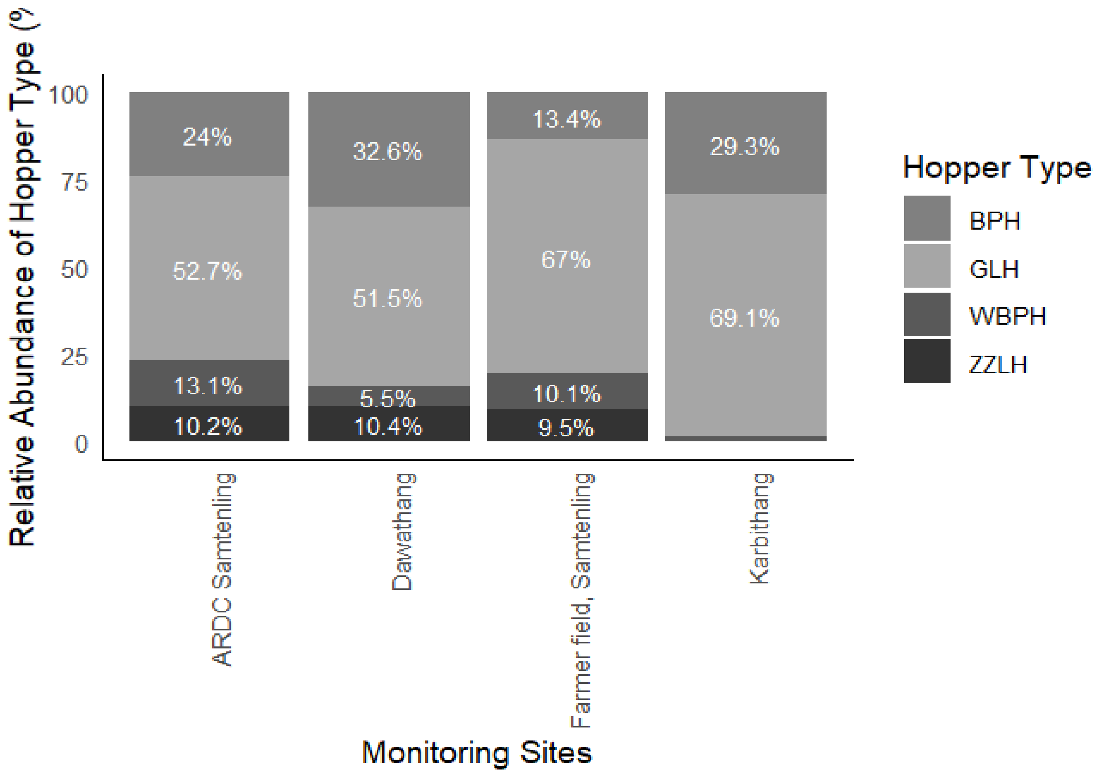

Figure 24. Relative abundance (%) of different hopper species across monitoring sites. The proportions of each species: GLH, BPH, WBPH, and ZZLH are stacked to illustrate inter-annual variations in species composition. *Note: WBPH relative abundance in Karbithang (1.6%) is not labelled due to its small value.*

Similar observations of GLH abundance have also been reported in Bangladesh (Rahman, Maleque, Uddin, & Ahmed, 2017). The GLH's dominance in rice fields is concerning due to its role in transmitting the tungro virus, a major threat to rice crop (Rosida, Kuswinanti, Nasruddin, & Amin, 2020). Rice Tungro Disease (RTD) is the most damaging viral disease of rice in South and Southeast Asia with numerous outbreaks in Bangladesh, Malaysia, the Philippines, China, Thailand, and India (Dey et al., 2024). Tungro virus infection causes stunted growth, yellow to orange-yellow leaves with brown spots, discoloration from the tip to the base, fewer tillers, and mostly hollow grains (Kim, Raymundo, & Aikins, 2019).

BPH was the second most abundant species. The presence of BPH is alarming as they cause hopper burn leading to significant crop damage. BPH is the most destructive rice insect pest in temperate and tropical regions of East and South Asia (Satturu et al., 2020). They transmit viral diseases such as grassy and ragged stunt viruses (Normile, 2008). In 2005, the brown plant hoppers caused an estimated 1.88 million tons of rice yield loss in China (Gurr et al., 2011). Extensive pesticide uses to manage brown plant hoppers has led to resistance to these chemicals (Tanaka, Endo, & Kazano, 2000).

3.3 Relative Abundance by Monitoring Year

The relative abundance of hopper species varied across the monitoring years. In 2018, GLH were the most dominant, comprising 75.7% of the total catch, followed by brown BPH at 23.4%, while WBPH and ZZLH were nearly absent. In 2020, GLH and BPH showed nearly equal abundance, accounting for 42.0% and 41.0% respectively, with WBPH and ZZLH contributing 10.8% and 6.1%. The trend shifted in 2021, where GLH maintained dominance at 46.2%, followed by BPH (32.7%), ZZLH (11.1%), and WBPH (10.0%). In 2022, GLH remained the most abundant species at 68.2%, with WBPH (11.3%), ZZLH (10.4%), and BPH (10.1%) showing comparable and lower proportions. These patterns highlight year-to-year fluctuations in species dominance, with GLH consistently being the most prevalent hopper across all years (Figure 6).

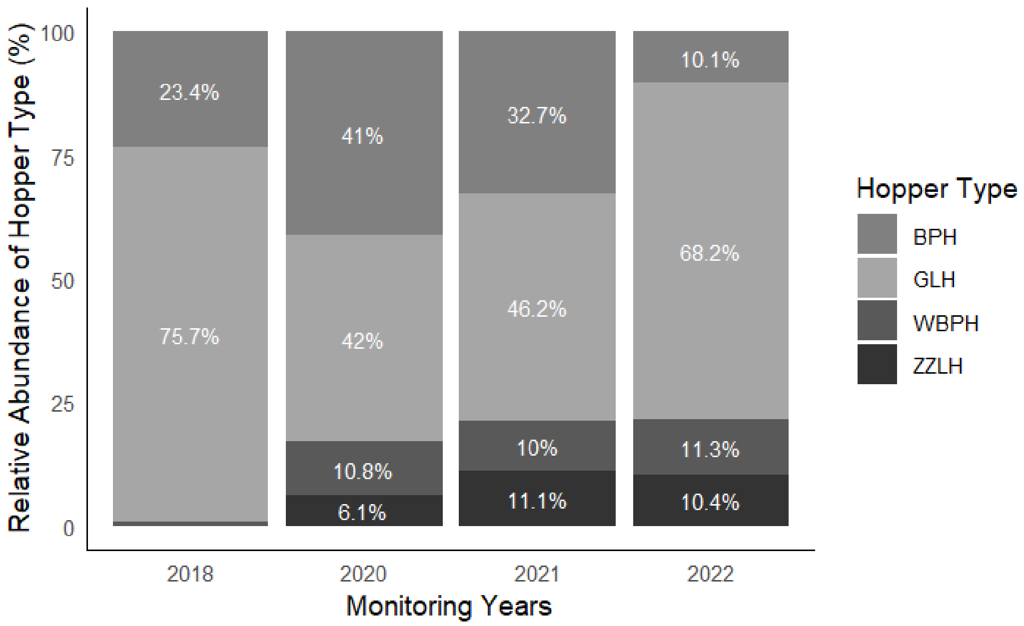

Figure 25. Relative abundance (%) of different hopper species across monitoring years. The proportions of each species: GLH, BPH, WBPH, and ZZLH are stacked to illustrate inter-annual variations in species composition. *Note: WBPH relative abundance in 2018 (0.86%) is not labelled due to its small value.*

The reasons for variations in abundance could not be conclusively determined. One possible explanation is that the light trap catches might have been influenced by the type of light used in the study. Variations in factors such as light intensity, wavelength, and trap design can affect the efficiency of trapping different species (Bowden, 1982). Future studies could explore the impact of different light trap types on hopper catch rates to optimize monitoring methods and ensure consistency in data collection.

Other possible reasons include changes in temperature, humidity, and rainfall, which can directly impact the life cycles and reproductive rates of hopper species (Laszlo et al., 2012; Sarkar, Baliarsingh, Mishra, Nanda, & Panigrahi, 2018; Haider et al., 2021). Variations in agricultural practices, such as the timing of planting, and crop stage could have contributed to changes in the population dynamics (Sharma, Raju, Singh, & Babu, 2023; Prabowo, Hidayat, Wiyono, & Dadang, 2023). Additionally, natural predation by predators and parasitoids might have affected hopper populations (Gurr et al., 2011).

3.4 Hopper Population Trends by Paddy Stage

Hopper pressure in the rice crop varied across different growth stages (Figure 7). During the tillering stage, hopper pressure was minimal, with mean counts of GLH at 52 per trap, BPH at 59 per trap, WBPH at 50 per trap, and ZZLH at 35 per trap. This observation aligned with the findings of Heong & Hardy (2009), who found that the early stages of rice growth were less conducive to hopper reproduction due to limited food availability.

As paddy progressed to the booting stage, hopper populations increased significantly, with mean counts of GLH at 1236 per trap, BPH at 171 per trap, WBPH at 117 per trap, and ZZLH at 110 per trap. Cheng, Zhu, & He (2013) highlighted that the booting stage offers a more favorable environment for hopper activity, with the denser crop canopy and higher nutrient levels promoting their reproduction. This stage represents a critical period for pest management interventions to prevent further increases in pest pressure.

The grain-filling stage experienced the highest pest pressure, with mean counts of GLH at 1484 per trap, BPH at 674 per trap, WBPH at 245 per trap, and ZZLH at 346 per trap. According to Han, Wu, Yang, Zhang, & Xiao (2018), the rice plants at this stage provide abundant nutrients for pest growth. Effective pest control during this phase is essential to safeguard yield potential.

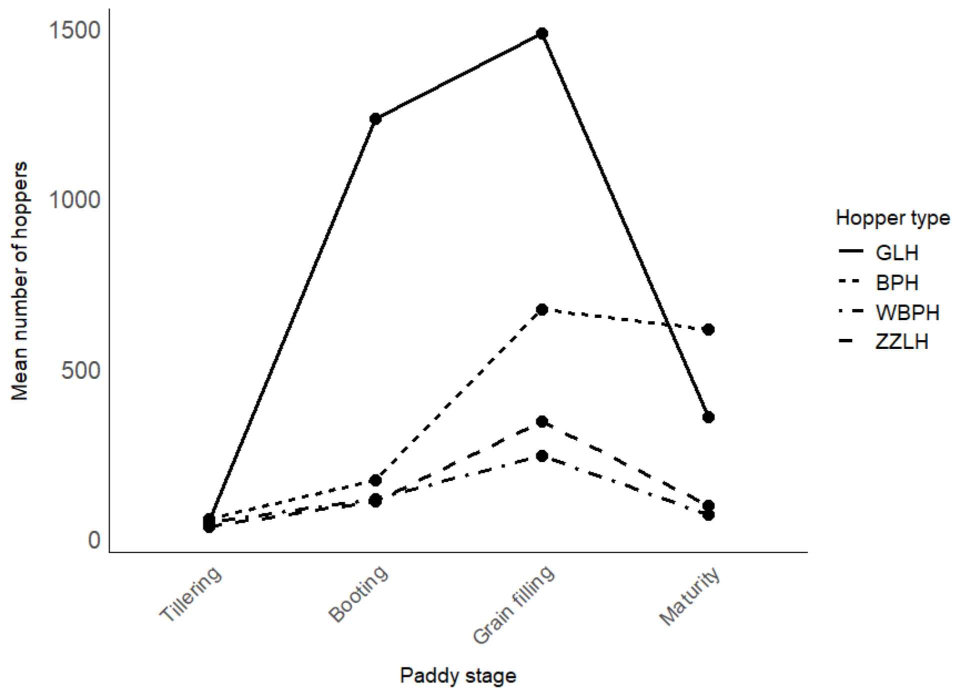

Figure 26. Mean number of hoppers trapped across different paddy growth stages.

At maturity, the mean counts showed variation, with GLH at 359 per trap, BPH at 616 per trap, WBPH at 71 per trap, and ZZLH at 96 per trap. Despite the decline in GLH and WBPH populations, BPH and ZZLH remained active, which supports Heong & Hardy (2009) findings that BPH remained persistent late into the rice cycle, potentially affecting final yields.

4 Conclusion

The study provides an understanding of the population dynamics, site variations, and seasonal patterns of major hopper species in rice fields, offering important information for sustainable pest management strategies. Among the four hopper species monitored, the green leafhopper was the most abundant across four different monitoring sites and years, highlighting its significant potential to impact rice crops. Its ability to spread viral diseases such as the tungro virus makes it a critical pest requiring focused management efforts. The brown planthopper was the second most abundant species, and it poses a major threat due to its role in causing hopper burn. The white-backed planthopper and zigzag leafhopper were less abundant but their population surged during the grain-filling and maturity stages, indicating that these stages are particularly vulnerable to pest pressure. Monitoring site-specific variations in hopper populations revealed that different environments could significantly influence pest abundance. Understanding these site-specific dynamics allows for targeted pest management interventions tailored to local conditions. Seasonal dynamics of hopper populations further highlighted the critical stages in the rice crop cycle that require intervention. The booting and grain-filling stages were identified as periods of peak hopper pressure, emphasizing the need for vigilant monitoring and timely pest control measures during these phases. Overall, the findings underscore the need for integrated pest management to minimize hopper populations and their impact on rice yields. Future research that focuses on exploring the factors driving site-specific variations and the role of climate change in influencing hopper dynamics will enhance pest management strategies, ensuring sustainable rice production.

5 Acknowledgment

We sincerely thank the Asian Food and Agriculture Cooperation Initiative (AFACI) for their invaluable grant support. This generous financial assistance was crucial in facilitating our research and providing the necessary resources to conduct the study effectively. We are grateful to the farmers involved, whose cooperation was essential for the success of our study. Their contributions have been instrumental in achieving our research objectives.

6 Authors' contribution statement

- Conceptualization and Design: Tshelthrim Zangpo.
- Data Collection: Ratu Kinley, Chinta Mani Dhimal, Tashi Dawa.
- Writing – Original Draft: Tshelthrim Zangpo.
- Review & Editing: Tshelthrim Zangpo, Ratu Kinley, Sonam Gyeltshen, Thirtha Maya Ghalley, Tshencho Dem, Ugyen Tshering, Jigme Wangchuk, Yeshey Dema.

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ISSN 2616-3926