Agriculture Development Journal

Volume 19 ISSN: 2091-0738(Print), 2091-0746 (Online) June 2026

Government of Nepal
Ministry of Agriculture, Forests and Environment
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Published : June, 2026
Available at: www.aitc.gov.np/www.nepjol.info/index.php/adj
ISSN : 2091-0738 (Print), 2091-0746 (Online)

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https://doi.org/10.3126/adj.v19i1.97451

VERMICOMPOST QUALITY AND ITS VARIATION ON CHANGES IN MOISTURE CONTENT

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ABSTRACT

The Government of Nepal has developed quality standards for soil-amending organic products, including vermicompost. There has been considerable debate on moisture content vis-à-vis quality parameters of commercial vermicompost. This research addressed a pertinent issue for commercialization and quality control of vermicompost by assessing changes in nutrient content upon reducing moisture in ready-to-sale products. Vermicompost samples were collected from ten commercial farms in Kathmandu Valley, Pokhara, Chitwan and Syangja at three stages of production. Samples from the marketed stage (Stage 3) were laid out in a Completely Randomized Design in trays with three replicates and dried under ambient laboratory conditions during winter. Sampling was done at different stages of moisture reduction and physico-chemical parameters were assessed. Reduction in moisture content significantly increased nitrogen content (from 1.06% to 1.46%) but there was, however, significant variation in all tested parameters among products. Phosphorus and potassium content remained unaltered upon reducing moisture to 25%. Under ambient conditions, it took 28 days on average to reduce moisture from 54.28% to 25%, though this depends on prevailing climatic conditions.

Keywords: commercial vermicompost, drying, moisture content, nutrient content, quality standard, etc.

1. INTRODUCTION

Incorporation of farm yard manure (FYM) or compost has long been the tradition of soil fertility management in Nepal. After the introduction of chemical fertilizers, promotion of mechanization, and commercialization of agriculture, the use of organic amendments was rapidly supplemented by synthetic inputs. Chemical fertilizer has since become the primary nutrient source for crop production in the Terai and Hills. However, in recent years, organic fertilizers have gained growing importance in managing soil fertility, and among these, vermicompost has attracted major attention.

Vermicompost is a natural fertilizer produced through the bio-oxidation and stabilization of organic waste by earthworms and associated microorganisms (Pathma and Sakthivel, 2012). It is increasingly recognized for its role in sustainable agriculture due to its rich composition of essential plant nutrients and beneficial microorganisms (Mohite et al., 2024). This biologically

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active material enhances soil structure, nutrient availability, and overall soil fertility (Mohite et al., 2024), and enriches soil with nitrogen, phosphorus, and potassium alongside beneficial microorganisms. The quality of vermicompost is therefore a critical factor influencing its efficacy as a soil amendment and bio-fertilizer (Bharti et al., 2025).

Moisture content is one of the most critical parameters governing vermicompost quality during production and post-harvest storage. Active vermicomposting requires high moisture conditions (typically 70–90%) to sustain earthworm activity and microbial decomposition (USDA-AMS, 2011). However, the moisture content of a finished, packaged product must be considerably lower to ensure product stability, prevent pathogen proliferation, reduce transport weight, and facilitate mechanical application. The Government of Nepal (GoN) has set quality standards for organic fertilizers, including vermicompost in dust, granular, and vermicast forms. A continuous debate has centered on moisture content: the maximum permissible moisture content for vermicompost is 25% under GoN standards. Despite this, products available in the market routinely exceed this threshold, hampering government programs to procure and subsidize vermicompost products. Moisture content is a crucial parameter dictating stability, microbial activity, and handling characteristics of commercial vermicompost, directly impacting shelf-life and agronomic value (Garg et al., 2006; Misra et al., 2003). This research was therefore conducted to study how moisture content can be reduced to the permissible level without compromising the nutrient quality of vermicompost. The main hypothesis for the research was the nutrient content will vary with moisture content. The specific objectives of the study were: (i) to assess the moisture content and quality of vermicompost during the production stage; (ii) to assess the moisture content and quality of vermicompost prepared by manufacturing companies just before packaging; and (iii) to estimate the time required for vermicompost to reach approximately 25% moisture content and to characterize nutrient content at that level.

2. METHODOLOGY

2.1 COLLECTION OF VERMICOMPOST SAMPLES

Vermicompost samples were collected from ten commercial vermicompost-producing farms in Kathmandu Valley, Pokhara, Syangja, and Chitwan during Poush month of 2079 BS (December–January 2022–23). Representative samples were collected from three defined stages of the production-to-market chain: the production stage (Stage 1), the ready-for-packing stage (Stage 2), and the ready-for-sale or packed-bag stage (Stage 3). Sufficient sample quantities were secured at each stage and transported to the laboratory for analysis and further study. Sample weights were recorded in the field immediately after collection and again upon arrival at the laboratory to monitor moisture changes during transport.

2.2 REDUCING MOISTURE OF VERMICOMPOST IN THE LABORATORY

Stage 3 samples from all ten products were weighed and placed on laboratory tables to dry under ambient temperature conditions. Each product was replicated three times in a Completely Randomized Design using trays. During field visits, it was observed that none of the sampled farms had open-air or dedicated drying infrastructure; the laboratory ambient drying was therefore designed to harmonize with conditions comparable to typical producer storage settings. Moisture content was monitored at regular intervals using a moisture meter probe followed by gravimetric weight-loss measurements. The target moisture content was 25%.

Based on the monitored moisture content, the expected final weight of vermicompost was calculated prior to completion of drying, so that the 25% moisture target could be verified. Percentage moisture loss during drying was calculated on a dry weight basis as follows:

% Moisture Loss = [(Initial Weight – Final Weight) / Final Weight] × 100

Following this formula and upon laboratory verification of moisture content, the samples were considered to have reached Stage 4 (reduced to 25% moisture content).

2.3 LABORATORY ANALYSIS

Laboratory analysis of vermicompost samples was conducted following standard procedures for: pH (1:2.0 soil:water suspension), organic carbon (OC %) by the Walkley-Black wet oxidation method, total nitrogen (N %) by the Kjeldahl method, total phosphorus (P %) by colorimetric method after acid digestion, and total potassium (K %) by flame photometry after acid digestion. All nutrient analysis were done on a dry weight basis at the National Soil Science Research Center, NARC, Khumaltar.

2.4 DATA OBSERVATION AND ANALYSIS

Periodic moisture content (measured via moisture meter probe and weight loss), nutrient content, pH, and organic carbon content were analyzed in the laboratory. Observed data were statistically analyzed for test of significance among products using GENSTAT software, and findings are presented in tabular and graphical forms. Descriptive analysis to estimate variance, range, and other statistics among tested products was performed using MINITAB. Analysis of variance (ANOVA) was done and mean separation employed the Least Significant Difference (LSD) test at the 5% probability level.

3. RESULTS AND DISCUSSION

The results from Stage 1, Stage 2, and Stage 3 samples showed high variation in moisture content and organic carbon content among the products tested (Tables 1, 2, and 3). Descriptive analysis was conducted to characterize product statistics at each stage. The moisture content during the production stage was approximately 68% (Table 1), declining to about 59% at the ready-to-sale stage (Table 2). Moisture in packed bags was found to be around 54% (Table 3) — well above the GoN standard of 25% and therefore of substandard quality. Orkmaz Belliturk (2018) reported that finished vermicompost should contain less than 35% moisture to reduce transport costs and facilitate mechanical application. Tamil Nadu Agricultural University, India recommends a minimum of 40% moisture for stored vermicompost, with water sprinkling advised to maintain quality and microbial populations (https://agritech.tnau.ac.in).

3.1 PRODUCTION STAGE (STAGE 1)

Table 1. Descriptive statistics of vermicompost samples at the production stage (Stage 1, n = 10)

Variable	Mean	SE Mean	StDev	Variance	CoefVar	Minimum	Median	Maximum	Range
Moisture (%)	67.89	2.19	6.94	48.14	10.22	53.11	67.96	77.72	24.61
pH	7.721	0.22	0.696	0.484	9.01	6.85	7.71	8.83	1.98
OC (%)	16.72	1.25	3.95	15.58	23.61	10.33	18.21	22.00	11.67
Total N (%)	0.947	0.069	0.217	0.047	22.92	0.60	0.915	1.379	0.779
Total P (%)	1.623	0.118	0.372	0.138	22.92	1.124	1.63	2.276	1.152
Total K (%)	0.866	0.132	0.419	0.175	48.33	0.35	0.80	1.43	1.08

OC = Organic Carbon; SE = Standard Error; StDev = Standard Deviation; CoefVar = Coefficient of Variation; N= Nitrogen; P=Phosphorus; K=Potassium; %=Percent; n= Number of products tested

The mean moisture content at Stage 1 was 67.89%, with a range of 24.61 percentage points (53.11–77.72%), reflecting the high variability inherent in freshly produced vermicompost. This high moisture level is expected during active production. The USDA-AMS (2011) recommends maintaining 70–90% moisture during vermicomposting to support adequate earthworm activity and microbial decomposition. Hossen et al. (2022) established 70% as optimal initial moisture content for cattle-manure based vermicomposting. Mean pH was 7.721 (near-neutral to slightly alkaline, consistent with mature earthworm castings), mean organic carbon was 16.72% (CoefVar = 23.61%), mean total N was 0.9472%, mean total P was 1.623%, and mean total K was 0.866%. The high coefficient of variation for potassium (48.33%) underscores the strong influence of feedstock materials on the final mineral nutrient composition — a widely recognized phenomenon in vermicompost production (Rakib et al., 2025; Mulatu and Bayata, 2024).

3.2 PRE-PACKING STAGE (STAGE 2)

Table 2. Descriptive statistics of vermicompost samples at the pre-packing stage (Stage 2, n = 8)

Variable	Mean	SE Mean	StDev	Variance	CoefVar	Minimum	Median	Maximum	Range
Moisture (%)	55.81	3.43	9.71	94.31	17.40	38.75	59.54	64.91	26.16
pH	7.401	0.254	0.717	0.515	9.69	6.06	7.535	8.25	2.19
OC (%)	17.34	1.00	2.84	8.07	16.39	11.81	17.86	20.27	8.46
Total N (%)	1.208	0.105	0.297	0.088	24.54	0.646	1.206	1.663	1.016
Total P (%)	1.767	0.167	0.472	0.222	26.68	1.068	1.747	2.604	1.535
Total K (%)	1.168	0.150	0.424	0.180	36.32	0.65	1.13	1.97	1.32

OC = Organic Carbon; SE = Standard Error; StDev = Standard Deviation; CoefVar = Coefficient of Variation; N= Nitrogen; P=Phosphorus; K=Potassium; %=Percent; n= Number of products tested

Mean moisture at Stage 2 declined to 55.81% from 67.89% at Stage 1, reflecting some natural moisture loss during the interval between harvest and packing, but still far above the 25% threshold. Mean pH (7.401), OC (17.34%), total N (1.208%), total P (1.767%), and total K (1.168%) all remained broadly stable or showed slight increases reflecting the modest concentration effect of partial moisture loss.

3.3 MARKETED (PACKED) STAGE (STAGE 3)

Table 3. Descriptive statistics of vermicompost samples from marketed packed bags (Stage 3, n = 10)

Variable	Mean	SE Mean	StDev	Variance	CoefVar	Minimum	Median	Maximum	Range
Moisture (%)	54.28	2.89	9.15	83.80	16.86	36.15	54.01	68.47	32.32
pH	7.49	0.243	0.767	0.589	10.37	6.42	7.555	8.53	2.11
OC (%)	17.58	0.867	2.742	7.518	15.48	13.189	18.12	21.529	8.34
Total N (%)	1.06	0.083	0.262	0.069	23.29	0.692	1.108	1.526	0.833
Total P (%)	1.72	0.118	0.372	0.138	20.85	1.382	1.713	2.622	1.24
Total K (%)	1.20	0.216	0.684	0.468	60.87	0.35	1.13	2.33	1.98

OC = Organic Carbon; SE = Standard Error; StDev = Standard Deviation; CoefVar = Coefficient of Variation; N= Nitrogen; P=Phosphorus; K=Potassium; %=Percent; n= Number of products tested

Mean moisture content in marketed products was 54.28% (range 36.15–68.47%), more than double the GoN threshold of 25%. This has significant implications: consumers purchasing products by weight are effectively paying for water rather than nutrient-rich organic matter, and the high moisture presents risks of microbial spoilage during storage and transport. High moisture also promotes ammonia volatilization during storage, which can reduce nitrogen content over time (Das et al., 2014; Varsha Kumari et al., 2021). Mean pH was 7.49, mean OC was 17.58%, mean total N was 1.06%, mean total P was 1.72%, and mean total K was 1.20%. The potassium CoefVar at Stage 3 (60.87%) was particularly elevated, reflecting diverse feedstocks and processing practices across producers. This inter-product variability is consistent with the observation that, unlike standardized chemical fertilizers, vermicompost NPK ratios are highly feedstock-dependent (Rakib et al., 2025).

3.4 EFFECT OF MOISTURE REDUCTION ON PH AND ORGANIC CARBON (STAGE 3 VS. STAGE 4)

The nutrient content of vermicompost at Stage 3 was compared with Stage 4 (after reducing moisture to 25%). The nutrients did not change substantially upon reducing moisture content to 25% (Table 4). However, the average data revealed that organic carbon (OC) increased from 17.58% to 19.89% — primarily a concentration effect resulting from water removal. The C/N ratio is a key indicator of vermicompost quality and maturity; as organic carbon concentrates upon drying, the C/N ratio may shift slightly, but this does not necessarily indicate quality deterioration (Misra et al., 2003; Lin et al., 2024). Differences in OC content were observed among individual product samples, reflecting the diversity of feedstock inputs. pH of the samples was largely unaltered upon moisture reduction, consistent with the well-buffered nature of mature vermicompost (Pathma and Sakthivel, 2012). However, the pH varied significantly among the products (Table 4).

Previous studies have explored vermicompost quality primarily focusing on feedstock combinations and their impact on nutrient enrichment and earthworm performance (Utami et al., 2025). Research indicates that vermicompost significantly enhances plant growth, increases soil microbial biomass and diversity, and acts as a source of macro- and micronutrients (Malal et al., 2024). Abbey et al. (2013) specifically reported that drying and rehydration of vermicasts did not affect nutrient bioavailability or seedling growth, further supporting the conclusion that ambient drying to 25% moisture does not compromise product agronomic value.

Table 4. Variation in pH and organic carbon content before (Stage 3) and after moisture reduction to 25% (Stage 4) (n=10)

Product/Sample (coded)	pH – Stage 3	pH – Stage 4	OC (%) – Stage 3	OC (%) – Stage 4
CD	7.53	7.55	19.11	21.83
D	6.43	6.43	15.44	18.16
P	6.47	6.54	21.53	24.56
KP	7.97	7.96	20.33	20.72
PB	7.58	7.54	17.13	17.36
BS	8.00	7.60	20.09	20.79
GD	8.02	8.01	15.62	17.88
SY	7.31	7.04	11.81	16.46
LAMA	7.03	8.50	15.36	23.82
SV	8.53	6.98	19.38	17.29
Grand Mean	**7.49**	**7.41**	**17.58**	**19.89**
LSD	–	**0.3437**	–	**4.528**
SEM ±	–	**0.1636**	–	**2.155**
F test (P>F)	–	***	–	*
CV (%)	–	**2.7**	–	**13.3**

**** p<0.001; * p<0.05; LSD = Least Significant Difference; SEM = Standard Error of Mean; CV = Coefficient of Variation; S3 = Stage 3; S4 = Stage 4*

3.5 EFFECT OF MOISTURE REDUCTION ON NITROGEN, PHOSPHORUS AND POTASSIUM

The total nitrogen content varied significantly but phosphorus, and potassium content of the vermicompost samples did not change significantly upon reducing moisture content to 25%

(Table 5). The average data showed that total nitrogen, total phosphorus, and total potassium changed from 1.06 to 1.461%, 1.72 to 1.69%, and 1.20 to 1.208%, respectively. The results revealed differences in nutrient contents among products, but no consistent detrimental effect of drying on macronutrient levels.

The increase in total nitrogen upon drying (1.06 to 1.461%) reflects a concentration effect as water is removed, rather than any biological fixation. This finding is consistent with Abbey et al. (2013), who showed that drying of vermicasts did not diminish nitrogen bioavailability. However, this differs from the high-temperature artificial drying scenario reported by Manyuchi et al. (2013), where drying fresh vermicompost at 105°C reduced total nitrogen by 31.25%, highlighting that the method and temperature of drying are critical determinants of nitrogen retention. The present study's ambient drying approach (without heat application) appears to preserve nitrogen more effectively, which is an important practical distinction for producers.

Das et al. (2014), studying nutrient dynamics in stored vermicomposts prepared from cattle manure, paddy straw, municipal solid waste, and fly ash over 180 days, found that nitrogen initially increased in the first 90–105 days before declining, while phosphorus and potassium steadily declined — a pattern driven by leaching and microbial consumption at high moisture levels. The present results suggest that reducing moisture to 25% by ambient drying effectively halts or slows these loss pathways, since the nutrient concentrations were maintained in potassium content and slightly decreased in phosphorus content. Varsha Kumari et al. (2021) similarly documented progressive decreases in N, P, K and S during storage at higher moisture contents, alongside reductions in microbial populations and enzymatic activity, underscoring the value of moisture reduction for product preservation.

Anandkumar et al. (2016) reported that moisture content of 80.32±1.6% was reduced to 23.34±3.02% in 120 days under natural conditions, and Harit et al. (2014) observed a reduction from 77.4±3.5% to approximately 20% over 90–120 days of storage. The duration required in the present study (28 days to reduce from ~54% to 25%) was shorter, likely because the initial moisture was lower and conditions were controlled indoor settings harmonizing with typical producer facilities. The high inter-product variability in potassium content (CoefVar up to 60.87%) observed across products is attributable to feedstock differences, as potassium levels in vermicompost are predominantly determined by feedstock mineral composition rather than the vermicomposting or drying process itself (Garg et al., 2006).

Table 5. Variation in total N (%), total P(%), and total K (%) before (Stage 3) and after moisture reduction to 25% (Stage 4) (n=10)

Product (coded)	N% S3	N% S4	P% S3	P% S4	K% S3	K% S4
CD	1.27	1.687	1.84	1.520	1.19	1.24
D	1.09	1.327	1.61	1.723	0.35	0.43
P	1.53	1.907	1.67	1.607	0.83	0.93
KP	1.35	1.503	1.79	1.343	1.73	1.74

Product (coded)	N% S3	N% S4	P% S3	P% S4	K% S3	K% S4
PB	1.12	1.613	2.62	1.897	1.07	0.87
BS	0.97	1.150	1.38	1.897	1.19	1.17
GD	0.69	1.447	1.75	1.527	1.79	1.72
SY	0.65	1.093	1.59	1.537	0.83	0.81
LAMA	1.10	1.587	1.50	1.783	0.65	2.35
SV	0.78	1.300	1.48	2.073	2.33	0.81
Grand Mean	**1.06**	**1.461**	**1.72**	**1.651**	**1.20**	**1.208**
LSD	–	**0.2402**	–	**0.3681**	–	**0.1656**
SEM ±	–	**0.1144**	–	**0.1752**	–	**0.0788**
F test (P>F)	–	***	–	*	–	***
CV (%)	–	**5.6**	–	**12.7**	–	**8.0**

**** p<0.001; * p<0.05; LSD = Least Significant Difference; SEM = Standard Error of Mean; CV = Coefficient of Variation; S3 = Stage 3; S4 = Stage 4; N= Nitrogen; P=Phosphorus; K=Potassium; %=Percent; n= Number of products*

3.6. RELATIONSHIP BETWEEN MOISTURE REDUCTION AND DURATION OF DRYING UNDER NATURAL CONDITION

The moisture content of the samples was observed at regular intervals and a moisture content vs. duration curve was plotted (Figure 1). The results showed that increasing number of drying days reduced the moisture content in a declining curve typical of evaporative drying under ambient conditions. Mean values of the samples indicated that reaching 25% moisture content required 28 days on average. However, this may vary with season and diurnal temperature and humidity fluctuations.

The drying rate observed in this study — approximately 28 days under winter ambient indoor conditions — is considerably faster than the 90–120 days reported by Harit et al. (2014) and Anandkumar et al. (2016) under comparable natural conditions, owing primarily to the lower initial moisture content of the Stage 3 samples (~54%) compared to freshly harvested vermicompost (~77–80%). Kleawklaharn and Iwai (2014) demonstrated that storage duration significantly influences vermicompost quality, with longer storage at high moisture leading to deterioration of nutrient content. This underscores the practical importance of rapid moisture reduction: by bringing moisture to 25% within 28 days, producers can arrest the nutrient deterioration associated with prolonged high-moisture storage.

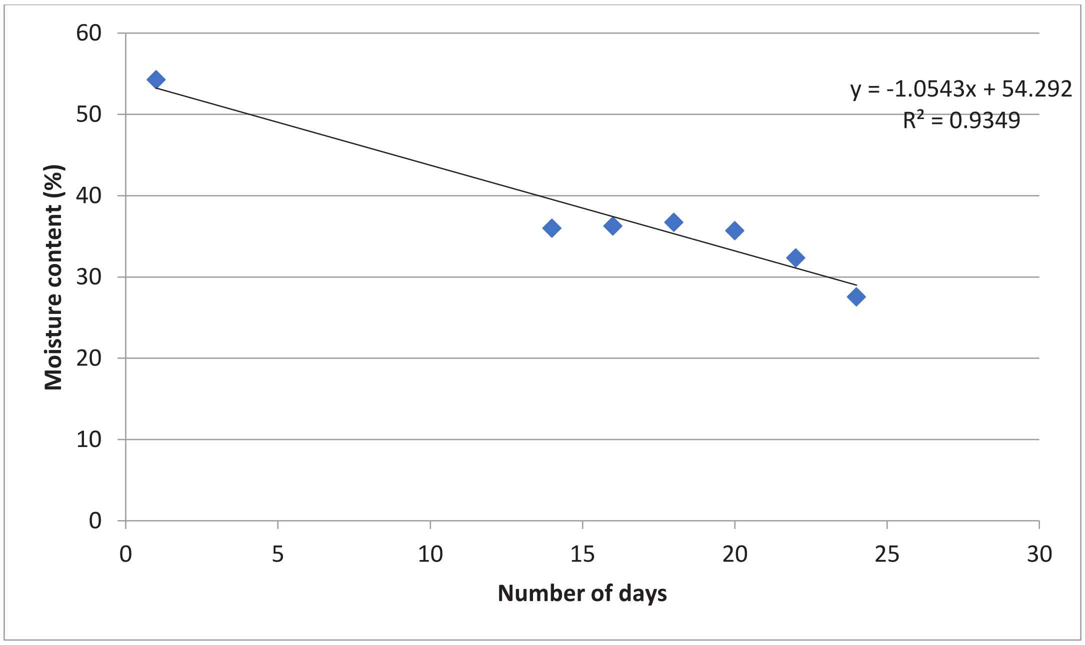

Figure 1. Moisture content (%) versus drying duration (days) under ambient laboratory conditions — mean across all products (n=11, three replicates each)

While comparing the moisture content at various stages of the production chain with their nutrient contents, results showed no significant correlation between moisture content and nutrient content of the vermicompost samples (Figure 2). There was a slight but non-significant increment in nitrogen content of vermicompost on reducing the moisture content of the product.

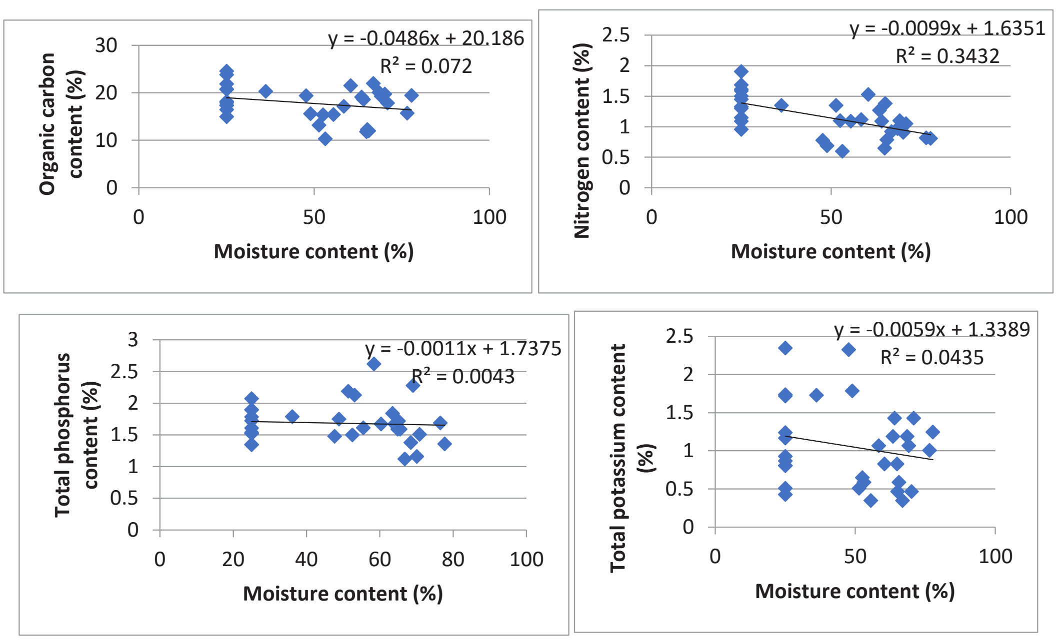

Figure 2. Correlation between moisture content (%) and nutrient concentrations (N, P, K) across vermicompost samples at different production stages

4. SUMMARY AND CONCLUSION

Reduction in the moisture content of vermicompost significantly increased nitrogen content of the products and there was significant variation in all tested parameters among the products. Regarding phosphorus, it slightly decreased and potassium content remained largely unaltered upon reducing moisture content to 25%. Under ambient (natural) conditions during winter, it took an average of 28 days to reduce moisture from 54.28% to 25%. This duration is expected to vary with climatic condition and season.

The findings confirm that reducing vermicompost moisture to the GoN-mandated limit of 25% does not compromise — and in several respects improves — its nutrient quality on a dry weight basis. The concentration of nitrogen and organic carbon increases as a result of water removal, making the dried product more potent per unit weight without any harmful processing. The lack of correlation between moisture content and nutrient content across products further confirms that nutrient quality is primarily determined by feedstock composition rather than moisture level per se.

The present study provides evidence that producers can adhere to the GoN standard of 25% maximum moisture which can be achieved through appropriate post-harvest ambient drying without loss of product quality. It is therefore recommended to go for post-harvest drying in order to comply with the moisture content standard of vermicompost.

ACKNOWLEDGEMENT

We acknowledge the support from MoALD and NARC for carrying out this study. We thank all the farm owners for their generous support during sampling of vermicompost and also highly acknowledge the support from NSSRC staffs during the study period.

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ANNEXES

Annex 1

Moisture Content, pH, and Organic Carbon (%) of Vermicompost at Different Production Stages

Product (codes)	MC% S1	pH S1	OC% S1	MC% S2	pH S2	OC% S2	MC% S3	pH S3	OC% S3
CD	69.07	7.25	19.30	62.53	7.75	18.87	63.47	7.53	19.11
D	66.85	6.88	22.00	54.82	6.74	15.18	55.50	6.43	15.44
P	70.10	6.85	19.76	43.27	6.06	20.27	60.37	6.47	21.53
KP	64.06	7.86	18.57	38.75	8.03	18.40	36.15	7.97	20.33
PB	70.88	8.53	17.86	58.51	7.74	17.31	58.40	7.58	17.13
BS	76.48	8.11	15.73	63.11	7.33	20.27	68.47	8.00	20.09
GD	77.72	8.21	19.42	60.56	8.25	16.58	48.89	8.02	15.62
SY	65.55	7.13	11.95	64.91	7.31	11.81	–	–	–
LAMA	65.10	7.56	12.26	–	–	–	52.52	7.03	15.36
SV	–	–	–	–	–	–	47.68	8.53	19.38

MC = Moisture Content; OC = Organic Carbon; S1 = Stage 1; S2 = Stage 2; S3 = Stage 3; '–' = sample not available

Annex 2:

Total N (%), P (%), and K (%) of Vermicompost at Different Production Stages

Products (codes)	N% S1	P% S1	K% S1	N% S2	P% S2	K% S2	N% S3	P% S3	K% S3
CD	1.10	2.28	1.07	1.19	1.46	1.19	1.27	1.84	1.19
D	0.92	1.12	0.35	1.06	1.07	0.65	1.09	1.61	0.35
P	0.91	1.16	0.47	1.66	1.68	0.89	1.53	1.67	0.83
KP	1.09	1.67	1.43	1.22	2.18	1.55	1.35	1.79	1.73
PB	1.05	1.51	1.43	1.32	2.60	1.07	1.12	2.62	1.07
BS	0.82	1.69	1.01	1.12	1.47	1.19	0.97	1.38	1.19
GD	0.81	1.36	1.25	1.43	1.85	1.97	0.69	1.75	1.79
SY	0.79	1.59	0.59	0.65	1.81	0.83	–	–	–
LAMA	1.38	1.72	0.47	–	–	–	1.10	1.50	0.65
SV	–	–	–	–	–	–	0.78	1.48	2.33

N = Total Nitrogen; P = Total Phosphorus (as P_2O_5); K = Total Potassium (as K_2O); S1–S3 = Stages 1–3; '–' = sample not available

https://doi.org/10.3126/adj.v19i1.97453

POLLINATOR-INTEGRATED AGRICULTURE: A POLICY AND EXTENSION FRAMEWORK

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ABSTRACT

Pollinators are vital ecosystem-service providers that support biodiversity, crop productivity, nutrition, and food security. In Nepal, the cultivation of pollinator-dependent crops increased by 91% over the past two decades, creating greater reliance on pollination services even as pollinator populations decline. Field studies from Chitwan and Makwanpur districts demonstrate significant yield gains through managed pollination, increasing rapeseed yields by 27–54% and buckwheat yields by 25–40%. However, climate change, habitat loss, and pesticide misuse threaten these benefits. Despite supportive national policies, a critical implementation gap persists at the local government level due to a honey-centric policy bias, limited technical capacity, and the lack of actionable metrics. Drawing on comparative household surveys (n = 240), field studies, and policy analysis, this paper addresses this "pollination paradox" through two complementary frameworks: the PEAR–IEDM–CEAL Integrated Action Framework and the Pollinator-Integrated Local Extension Framework (PILEF). Designed for municipal governance under Nepal's federal system, these frameworks integrate practical indicators, including the Pollination Dependence Index (PDI), a yield-gap metric derived from caged versus open-pollination trials, and the Pollinator-Friendly Habitat Score (P-FHS), the percentage of farm area under floral strips or hedgerows. By incorporating gender-responsive and indigenous-focused strategies, PILEF offers a scalable pathway to strengthen productivity, food security, and ecological resilience in Nepal's smallholder farming systems.

Keywords: Agricultural extension, beekeeping, ecosystem services, Nepal, policy integration, pollination

INTRODUCTION

Nepal's agrarian economy supports two-thirds of the population and contributes one-fourth to GDP, dominated by smallholder farms critically dependent on ecosystem services, particularly animal-mediated pollination. A diverse bee-pollinators community including native species (*Apis cerana* Fabricius, *Apis dorsata* Fabricius, *Apis laboriosa* Smith, *Bombus* spp.) and introduced species (*Apis mellifera* Linnaeus) sustains the production of fruits, vegetables, oilseeds, and seed crops essential for food security, nutrition, and the rural economy (Neupane et al., 2025). This reliance is accelerating; between 2001 and 2018, the cultivated area of pollinator-dependent crops expanded by 91%, a rate 3.7 times faster than for non-dependent

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crops, creating a dangerous and widening pollination deficit (Devkota et al., 2024). This vital resource is under unprecedented threat from synergistic pressures: agricultural intensification, habitat loss, pesticide misuse, and climate change.

Pollination is a keystone ecosystem service, underpinning approximately 75% of the world's leading food crops and contributing substantially to global agricultural production (Klein et al., 2007; PBES, 2016). 'Beyond yield improvement, pollination enhances crop quality attributes such as fruit size, seed viability, oil content, and nutrient density in key pollinator-dependent crops including rapeseed/mustard, buckwheat, apple, cucurbits (bitter gourd, cucumber), and citrus (Aizen et al., 2019; Poudel & Tiwari, 2025; Reilly et al., 2022). In Nepal, pollination services are foundational to the productivity of key crops, including apples, citrus, cucurbits, mustard, and buckwheat (Sharma et al., 2023). A recent national-scale assessment conservatively values insect pollination at USD 477 million annually; equivalent to 9% of total agricultural revenue (Shrestha et al., 2024). These crops are also pillars of human nutrition, with pollinator-dependent plants providing 40% of plant-derived vitamin A and 14% of vitamin C in the national diet (Chapagain et al., 2021). However, this immense economic and nutritional value is jeopardized by severe pollinator decline. Mirroring global trends driven by habitat loss, pesticide misuse, climate change, and pests (Potts et al., 2010; Sánchez-Bayo & Wyckhuys, 2019), Nepal is experiencing alarming losses. A longitudinal study in Jumla District documented a 44% decline in occupied beehives and a 50% decline in honey yield per hive over a decade (Gurung et al., 2024), signaling a critical degradation of pollinator capacity, which necessitates a robust policy and extension framework for sustainable management.

Despite clear evidence, a profound governance-implementation gap persists. 'While national policies like the Agriculture Development Strategy (2015–2035), the Bee Promotion Policy (2017), and the National Biodiversity Strategy and Action Plan (NBSAP 2014–2020) exist, they lack operational metrics, budgetary mechanisms, and localized technical guidance for Nepal's 753 local governments post-federalization. This disconnect is compounded by a foundational knowledge deficit; a survey in Jumla found only 14% of farmers were aware of the benefits bees provide to their crops (Darwin Initiative, 2024). Extension systems emphasize pest control while largely neglecting pollination services, leaving frontline workers ill-equipped to advice on pollinator ecology. This problem echoes a global pattern where agricultural innovation systems can suffer from a "flatland bias," focusing on technologies and policies suited to large, flat areas while neglecting the unique needs of complex, small-scale hillside farming systems where most pollination services are rendered.

This research directly addresses the critical gap between national policy intention and local implementation in Nepal's agricultural governance. By synthesizing field-level evidence from Chitwan and Makwanpur, conducting a policy review, and introducing the Pollinator-Integrated Local Extension Framework (PILEF), this study aims to bridge the science-policy-practice divide to suggest the science-based bee conservation and promotion strategy. The subtropical hill regions of Chitwan and Makwanpur represent a critical microcosm of these intersecting ecological and institutional challenges, providing an ideal context for developing and testing integrated solutions. Therefore, this paper addresses four primary objectives:

1. To synthesize empirical evidence on pollination benefits and threats from Nepal, with a focused analysis from Chitwan and Makwanpur districts.
2. To review and critique the existing policy and institutional landscape governing agriculture and apiculture, with specific attention to their connectivity with pollinator conservation and pollination management.
3. To propose comprehensive, evidence-based frameworks for integrating pollinator metrics into local extension and development planning, with explicit consideration for gender and social inclusion.

METHODOLOGY

This study employs a mixed-methods, multi-evidence approach to develop actionable frameworks for integrating pollinator conservation into local governance in Nepal. The methodology was structured in five integrated phases:

STUDY AREA

The study focuses on the subtropical regions of Chitwan District (inner-Terai lowland, 300–500 masl) and Makwanpur District (mid-hills, 500–1,200 masl) in central Nepal. Chitwan represents commercialized, diversified cropping systems with strong market connectivity. Makwanpur represents subsistence-oriented, mixed crop-livestock-forest systems with higher topographic complexity and reliance on forest resources. This contrast allows for a comparative analysis of pollinator dynamics across different agro-ecological and socio-institutional contexts.

DATA COLLECTION AND SYNTHESIS

Household Survey and KII: A total of 240 households (120 HH/district) engaged in farming and/or beekeeping were selected using stratified random sampling. Data were collected through structured questionnaires, field observations of pollinator activity and floral resources, and key informant interviews (KIIs) with extension officers, cooperative leaders, and municipal planners during August-December 2024.

Desk Review, Synthesis and Analysis of Secondary Data: Empirical data on pollinator diversity, crop yield dependencies, and population trends were extracted from peer-reviewed literature, university thesis (notably from Agriculture and Forestry University and Institute of Agriculture and Animal Sciences), and project reports. A core dataset was derived from the Ph.D. dissertation "Pollinators' Deficit on Rapeseed, Buckwheat and Bittergourd Production in Chitwan, Nepal" (Poudel & Tiwari, 2025; Rijal, 2019) and related studies (Pokhrel & Thapa, 2012; Rijal et al., 2018).

Policy and Institutional Analysis: National and sub-national policy documents (e.g., Bee Promotion Policy 2017, Local Government Operation Act 2017, municipal agricultural plans) were critically analyzed using content analysis to identify objectives, implementation mechanisms, and gaps.

Stakeholder Consultations: Participatory sessions were held with farmers, cooperatives, and local government officials in both districts to ground-truth findings and co-develop framework components.

STATISTICAL AND ANALYTICAL FRAMEWORK

Descriptive statistics were computed for all variables. Independent-sample t-tests were used to compare district means for continuous variables (e.g., yield, income). Chi-square tests assessed associations for categorical variables (e.g., access to training). One-way ANOVA tested for differences across multiple agro-ecosystems. Significance was evaluated at $\alpha = 0.05$. Qualitative data from policy reviews and KIIs were analyzed thematically. The Promoting Action on Research Implementation in Health Services (PARiHS) framework was adapted to structure the development of implementation frameworks, emphasizing the interplay of evidence, context, and facilitation.

RESULTS AND DISCUSSION

THE POLLINATION PARADOX: EMPIRICAL EVIDENCE FROM CHITWAN AND MAKWANPUR

The subtropical system of Chitwan and Makwanpur (300–1,200 masl) hosts a diverse farming system highly reliant on pollination services. Field studies provide robust evidence of a critical "pollination paradox" where agricultural dependence on pollinators is skyrocketing while pollinator security is plummeting.

Quantifiable yield and economic benefits: Empirical evidence demonstrates that managed pollination is a fundamental driver of crop production. Research in Chitwan quantifies substantial yield gaps and dramatic gains achievable through managed pollination (Table 1a, 1b).

Table 1a: Yield gain from open pollination for major crops in Saktikhor (Chitwan) and Silinge (Makwanpur), 2023/24

Crop	Pollination treatment	Grain yield (Saktikhor, Chitwan)	Yield gain over Control (%)	Yield (Silinge, Makawanpur)	Yield gain over Control (%)
Rapeseed	Open pollination	1044 kg/ha	27	1020 kg/ha	54
Buckwheat	Open pollination	950 kg/ha	25	860 kg/ha	40

Source: Primary field experiment data collected by the authors in Chitwan and Makwanpur districts, Nepal in 2023–2024.

Table 1b: Comparative crop yield and percentage gain under different pollination treatments in Chitwan, Nepal, 2012-2014.

Crop	Pollination treatment	Yield (kg/ha)	Yield gain vs. Control (%)	Source
Rapeseed/Mustard	Managed *Apis mellifera*	1071.0 kg/ha	57.8	Rijal (2020)
	Open pollination	1078.8 kg/ha	58.1	
Buckwheat	Managed *Apis mellifera*	99.2 g/m²	98.9	Rijal et al. (2018)
	Open pollination	88.9 g/m²	88.5	
Bitter Gourd	Managed *Apis mellifera*	1.9 kg/plant	59.6	Rijal (2020)
	Open pollination	2.0 kg/plant	61.7	

Source: Rijal, 2020.

Data in Table 1a show that the grain yield of local rapeseed increased by 27% in Saktikhor, Chitwan, and by 54% in Silinge, Makwanpur, under open pollination compared to control. Similarly, buckwheat yield gain from pollination was 25% in Saktikhor and 40% in Silinge.

Table 1b presents a compelling economic case. 'The yield gain of 57.8–58.1% in rapeseed falls within the 30–60% range reported globally for oilseeds (Klein et al., 2007; Garibaldi et al., 2016). The 88.5–98.9% increase for buckwheat reflects its extreme pollinator dependency as an obligate cross-pollinated crop (Jacquemart et al., 2007), while the high dependency for bitter gourd (59.6–61.7%) aligns with global findings for cucurbits (Martin et al., 2023). These figures translate the abstract value of ecosystem services into tangible, farm-level productivity metrics, which are essential for convincing farmers and policymakers of their importance.

On-farm agrobiodiversity as a foundation for pollinators: Farm-level crop diversification is a key structural attribute that influences habitat heterogeneity and floral resource continuity. Household surveys in both districts assessed the number of distinct crop species cultivated per holding, providing comparative insight into the farming systems (Table 2).

Table 2: Crop species richness* per farm holding in Chitwan and Makwanpur districts

District	Sample Size (n)	Mean Crop Species per Holding	Standard Deviation (SD)	Minimum	Maximum
Chitwan	120	8.6	2.1	4	14
Makwanpur	120	8.8	2.3	3	15
Overall	240	8.7	2.2	3	15

Source: Household surveys in 2023–2024.

* Crop species richness refers to the total number of distinct cultivated crop species maintained by a household within one agricultural year.

The surveys reveal a relatively high and comparable level of on-farm crop diversity in both districts, with an overall mean of 8.7 species per holding. This reflects the persistence of diversified smallholder systems typical of Nepal’s subtropical hills (Altieri, 1999). The marginally higher mean in Makwanpur may be associated with greater reliance on subsistence-oriented, mixed farming compared to the more commercialized systems in parts of Chitwan. This existing agrobiodiversity is a critical asset, as diverse cropping systems provide extended flowering periods and heterogeneous resources that support pollinator abundance and yield stability (Garibaldi et al., 2016; FAO, 2019). Extension programs can build upon this strong foundation by encouraging the strategic inclusion of gap-filling forage species.

Comparative analysis of farming systems and forage context: The agro-ecological and socio-economic contexts of Chitwan and Makwanpur create distinct landscapes for pollinators and beekeeping, particularly regarding forage sources and vulnerabilities (Table 3).

Table 3: Comparative farming system and bee forage context

Parameter	Chitwan	Makwanpur	Implications for pollinators
Dominant System	Commercial mixed cropping (market-oriented).	Subsistence mixed farming with forest linkage.	Chitwan offers abundant but ephemeral floral resources; Makwanpur provides stable, native forest forage.
Key Forage Source	Mustard, maize, rice, buckwheat, litchi; Community Forests (Sal-dominated), Riparian zones.	Community Forests; Chiuri tree (*Diploknema butyracea*), buckwheat, mustard.	Makwanpur's reliance on Chiuri, a keystone forest species, makes apiculture highly vulnerable to its erratic, climate-affected flowering (Bhusal, 2022).
Forage Gap/ Risk	Severe monsoon gap (May-August); maize provides only pollen.	Moderate gap; Chiuri bridges late-season but is unreliable.	Both districts face seasonal dearth, requiring strategic planting of gap-filling forage species.

Source: Household surveys in 2023–2024.

The contrasting contexts are crucial for tailoring interventions. Makwanpur's dependence on the Chiuri tree (*Diploknema butyracea*), a keystone species now flowering unpredictably due to climate change (Bhusal, 2022), underscores a unique vulnerability and the need for forest conservation and climate-resilient forage planning. The severe monsoon forage gap common to both districts highlights a universal challenge, pointing to the necessity of targeted extension on planting summer-flowering legumes (FAO, 2018).

Analysis of beekeeping production and adoption: The distinct agro-ecological contexts also create significant differences in beekeeping production and adoption (Table 4).

Table 4: Comparative analysis of beekeeping production and adoption

Indicator	Chitwan (Mean ± SD)	Makwanpur (Mean ± SD)	t-value / χ^2	p-value
Colony density (colonies/HH)	18.4 ± 6.2	11.7 ± 4.9	5.21	< .001
Honey yield (kg/colony/year)	50.6 ± 5.4	41.3 ± 4.8	6.03	< .001
Annual beekeeping income (Rs.)	164000 ± 180	141000 ± 150	4.87	< .001
% HH receiving training	72%	46%	χ^2=12.6	< .001
% HH using modern hives	81%	54%	χ^2=14.3	< .001

Source: Household survey of beekeeping farmers in 2024–2025.

Table 4 having significantly higher colony density in Chitwan reflects stronger commercialization, better access to inputs, and larger landholdings suitable for apiary placement. This commercial gradient is common in developing countries where beekeeping transitions from a forest-based subsistence activity to a farm-based enterprise (Bradbear & Fisher, 2014). Higher yields in Chitwan are attributed to intensive cultivation of high-nectar crops like mustard and litchi, and better colony management practices. While, lower yield in Makwanpur is linked to dependence on erratic Chiuri (*Diploknema butyracea*) flowering (Bhusal, 2022) and longer seasonal forage gaps. This yield gap presents a clear target for intervention through forage cultivation and improved management. The income disparity stems from both yield and market differences. Chitwan's proximity to major markets (Bharatpur, Kathmandu) ensures better prices. Enhancing market linkages and value-added products (e.g. Chiuri, honey, butter) in Makwanpur is crucial for equity, as seen in other remote honey-producing regions (Gemeda et al., 2018). The stark difference in extension access is a critical institutional gap. Chitwan benefits from the presence of agricultural universities and NGOs. Makwanpur has lower access and limits adoption of improved practices. This echoes global findings that effective extension is a primary driver of beekeeping success (Anderson & Feder, 2007). In Nepal, NGOs such as LI-BIRD and beekeeping cooperatives play a critical role in this ecosystem by providing technical training (colony management, queen rearing, disease control), facilitating access to inputs (hives, protective gear, sugar), and linking producers to formal honey markets — functions that government extension services often cannot fulfil at adequate scale or frequency (Neupane et al., 2025). Higher adoption of modern hives (e.g. Langstroth) in Chitwan correlates with training access and commercialization goals. Makwanpur's persistence of modern hive with traditional log hives, while culturally important, limits honey extraction efficiency and colony health monitoring. A balanced approach promoting improved traditional hives may be more adoptable in hill contexts.

Habitat dependence and growing threats: Pollination services are strongly mediated by landscape structure, particularly the type and proximity of natural habitats. A study on bitter gourd in Chitwan reported a significant negative correlation between yield and distance from natural habitat, with yields declining by 20.9% at 400 meters from the habitat edge (Rijal, 2019). In this case, the natural habitat consisted primarily of Sal-dominated community forests

(*Shorea robusta*) and associated riparian vegetation corridors, which are the dominant semi-natural landscape features of the inner-Terai region. These habitats function as key pollinator reservoirs by providing nesting sites, refuge, and supplementary forage for wild bee species such as *Apis cerana*, *Apis dorsata*, and *Bombus* spp. The yield decline with increasing distance highlights the importance of maintaining forest patches close to agricultural fields, supporting the landscape moderation hypothesis (Garibaldi et al., 2020)

Table 5: Effect of distance from natural habitat on grain yield of buckwheat in Chitwan, 2013/14

Distance from natural habitat (m)	Grain yield (kg/ha)	Yield reduction over 500m (Baseline)
500	812.4	Baseline
1000	758.2	-6.7%
2000	706.9	-12.9%
3000	605.6	-25.5%
F-test (ANOVA)	P < .01	

Source. Rijal *et al* (2018).

Table 5 quantifies the landscape moderation of pollination services in buckwheat. The significant yield decline with distance (25.5% at 3000m) provides robust, local evidence for land-use planning. Similar distance-decay effects are reported globally, emphasizing that conserving natural habitat within 200-300m of farms is crucial for maintaining pollination (Ricketts et al., 2008; Garibaldi et al., 2020). However, these services are under severe threat from pesticide misuse, habitat loss, and climate change. Beekeeper surveys report 40% colony loss during extreme heat events (ICIMOD, 2022; MoALD, 2023).

Policy and implementation gaps in the local context: Despite clear evidence, a profound policy-implementation disconnect persists in governing agriculture and apiculture. An analysis of key national policies and their translation into local planning reveals systemic gaps (Table 6).

Table 6: Gaps in the national policy framework and local planning

Policy/Planning component	Status in national documents	Status in local plans	Critical gap identified
Pollination as Ecosystem Service	Mentioned (low priority)	Not explicitly mentioned	Emphasis remains solely on honey production.
Pollinator Conservation Strategies	Largely absent	Largely Absent	No targets for habitat or species protection.
Measurable Ecological Metrics	Absent (focus on hive numbers)	Absent (focus on crop output)	No mechanism to monitor pollinator health.
Dedicated Budgetary Allocation	Minor, bundled under apiculture	Minor, bundled under crop support	Insufficient resources for integrated management.

Source: Compiled from Government of Nepal agricultural, biodiversity, and climate policies (2004–2019), LAPA framework, and Kafle, 2025.

An analysis of key policies and institutions reveals a fragmented landscape with weak coordination and a production-centric focus, failing to operationalize pollination as an ecosystem service. The Nepal Bee Promotion Policy (2017) exemplifies a "Honey-only bias", treating apiculture as a commodity-based livelihood rather than a service-based agricultural input (Dicks et al., 2016; Kafle, 2025). This bias is mirrored institutionally. Post-federalization, while municipalities (Palikas) have the mandate over agriculture, they lack the technical expertise in pollination ecology, leading to poor coordination and critical "Policy voids" in areas like pesticide regulation and habitat conservation (Gautam & Basnet, 2024). Furthermore, planning is often gender-blind, overlooking the distinct roles and indigenous knowledge of women and marginalized communities like the Chepang in Makwanpur, who are primary managers of key forage species.

Table 7: Key national policies relevant to agriculture and apiculture in Nepal

Policies and Year	Main focus	Reference to apiculture / Pollinators	Relevance to Chitwan & Makwanpur
ADS (2015–2035)	Commercialization, competitiveness. indirect support for apiculture through broader strategy	Mentions beekeeping as high-value enterprise	Guides provincial & local agriculture plans
National Agriculture Policy (2004)	Promotion of beekeeping sector	Strong focus on honey production, weak on ecosystem services	Poorly operationalized at local level
National Biodiversity Strategy and Action Plan (NBSAP) 2014–2020	Biodiversity conservation	Recognizes biodiversity including pollinators, Recognizes pollinators	Limited translation into farm programs
Bee promotion policy 2017	Bee promotion and no restriction in migration and forage	Explicit policy supporting beekeeping and pollination-related activities.	Gaps between national policy intent and local-level
Climate Change Policy 2019 & LAPA Framework	Broad climate adaptation strategies in agriculture and focus on climate-resilient agriculture	No specific pollinator provisions	Implementation Influences LAPA formulation
National Forest Policy 2018	Sustainable forest management; community forestry	Indirectly supports pollinator habitat through community forest conservation provisions	Community forests in Chitwan (Sal) and Makwanpur (Chiuri habitat) are key pollinator reservoirs

Policies and Year	Main focus	Reference to apiculture / Pollinators	Relevance to Chitwan & Makwanpur
National Adaptation Plan (2021–2050)	Sectoral adaptation. long-term adaptation priorities for climate risks across sectors including agriculture	CSA prioritized; pollinators implicit	Opportunity for integration

*Authors' synthesis based on Ministry of Forests and Soil Conservation (2014), Ministry of Forests and Environment (2019), LAPA framework, and Kafle,2025.Top of FormBottom of Form

Strength and Gaps: A comparison between study sites: Chitwan shows stronger market orientation and beekeeping adoption, while Makwanpur emphasizes subsistence and has emerging cooperatives. Neither district has pollinator-focused programs in local plans. Stakeholder consultations revealed that while 83% recognize bees increase yields, however, only 21% are aware of the pollination deficit, and none of them are trained on habitat management.

Table 8: Institutional landscape and functional roles

Institution	Level	Mandate	Current Activities	Observed Gap
Ministry of Agriculture & Livestock Development (MoALD)	Federal	Policy, standards	ADS, NAP, subsidy programs	No pollinator indicators
Provincial MoLMAC	Provincial	Implementation	Input distribution, training	Apiculture marginal
District Agriculture Office previously named as Agriculture Knowledge Centers (AKC)	District	Extension	Crop & livestock advisory	No pollination advisory
Municipal Agriculture Sections	Local	Planning & service delivery	Farmer groups, subsidies	Lack technical capacity
NGOs / Cooperatives	Local	Livelihoods	Beekeeping training	Fragmented

Source: Authors' synthesis based on (MoALD, 2020; FAO, 2016, 2017; LI-BIRD, 2025; World Bank, 2012; IPBES, 2016)

Extension Worker Awareness and Capacity Building: A critical precondition for any pollinator-integrated agricultural system is the awareness and technical competency of frontline extension workers. Key informant interviews of extension officers conducted in both districts revealed that none had received formal training on pollination ecology or pollinator monitoring. While all officers were familiar with standard crop advisory services (fertilizer management, pest control, varietal recommendations), knowledge of pollination dependence, bee forage management, or bee-safe pesticide protocols was largely absent. The PILEF's Tier 2 (Extension Delivery) directly addresses this gap through the designation of "Pollinator-Smart Advisors" - trained extension officers equipped with a standardized pollinator literacy curriculum and practical field skills. The PLR (Extension Officer Pollination Literacy Rate) metric, proposed in Table 9, provides a mechanism to monitor and ensure sustained capacity building over time

PROPOSED INTEGRATED FRAMEWORKS FOR ACTION

To systematically bridge the evidence-policy-practice gap, we propose two complementary, evidence-based frameworks tailored for municipal-level action within Nepal's federal structure:
i) Foundational Metrics and the PEAR–IEDM–CEAL Integrated Action Framework

The first one is simple, actionable metrics for local governments to integrate into planning and monitoring (Table 9). The PEAR–IEDM–CEAL integrated action framework adapts principles from implementation science, particularly the i-PARIHS framework, by integrating context assessment, evidence-informed intervention design, facilitation, implementation, and iterative evaluation to support the scaling of evidence-based practices (Harvey & Kitson, 2015).

1. Diagnose & define (Context): Engage stakeholders to map local "Pollination deficits."
2. Evidence & design (Evidence): Synthesize and present local research to co-design interventions.
3. Implement & adapt (Facilitation): Pilot tailored interventions "Buckwheat pollination package".
4. Review & scale (Evidence + Context): Monitor outcomes using simple metrics to refine and scale policy.

Table 9: Proposed core pollinator metrics for local agricultural extension

Metric domain	Proposed indicator*	Measurement method (Local extension)	Policy/Planning use
Outcome (Impact)	Pollination Dependence Index (PDI)	Simple field trials (caging vs. open pollination).	Measure yield gap; allocate resources to high-risk crops.
Output (Activity)	Pollinator-Friendly Habitat Score (P-FHS)	Percent farm area with floral strips/hedgerows.	Guide land-use planning; incentivize habitat conservation.
Process (Risk)	Pesticide Risk Index (PRI)	Survey on use of bee-toxic pesticides & timing.	Trigger IPM training; regulate spraying near bloom.
Knowledge/ Capacity	Extension Officer Pollination Literacy Rate (PLR)	Annual test/assessment of extension staff knowledge.	Ensure adequate training and capacity building.

* Authors' synthesis based on Giovanetti, (2021), Mirrare et al. (2021) , Klein, et al., (2006), Allebone-Webb (2024), Christmann (2021) and Pardee, et al. (2023)

(ii) The second one is Pollinator-Integrated Local Extension Framework (PILEF). The PILEF provides the concrete operational structure for extension services, guided by a five-step evidence-based practice cycle (Ask, Acquire & Appraise, Apply, Adapt, Assess) and implemented through a three-tier model (Table 10). Here, Gender and Social Inclusion (GESI) is a core design principle. The framework mandates proactive strategies such as >65% women's participation in FFS, employs female extension facilitators, and tailors programs for indigenous communities (e.g. Chepang in Makwanpur) to ensure interventions are equitable and leverage unique local knowledge.

Table 10: The pollinator-integrated local extension framework (PILEF)

Tier	Focus	Key Actions & Tools*	Proposed Metrics for Integration
Tier 1: Municipal Planning	Policy & Budget	Integrate pollinator metrics into annual agricultural plans and budgets.	Pollinator Habitat Index (PHI); Pesticide Risk Score (PRS).
Tier 2: Extension Delivery	Capacity & Advisory	Train extension workers as "Pollinator-Smart Advisors"; deploy bee-safe IPM protocols.	Extension Officer Pollination Literacy Rate (PLR).
Tier 3: Farmer Action	Awareness & Practice	Conduct Farmer Field Schools (FFS) with demonstration plots; promote forage planting.	% farmers adopting ≥2 Pollinator-Friendly Practices.

*Authors' synthesis based on LI-BIRD's Farmers Field School Manual on Pollination Management (2025) and project documentation on embedding sustainable pollination management into Nepalese agriculture (LI-BIRD).

Roadmap for pilot implementation and national scaling: A phased, learning-oriented approach is proposed, beginning in the evidence-rich districts of Chitwan and Makwanpur. These pilot sites will be designed to function as a National Learning Hub (see Table 11). Key recommendations include:

1. Shift to service subsidies: Provide forage planting subsidies for bee-friendly plants instead of only hive/sugar subsidies.
2. Establish pollination desks: Create specialized cells within Agriculture Knowledge Centers (AKCs) /ADO to track bloom times and issue bee-safe spray advisories via mobile apps.
3. Designate a national learning hub: Leverage the altitudinal gradient of Chitwan-Makwanpur as a pilot region for testing and scaling the PILEF nationally.

Table 11: Roadmap for pilot implementation and scaling for five years (2026-2030)

Phase	Timeline	Key activities*	Success indicators
Phase 1: Strategic Piloting	Years 0–2	Establish pilot "Pollinator-Smart" municipalities; train advisors; launch FFS; integrate metrics.	Municipal budget line created; 40+ staff trained; 30% farmer adoption.
Phase 2: Consolidation & Vertical Scaling	Years 2–4	Evaluate pilots; develop policy briefs; advocate for provincial integration.	15–25% yield increase documented; metrics adopted in Provincial Agricultural Plan.
Phase 3: National Mainstreaming	Years 4–6	Synthesize evidence for national dialogue; support a National Pollinator Strategy.	National Pollinator Strategy endorsed; metrics in National Agricultural Census.

*Authors' synthesis based on FAO (2018), IPBES (2016), Rogers (2003), World Bank (2012), and Nepal national agricultural policy frameworks (2061).

CONCLUSION

The widening "Pollination deficit" in Nepal represents a critical but addressable vulnerability in its agricultural system. Consolidated evidence from Chitwan and Makwanpur districts proves that integrating pollinator management is a viable and high-impact strategy for enhancing productivity (25–70%+ yield gains), nutrition, and climate resilience on smallholder farms.

The proposed Pollinator-Integrated Local Extension Framework (PILEF), supported by the PEAR–IEDM–CEAL action cycle, offers a comprehensive, scalable, and socially inclusive model to bridge the current policy-implementation gap. It moves beyond a "Honey-only" focus to position pollination as a measurable agricultural input. By equipping municipalities with actionable metrics, empowering extension workers as pollinator-smart advisors, and ensuring gender-responsive and inclusive interventions, Nepal can systematically transform pollination from an invisible "hidden input" into a managed and protected pillar of its agricultural economy. It is recommended as immediate designation of Chitwan and Makwanpur a National Learning Hub to pilot, refine, and demonstrate the PILEF. This pragmatic first step can generate the necessary evidence and political will for national scaling, positioning Nepal as a regional leader in harmonizing agricultural development with essential ecosystem stewardship.

ACKNOWLEDGEMENT

The authors sincerely thank the farming households and beekeepers of Chitwan and Makwanpur districts who participated in this study, as well as the extension officers and local government officials who provided their time and insights during key informant interviews.

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BRIDGING THE LAST-MILE GAP: A CRITICAL ASSESSMENT OF THE COMMUNITY BUSINESS FACILITATOR MODEL IN NEPAL'S AGRICULTURAL EXTENSION LANDSCAPE

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ABSTRACT

Agricultural extension in Nepal faces challenges like limited outreach, insufficient technical personnel, and weak linkages between farmers, input suppliers, and markets. In response, development programs have introduced the Community Business Facilitator (CBF) model. The model is a market-oriented approach where selected local individuals are trained and supported to develop as entrepreneurs and facilitate extension services in their community. This qualitative study assesses the effectiveness, motivations, and operational constraints of the CBF model across selected districts of Nepal and suggests model improvements for sustainability. Data were collected through document review, field observations and key informant interviews with 16 CBFs and 4 project officers and analyzed using thematic analysis. Findings indicate CBFs have a positive impact on farmer's access to knowledge, services and adoption of new tools and technologies. Income opportunities, social recognition and skill enhancements were key drivers of CBF engagement. The model faced several structural, operational, and socio-economic constraints and few strategic recommendations have been suggested for its institutionalization.

Keywords:

Agri-entrepreneurship, Agriculture extension, Community Business Facilitator, Last-mile supply chain, Market-led extension

1. INTRODUCTION

Nepal's economy is deeply rooted in agriculture. The livelihood of over 50% of the total population of Nepal depends on agriculture (National Statistics Office, 2023) that contributes nearly one-fourth to the national Gross Domestic Product (Nepal Rastra Bank, 2024). The current agriculture extension system in Nepal is dominated by the public sector where local governments are responsible for all operation and management (Timsina et al., 2024) of the service delivery. At the same time, I/NGOs and other private organizations are also emerging as important actors in supporting extension activities (Shrestha, 2023).

Despite these efforts, the overall performance of agriculture extension has been mediocre. Limited budget, poor institutional setup, lack of technical human resources and lack of coordination between governments hinder the efficacy of the public extension system (Timsina

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et al., 2024). To increase the efficiency of public extension services, Nepal has been practicing several extension service delivery models and approaches but the coverage is limited being as low as 25% (Ghimire et al., 2021). This limited reach has created a strong need for a paradigm shift in the way extension services are designed and delivered.

The CBF model has emerged as one of the alternative extension approaches that integrates service delivery with market-based incentives (iDE, 2025). iDE's CBF also known as Farm Business Advisors (FBAs) globally, comprises 3500 active independent entrepreneurs who each support between 80 and 120 farmers (iDE, 2026). FBAs have already increased incomes and production of 600,000 farmers and actively complement government extension systems in iDE working countries globally (iDE, 2026). This model engages local entrepreneurs as facilitators who connect farmers with agricultural inputs, services, and technical information while operating as independent business actors (iDE, 2025). Because CBFs are locally based, they can better understand the needs of their community farmers, ensure better engagement and timely access to inputs and advisory support.

A selected CBF for extension is at least ten-class passed. He/she receives sales skill training and agriculture technical training. CBF presents agriculture inputs and new technologies to farmers or consumers through household visits and Group Sales Presentation (GSP) from which demand for products is collected. The demand is passed to agro-vets or vendors who are in pre-contract to the CBF. CBF then collects products from these private dealers and delivers them to farmers or the last-mile. CBFs earn through commission from these dealers. Unlike conventional approaches, through this model extension agents are financially sustained without putting burden on either demand and supply ends. The commission is a performance-based incentive to actively reach farmers and promote relevant technologies. The higher the sales, the higher is the commission amount. At the same time, input suppliers get benefits due to higher sales.

The overall objective is to explore the effectiveness of the CBF model as a last-mile agricultural extension approach in Nepal. It explores the key factors influencing the model's performance and compares it with the public extension system to identify complementarities and ways to address gaps in each system. It identifies challenges in the existing CBF model and offers recommendations on the model's improvements for sustainability and institutionalization. The results are expected to guide policymakers, development practitioners and extension agencies working to enhance service delivery to smallholder farmers in Nepal and beyond.

2. METHODOLOGY

This assessment used the qualitative approach, capturing data across diverse market dynamics. The assessment combined a review of unpublished project documents with Key Informant Interviews (KIIs) involving CBFs and project officers. As the study was conducted with limited respondents and geography, this may limit the generalizability of the findings. Ethical considerations were ensured through voluntary participation, and treating responses with confidentiality. A systematic review was conducted of internal and unpublished documents made available by the implementing agency. These included project proposals, annual and quarterly progress reports, training manuals, monitoring formats, supervision records, and internal evaluation summaries.

Similarly, primary data was collected through 4 field visits and 20 KIIs in Rautahat, Rupandehi, Kapilvastu, and Dang districts of Nepal because of the presence of CBFs in these districts. The list of CBFs in each district (10, 14, 15 and 12 CBFs in Rautahat, Rupandehi, Kapilvastu, and Dang respectively) served as the sampling frame, from which four facilitators were selected per district using simple random sampling. One of the respondents had discontinued participation in the program, which provided insight into both active engagement and program dropout. Additionally, one project officer from each district was interviewed to provide supplementary insights on the CBF model and to enable triangulation of the findings.

Structured open-ended questionnaires were prepared for the interview. Face-to-face interviews were conducted with respondents where notes were taken during discussions, and responses were documented systematically. For thematic analysis, data from both document review and interviews were examined to identify recurring patterns, ideas, and issues. Recurring patterns and emerging issues were grouped into common themes and headings. These thematic categories were then used to organize and present the findings descriptively.

For the comparison of public extension and CBF model, determinants of effective extension approach were adopted from Abdel-Maksoud (2019) and compared under the determinants as presented in table 1.

Table 1 Determinants used for comparing Public Extension and CBF Model

Determinants	Description
Organizational	Compared on institutional structure, efficiency of coordination, strength of linkages among research centers, input suppliers, farmer organizations, and the presence of supportive policies and institutionalization.
Farmer	Evaluated on accessibility and inclusivity of services, farmer participation in planning, evaluating activities, and technology generation, as well as perception, trust, and satisfaction with services.
Extension personnel	Compared on competence and training of service providers, motivation and commitment influenced by incentives, and coverage capacity in terms of staff-to-farmer ratios.
Economic	Measured improvements in crop productivity, germination rates, net profits, and the ability of farmers to convert surplus production into economic gain.
Marketing	Assessed provision of market information, access to price and demand data, and the effectiveness of linkages with collection centers, traders, and cooperatives.
Communication	Compared methods used for knowledge dissemination, efficiency of communication channels, and their effectiveness in building farmer awareness, confidence, and adoption of technologies.

3. RESULTS AND DISCUSSION

3.1 IMPACT ON KNOWLEDGE, PRODUCTION AND INCOME

During GSPs, CBFs promoted improved agricultural practices, including the use of improved seeds, organic fertilizers and pesticides, and labor-saving tools and technologies. These sessions enhanced farmers' knowledge and awareness of modern agricultural practices, increasing their confidence and willingness to adopt improved inputs and techniques. Farmers of Rupandehi were unaware of improved agricultural practices like mulching, maintaining seed spacing at sowing and growing plants in grow bags that were introduced through GSPs. Additionally, as trust deepened through repeated interaction and reliable service, farmers became more receptive to adopting improved agricultural practices and technologies promoted by CBFs.

According to farmers, CBFs provided regular farm visits, timely advice on pest and disease management, and quick support through phone consultations, which had improved access to agricultural guidance. Farmers also appreciated the doorstep delivery of inputs such as seeds and pesticides, noting that the approach saved time, reduced travel, and provided reliable technical support during production cycles (iDE Nepal, 2022).

From KIIs, it was discovered that agri-inputs presented for sale were bought by at least 20% of the participants. A CBF of Rupandehi reported purchase rate to be more than 100% as people who were not in GSPs were also demanding the improved agri-inputs and WASH (Water Sanitation and Hygiene)-kits presented for sale. This suggests GSPs effectively encouraged farmers to adopt improved technologies. Higher sales means higher commission for CBFs which motivates for more GSPs and higher area coverage. In addition to their promotional role, CBFs served as local resource persons who provided practical guidance and connected farmers with agri input suppliers and service providers to address farm level challenges. As per Maharjan (2023), a CBF helped farmers receive minitiller in 50% subsidy connecting them to the local government program. This improved CBF's social capital and indirectly supported farm income.

Farmers in Rupandehi reported higher germination rates and increased yields after adopting improved seeds along with recommended spacing practices. Similarly, households in Kapilvastu began producing organic food for household consumption using organic fertilizers and pesticides, contributing to healthier diets and reduced dependence on chemical inputs. Adoption of agricultural tools such as electric knapsack sprayers, mini tillers, and grow bags improved labor efficiency and supported small-scale mechanization where access was available.

The use of improved agricultural practices has increased overall production, resulting in a greater marketable surplus of vegetables and other crops. This has created new income generating opportunities for subsistence farmers and contributed to improved livelihoods (iDE Nepal, 2022). CBFs further supported this process by linking farmers with local markets, traders, and cooperatives, strengthening market access and enabling farmers to convert increased production into economic gains. CBF in Rupandehi linked a vegetable farmer to a nearby collection center, who then actively sold vegetable produce for the livelihood of his family. Overall, the activities of CBFs not only enhanced farmers' knowledge and adoption of improved practices but also strengthened production, income, and social capital.

3.2 DRIVERS OF CBF ENGAGEMENT

All CBFs in the study agreed on primary motivation to enroll and continue as a CBF was the potential to earn income. A CBF each of Rupandehi and Rautahat districts reported that many people in their community were interested in becoming CBF after seeing them earn. However, none of the respondents considered becoming CBF as their major occupation. Out of 16 CBFs, 10 were engaged in other income generating activities like farming, construction and shopkeeping, 2 respondents were students, 2 were housewives and other 2 were unemployed who reported CBF as a temporary or supplementary source of income.

Additionally, social recognition was considered another major driver for CBF engagement by 10 respondents. Members of the same tole/community trust CBFs because they are locally based and socially connected. Regular household visits for demand collection and delivery of agricultural inputs further reinforced these relationships over time. Positive feedback from beneficiaries added intrinsic motivation to continue as CBF and even increased beneficiary reach. Social capital grew to the extent that a CBF in Rupandehi even plans to contest in the upcoming election.

Few respondents indicated training and capacity building as one of the drivers for CBF engagement. CBFs were provided with trainings on nutrition, agriculture, WASH and sales skill training that improved their knowledge, skills and confidentiality. Hands-on experience in field demonstration and sales management enhanced self-efficacy and entrepreneurial confidence that contributed to sustained participation even under financial constraints.

3.3 DIVERGENT REALITIES

In terai, the model faces market competition. Local agrovets were viewed as rivalries by 5 out of 16 CBFs. Proximity to the Indian border, agro-vets allowed farmers to bypass CBFs for cheaper, often lower-quality inputs. This limited the dependency on CBF, establishing long-term customer relationships and income potential. Further, the “Last Mile” is physically short distance and the road infrastructure is better in the terai, making input procurement and delivery easier. This limits the advantage of locally embedded CBFs and faces more competition. Alternately, improved road network and closer household proximity allowed CBFs to reach more beneficiaries. Among the interviewed CBFs, the average number of beneficiary reach was 339 (25-800) farmers.

Study by Kothari et al., (2023), CBF is an essential auxiliary agent in the hill district. Urban agro-vets are inaccessible due to difficult topography. In this case, the model is complementary and creates a market. Agro-vets in hills (Kaski and Dadeldhura) were happy to host CBFs and were keen on having more CBFs in the future. However, the reach of an individual CBF remains limited, averaging 144 beneficiaries. This was largely due to difficult topography, scattered household and lack of motorable roads, which restricted frequent contact with farmers and limited the scale of service delivery.

Table 2 Comparison of CBF Functioning and Market Dynamics in Hill and Terai Districts

Feature	Hill Districts (Kothari et al., 2023)	Terai Districts
Role of CBF	Market creation, complementary to urban agro-vets	Market competitor, competing with local/cross-border agrovets
Agro-vet access	Limited due to topography	Easily accessible; cheaper cross-border inputs
Agro-vet relation	Welcomed by local agro-vets (Kaski, Dadeldhura)	Viewed as competitors by some CBFs
Beneficiary reach	Avg. 144	Avg. 339 (range 25–800)
Constraints	Difficult terrain, scattered households, poor roads	Short distances, good road network, reduces CBF advantage

3.4 NAVIGATING CONSTRAINTS

Despite its potential to strengthen last-mile service delivery, the CBF model faced several structural, operational, and socio-economic constraints. Many facilitators perceived their engagement as temporary and discontinued participation after project completion or when more stable employment became available. This highlights the necessity of improvements in the CBF model for better sustainability.

CBFs encountered significant logistical barriers related to product procurement, transportation, and distribution. Facilitators often collected products from distant vendors and delivered them to geographically dispersed households, resulting in high transport costs and operational inefficiencies, particularly when demand volumes were low. Five of sixteen CBFs responded that the commission amount could hardly cover the logistics cost incurred. It was more difficult for the CBFs who did not have their own vehicle and had to hire an autorickshaw for the logistics which was relatively expensive and time consuming.

The commission-based income structure resulted in irregular and often insufficient earnings, making the role financially insecure. Income variability was influenced by seasonal demand, product availability, and market conditions, which limited the model's capacity to provide a stable livelihood. According to a CBF of Rupandehi, income through CBF was not enough to feed the family of three. All project officers agreed that insufficient and irregular income of CBF model was the major reason for the dropping of CBF. A dropped CBF from Rautahat responded her reason for dropping was getting a job of a cooperative agent that gave her regular income while income through CBF model was unstable and temporary.

Some CBFs faced problems due to vendor practices. CBF's commission-amount was delayed or paid incomplete. Some vendors sold directly to buyers from the demand-list collected by CBF, violating vendor-CBF contracts. This reduced operational motivation and financial reliability as a CBF. Also, CBFs faced challenges in establishing credibility and acceptance among community members, particularly during initial engagement. In the study, 9 of 16 of the CBFs identified a trust deficit. Farmers frequently have doubts about private agents because they believe they are more motivated by profit than by interest extension. This hinders adoption of promoted products and services. In Rupandehi, some farmers accused CBFs of selling products which they believed were provided for free distribution.

Gender norms, age of CBF and cultural beliefs also influence operational effectiveness. Female CBFs are effective in nutrition-sensitive agriculture and WASH reaching other women while male facilitators reported difficulty engaging with female beneficiaries in household-level interventions. Younger CBFs faced less difficulty engaging with beneficiaries as people were more welcoming to young ones. This result is different to Kothari et al. (2023) where younger CBFs and females faced resistance in service delivery from older farmers. This might be due to the difference in nature of products CBFs were selling. CBFs interviewed were selling Nutribeads and Redcycle beads. Nutribead make mothers aware about nutritional requirements for the child and Redcycle bead help track the female menstruation cycle which are both targeted to and used by females. Similarly, cultural and religious considerations affect adoption of certain nutrition-related products in specific communities. CBFs of Rupandehi and Dang reported some houses believed Pumpkin and Sponge gourd brought bad omen and were unwilling to grow which actually had high nutritious importance.

In the regions close to the Indian border, easy access to alternative markets, including cross-border suppliers, reduced reliance on CBF-mediated supply chains. Farmers often preferred lower-cost imported products, limiting demand for locally facilitated services. Additionally, CBFs reported insufficient practical and technical guidance to effectively provide advisory services and promote products. This gap constrained their ability to perform as credible extension intermediaries and limited their effectiveness in influencing farmer behavior and technology adoption.

3.5 CBF MODEL VS PUBLIC EXTENSION

3.5.1 Organizational Determinants

With the federal restructuring in Nepal, the agricultural extension services are provided at all three government levels. The commodity development centers and national priority projects of the Ministry of Agriculture and Livestock Development handle them at the federal level. Directorates, centers, laboratories, and community farms, which are subordinate to the Ministry of Land Management, Agriculture, and Cooperatives, work at the provincial level, and the local governments offer extension services through Agriculture and Livestock Development Sections in municipalities (Timsina et al., 2024). This decentralization was intended to foster bottom-up planning. However, it currently suffers from poor coordination between layers and the persistent "top-down" bureaucratic mindset (Shrestha, 2023; Tamang et al., 2020). Literature suggests linkages between research (Nepal Agricultural Research Council), education, and extension remain inadequate (Tamang et al, 2020). In contrast, the CBF model acts as a market-based "last-mile" bridge. CBFs serve as local contact points that link farmers to a wide array of systems, including input suppliers, cooperatives, and government programs. However, the CBF model lacks formal institutional longevity of the public system and often relies on temporary project funding. It can complement the public extension system by strengthening local-level coordination, improving farmer outreach, and bridging gaps between farmers, markets, and service providers. Integration of CBFs within the formal extension structure could enhance the effectiveness and responsiveness of agricultural service delivery.

3.5.2 Farmers determinants

Public extension has critically low coverage, reaching only 25% of farmers (Ghimire et al., 2021). It has historically neglected the rural poor and socially disadvantaged, with large farmers often capturing the most benefits (Tamang et al., 2020). Farmers are often viewed as passive recipients rather than active participants. Conversely, CBFs are embedded within the community, allowing them to understand local needs and foster deep social capital. Farmers show high participation in CBF activities like GSPs, with technology adoption rates often reaching 100%. CBFs can complement public extension by improving reach among underserved farmers, strengthening participation, and enhancing adoption of innovations through closer community engagement.

3.5.3 Extension personnel determinants

The public system faces a severe shortage of personnel, with one agent serving 1,200 farmers (Shrestha, 2023). While public agents have stable civil servant status, they often prefer central or provincial postings over remote local units (Timsina et al., 2024). CBFs are driven by performance-based incentives, such as commissions/social-recognition, which motivates them to actively reach farmers. However, the role is often financially insecure due to irregular income and high logistical costs, leading to high turnover when project funding ends or more stable employment is found. The CBF model can complement public extension by expanding field-level human resource capacity, improving farmer contact frequency, and reducing service gaps in hard-to-reach areas.

3.5.4 Economic determinants

Public extension is constrained by a limited budget (less than 1% of the national agriculture budget), making it difficult to significantly impact farm-level productivity (Shrestha, 2023). The CBF model demonstrates clear economic benefits by promoting improved seeds and technologies that lead to higher germination rates and increased yields. This allows subsistence farmers to generate a marketable surplus, though CBFs themselves often find their commissions barely covering the high transport costs. The CBF model can complement public extension by improving cost-effective service delivery, supporting productivity gains at farm level, and enhancing the economic viability of extension outreach in resource-constrained settings.

3.5.5 Marketing determinants

The Government of Nepal has prioritized investing in cooperatives for the commercialization of agriculture. However, it has not been able to meet its goal largely due to focusing on financial services like savings and loans, with little attention to supporting agricultural production or marketing (Dhakal & Mueser, 2023). Additionally, the public sector has introduced Agriculture Market Price Information System to provide market price information for agriculture commodities (DOA, 2026) and is beginning to address standards and food safety (Tamang et al., 2020). Despite these efforts, timely and effective delivery of market information remains limited, especially with smallholder farmers (Timsina et al., 2023). The CBF model explicitly integrates marketing, linking farmers directly to the vegetable collection Centers, traders, and cooperatives. It can complement public extension by identifying market demand, organizing collection systems, and facilitating value chain activities, thereby strengthening their role in agricultural commercialization.

3.5.6 Communication channel

Nepal's federal restructuring has established agriculture institutions at the local level that has increased farmer's access to extension services (Burlakoti & Nettle, 2023). Additionally, use of Information Communication Technology (ICT) as a communication tool in agriculture is increasing with the government emphasizing digitization in agriculture (Timsina et al., 2023). However, there is limited ICT adoption due to various challenges. Extension systems still largely rely on the assumption that information shared with "leader farmers" will naturally spread to other farmers, which is not always true (Timsina et al., 2023). Similarly, a language barrier exists with farmers not understanding the official Nepali language (Ghimire et al., 2021). As a result, a significant proportion of smallholder farmers remain unreached and excluded from timely agricultural information. The CBF model uses more intensive, direct communication channels, including household visits, field demonstrations, and GSPs. These methods are highly effective at increasing farmer confidence and awareness. The model can complement public extension by strengthening last-mile communication, reducing reliance on indirect information diffusion, and ensuring more timely and direct access to agricultural knowledge for smallholder farmers.

Table 3 Comparison of public extension and CBF model

Determinant	Public Extension	CBF Model	CBF complementing public extension
Organizational	Multi-level, weak coordination, top-down, poor research linkage	Local, networked, project-based, flexible	Improves coordination and last-mile service delivery
Farmers	Low coverage, elite-focused, passive	Embedded, participatory, high adoption, trust issues	Expands reach and farmer participation
Extension Personnel	Shortage, central preference, low motivation	Incentivized, active, unstable, high turnover	Fills human resource and outreach gaps
Economic	Limited budget, low productivity impact	Increased yield, marketable surplus, modest commission	Supports cost-effective productivity improvement
Marketing	Production-oriented, AMPIS,	Direct linkages, cooperatives, traders	Strengthens market and value chain linkages
Communication	Short due to decentralization, ICT, traditional transfer	Direct, intensive, demonstrations, group sessions	Enhances last-mile communication and information access

3.6 STRATEGIC RECOMMENDATIONS FOR INSTITUTIONALIZATION

3.6.1 Common Institutional Linkage Point

CBFs can be developed as local contact persons who connect farmers with various public and private institutions. CBF can act as extension agents for input suppliers, cooperatives, financial institutions, I/NGOs and government agencies. CBFs can be a good extension strategy for input suppliers to market new products, cooperatives for input distribution and product collection, financial institutions to provide credit services and government offices to disseminate information on agriculture services and subsidies. Extension through CBFs can be an effective strategy for local governments with limited budgets in agriculture. Furthermore, as CBFs are directly connected to household level and have a strong understanding of farmer's real challenges and needs. Integrating CBFs into national extension planning could therefore improve the relevance, reach, and effectiveness of agricultural service delivery.

3.6.2 Hybrid Compensation Framework

To retain CBFs a hybrid compensation framework is suggested including monthly minimum stipend, service fees, business commission and bonus based on work. Minimum monthly stipend should be provided by institutions where CBFs have been working permanently. Service fees should be provided for training, visit for product collection/delivery, sales presentation and dissemination of information. Timely and pre-determined compensation should be provided to CBFs for the product sales. Provision of bonus or prize to best CBFs should be made to motivate CBFs.

3.6.3 Strategic Targeting

Matching CBFs to the target audience and product type ensures more effective service delivery and greater adoption at the community level. Strategic targeting for CBF selection should align facilitator characteristics with community dynamics and the nature of the products or services. Younger CBFs tend to connect more easily with innovators and early adopters, while the late majority and laggards are more likely to trust facilitators who are older or socially closer to them. Female CBFs can be prioritized for maternal health or nutrition initiatives to build trust and access.

3.6.4 Capacity and Non-monetary incentives

Formal Identity Cards help CBFs build trust among farmers. Certificates through institutions and inclusion in community level meetings motivate and provide opportunity for their voice. Access to training and refresher courses is important to CBFs. To operate as CBF standard licensing certification should be introduced. Skill oriented training helps CBFs earn more. CBF trained through CABI's Plantwise programme were called CBF-Plant doctors who earned on an average of five dollars higher compared to non plant doctors (Kothari et al., 2023). As CBFs are connected to last-mile, they must be well informed of public and private services, available products and improved tools and technologies on agriculture, so that they can effectively identify and solve famer's problems.

3.6.5 CBF as an entrepreneur

Attempts can be made in developing CBFs into commercial farmers. When CBFs actively practice improved farming, they strengthen their credibility, demonstrate economic benefits and promote improved agriculture. This is evident in Dang, where a CBF raised and sold improved vegetable seedlings earning an additional seasonal income of 10 thousand nepali rupees. Along with input supply services, they can develop agriculture learning centers, provide post-harvest and value addition services.

3.6.6 Diversification of services

Multiple linkages diversify income. Working as sales agent for input suppliers, field agents for deposit collection and product delivery for cooperatives, insurance agent for insurance companies and extension agent for local government and I/NGOs, diverse income opportunities for CBFs. Additionally, developing capable CBFs as service providers like Plant doctors (Kothari et al., 2023) and as suppliers of agricultural inputs and farm products further diversify their income.

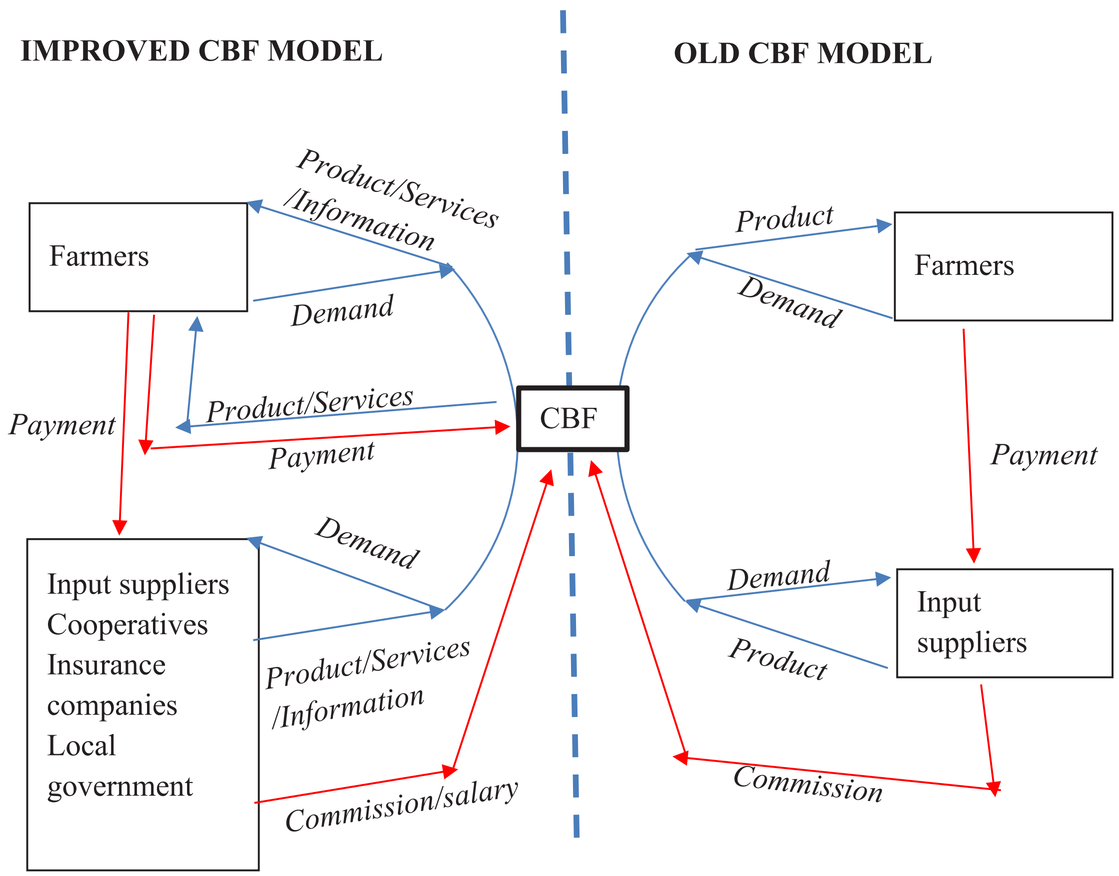

Figure 1 Improved CBF model with diversified services

4. CONCLUSION

CBFs are instrumental in creating awareness and promoting the use of better agricultural technologies. CBFs play a significant role in the development of agriculture by offering efficient access to agricultural inputs and strengthening the market connections. Their local presence builds trust and social capital, which promotes the spread of innovations. However, the effectiveness of the CBF model is limited due to irregular and commission-based income, logistical challenges, and socio-cultural norms. Currently, CBFs' work is mostly limited to temporary agriculture projects. Institutionalization through standard licensing, expansion of service areas, hybrid compensation schemes combining stipends, service fees, commissions, and performance-based incentives, alongside capacity building and formal recognition with clear operational systems can make it substantially more effective.

DECLARATION

The authors declare no conflict of interests.

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CHEMICAL FERTILIZER SUPPLY CHAIN MANAGEMENT IN NEPAL

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ABSTRACT

Nepal's chemical fertilizer supply chain is crucial for ensuring the timely availability of chemical fertilizer to improve agriculture productivity, but fail to meet the demand in term of timeliness and quantity. This study critically analyze the fertilizer demand and supply scenario, procurement systems, subsidies allocation, distribution mechanisms, and private sector participation mainly focusing on subsidized fertilizers over fiscal years 2013/14–2024/25. Mixed-method combining institutional secondary data from MoALD, KSCL, and STCL and semi-structured key informant interviews were used to collect the data and information. Findings show that over the study period fertilizer supply increased up to 441,315 MT but remains below estimated demand of 800,000 MT. Supply proportion of Urea is higher than the technical recommendation. Fertilizer supply are largely managed by public institutions, with limited private sector involvement. The procurement process is lengthy and bureaucratic, and average procurement lead times frequently exceed the 210-day legal standard, leading to delayed imports and frequent shortages. Fertilizer subsidies have improved affordability for farmers but have also generated increasing fiscal pressure due to rising international fertilizer prices. Supply is constrained by weak demand forecasting, insufficient subsidy budget, inadequate storage and external market uncertainties. Procurement reform, strengthening demand forecasting, enhancing storage and distribution, sales price adjustment and private sector participation can support to improve supply chain efficiency.

Keywords: Distribution, Fertilizer, Procurement, Supply Chain, Subsidy

1. INTRODUCTION

Agriculture remains the backbone of Nepal's economy, employing a significant proportion of the population and contributing to national food security and livelihoods. The productivity of the agricultural sector largely depends on the timely availability and efficient use of key inputs. Among these, chemical fertilizer is essential for maintaining soil fertility and improving crop yields (Ezeh *et al*., 2008), thereby contributing significantly to agricultural growth. In recent years, fertilizer demand in Nepal has steadily increased, mainly due to the intensification of cropping systems (MoALD, 2026; Vanlauwe *et al*., 2016) and the need to enhance productivity.

The use of chemical fertilizer began in the 1950s, when private traders imported small quantities of ammonium sulphate from India. During the early 1960s, the government entered in this sector through National Trading Limited, importing fertilizers from countries such as China and

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Russia. Government established Agriculture Input Corporation in 1996 to facilitate fertilizer import and distribution.

Nepal introduced fertilizer subsidy in 1953 through price and transportation support to improve fertilizer access, particularly in hilly regions. The subsidy program was gradually withdrawn in the mid-1990s as part of economic liberalization and market deregulation. However, the private sector failed to ensure an adequate and timely supply of quality fertilizers. Rising international prices, competition from subsidized Indian agricultural products, and the inflow of illegally traded fertilizers further constrained fertilizer availability (Shrestha, 2011). Accordingly, many smallholder farmers faced difficulties accessing affordable and quality fertilizers. Then, the government reintroduced a targeted fertilizer subsidy program in 2009 to improve accessibility and address market inefficiencies. Currently, subsidized fertilizer procurement and distribution are mainly handled by public enterprises, including Krishi Samagri Company Limited (KSCL) and Salt Trading Corporation Limited (STCL). Private sector only participate in import and sales of non-subsidized fertilizer.

Nepal's fertilizer sector is guided by several legal and policy instruments, including Fertilizer Control Order, 1999 (FCO, 1999), the Chemical Fertilizer Directive, 2000, the National Fertilizer Policy, 2002, and the Subsidized Fertilizer Distribution Directive, 2020. These frameworks govern fertilizer quality, import, distribution, and subsidy management. While, the procurement of subsidized fertilizers is carried out in accordance with the Public Procurement Act, 2007 and Public Procurement Regulation, 2007.

Despite its importance, the chemical fertilizer supply chain in Nepal has many problems (Panta, 2018). The country is almost entirely dependent on imports, mainly from India, China and Gulf countries making the supply system highly vulnerable to external market dynamics, trade policies and logistic disruptions. The complex procurement procedure, and limited storage infrastructure exacerbate the supply system resulting periodic shortage, particularly during peak planting season (Gautam *et al.,* 2022). Moreover, geographical constraints and inadequate transportation networks, worsen the distribution process especially in remote and mountainous regions (Bhandari & Neupane, 2021). At present, Nepal's fertilizer supply chain involves a complex network of international suppliers, government agencies, cooperatives, private distributors, and farmers (Panta, 2018). While KSCL and STCL play central roles in the import and distribution of subsidized fertilizer, they often struggle to meet national demand due to limited subsidy budgets, bureaucratic delays, and inadequate infrastructure.

In this context, effective supply chain management is essential to ensure the timely availability, accessibility, and equitable distribution of fertilizer across the country. Therefore, this study aims to analyze the structure, performance, barriers, and uncertainties of Nepal's chemical fertilizer supply chain and identify measures for improving its efficiency and reliability.

2. METHODOLOGY

This study examined the chemical fertilizer supply chain in Nepal with special focus on subsidized fertilizers over fiscal years 2013/14–2024/25. This study is primarily based on secondary information obtained from publications and records of the MoALD, KSCL, STCL.

Data on fertilizer procurement, total lead time, sales, subsidy expenditure, and distribution were compiled and analyzed. Relevant legal and policy documents were reviewed to assess the institutional and regulatory framework which guide fertilizer supply. Key informants were purposively selected from the MoALD, KSCL, and STCL based on their roles, experience, and involvement in fertilizer procurement, distribution, and policy implementation. A semi-structured questionnaire was used to collect qualitative information on procurement, distribution, policy, and operational challenges and uncertainties. The responses were analyzed thematically to identify key issues affecting fertilizer supply. In addition, published literature, journal articles, technical reports, and research studies related to fertilizer demand, supply chains, subsidy policies, and agricultural input management were reviewed to provide supporting evidence and contextual understanding. Descriptive statistics were applied to examine changes in supply, prices, lead time, subsidy spending, and provincial allocation patterns.

The study was primarily based on secondary data, and institutional records, which are subject to limitations in availability, completeness. Consequently, some analyses did not cover the entire study period.

3. RESULTS AND DISCUSSION

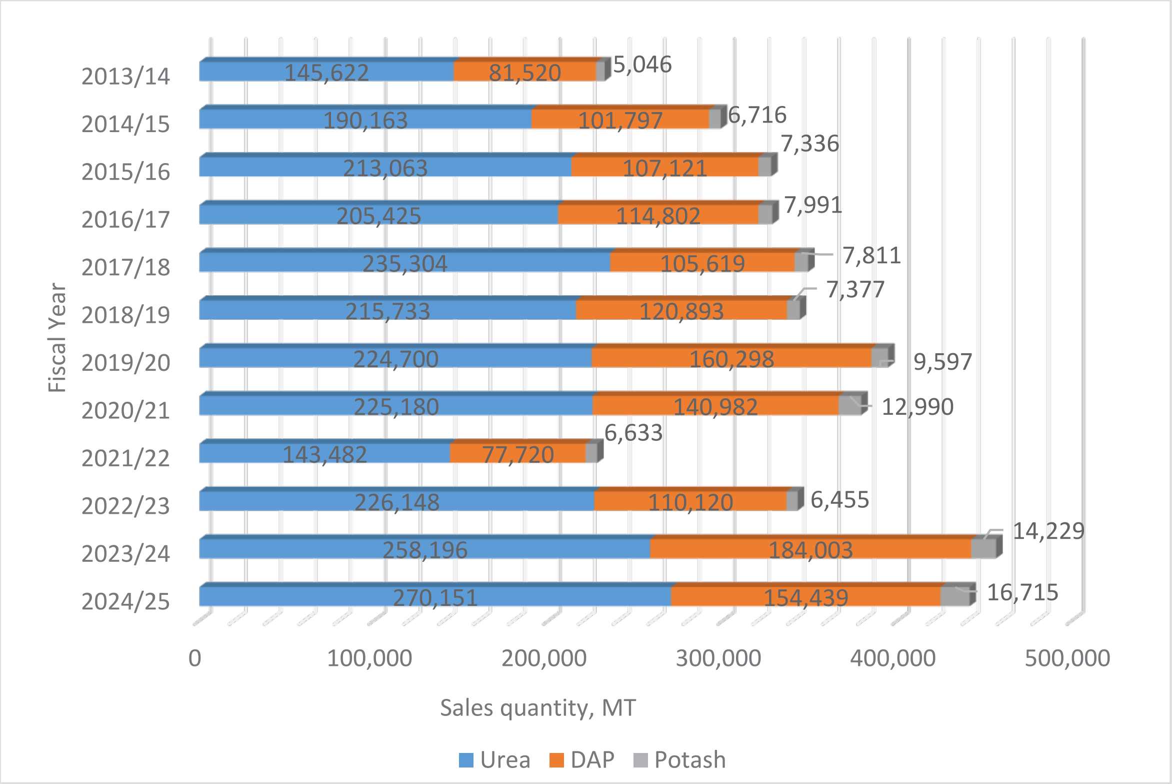
3.1 DEMAND AND SUPPLY OF CHEMICAL FERTILIZER IN NEPAL

Demand

The estimation of fertilizer demand in Nepal is complex task due to the absence of a systematic and scientific forecasting mechanism. It is believed that the substantial amount of fertilizer is informally imported from India, but the reliable database is not available. So it is challenging to calculate the effective demand in Nepal. Gautam *et al*. (2017) projected total effective demand of major fertilizer was 603,500 metric tons (MT). But Ghaire *et al*. (2022) reported that the technical requirement for major fertilizer was 1,296,799.02 MT, and estimated effective demand for major fertilizers (Urea, Diammonium phosphate (DAP), and Muriate of Potash (MoP)) at 520,000 MT. More recent estimates from MoALD revealed that the annual demand for subsidized chemical fertilizers has increased to approximately 800,000 MT (440,000 MT Urea, 280,000 MT DAP and 80,000 MT MoP). This estimates are based on crop-specific nutrient recommendations, Agriculture Census 2021 data, provincial demand assessments, and fertilizer sales trends over the past five years (MoALD,2026a).

Supply

Fertilizer sales scenario of last twelve year have shown a gradual but inconsistent upward trend rising from 232,878.89 MT in FY 2013/14 to 441,314.7 MT in FY 2024/25 (Figure 1). The share of Urea to total supply is consistently high, followed by DAP, while the supply of potash is minimal compared to other two. The supply trends showed a noticeable fluctuations, including a sharp decline in FY 2021/22, followed by a recovery in subsequent years, with the highest supply recorded in FY 2023/24 over the study period. Despite this overall increase, the total supply remains significantly below the estimated demand, indicating a persistent supply–demand gap.



Source: MoALD, 2025 and MoALD, 2026b

Figure 1. Subsidized fertilizer supply scenario during 2013/14 to 2024/25 (in metric tons)

COMPOSITION OF FERTILIZER BASKET

Over the last twelve years, the average composition of fertilizer supplied was 62% Urea, 35% DAP, and only 3% MoP (Figure 2). According to MoALD (2026a), the technically recommended shares of Urea, DAP, and MoP are 49%, 29%, and 22%, respectively. This deviation from these recommendations indicates that public-sector fertilizer supply system has prioritized Urea.

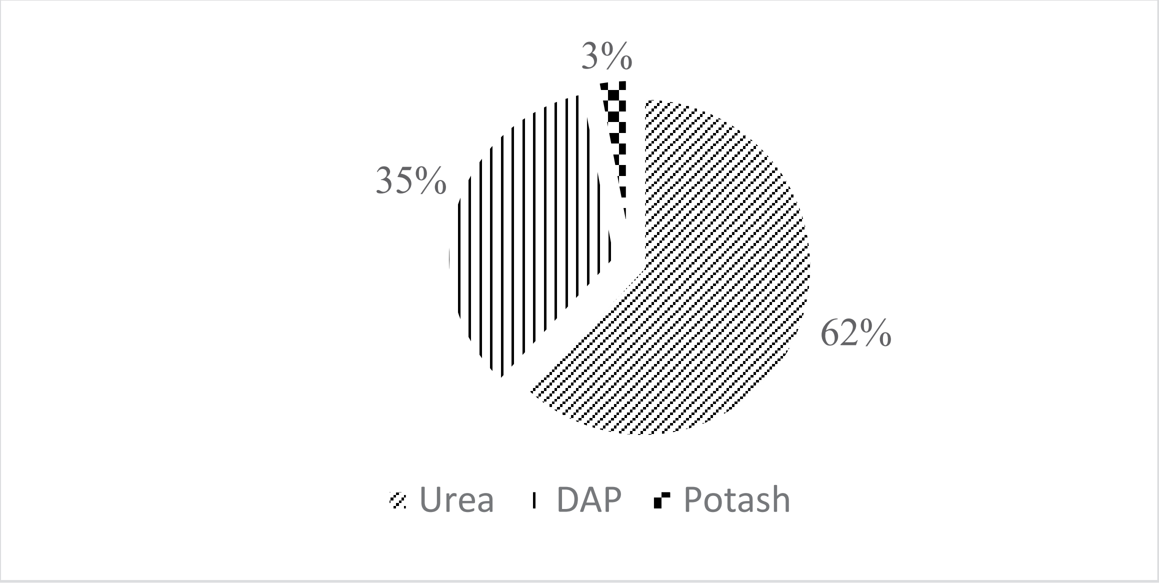


Figure 2: Share of Urea, DAP and MoP to total amount of subsidized fertilizer sales in Nepal (2013/14-2024/25)

3.2 PROCUREMENT PROCESS AND DURATION

Procurement process

The procurement process of subsidized fertilizer is a centralized, government-led system primarily managed by the MoALD, with operational responsibilities assigned to KSCL and STCL. This process starts with annual demand estimation based on provincial demand, followed by subsidy budget allocation.

The procurement process is solely based on the Public Procurement Act 2007 and its regulation, 2007. Usually global tender process of procurement is applied, but in case of urgency and supply shortage Government- to- Government agreement is also used.

In accordance with the Public Procurement Act, 2007 and its regulation, the current procurement process is time-consuming and needs to be defined as a stepwise process (Figure-3). Prior amendment procurement act in 2026 it demands 45 days for international competitive bidding, which is significant in the tender process. So the tender process has been one of the major drawbacks of the unsuccessful supply of fertilizer in Nepal (Ghaire *et al*., 2022).After the tender announcement, bids are evaluated on technical and financial criteria, and contracts are awarded to qualified suppliers.

PROCUREMENT PROCESS AS PER LEGAL PROVISION (BEFORE AMENDMENT)

	STEPS	DAYS REQUIRED
1	Cost estimate and bid document preparation	2
2	Tender notice	46
3	Technical evaluation	3
4	Financial proposal call	16
5	Financial evaluation	1
6	Letter of intent	7
7	Bid approval	1
8	Call for agreement	15
9	Performa Invoice submission	5
10	LC opening	7
11	Supply period after LC opening	107
	TOTAL DURATION	210

PROCUREMENT PROCESS AS PER LEGAL PROVISION (AFTER AMENDMENT ON ACT IN 2026)

	STEPS	DAYS REQUIRED
1	Cost estimate and bid document preparation	2
2	Tender notice	31
3	Technical evaluation	3
4	Financial proposal call	8
5	Financial evaluation	1
6	Letter of intent	7
7	Bid approval	1
8	Call for agreement	15
9	Performa Invoice submission	5
10	LC opening	7
11	Supply period after LC opening	107
	TOTAL DURATION	187

Source: KII, 2026

Figure 3: Procurement process and time requirement for each activities

Based on the contact agreement the selected suppliers then import fertilizers mainly via Indian transit routes followed by quality inspection at entry points. Then, fertilizers are distributed through KSCL and STCL warehouse to cooperatives, agro-vets for final delivery to farmers at subsidized rates. Prior to the 2026 amendment of the Public Procurement Act, the legally prescribed procurement process required approximately 210 days to complete procurement process, but after amendment, there is significant shorten in the tender notice duration and requires 187 days to complete process (Figure -3).

Procurement lead time

As per the Public Procurement Act and Regulations' provision (prior amendment) the procurement process should be completed within 210 days. But over the FY 2018/19–2024/25, it is found that the procurement lead time for fertilizer imports often differs considerably from standard. The average number of days taken to complete fertilizer imports (Urea, DAP, and MoP) over FY 2018/19–2024/25 is given in table-1. The average lead time taken to import Urea was 214–249 days in the early years but spiked sharply to 485 days in FY 2021/22, with extremely high variability, indicating major disruptions in procurement and logistics. The average day taken to import DAP was relatively more stable, ranging from about 140 to 239 days. Potash data are limited, but available figures have suggested moderate import durations.

The variation in procurement lead time might be due to the variation in supply period after letter of credit (LC) opening as tender publication, bid evaluation, contract signing, and LC opening step of procurement process need to be performed under established procedures and remain within the control of procuring agencies, but shipment period is influenced by external factors beyond control of procuring agency.

Table 1 Lead time taken to complete the import of fertilizer during 2018/19 to 2024/25

FY	Type of fertilizer	Average lead time taken to complete the import of fertilizer	Range, days	SD, days
2024/25	Urea	258.0	141-499	109.60
	DAP	220.6	183-273	42.41
	MoP	192.0	184-200	11.31
2023/24	Urea	295.5	87*-616	155.70
	DAP	167.5	103-232	91.22
	MoP	167.5	103-232	91.22
2022/23	Urea	183.9	104-236	50.42
	DAP	185.4	125-228	42.97
	MoP	NA	NA	NA
2021/22	Urea	485.2	104-1164#	507.94
	DAP	140.5	112-169	40.31
	MoP	249.0	NA	NA
2020/21	Urea	172.3	115-198	29.60
	DAP	239.0	174-318	64.36
	MoP	163.0	131-195	45.25

FY	Type of fertilizer	Average lead time taken to complete the import of fertilizer	Range, days	SD, days
2019/20	Urea	214.0	203-225	15.55
	DAP	223.0	NA	NA
	MoP	219.0	NA	NA
2018/19	Urea	248.7	230-260	16.28
	DAP	223	163-272	55.32
	MoP	NA	NA	NA

* Consignment of STCL (STCL as short procurement process compare to process prescribed in procurement act)

for this particular consignment producer country is China, during shipment time China banned export of fertilizer for some period, which extended shipment and delivery times beyond normal expectations.

Source: MoALD, 2026b

Delays in supply often occur when suppliers lack secured stocks or postpone shipments in response to international price fluctuations. Port congestion, railway wagon shortages, and transit bottlenecks further increase lead times (MoALD, 2021). In addition, global disruptions such as the COVID-19 pandemic, the Russia–Ukraine conflict, and export restrictions imposed by producing countries have adversely affected fertilizer supply chains (NewBiz Report, 2025). In many cases suppliers fail to fulfill contracts due to rising international prices, resulting in fertilizer shortages during critical agricultural seasons (NPC, 2022).

3.3 PROCUREMENT AND SUBSIDY

Purchase price

The procurement price of fertilizer in Nepal is determined through international competitive bidding, remains changing due to the regular change in price of fertilizers in international market. There was a 20.1 % increase in price of Urea with a CAGR of 3.45 % during last 12 year. While, the price of DAP increased by 38.3 % with a CAGR of 4.5 % in the same period. But The MoP price growth was somewhat slow and stable during the period. The table-2 highlights the increasing procurement price of fertilizer over time.

Table 2

Average procurement price of fertilizer during FY 2013/14 to 2024/25 (in Rs/ kg)

FY	Urea	DAP	Potash
2024/25	60.10	93.3	59.08
2023/24	60.3	94.09	59.25
2022/23	90.03	121.65	73.71
2021/22	96	124	106
2020/21	46	53	38
2019/20	40	54	46
2018/19	43	61	32

FY	Urea	DAP	Potash
2017/18	38	49	
2016/17	36	47	34
2015/16	41	58	39
2014/15	41	60	43
2013/14	40	55	53

Source: MoALD, 2026b

Procurement volume and subsidy budget

Fertilizer subsidy expenditure in Nepal increased nearly fivefold during FY 2013/14–2024/25, rising from NRs 5,328 million to NRs 26,839 million, though fertilizer procurement volume only approximately doubled with considerable annual fluctuations (Table-3). There was sharp increase in subsidy expenditure particularly after FY 2020/21, mainly due to global fertilizer price shocks associated with the Russia–Ukraine war and other supply chain disruptions. Although procurement volumes generally increased and reached a peak of 523,766 Mt in FY 2023/24, temporary supply disruptions caused a notable decline in FY 2021/22. Over the same period, data shows that the share of fertilizer subsidies to total agricultural budget has been increasing, rising from 18–30% before FY 2020/21 to more than 50% in recent years and the highest at 69% in FY 2022/23, indicating growing fiscal pressure.

However, this subsidy expenditure is not only influenced by external price factors and total quantity procured. As Nepal relies heavily on fertilizer imports, fluctuations in international fertilizer prices and depreciation of the Nepalese Rupee against the US Dollar substantially affected import costs. The exchange rate increased from NRs 94.8 per USD in FY 2013/14 to NRs 131.2 per USD in FY 2024/25, increasing the domestic cost of fertilizer imports. Since retail fertilizer prices are fixed under the subsidy program, these higher import costs were largely absorbed by the government, resulting in increased subsidy expenditures.

Table 3

Total procured quantity, subsidy budget, share of subsidy in the agriculture budget and average subsidy per kg during 2013/14 to 2024/25

FY	Procured quantity, MT	Total subsidy expenditure NRs (in million) (TSE)	Expenditure on the allocation of subsidy budget (%)(TSE/ TSB*100%	Subsidy budget as % total agriculture budget	Average subsidy, in NRs./kg (all product)
2024/25	486883	26839.32	98.08.	50.66	55
2023/24	523766	24345.32	84.9	54.54	46
2022/23	406233	31203.35	100	69.0 #	77
2021/22	177507	14396.76	87	37	81
2020/21	400209	9412.95	78	32	24
2019/20	395905	8315.02	79	30	21

2018/19	327488	8085.33	96	28	25
2017/18	338599	5991.32	125	20	18
2016/17	307771	4840.64	101	18	16
2015/16	293628	5668.08	104	25	19
2014/15	278082	5820.86	104	24	21
2013/14	273239	5328.02	93	27	19

NRs 150 million budget was allocated first, but more NRs 230 million was added later through source confirmation by the Ministry of Finance.TSB (total subsidy budget)

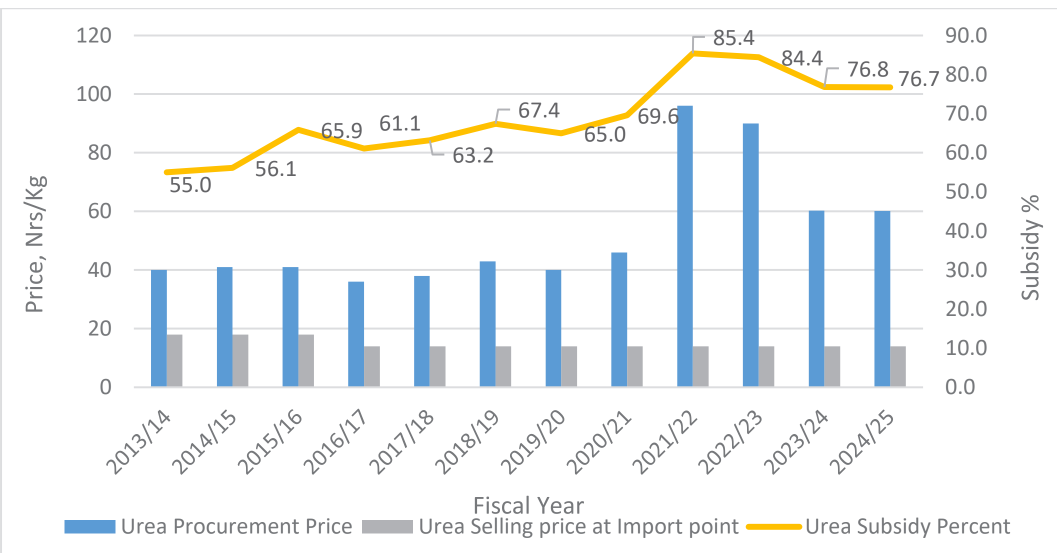
Source: MoALD, 2026b.

Moreover, data shows there was substantial fluctuations of average per kg subsidy given to subsidized fertilizer over the past 12 years (2013/14–2024/25 which was closely linked with changes in international purchase prices and exchange rate of USD. Overall, subsidy levels increased sharply from 2018/19 to a peak in 2021/22, then dropped in 2022/23 before partially stabilizing in 2023/24 (Table 3).

Subsidy by fertilizer type

For subsidy purposes, the government has fixed the selling price Rs 14, Rs 43 and Rs 31 per kg of Urea, DAP, and MoP respectively at the import point. The per-unit subsidy is calculated as the difference between the procurement price and the fixed selling price.

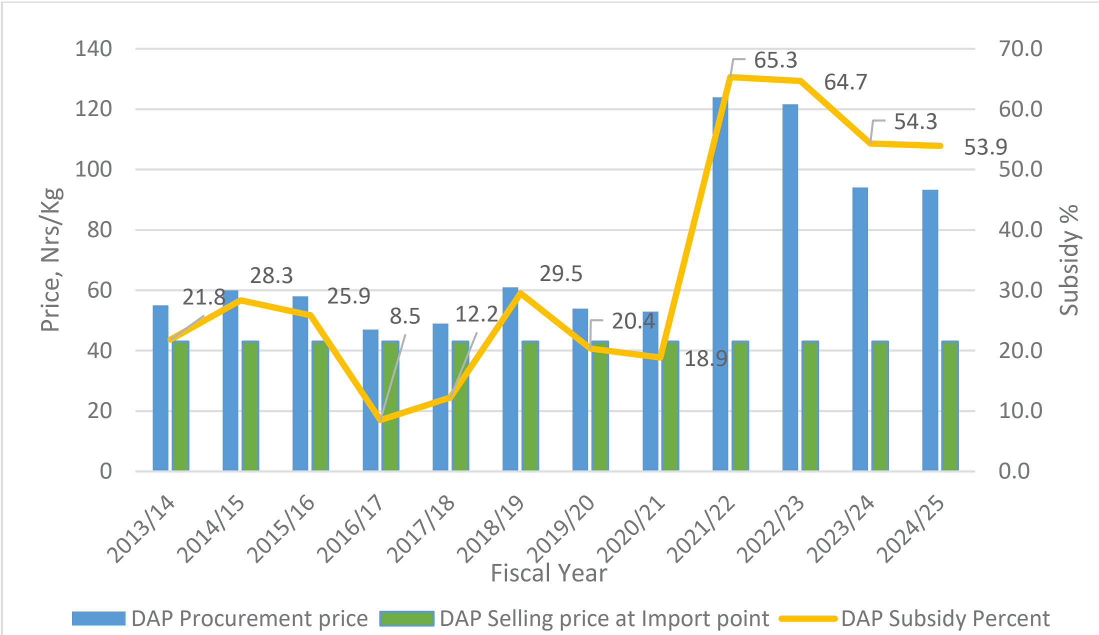
Figure 4 illustrates the trend of procurement price, selling price, and subsidy percentage for Urea over the study period (2013/14–2024/25).The average subsidy level for Urea was 68.9%, indicating a substantial and sustained fiscal commitment by the government to maintain affordable prices for farmers. This subsidy was at the lowest point at 55.0 % in 2013/14 and reached a peak of 85.4 % in 2021/22 and showed decline in subsequent year.



Source: MoALD, 2026b

Figure 4: Procurement price, selling price and subsidy % for Urea over study period (2013/14-2024/25)

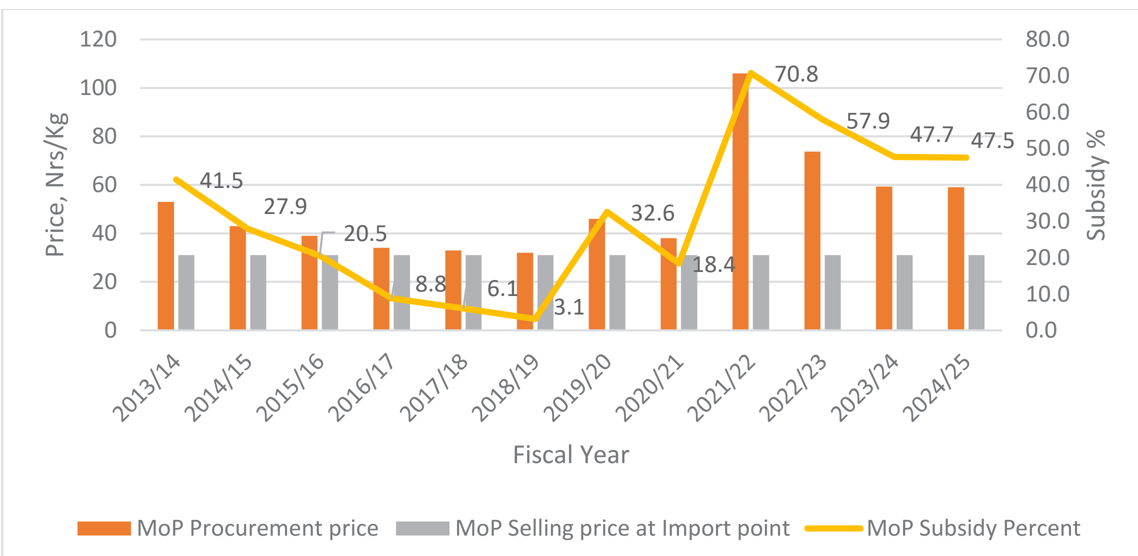
Compared to Urea, DAP consistently received a lower level of subsidy, with an average subsidy of 33.6% during the study period (Figure-5). The subsidy was lowest level at 8.5 % in 2016/17 and highest at 65.3 % in 2021/22 and the subsidy percentage declined in subsequent years.



Source: MoALD, 2026b

Figure 5: Procurement Price, selling price at import point and subsidy percent for DAP over study period (2013/14-2024/25)

For MoP, subsidy was consistently low as compare to Urea and DAP, with average of 31.9% over the period of FY 2013/14-2024/25. It showed continually declining and reached lowest at 3.1% in 2018/19. However, the subsidy increased sharply thereafter, peaking at **70.8% in 2021/22,** and declined in subsequent years due to the reduction in procurement costs.



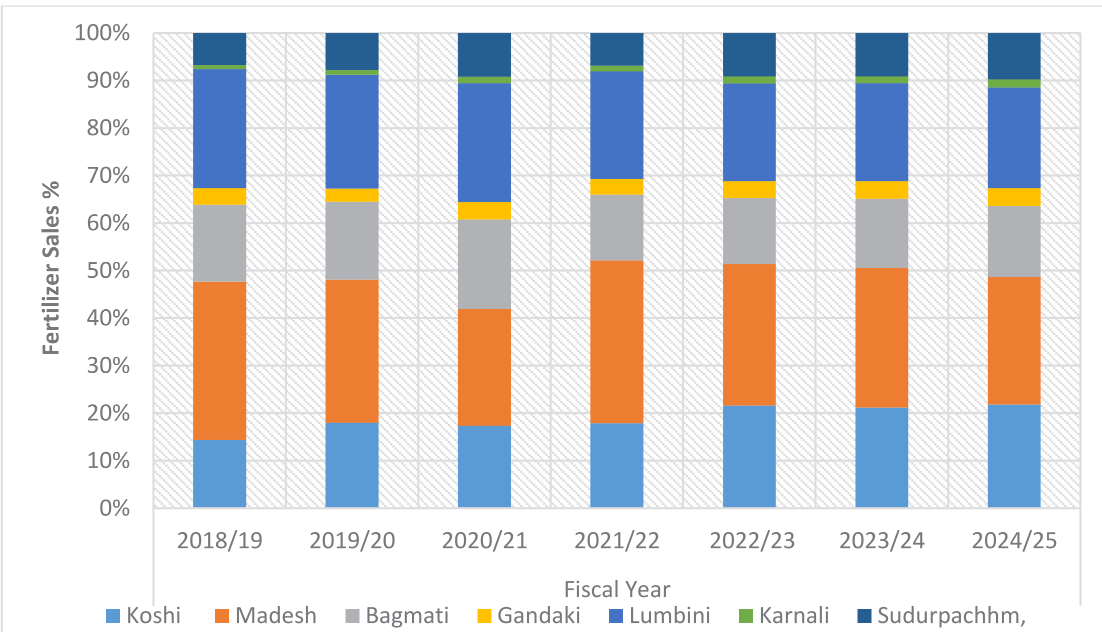
Source: MoALD, 2026b

Figure 6: Procurement price, selling price and subsidy % for MoP over study period (2013/14-2024/25

3.4 DOMESTIC DISTRIBUTION SYSTEM

Nepal's fertilizer distribution system follows a multi-tier structure guided by the Subsidized Fertilizer Distribution Directive and Procedure (GoN, 2020; GoN 2025). The federal committee, Fertilizer Supply and Distribution Management Committee allocates fertilizer quota among provinces based on agricultural indicators such as cultivated area, cropping intensity, irrigation coverage, and commercialization. About 10% of imports are maintained as buffer stock, while the remaining 90% is distributed through provincial and local mechanisms.

Subsequently, provincial-level distribution committees further disaggregate these quotas to local levels, where local committees are responsible for identifying authorized distributors and supervising end user delivery. The operational distribution is primarily managed by KSCL and STCL through their provincial and district offices. Fertilizers are transported from import points to provincial warehouses, then to district-level depots, and finally distributed to cooperatives and private agro-dealers at the village level according to allocated quotas. Transportation services are procured in compliance with the Public Procurement Act 2007 and its regulations, ensuring standardized procedures for contractor selection and pricing. Additionally, distribution agencies have adopted digital systems to improve transparency and tracking in distribution.



Source: MoALD, 2025, MoALD, 2026b

Figure 7: Province wise sales percentage of total sales of subsidized fertilizer

The provincial distribution pattern of total fertilizer sales revealed remarkable regional disparities over recent fiscal years (FY 2018/19-2024/25) (Figure-7). Madhesh province consistently have received the largest share, followed by Koshi and Lumbini provinces, each receiving around 21–22% of total sales. Similarly, Bagmati province showed a moderate but gradually increasing share, rising from about 14% to 18%, possibly due to expanding peri-urban agriculture and commercialization. In contrast, Gandaki province and Karnali received a relatively smaller share, Sudurpashchim (Far West) province received a stable share of around 9–10%. The distribution trend suggests that fertilizer allocation in Nepal is closely aligned with agricultural potential and production needs, although regional inequalities persist due to geographical and structural differences. According to fertilizer sales data for FY 2024/25, the application rate of subsidized fertilizer varied considerably across provinces. Madhesh Province recorded the highest use at 218 kg/ha, followed by Lumbini (172 kg/ha), Bagmati (170 kg/ha), Sudurpashchim (138 kg/ha), Koshi (135 kg/ha), Gandaki (45 kg/ha), and Karnali (34 kg/ha).

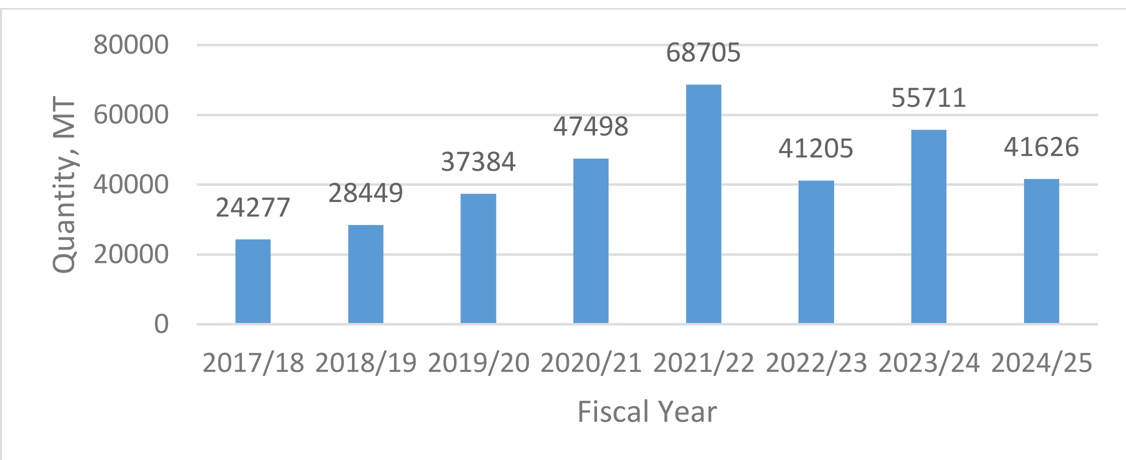
3.5 QUALITY ASSURANCE MECHANISM

Fertilizer Control Order, 1999 has specified quality aspects of chemical fertilizer to be imported in Nepal. The fertilizer trading enterprise has to provide quality assurance certificate issued by producer, independent international surveyor at load port and at the custom entry point. Custom authorities only allow entry once importer provide quality assurance certificate.

FCO, 1999 has provision of surveyor, who issued certificate of the quality, quantity and labeling and packing of imported fertilized whether it is as per FCO or not. The FCO has set standards to ensure the quality of fertilizers imported into the country. These standards have specified the permissible nutrient content, physical properties, and labeling requirements that fertilizers must meet. By following this guidelines, the FCO has ensured only high-quality fertilizers are available to farmers, promoting agricultural productivity and environmental safety. Moreover, the government has appointed fertilizer inspectors, to regulate and control the quality of fertilizer in distribution point.

3.6 PRIVATE SECTOR PARTICIPATION

FCO, 1999, regulate the import and distribution of chemical fertilizer in Nepal, which allows all state and private actors to participate in fertilizer supply management. In case of subsidized fertilizer, the ground is not leveled as subsidy is only disbursed for STCL and KSCL supplies. Therefore, the private sector cannot participate in the Urea, DAP and MoP supplies as the price is so high without subsidy. But in case of non-subsidized fertilizers total supplies managed by private sector.



Source: Author compilation based on data of custom department

Figure 8 Non subsidized chemical fertilizer imported by private sectors over FY 2017/18 to 2024/25

The figure 8 presents the volume of non-subsidized chemical fertilizer imported by the private sector in Nepal over seven fiscal years (2018/19–2024/25). Overall, the data shows an increasing trend with some fluctuations in imported quantities. The imports increased from 24,277 Mt in 2017/18 to a peak of 68,705 Mt in 2021/22, reflecting the growing role of private traders in fertilizer supply. However, imports subsequently declined to 41,205 Mt in 2022/23, recovered to 55,711 Mt in 2023/24, and fell again to 41,626 Mt in 2024/25, indicating year-to-year volatility. These fluctuations may be attributed to changing market conditions, policy environments, and the availability of subsidized fertilizers. Although the private sector has consistently supplied NPK-containing fertilizers, the variability in import volumes suggests that its contribution to the national fertilizer supply remains unstable.

In case of subsidized fertilizer private sector is participate in end user distribution. The Subsidized Fertilizer Distribution Directives, 2020 end the monopoly of cooperatives, allowing local government to license private sector companies and firms to distribute fertilizer along with cooperatives. Thus, private sector involvement have led to a more equitable and efficient distribution of subsidized fertilizer (Thapa *et al.,* 2023)

3.7 CHALLENGES AND UNCERTAINTIES

This study identified several challenges and uncertainties affecting the fertilizer supply chain in Nepal. Key informant interviews revealed Nepal's fertilizer supply system faces persistent challenges, cumbersome import and multilayer distribution mechanisms, inadequate infrastructure, budget constraints, and poor demand forecasting. These issues lead to delayed delivery to farmers and threaten food security.

Table 4

Thematic analysis of key informant interview on challenges and uncertainties of Nepal's chemical fertilizer supply chain

Theme	**Key issues identified by Key Informants**	**Implication in Fertilizer Supply chain**
Weak Demand Forecasting Systems	Lack of reliable demand data, limited information systems	Supply-demand mismatches and recurrent fertilizer shortages during peak cropping seasons
Procurement and Distribution Inefficiencies	Lengthy procurement procedures, insufficient subsidy budget, multiple administrative layers, weak coordination among agencies	Delayed fertilizer procurement and distribution, resulting in untimely availability to farmers
Infrastructure and Logistics Constraints	Limited storage, poor inland transport, inefficient port handling	Increased costs, longer delivery times, and reduced responsiveness to seasonal demand

Theme	Key issues identified by Key Informants	Implication in Fertilizer Supply chain
Market and Institutional Challenges	Weak regulatory capacity, limited private sector participation, cross-border smuggling from India, quality control concerns	Market distortions, unfair competition, and risk of substandard fertilizer products, reducing competition and efficiency.
External Dependency and Supply Chain Uncertainty	Dependence on imports, international price fluctuation, exchange rate fluctuations, export restrictions, geopolitical disruptions	Uncertainty in fertilizer availability, affordability, and supply stability

Source: KII, 2026

This analysis of challenges and uncertainties was primarily based on perceptions and experiences shared by a limited number of key informants from government agencies and fertilizer-importing institutions. So, this findings may not fully capture the views of other stakeholders, including private sector actors, transport service providers, local distributors, and farmers.

4. CONCLUSION AND RECOMMENDATION

The chemical fertilizer supply chain in Nepal remains heavily import dependent, and operationally inefficient. Despite significant government investment on subsidies, there is always issues of delayed and inconsistent supply. The huge gap between demand and supply highlights poor planning and execution. Procurement lead time, averaging over seven months, significantly disrupt timely availability of, particularly during peak seasons. Almost no participation of private sector and dominance of state agencies has constrained competition within the supply chain. At the same time, the increasing share of fertilizer subsidies to total agriculture budget has raised questions about the government's ability to allocate subsidy budget in long run.

This study suggest that Nepal's fertilizer supply chain needs a comprehensive reform focused on efficiency, sustainability. Shortening procurement procedures and introducing multi-year contracts can reduce delays and ensure timely supply. Strengthening demand forecasting systems based on crop patterns and regional needs is essential for accurate planning. Investment in storage, transportation, and distribution infrastructure particularly in remote areas will enhance timely availability at end user level. Ensuring private sector participation through policy and subsidy reforms can improve competition and system efficiency. Regular sales price adjustment as per the international price can help to address the issue of fiscal burden. At the same time, use of voucher system to better target smallholder farmers. Strengthening monitoring and regulatory mechanisms is critical to control illegal imports and ensure fertilizer quality.

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SCREENING OF GINGER GENOTYPES AGAINST RHIZOME FLY, *Mimegralla sp.* (DIPTERA: MICROPEZIDAE) IN KAPURKOT, SALYAN, NEPAL

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ABSTRACT

An experiment was conducted to evaluate 25 indigenous ginger genotypes against rhizome fly, Mimegralla sp. at the Ginger Research Program, Kapurkot, Salyan, Nepal in 2024/25 and 2025/26. Planting was done at the crop geometry of 30 cm x 30 cm in the plot size of 3 m x 0.6 m (1.8 m2) during the last week of March and each experimental plot was replicated thrice in Randomized Complete Block Design (RCBD). Tiller number, plant height and rhizome fly infected plants scoring were recorded at the full crop growth stages whereas rhizome yields were recorded during harvesting. The rhizome fly infestation was scored by using 1 -5 scoring scale (GRP, 2014), as 1 = not infected, 2 = 0 to 25% infected, 3 = 25 – 50% infected, 4 = 50 – 75% infected and 5 = 75 – 100% infected rhizome. Analysis of variance (ANOVA) was employed to detect significant differences and mean comparisons was done by Duncan's Multiple Range Test (DMRT). Significant difference occurred among the ginger genotypes in terms of growth traits, pest infestation levels, and fresh rhizome yields. Ginger genotypes ZI 9805, ZI 0403 and ZI 0515 produced significantly the highest fresh rhizome yield (27.07-27.56 t/ha, 24.49-27.50 t/ha and 24.39-27.20 t/ha, respectively). Ginger genotypes ZI 9805 was found highly promising for lower rhizome fly infestation (0.0-0.5% rhizome fly infested, 1.0 rhizome fly scoring, 0.13-0.33 maggots/rhizome, 0.07-0.20 pupae/rhizome and 0.40-0.41 t/ha rhizome fly infested ginger) and higher ginger rhizome yield (27.07-27.56 t/ha fresh ginger) followed by fly tolerant genotype ZI 0403 (24.49-27.50 t/ha fresh ginger). The results indicated that utilizing resistant and tolerant genotypes like ZI 9805 and ZI 0403 could be the sustainable strategy to mitigate pest damage and increase production/productivity of ginger in Nepal.

Keywords: *Maggots, pupae, resistant, rhizome fly incidence, rhizome yield and tolerant*

INTRODUCTION

Ginger, *Zingiber officinale* (Roscoe, 1807) is a high-value spice and medicinal crop in Nepal with great export potential (FAO, 2023). However, the average productivity of ginger is very low (12.98 t/ha) in Nepal as compared to its potentiality (30 t/ha) of released Kapurkot Aduwa-1 variety (GRP, 2024; MoALD, 2024). This high yield gap is primarily caused by poor crop management, unavailability of high-quality seed of ginger variety and biotic factors (Gautam,

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2025). In Nepal, ginger production faces various challenges, like crop management practices and variety selection resistance/tolerant to biotic factors. The productivity and quality of ginger are significantly influenced by various crop management practices including variety selection (Kandiannan et al., 2009).

The ginger rhizome fly, *Mimegralla sp.* (Macquart 1844) is the devastating pests that causes significant yield losses and is becoming serious threat in major ginger growing districts of Nepal with the maximum infestation of 31.12% (Gautam & Acharya, 2014; Gautam et al., 2021). In Nepal, some chemical pesticides like chlorpyrifos have been recommended for ginger rhizome fly management but they pose pesticide residue in final products which is the main limiting factor for export of Nepalese ginger to international market, for which organic and quality standard are compulsory (GoN, 2016; Gautam & Ahamad, 2020).

A significant research gap exists in the Nepalese context regarding the development and identification of pest-resistant genotypes. In the past, most of the studies were focused on chemical management rather than systematic screening of indigenous landraces. There is a lack of systematic, multi-year screening of indigenous landraces and germplasm to identify genotypic resistance or tolerance against the *Mimegralla* species. Studies conducted in India (specifically Kerala and Karnataka) have identified that certain cultivars, such as 'Rio-de-Janeiro' and 'Humnabad local,' exhibit lower infestation rates, suggesting that varietal selection is a viable and sustainable management strategy (IISR, 2018). However, the performance of Nepalese indigenous genotypes under local climatic conditions at various altitudes remain largely undocumented. To address this gap, the current study was carried out to evaluate 25 indigenous ginger genotypes at the Ginger Research Program in Kapurkot, Salyan during 2024/025 and 2025/026. The objective of this varietal screening was to identify promising genotypes with field resistance to the rhizome fly and high-yield potential, thereby providing a pesticide-free solution for sustainable ginger production while enhancing Nepal's export competitiveness in the global market.

MATERIALS AND METHODS

Two years field experiments were conducted at Ginger Research Program, Kapurkot (870 masl, $27^0$58'25" N latitude and $83^0$25'30" E longitude), Salyan during 2024/025 and 2025/026 to screen the promising ginger genotypes against ginger rhizome fly. Total 25 indigenous ginger genotypes [ZI 9304, ZI 9805, ZI 0403, ZI 0515, ZI 1007, ZI 1010, ZI 1025, ZI 1026, ZI 1302, ZI 1303, ZI 1609, ZI 1616, ZI 1620, ZI 1904, ZI 1905, ZI 1906, ZI 2201, ZI 2401, ZI 2402, ZI 2403, ZI 2404, ZI 2405, ZI 2406, including standard check Kapurkot Aduwa-1 (KK-1) and Kapurkot Aduwa-2 (KK-2)] collected from Ginger Research Program, Kapurkot, Salyan were used in this study. The temperature during the germination period ranged from minimum 12.90^0C in February to maximum 30.03^0C in June with cumulative rainfall 74.00 mm and average relative humidity 62.25%. Similarly, during the full crop growth stages from July to September the temperature ranged from minimum 19.63^0C in September to maximum 26.97^0C in July with cumulative rainfall 1744.30 mm and average relative humidity 73.70%.

Planting of 60 g seed rhizome size was done at the spacing of 30 cm x 30 cm in the plot size of 3 m x 0.6 m (1.8 m^2) during the last week of March, and each experimental plot was replicated thrice in Randomized Complete Block Design (RCBD). Recommended doses of manure and fertilizers were applied @ 30 t FYM and 75: 50: 50 kg NPK per hectare, respectively. Full dose of FYM, phosphorus and half dose of potash was applied as a basal dose in furrow before planting of rhizome. The half dose of nitrogen was applied through side dressing one months after germination. The remaining half dose of potash and nitrogen was applied after two months of germination. Immediately after planting 10-15 cm thick dry leaves mulching was done with wooden sticks over the mulch to protect from wind. Manual weeding and hoeing were done two times first at one month and second at two months after ginger germination. No irrigation was used during the ginger growing period. Data on yield attributing traits, such as tiller number, plant height and rhizome fly infected plants scoring were recorded at the full growth stages of crop during the last week of September. Infected rhizome yield and fresh rhizome yield were recorded. The rhizome fly infestation was scored by using 1 -5 scoring scale (GRP, 2014), as 1 = not infested, 2 = 0 to 25% infested, 3 = 25 – 50% infested, 4 = 50 – 75% infested and 5 = 75 – 100% infested rhizome. The plants were harvested during the last week of November when the leaves were dry and pseudo stem fallen down. Data on maggot and pupal number per infected rhizome and various categories of rhizome yield were recorded. Data were entered in Microsoft Excel and analyzed using Statistical Tool for Agricultural Research (STAR) version 2.0.1 (IRRI, 2017). Analysis of variance (ANOVA) was employed to detect significant differences among ginger rhizome seed sizes and varietal traits, and mean comparisons by Duncan's Multiple Range Test (DMRT), and Least Significant Differences (LSD) for all significant traits (Gomez & Gomez, 1984).

RESULTS

Expression of ginger genotypes in relation to yield traits and rhizome fly incidence

Evaluation of 25 ginger genotypes screening against ginger rhizome fly at the Ginger Research Program in Kapurkot is shown in Figure 1. The effect of 25 indigenous ginger genotypes during 2024/025 and 2025/026 revealed significant different yield attributing traits and rhizome fly incidence (Table 1). Statistically significant differences were observed among all evaluated parameters, including germination percentage, tiller number, plant height, and rhizome fly infestation, which were significantly influenced by the genotype in both years. Among tested genotypes, 100% ginger germination percentage was found in ZI 2403 during 2024/025 and in ZI 9805 during 2025/026. The tiller number was found consistently the highest in ZI 1303 genotype in both years (14.93 and 14.53 during 2024/25 and 2025/26, respectively). The genotypes ZI 9805 (71.67–72.00 cm) and KK-2 (68.00–71.00 cm) were the tallest, whereas ZI 1906 (55.33–56.00 cm) and ZI 1025 (56.33–57.67 cm) were the dwarf genotypes. The rhizome flies infested plant percentage significantly differed from 0.00 – 5.00% in ZI 9805 to 16.15 – 21.46% in ZI 0515 genotypes. The genotypes ZI 9805 was found highly promising with minimum (0.00 – 5.00%) infested plants and the low infestation score (1.00).

Figure 1: Screening of ginger genotypes against rhizome fly at Kapurkot, Salyan during 2024/25 and 2025/26

Table 1: Yield attributing traits and rhizome fly incidence of ginger genotypes at Kapurkot, Salyan during 2024/25 and 2025/26

Genotypes	Germination (%)		Tiller (No./plant)		Plant height (cm)		Rhizome fly infested plant (%)		Rhizome fly scoring (1-5 scale)	
	2024/25	2025/26	2024/25	2025/26	2024/25	2025/26	2024/25	2025/26	2024/25	2025/26
ZI 9304	93.33^{a-d}	96.67^{ab}	13.27^{a-c}	14.13^{a-d}	66.33^{a-e}	69.00^{a-c}	7.05^{c-h}	5.19^{f}	1.33^{de}	1.33^{cd}
ZI 9805	95.00^{a-c}	100.00^{a}	13.33^{ab}	14.33^{a-c}	72.00^{a}	71.67^{a}	0.00^{h}	5.00^{f}	1.00^{e}	1.00^{d}
ZI 0403	90.00^{a-e}	96.67^{ab}	13.00^{a-e}	14.07^{a-e}	66.67^{a-d}	69.33^{a-c}	14.69^{a-c}	15.53^{a-c}	2.00^{b-d}	1.67^{b-d}
ZI 0515	86.67^{b-g}	93.33^{ab}	13.10^{a-d}	14.00^{a-e}	64.67^{b-g}	67.00^{a-d}	21.46^{a}	16.15^{ab}	1.33^{de}	2.00^{a-c}
ZI 1007	88.33^{b-f}	90.00^{b-d}	11.60^{b-i}	11.80^{a-f}	60.33^{e-j}	62.67^{d-g}	3.98^{f-h}	7.35^{d-f}	1.33^{de}	1.33^{cd}
ZI 1010	96.67^{ab}	95.00^{ab}	10.67^{g-i}	11.60^{b-f}	58.33^{h-j}	58.33^{f-h}	7.04^{c-h}	8.63^{d-f}	1.33^{de}	1.33^{cd}
ZI 1025	88.33^{b-f}	90.00^{b-d}	12.27^{b-h}	12.60^{a-f}	56.33j	57.67^{gh}	15.07^{ab}	18.46^{a}	2.33^{bc}	2.00^{a-c}
ZI 1026	91.67^{a-d}	91.67^{a-c}	11.20^{d-i}	11.47^{d-f}	58.33^{h-j}	58.00^{gh}	7.15^{b-h}	10.92^{b-f}	1.33^{de}	1.33^{cd}
ZI 1302	85.00^{c-g}	90.00^{b-d}	10.93^{f-i}	11.00f	57.00^{ij}	59.67^{e-h}	6.02^{d-h}	7.42^{d-f}	1.67^{c-e}	2.00^{a-c}
ZI 1303	88.33^{b-f}	95.00^{ab}	14.93^{a}	14.53^{a}	69.33^{ab}	70.33^{ab}	9.48^{b-g}	8.79^{d-f}	1.00^{e}	1.33^{cd}
ZI 1609	85.00^{c-g}	90.00^{b-d}	10.40^{hi}	10.87^{f}	57.33^{ij}	58.00^{gh}	13.75^{a-d}	11.34^{b-f}	2.67^{ab}	2.33^{ab}
ZI 1616	85.00^{c-g}	90.00^{b-d}	11.73^{b-i}	12.20^{a-f}	65.00^{b-g}	64.00^{c-f}	5.56^{e-h}	11.03^{b-f}	1.00^{e}	1.00^{d}
ZI 1620	80.00^{e-g}	83.33^{cd}	13.07^{a-d}	12.93^{a-f}	67.67^{a-c}	69.33^{a-c}	10.31^{b-g}	12.04^{a-e}	1.33^{de}	1.67^{b-d}
ZI 1904	78.33^{fg}	81.67^{d}	12.73^{b-f}	12.80^{a-f}	68.00^{a-c}	68.67^{a-c}	6.25^{d-h}	10.05^{b-f}	2.00^{b-d}	2.00^{a-c}
ZI 1905	76.67^{g}	83.33^{cd}	11.00^{e-i}	11.07^{f}	59.67^{f-j}	60.33^{e-h}	8.61^{b-g}	10.05^{b-f}	1.00^{e}	1.33^{cd}
ZI 1906	91.67^{ad}	96.67^{ab}	11.93^{b-h}	12.27^{a-f}	55.33^{j}	56.00^{h}	10.85^{b-g}	13.70^{a-d}	2.33^{bc}	2.00^{a-c}

Genotypes	Germination (%)		Tiller (No./plant)		Plant height (cm)		Rhizome fly infested plant (%)		Rhizome fly scoring (1-5 scale)	
	2024/25	2025/26	2024/25	2025/26	2024/25	2025/26	2024/25	2025/26	2024/25	2025/26
ZI 2201	86.67^{b-g}	90.00^{b-d}	10.73^{f-i}	11.27^{ef}	59.00^{g-j}	60.00^{e-h}	13.75^{a-d}	12.84^{a-e}	2.33^{bc}	2.00^{a-c}
ZI 2401	85.00^{c-g}	91.67^{a-c}	13.40^{ab}	10.40f	64.33^{b-h}	65.33^{b-e}	11.90^{b-f}	10.92^{b-f}	1.67^{c-e}	1.33^{cd}
ZI 2402	90.00^{a-e}	91.67^{a-c}	12.20^{b-h}	13.13^{a-f}	67.67^{a-c}	67.67^{a-d}	9.62^{b-g}	9.34^{c-f}	1.33^{de}	1.33^{cd}
ZI 2403	100.00^{a}	96.67^{ab}	11.27^{c-i}	11.53^{c-f}	62.67^{c-i}	62.33^{d-g}	3.33^{g-h}	6.93^{ef}	1.00^{e}	1.33^{cd}
ZI 2404	83.33^{d-g}	91.67^{a-c}	10.73^{f-i}	10.40^{f}	61.00^{d-j}	62.00^{d-g}	12.50^{b-e}	9.16^{c-f}	2.67^{ab}	1.67^{b-d}
ZI 2405	93.33^{a-d}	91.67^{a-c}	10.27^{hi}	11.07^{f}	60.33^{e-j}	60.00^{e-h}	3.52^{gh}	9.11^{c-f}	1.33^{de}	1.33^{cd}
ZI 2406	90.00^{a-e}	91.67^{a-c}	9.73^{i}	10.47^{f}	60.67^{d-j}	62.67^{d-g}	5.57^{e-h}	9.06^{c-f}	1.33^{de}	1.33^{cd}
KK-1	90.00^{a-e}	96.67^{ab}	12.47^{b-g}	14.40^{ab}	65.33^{b-f}	67.67^{a-d}	11.23^{b-g}	10.35^{b-f}	3.33^{a}	2.67^{a}
KK-2	85.00^{c-g}	98.33^{ab}	13.60^{ab}	14.07^{a-e}	68.00^{a-c}	71.00^{ab}	7.87^{b-h}	6.84^{ef}	1.67^{c-e}	1.33^{cd}
Mean	88.13	92.13	11.98	12.34	62.85	63.95	9.06	10.25	1.67	1.60
CV (%)	8.03	6.49	10.50	13.99	6.05	5.61	53.78	38.55	32.19	32.84
P-Value	*	*	**	*	**	**	**	*	**	*
LSD(0.05))	11.61	9.81	2.07	2.83	6.24	5.89	8.00	6.48	0.88	0.86

*Note: ZI=Zingiber indigenous, KK-1=Kapurkot Aduwa–1, KK-2=Kapurkot Aduwa – 2, *=Significant, **=highly significant, CV=Coefficient of variation, LSD=Least significant different*

Reactions of ginger genotypes on rhizome fly incidence and rhizome yield

The maggots and pupae population as well as different categories of harvested ginger rhizome showed highly significant variation among the genotypes (Table 2). The consistently minimum maggots (0.07 – 0.33 maggots/rhizome) and pupae (0.07 – 0.33 pupae/rhizome) numbers were found in ZI 2403 and ZI 9805. The highest number of maggots was found in ZI 0515 (8.40 - 9.27) and ZI 0403 (6.40 - 7.60). Similarly, the pupae count was found the highest in ZI 0403 (3.73 and 4.60) and ZI 0515 (3.27 and 4.00). Mother rhizome yield was found significantly higher in ZI 1302 (4.56 t/ha) followed by ZI 1302 (4.19 t/ha). The lowest rhizome fly infested yield (0.25 -0.57 t/ha) was found in genotypes ZI 2403, ZI 9304, ZI 9805, ZI 2405 and ZI 2402. The released ginger variety KK-1 and genotypes ZI 1025, ZI 0515, ZI 2401ZI 1616, ZI 1010 and ZI 1906 were found more prune (rhizome fly infested yield of 1.47 – 2.18 t/ha during 2024/25 and 1.50 – 2.03 t/ha in 2025/26) to ginger rhizome fly. Fresh rhizome yield was significantly affected by the genotype where ZI 9805, ZI 0403, ZI 0515, ZI 1904, ZI 2402 and KK-2 were found superior with the yield potential of 23.44 -27.56 t/ha in both the experimental years. During 2024/25, the highest fresh yield (27.56 t/ha) was recorded in genotype ZI 9805 followed by ZI 2402 (24.93 t/ha) and KK-2 (24.80 t/ha) whereas ZI 0403 produced the highest fresh yield (27.50 t/ha) in the 2025/26. Ginger genotype 9805 was found highly promising as it was more tolerant to rhizome fly and had higher yield.

Among the screened genotypes, seven promising genotypes are shown in Figure 2. A notable observation was the yield performance of ZI 0403, which resulted in the highest fresh yield (27.50 t/ha) despite having a moderate infection score (1.67-2.00). This genotype is more tolerant and maintains high productivity even under low pest pressure.

Figure 2: Fresh rhizome yield of promising ginger genotypes at Kapurkot, Salyan during 2024/25 and 2025/26

Table 2: Rhizome fly infestation and fresh yield of ginger genotypes at Kapurkot, Salyan during 2024/25 and 2025/26

Genotypes	Maggots (No/ rhizome)		Pupae (No/ rhizome)		Rhizome yield (t/ha)					
					Mother		Rhizome fly infested		Fresh rhizome	
	2024/25	2025/26	2024/25	2025/26	2024/25	2025/26	2024/25	2025/26	2024/25	2025/26
ZI 9304	0.27^{i-k}	0.22^{f}	0.13^{hi}	0.27^{jk}	2.11^{h-l}	2.20^{h-k}	0.35^{lm}	0.43^{j-l}	22.99^{a-c}	25.39^{a-c}
ZI 9805	0.13^{jk}	0.33^{f}	0.07^{i}	0.20^{k}	2.55^{e-j}	2.60^{f-j}	0.41^{k-m}	0.40^{kl}	27.56^{a}	27.07^{ab}
ZI 0403	6.40^{c}	7.60^{b}	3.73^{a}	4.60^{a}	2.89^{b-h}	2.70^{f-i}	1.84^{b}	1.73^{ab}	24.49^{ab}	27.50^{a}
ZI 0515	8.40^{a}	9.27^{a}	3.27^{b}	4.00^{b}	4.04^{ab}	4.17^{a-c}	1.93^{ab}	1.86^{ab}	24.39^{ab}	27.20^{ab}
ZI 1007	0.47^{g-j}	0.54^{f}	0.27^{g-i}	0.27^{jk}	3.04^{d-g}	3.21^{d-g}	1.20^{de}	1.19^{d-f}	14.85^{e-i}	16.37^{f-j}
ZI 1010	0.67^{f-h}	1.07^{f}	0.47^{fg}	0.80^{f-h}	4.49^{a}	4.56^{a}	1.61^{bc}	1.55^{b-d}	16.67^{d-g}	17.13^{e-j}
ZI 1025	7.13^{b}	5.68^{c}	3.07^{b}	3.27^{c}	1.11^{m}	1.19^{l}	2.18^{a}	2.03^{a}	10.51^{g-j}	12.02^{i-l}
ZI 1026	0.33^{h-k}	0.60^{f}	0.47^{fg}	0.67^{g-j}	3.19^{c-f}	3.31^{c-f}	1.04^{e-h}	1.17^{d-g}	13.41^{f-j}	14.06^{g-k}
ZI 1302	0.33^{h-k}	0.73^{f}	0.33^{f-i}	0.40^{h-k}	3.89^{a-c}	4.19^{ab}	0.75^{h-j}	0.89^{f-i}	10.48^{h-j}	10.87^{j-l}
ZI 1303	0.53^{f-i}	0.93^{f}	0.40^{f-h}	0.67^{g-j}	3.59^{b-d}	3.92^{a-d}	0.55^{i-m}	0.66^{i-l}	21.66^{a-d}	20.05^{c-g}
ZI 1609	2.47^{e}	3.13^{d}	1.60^{d}	2.13^{d}	1.43^{lm}	1.85^{i-l}	1.17^{d-f}	0.87^{f-i}	9.73^{ij}	7.58^{l}
ZI 1616	0.40^{g-k}	0.93^{f}	0.60^{f}	0.73^{f-i}	1.68^{k-m}	1.85^{i-l}	1.84^{b}	1.70^{a-c}	14.43^{e-j}	14.74^{g-k}
ZI 1620	0.33^{h-k}	0.53^{f}	0.47^{fg}	0.20^{k}	1.90^{i-m}	1.93^{i-l}	0.62^{i-l}	0.72^{i-l}	20.18^{b-e}	21.11^{b-f}
ZI 1904	0.33^{h-k}	0.87^{f}	0.27^{g-i}	0.47^{g-k}	2.64^{e-i}	2.89^{e-h}	0.73^{h-k}	0.73^{h-l}	23.44^{a-c}	24.61^{a-d}
ZI 1905	0.33^{h-k}	0.67^{f}	0.33^{f-i}	0.47^{g-k}	1.67^{k-m}	1.74^{j-l}	0.77^{g-j}	0.80^{f-j}	13.27^{f-j}	14.74^{g-k}
ZI 1906	2.40^{e}	2.87^{de}	0.60^{f}	1.13^{ef}	1.78^{j-m}	1.83^{i-l}	1.47^{c-d}	1.50^{b-e}	13.20^{f-j}	14.27^{g-k}
ZI 2201	0.87^{f}	1.40^{ef}	1.00^{e}	0.87^{fg}	1.73^{k-m}	1.69^{kl}	1.36^{c-e}	1.31^{c-e}	11.97^{f-j}	12.91^{h-l}
ZI 2401	0.73^{fg}	1.07^{f}	0.27^{g-i}	0.60^{g-k}	2.43^{f-k}	2.57^{f-j}	1.85^{ab}	1.70^{a-c}	16.50^{d-h}	17.30^{e-i}
ZI 2402	0.27^{i-k}	0.60^{f}	0.40^{f-h}	0.47^{g-k}	1.98^{i-l}	2.21^{h-k}	0.51^{j-m}	0.56^{i-l}	24.93^{ab}	25.99^{a-c}
ZI 2403	0.07^{k}	0.33^{f}	0.07^{i}	0.33^{i-k}	4.00^{ab}	4.14^{a-c}	0.26^{m}	0.36^{l}	17.56^{c-f}	18.83^{d-h}
ZI 2404	0.47^{g-j}	0.87^{f}	0.40^{f-h}	0.47^{g-k}	3.32^{b-e}	3.61^{b-e}	1.06^{e-h}	1.16^{d-g}	10.09^{ij}	11.57^{i-l}
ZI 2405	0.53^{f-i}	0.73^{f}	0.27^{g-i}	0.60^{g-k}	1.84^{i-m}	1.90^{i-l}	0.41^{k-m}	0.57^{i-l}	8.51^{j}	9.48^{kl}
ZI 2406	4.33^{d}	5.07^{c}	2.53^{c}	3.00^{c}	2.27^{g-k}	2.35^{g-k}	1.10^{e-g}	1.13^{e-h}	9.09^{ij}	9.10^{kl}
KK-1	2.27^{e}	2.73^{de}	0.93^{e}	1.47^{e}	3.13^{c-f}	3.19^{d-g}	1.93^{ab}	1.98^{a}	22.27^{a-d}	23.18^{a-e}
KK-2	0.33^{h-k}	0.40^{f}	0.33^{f-i}	0.33^{i-k}	2.79^{d-h}	3.18^{d-g}	0.85^{f-i}	0.78^{g-k}	24.80^{ab}	25.59^{a-c}
Mean	1.63	1.97	0.891	1.14	2.62	2.76	1.11	1.11	17.08	17.95
CV (%)	14.12	47.06	21.41	24.22	18.63	19.26	18.44	22.00	22.09	21.53
P-Value	**	**	**	**	**	**	**	**	**	**
LSD (0.05)	0.38	1.52	0.31	0.45	0.80	0.87	0.34	0.40	6.19	6.34

*Note: ZI=Zingiber indigenous, KK-1=Kapurkot Aduwa–1, KK-2=Kapurkot Aduwa – 2, **=highly significant, CV=Coefficient of variation, LSD=Least significant different*

DISCUSSION

Evaluation of 25 ginger genotypes at the Ginger Research Program in Kapurkot revealed significant genetic variability in growth, yield, and resistance to the rhizome fly (*Mimegralla* sp.). There was great variation in plant height (53.33 – 72.00 cm) and tiller number (9.53 – 14.93 per clump) that can be a broad genetic base among indigenous Nepalese ginger germplasm. It has been reported that genotypes with higher vigor expressed through increased plant height and tillering consistently demonstrated superior photosynthetic capacity and subsequent rhizome bulking (Anargha et al., 2021; Karthikeyan et al., 2018). For instance, good growth performance and tolerant to ginger fly of ZI 9805 and ZI 1303 in this study aligns with previous findings (Gautam, 2025) that high-vigor of Kapurkot Aduwa-2 (KK-2) variety established a strong canopy, influenced their ability to withstand biotic stress.

The screening for rhizome fly revealed ZI 9805 as a highly promising genotype, exhibiting the least infestation (score 1.00). This resistance profile is exceptional. Management research conducted at Salyan confirmed that the chemical and organic drenching can mitigate fly damage (Gautam & Mainali, 2016). The low infestation levels in ZI 9805 and ZI 2403 suggest possession of potential antibiosis or antixenosis resistance mechanisms, which are critical to rhizome fly damage as the precursor to devastating rhizome rot complexes (Gautam & Acharya, 2014). The selection of resistant varieties remains the most sustainable strategy.

A notable observation was the yield performance of ZI 0403, which also resulted in the highest fresh yield (27.50 t/ha) in 2025/26 despite having infestation score (1.67-2.00). This genotype is more tolerant and maintains high productivity even under-pest pressure. Further, among the tested ginger genotypes, ZI 0515 (24.39-27.20 t/ha), ZI 2402 (24.93 - 25.99 t/ha), ZI 9304 (22.99-25.93) and ZI 1904 (23.44-24.61 t/ha) were found better performing whereas in coordinated varietal trial significantly the highest total rhizome yield was recorded in genotype ZI 1303 (24.9 t/ha) followed by ZI 1007 (21.4 t/ha) with higher fresh rhizome yield (GRP, 2021). Singh et al. (2013) emphasized that certain ginger genotypes possessed physiological resilience to compensate the rhizome tissue loss. Conversely, ZI 2405 and ZI 2406 genotypes proved susceptible land races with low vigor and yield. Usually, there exists positive correlation between tiller number and yield. In this study ZI 1303 recorded the highest tillers and maintained competitive yields.

The warm and humid climate with 21–32°C temperature, 1500-2000 mm annual rainfall and above 60% relative humidity are ideal for ginger production. High temperatures can induce heat stress in ginger plants, resulting in wilting, reduced photosynthesis, and damage to plant tissues. Rising temperatures also create favorable conditions for pests and diseases, affecting ginger plants. Conversely prolonged exposure to cold conditions can cause stunted growth and diminished productivity (Kumar et al., 2025). Our findings also reveal similar environmental conditions during rhizome growing period for satisfactory rhizome fly management and rhizome yield.

The identification of ZI 9805 as a resistant, high-yielding genotype and ZI 0403 as a tolerant, high-yielding genotype provides a valuable foundation for ginger breeding programs in Nepal. These genotypes offer a viable alternative to susceptible local varieties, potentially reducing 20–31% yield loss typically attributed to rhizome fly infestation in the mid-hills (Gautam, 2025). Future research should focus on the mechanisms of host plant resistance and biochemical markers associated with the resistance in ZI 9805 to facilitate the development of fly-resistant cultivars for commercial ginger cultivation.

CONCLUSION

The field study conducted at Kapurkot, Salyan, from 2024 to 2026 identifies specific ginger genotypes that can significantly improve rhizome production and productivity. Among the 25 tested genotypes, ZI 9805 stands out as the most promising genotype as it is highly resistance to the rhizome fly, recording no pest maggots or pupae during the two-year evaluation. Productivity was also higher in genotypes ZI 0403, ZI 0515, ZI 2402, ZI 9304 and ZI 1904. While ZI 0403 showed some signs of infestation, it demonstrated a unique tolerance by maintaining high yields despite the pest pressure. Additionally, ZI 1303 was noted for its good growth vigor, consistently producing the highest number of tillers per plant.

Adopting these improved varieties is essential because low-yielding genotypes, such as ZI 2405 and ZI 2406, currently limit the agricultural potential in the ginger growing regions. Utilizing resistant and tolerant genotypes, like ZI 9805 and ZI 0403 offers a sustainable, pesticide-free strategy to mitigate yield losses, which range 20 - 31% in the mid-hills regions. Reducing reliance on chemical treatments, like chloropyrifos, which farmers were using in the past and banned in Nepal align Nepalese ginger with strict international organic standards, which is vital for enhancing export competitiveness. Therefore, future research should focus on mechanisms of resistance and identifying the specific biochemical markers that give ZI 9805 its natural resistance to support the development of resilient cultivars for commercial use.

DECLARATION

The authors declare no conflict of interests.

ACKNOWLEDGEMENTS

The authors are thankful to the Agriculture and Forestry University (AFU), Nepal Agriculture Research Council (NARC), and Ginger Research Program (GRP) for creating academic and favorable environment to carry out this study successfully.

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ECONOMIC PERFORMANCE AND CONSTRAINTS OF BEEKEEPING (*Apis mellifera* L.) IN CHITWAN DISTRICT, NEPAL

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ABSTRACT

Beekeeping has become an important component of Nepalese agriculture, contributing to household livelihood, employment generation, and enhancing agricultural productivity through pollination services. This study aims to assess the contribution of beekeeping sector to household income, evaluate its profitability, and identify the major production and marketing constraints faced by beekeepers in Chitwan district. A total of 60 commercial beekeepers were randomly selected from three municipalities, namely Kalika, Khairahani and Ratnanagar. Profitability was assessed using the benefit-cost ratio (BCR) and problems was ranked using the index ranking technique. The result revealed that beekeeping is the dominant livelihood enterprise, contributing 78% of total household income. The majority of beekeepers had more than a decade of beekeeping experience, managed 50-100 beehive colonies, and harvested honey at least three times per year. The average productivity of honey was found to be 28.2 kg/hive/year with a gross return of NPR 12644 per hive and a benefit cost ratio of 2.17. Among the costs, variable costs accounted for 66.72%, while fixed costs comprised 33.28%. Although honey was the major product, beekeepers also extracted beeswax, averaging 1.24 kg/hive/year. Disease and pest infestations emerged as the most severe production constraints, followed by pesticide exposure and forage shortages. Similarly, insufficient certification and laboratory testing, untrustworthy traders, and competition with imported honey were identified as major marketing challenges. Overall, beekeeping enterprises seem to be economically viable and can play significant role in improving the livelihood of beekeeping households in Nepal. The performance can be further improved through the better management of forage and addressing the production and marketing challenges.

Key words: Beekeeping, honey, BCR, household income and production constraints

1. INTRODUCTION

Beekeeping is a significant livelihood option in Nepal's rural economy, which involves the scientific management of honeybees and production of honey, beeswax, propolis, pollen, royal jelly, etc. (Khun & Serey, 2024; Samanta et al., 2024). The country produces approximately 4200-5000 metric tons of honey annually, with potential to increase this volume substantially through improved hive management, market development, and modern beekeeping practices

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(MoALD, 2025). Beekeeping is a low-cost investment enterprise that requires minimal capital, does not require land ownership, and involves only limited expenditure on beekeeping tools and equipment, while demanding relatively low inputs in terms of labour, and time and offering a diverse range of bee products (SAWTEE, 2015). Nepal is rich in honeybee diversity, with five species, four native species, namely *Apis cerana*, *Apis florea*, *Apis dorsata*, and *Apis laboriosa* and one exotic species, *Apis mellifera* (Banjade et al., 2024; Gyawali, 2025). Among these, *A. cerana* is widely distributed in the hilly regions, while *A. mellifera* was introduced from India in the early 1990s to promote commercial beekeeping in Nepal (Ahmad & Partap, 2008; Devkota, 2020; Sivaram, 2012).

The honeybee species composition with differences in management practices across various ecological zones, plays a crucial role in shaping productivity levels, production potential, and market performance within the beekeeping sector (Devkota et al., 2025). Nepal is regarded as a promising country for producing quality honey because of its diverse climate and rich floral biodiversity (Gyawali, 2025). The national average honey productivity was 17.58 kg per hive per year, produced from approximately 245,000 bee colonies (MoALD, 2024). However, the potential for commercial honey production remains largely underutilized. Nepal's *A. mellifera* honey is prized for its quality, especially Tori (Mustard), Chiuri (Butter tree), Masala (Eucalyptus), Litchi, Rudilo (*Pogostemon spp.*), and Fapar (Buckwheat) honey, but faces challenges related to quality control, certification, branding, and access to export markets (BDC, 2024). Nevertheless, most of the honey produced in Nepal is consumed in the domestic market, with only a very small proportion being exported (DoC, 2024; BDC, 2024). Within this context, Chitwan district seems to be the most potential district for beekeeping (BDC, 2024) where *A. mellifera* was distributed to farmers at the time of introduction in Nepal (Devkota, 2020; Pokhrel, 2005). Chitwan is one of the major honey-producing districts of Nepal with abundant bee flora, especially Butter tree (*Diploknema butyracea*) which attracts beekeepers from different regions for migration of bees to Chitwan district (Bhattarai et al., 2021; Chikanbanjar et al., 2021). Average annual honey yield from *A. mellifera* in this district is around 470 metric tons from 17,500 bee colonies (BDC, 2024). The understanding of economic dynamics of the beekeeping enterprises, particularly in terms of financial viability and economic returns, is vital for enhancing the performance and sustainability of beekeeping practices (Çevrimli & Sakarya, 2019). Thus, an economic analysis of beekeeping at Chitwan district can provide valuable insights into profitability and constraints faced by beekeepers. Additionally, this study aims to assess the contribution of beekeeping on household income of beekeepers, estimate the cost of production, gross return and benefit cost ratio (BCR) of honey production and to identify major production and marketing constraints of beekeeping in the study area.

2. METHODOLOGY

Chitwan district was selected purposively as the study site because *A. mellifera* are reared commercially in this district. Among the seven local governments of the district, Kalika, Khairahani and Ratnanagar Municipalities were selected purposively due to their high concentration of commercial beekeeping enterprises and significant contribution to honey production (BDC, 2024). A list of beekeepers was obtained from the Agriculture Development Center and the

Beekeeping Development Center, Chitwan. This list served as the sampling frame for the study. A two-stage sampling procedure was employed. In the first stage, the three municipalities were purposively selected based on the intensity of commercial beekeeping activities. In the second stage, 60 commercial beekeepers were selected through simple random sampling from the official list of beekeepers. Equal representation from each municipality was ensured as far as possible to capture variations in management practices and production performance across the study area. The selected respondents were actively engaged in commercial beekeeping and maintained *A. mellifera* colonies as a primary or significant income-generating activity.

2.1 DATA COLLECTION

Both primary and secondary data sources were used in the study. Primary data were collected during 2025 through household surveys using a pre-tested structured questionnaire administered to the selected beekeepers. Information was gathered on socio-economic characteristics, colony management practices, production costs, honey yield, income from beekeeping, marketing channels, and production and marketing constraints.

To complement the survey data, focus group discussions (FGDs) were conducted with groups of beekeepers in each municipality to validate survey findings and gain deeper insights into local beekeeping practices and challenges. In addition, key informant interviews (KIIs) were conducted with officials from the Agriculture Development Center, Beekeeping Development Center, cooperative leaders, honey traders, and experienced beekeepers to obtain expert opinions and contextual information regarding the beekeeping sector in Chitwan.

Secondary data were collected from published and unpublished reports, government documents, journal articles, policy documents, annual reports of the Ministry of Agriculture and Livestock Development (MoALD), records of the Beekeeping Development Center (BDC), and other relevant institutional publications. These data were used to supplement and validate the primary information collected during the field survey.

2.2 METHOD AND TECHNIQUES OF DATA ANALYSIS

The collected data were coded, tabulated, and analyzed using descriptive statistics. The mean, frequency and percentage were calculated using the MS Excel and the results were depicted in the tables and figures. Similarly, the benefit-cost ratio was calculated to assess the economic feasibility of the beekeeping in the study area of Chitwan. In order to calculate the B:C ratio, the gross return and total cost were calculated. Both fixed cost, namely depreciation cost of the beekeeping equipment like beehive, honey extractor and other equipment and variable costs like supplementary feeding cost, disease and pest management cost, pasture management cost, transportation cost, labour cost, repair and maintenance cost, packaging cost, comb foundation cost were taken into consideration.

Gross return was calculated by multiplying the quantity of each beekeeping product by its average market price during the harvesting period and summing the values across all products. Gross margin was estimated as the difference between gross return and total variable costs. Gross margin and benefit–cost ratio (BCR) were calculated using the following formulas

(Paudel et al., 2025):

Gross Margin (GM) = Gross Return (GR) − Total Variable Cost (TVC)

Benefit–Cost Ratio (BCR) = Gross Return (GR) / Total Cost (TC)

2.3 Indexing

Beekeepers' perception on the severity of the different production and marketing constraints were assessed by using five-point scale rated as very low, low, average, high and very high with corresponding weights of 0.2, 0.4, 0.6, 0.8 and 1 respectively (Mehta & Khatiwada, 2025).

The index value of ranking was computed by using the following formula:

$I_{imp} = \Sigma\ (SiF_i\ /n)$

Where,

I_{imp} = Index value

= Summation

Si = Scale value of i^{th} level

F_i = Frequency of value of i^{th} level

n = Total numbers of respondents

3. RESULTS AND DISCUSSION

3.1 SOCIO-DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS

Out of the total respondents, 86.66 % were male, indicates the dominance of male population in the beekeeping sector (Table 1). Furthermore, Brahmin/Chhetri (71.66%) were the dominant group among respondents, followed by Janajati and Other (Chepang/Tharu). More than 2/3rd of the respondents' major occupation was beekeeping. Regarding the education status, majority of respondents (96.66%) were found to be literate, which is higher than the national literacy rate of 76.2% (NSO, 2025).

Table 1. Socio-demographic characteristics of respondents in the study area

Variables	Frequency	Percentage
Gender of beekeepers		
Male	52	86.66
Female	8	13.34
Ethnicity of beekeepers		
Brahmin/Chhetri	43	71.66
Janajati	14	23.34
Other	3	5.00

Variables	Frequency	Percentage
Major Occupation of beekeepers		
Beekeeping	40	66.67
Agriculture other than beekeeping	14	23.33
Business	4	6.67
Services	2	3.33
Education of beekeepers		
Illiterate	2	3.34
Literate	58	96.66

3.2 CONTRIBUTION OF BEEKEEPING TO HOUSEHOLD INCOME IN THE STUDY AREA

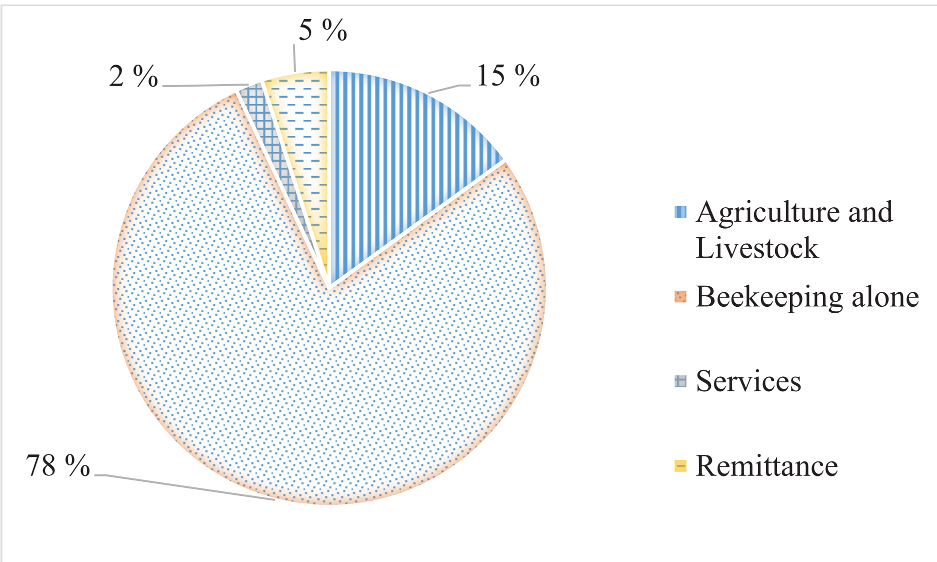

Figure 1. Contribution of beekeeping to household income

The income distribution showed that beekeeping was the dominant source of livelihood, contributing 78% of the total household income, indicating that farmers involved in beekeeping had major source of income through beekeeping (Figure 1). Agriculture and livestock (15%) provided supplementary income, while remittance and services contributed 5% and 2% respectively in the study area.

3.3 EXPERIENCE, NUMBER OF BEEHIVE AND HONEY HARVESTING FREQUENCY

The level of beekeeping experience is considered to be the number of years that an individual has been continuously engaged in beekeeping activity. The majority (35%) of the respondents had an experience of 10-15 years followed by 28.34% of the respondents that had an experience of more than 15 years as shown in Table 2. Similarly, more than half of the beekeepers had 50-100 beehive colonies. Only 15% of the beekeepers comprised less than 50 beehive colonies and 33% maintained more than 100 beehive colonies. In addition to this, regarding the honey harvesting, the majority (63.34%) of beekeepers harvested the honey five or more than five times whereas 25% of the beekeepers harvested four times annually. This finding is aligned with the study of Pokhrel (2009) which has mentioned that beekeepers extracted honey 3-7 times (mean 4.8) from *A. mellifera* in Terai.

Table 2. Experience, number of beehives and honey harvesting frequency in the study site

Variables	Frequency	Percentage
Years of experience		
< 5	9	15.00
5-10	13	21.66
10-15	21	35.00
>15	7	28.34
Number of beehive colonies		
< 50	9	15.00
50-100	31	51.66
> 100	20	33.34
Frequency of honey harvesting		
3	7	11.66
4	15	25.00
≥ 5	38	63.34

3.4 COST ANALYSIS OF HONEY PRODUCTION

For analyzing cost of production, fixed and variable cost items for honey production were considered. The variable cost included off-season feeding cost, pasture management cost, migration cost, disease and pest control cost, labor cost, comb foundation cost, packaging cost, repair and maintenance cost etc. The fixed cost included depreciation on hives, honey extractor, honey smoker, and other hive equipment. The study found that the variable cost was NPR 3884.75/hive, accounting for 66.72% of total cost while fixed cost was NPR 1938.52/hive, representing 33.28% (Table 3).

Table 3. Cost analysis of honey production in the study area

Items	Cost (NPR/hive)
Fixed cost	
Depreciation of beehives	697.30
Depreciation of honey extractor	786.67
Depreciation of other equipment's	454.55
Total fixed cost	**1938.52**

Items	Cost (NPR/hive)
Variable cost	
Artificial feeding cost	1833.34
Bee protection chemical cost	185.78
Pasture management cost	128.56
Transportation cost	258.14
Labor cost	722.56
Repair and maintenance cost	115.45
Packaging cost	247.12
Comb foundation cost	259.28
Miscellaneous cost	134.52
Total variable cost	**3884.75**
Total cost	**5823.27**

3.5 PRODUCTION STATUS AND PRICE OF HONEY AND BEESWAX

The average honey and beeswax productivity of *A. millifera* was found 28.2 kg/hive/year and 1.24 kg/hive/year, respectively. The minimum productivity of honey was recorded at 18 kg/hive/year and beeswax 0.75 kg/hive/year. Similarly, the maximum productivity of honey was recorded at 36 kg/hive/year and beeswax 3.0 kg/hive/year (Table 4). A study by Dhakal et al. (2017) reported the average annual honey production of 36 kg/hive in Chitwan, and Shrestha (2017) also reported 34.5 kg/hive in Bardiya, Nepal. Moreover, average number of bee hives in the study area was found 71±5.24 for honey production. As beekeepers produced honey of different flora, the average honey price per kg was ranging from NPR 300 to NPR 600, whereas average unit price of honey was calculated NPR 425/kg. Similarly, the average price of beeswax was found NPR 600/kg in the study area.

Table 4. Production status and price of honey and beeswax in the study area

Items	Average	Minimum	Maximum
Honey (kg/hive/year)	28.2	18	36
Beeswax (kg/hive/year)	1.24	0.75	3.00
Honey (NPR/kg)	425	300	600
Beeswax (NPR/kg)	600	500	700
Average number of hives/HH	71±5.24		

± Standard deviation

3.6 RETURN FROM HONEY AND OTHER PRODUCTS

The return from the beekeeping is the sum of the return from honey and beeswax. The income from the honey (NPR 11900) was 15 times higher than the income from the beeswax (NPR

744). The results show that the gross return of the beekeeping was found to be NPR 12644 as shown in Table 5.

Table 5. Return from honey and other products in the study area

Particulars	Amount (NPR)
Return from honey	11900.00
Return from beeswax	744.00
Gross return	12644.00

3.7 BENEFIT-COST RATIO

The average total cost/hive was NPR. 5823.27, which gives the return of NPR. 12644. Profitability analysis shows the beekeeping is economically viable with an overall gross margin of NPR 8759.25. The benefit cost ratio with beeswax income was found to be 2.17, whereas without beeswax income was 2.04 as shown in Table 6, showing that producing other bee products is more profitable than just producing the honey. In the study area, honey was identified as the primary apiary product, while beeswax contributed as a secondary income source. Other potential hive products such as pollen, propolis, and royal jelly were not practiced by beekeepers, suggesting scope for product diversification in the future.

These findings are consistent with previous studies in Nepal. For instance, Dhakal et al. (2017) reported a gross return of NPR 7482.12 per hive in Chitwan, while Shrestha (2017) found NPR 7392.12 per hive in Bardiya, and Budhathoki-Chhetri et al. (2021) reported NPR 9862.84 per hive in Dang. Similarly, benefit-cost ratio (BCR) was found 2.17, signifies that the beekeeping can be a profitable business, whereas 1.81 BCR reported by Devkota et al. (2016), 1.71 by Dhakal et al. (2017) in Chitwan and 2.15 by Budhathoki-Chhetri et al. (2021) in Dang.

Table 6. Benefit-cost ratio in the study area

Particulars	Amount (NPR)
Total fixed cost	1938.52
Total variable cost	3884.75
Total cost	5823.27
Gross return	12644
Gross margin	8759.25
BC ratio with beeswax	2.17
BC ratio without beeswax	2.04

3.8 HONEY MARKETING IN THE STUDY AREA

The Figure 2 shows the distribution of honey among different market actors. The beekeepers sold their honey directly to wholesaler (40%), indicating that a large portion of honey was sold in bulk through wholesale channel. Whereas consumer represent 30%, suggesting that the market is inclined toward local consumers. Local traders account for 18% that play an intermediary role in collecting and distributing honey within local markets. Retailers account 12%, indicating limited sell of honey from formal retail honey outlet.

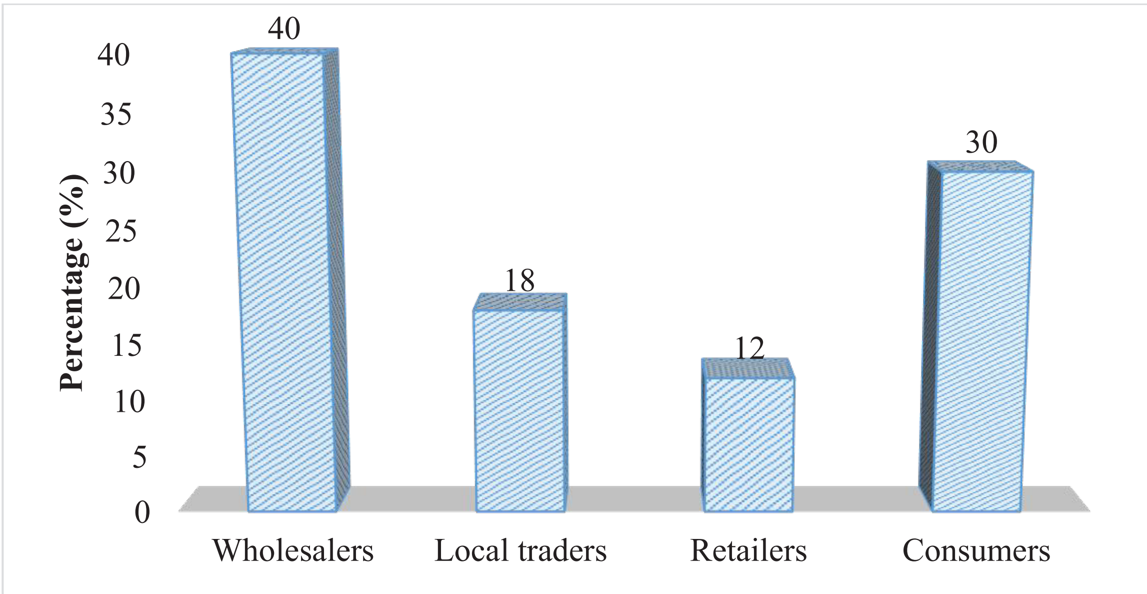

Figure 2. Marketing of honey in the study area

3.9 PROBLEMS IN HONEY PRODUCTION

The index analysis indicates that disease and pest's infestation was the most severe problem faced by beekeepers (0.85). Pesticide exposure is the second most critical constraint (0.73), underlining the negative impact of agrochemicals on beekeeping. Shortage of forages ranks third (0.68), suggesting seasonal and spatial limitations of floral resources (Table 7). The increase in number of beekeepers over the period results the lack of forages in Chitwan in recent years (FNBK, 2020). Similarly, Shrestha (2017) mentioned the high cost of bee hive and inadequate availability of modern equipment are major problems in beekeeping. Budhathoki-Chhetri et al. (2021) reported decreasing bee forage area, shortage of quality beekeeping equipment and pests, predator and pesticide threats some serious constraints of *A. mellifera* beekeeping in Dang valley.

Table 7 : Ranking of problems in beekeeping in the study area

Problem	Index Value	Ranking
Disease and pests infestation	0.85	I
Pesticide exposure	0.73	II
Shortage of forages	0.68	III
High cost of modern bee hive	0.56	IV
Lack of technical knowledge and skill	0.43	V

3.10 PROBLEMS IN HONEY MARKETING

The results show that insufficient certification and laboratory testing was the most serious marketing related problem (0.76) followed by abundance of untrustworthy traders (0.65), reflecting issues of market reliability. High competition with imported honey was the third major constraint (0.58), suggesting pressure on local honey producers in the market followed by the issue of adulterated honey (0.51), highlighting concerns over product authenticity and consumer trust. Moreover, Budhathoki-Chhetri et al. (2021) listed lack of market information, insufficient certification and lab tests and lack of collection and processing unit are some major problems of beekeeping sector in Nepal.

Table 8. Ranking marketing problems of beekeepers in the study area

Problem	Index Value	Ranking
Insufficient certification and lab test	0.76	I
Abundance of untrustworthy traders	0.65	II
High competition with the imported honey	0.58	III
Issue of adulterate honey	0.51	IV
Lack of processing, labelling and packaging	0.42	V

4. CONCLUSION

Beekeeping, contributing more than three quarters of total household income and benefit cost ratio (2.17), advocates very strongly on profitable potential of beekeeping in the study area. In the study area honey is major product and exploration of other high value hive products is negligible, suggests untapped opportunities for income diversification. Despite the profitability of beekeeping, beekeepers face several challenges, where disease and pest infestation and pesticide exposure were the most serious production constraints, threatening colony health and productivity. Similarly, lack of certification and laboratory testing facilities, the presence of untrustworthy traders, and competition from imported honey are major marketing problems. Overall, the findings suggest that intervention on disease and pest management, pesticide regulation, forage expansion and strengthening the honey certification will enhance the profitability of beekeeping to household livelihood economy.

DECLARATION

The authors declare no conflict of interest.

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ASSESSMENT OF CLIMATE-FRIENDLY PRACTICES ADOPTION IN DAIRY CATTLE FARMING IN BAGAMATI PROVINCE

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ABSTRACT

The dairy sector plays a central role in rural livelihoods, but it is increasingly exposed to climate related risks. The adoption of climate-friendly practices (CFPs) may help improve farm resilience while reducing emission intensity from dairy production. This study assessed the adoption of CFPs among 198 dairy cattle farmers selected from Chitwan, Dhading, and Makwanpur districts of Bagamati Province, Nepal. The study found that 59.60% of farmers reported familiarity with the term climate change, whereas 92.42% perceived climate related impacts on dairy farming after the concept was explained. Adoption was high for improved breeds (100.00%) and artificial insemination (96.46%), but low for silage making (14.65%), biogas use (24.24%), and manure composting (8.59%). Based on the adoption score, 55.35% of farmers were categorized as medium adopters, followed by low adopters (24.75%) and high adopters (19.70%). These findings suggest that farmers more readily adopt practices with immediate production or herd health benefits, whereas technically demanding or capital-intensive practices remain less common. The results indicate the need for stronger extension support, practical training, and clearer promotion of underused CFPs. Because the analysis is descriptive and cross sectional, the findings should be interpreted as patterns of adoption rather than casual relationships.

Keywords: Climate-smart agriculture, Greenhouse gas emission, Low emission strategy, Heat stress

1. INTRODUCTION

Climate change is causing a negative impact to global agricultural systems, affecting food security and livelihoods of people (IPCC, 2022). Nepal is vulnerable to climate change induced natural disasters, making adaptation strategies crucial to attain agricultural sustainability (UNDP, 2023). However, agricultural sector contributes significantly to greenhouse gas (GHG) emissions through various production activities (FAO, 2021). The livestock sector contributes about 14.50% of global human-induced greenhouse gas emissions and 32% of anthropogenic methane emissions, with cattle accounting for roughly two-third of these emissions, primarily

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through enteric fermentation and manure decomposition (FAO, 2023; Li et al., 2024). As the global demand for dairy products continues to rise, there is an urgent need to balance production growth with environmental sustainability (Steinfeld et al., 2006). In developing nations like Nepal, the dairy is a key sub-sector of the agricultural economy. (Gautam et al., 2017). Despite its importance, dairy farming in Nepal is highly vulnerable to the adverse impacts of climate change, such as rising temperatures, altered rainfall patterns, and an increased frequency of extreme weather events (Shrestha et al., 2019). These climatic shifts exert a direct threat to cattle health through heat stress, uprisal of cattle disease incidence, and disruption of feed and water resources (Sejian et al., 2015).

Climate-Smart Agriculture (CSA) serve as an integrated approach to manage agricultural landscapes to address the interlinked challenges of food security and climate change (World Bank, 2023). CSA is a set of agricultural practices and technologies which simultaneously boost productivity, enhance resilience and reduce GHG emissions (World Bank, 2024). Climate-friendly practices (CFPs) are sector-specific measures and technologies that reduces greenhouse gas emission and enhances resilience to climate impacts (Wreford et al. 2017). In the context of dairy farming, the objectives of CFP are achieved through adoption of adaptation and mitigation measures that simultaneously improve farm productivity (Rojas-Downing et al., 2017). Common CFPs include the use of improved and high-yielding cattle breeds, balanced and nutrient-rich feeding strategies, cultivation of improved fodder species, feed conservation techniques, efficient manure management through composting and biogas production, provision of improved housing and ventilation, and efficient water management practices (Rosa et al., 2025). Adoption of these practices can improve feed conversion efficiency, reduce enteric methane emissions, enhance animal health and productivity, and strengthen farmers' adaptive capacity to climate variability (Oduor et al., 2025; Zenda, 2025; Zuwarimwe & Tada, 2026). The perception of climate change and its impact on dairy farming plays a crucial role in the adoption of CFPs (Mekonnen et al., 2023). Socioeconomic characteristics, access to institutional services, and awareness about impact of climate change significantly influences the adaptation decisions (Ahmad et al., 2022). Understanding farmers' awareness and adoption patterns of CFPs is essential for developing effective policies and interventions to promote sustainable dairy farming (Aryal et al., 2020).

Although national policies in Nepal encourage the climate-resilient agriculture, empirical evidence on the farm level adoption of specific CFPs in the dairy system remains limited, particularly in relation to how adoption is distributed across practices and farmers (Aryal et al., 2018). This gap constrains the design of targeted extension and policy intervention. Therefore, this study aimed to assess the level of adoption of CFPs among dairy cattle farmers in Bagamati Province, Nepal. Specifically, the study sought to: (i) describe the socio-economic characteristics of sampled dairy cattle farmers; (ii) assess farmers' awareness and perceptions of climate change; (iii) estimate the adoption rates of selected CFPs; and (iv) classify farmers according to their overall adoption score. By focusing on these objectives, the study provided descriptive evidence on the current pattern of CFP uptake in the study area.

2. METHODOLOGY

This section describes the study design, study area, sampling procedure, survey instruments, adoption design, scoring procedure, and analytical techniques used in the study

2.1 STUDY SITES AND SAMPLING TECHNIQUES

The study was conducted in Bagamati Province, Nepal in three districts: Chitwan, Dhading, and Makwanpur from 2 March to 4 April, 2025. These sites were selected purposively because of their importance in dairy production and to capture variation in agroecological and socio-economic conditions. However, the findings should be interpreted within the context of the selected study sites rather than generalized automatically to all dairy farmers in Nepal.

A multistage sampling procedure was applied. First, Chitwan, Dhading and Makwanpur districts were selected purposively based on their contribution to dairy production. Second, one local unit was selected from each district: Khairahani Municipality in Chitwan, Dhunibesi Municipality in Dhading, and Makwanpurgadi Rural Municipality in Makwanpur. Third, one dairy cooperative was identified in each selected local unit on the basis of preliminary field visits and consultation with key informants from the livestock and dairy development sector. Finally, the study population was defined as active member households of the selected cooperatives, and respondents were selected using simple random sampling from the cooperative membership lists.

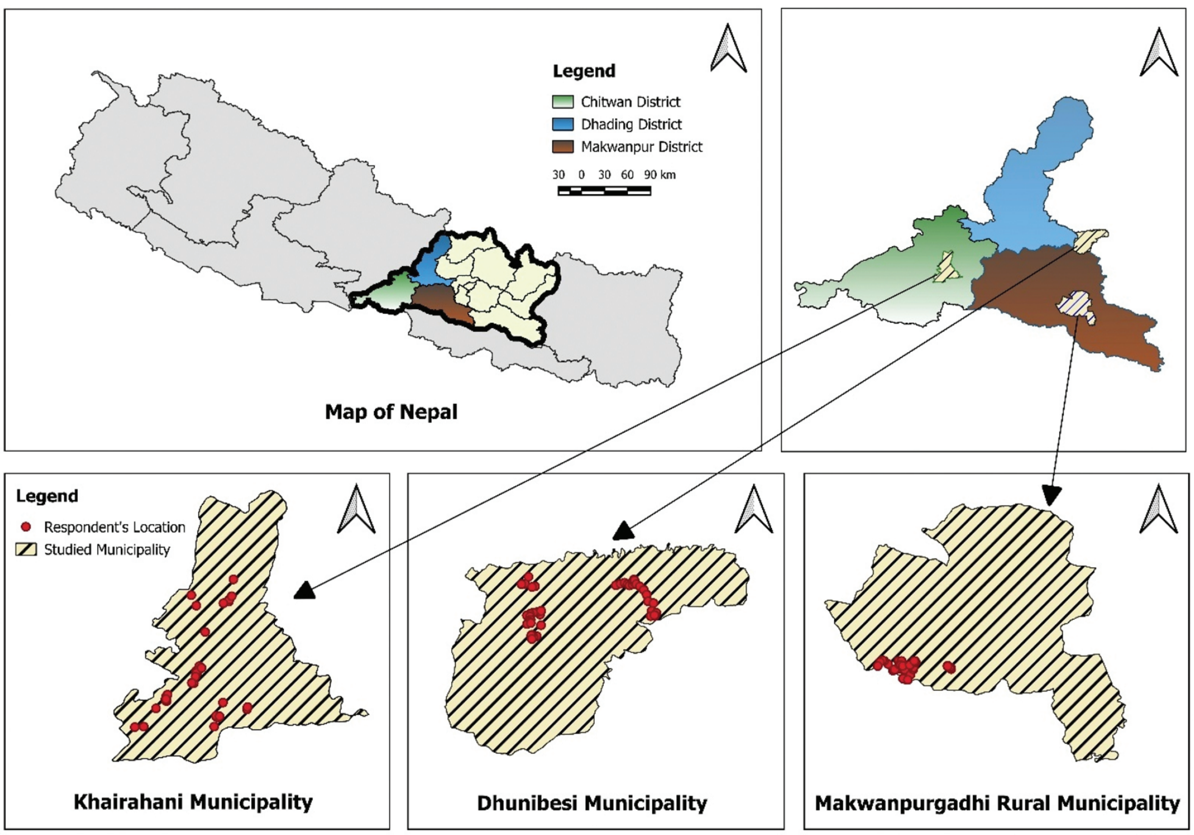

Figure 1. Map of Nepal showing study areas and respondent locations

Source: QGIS (version 3.34.10)

2.2 SURVEY DESIGN

Primary data were collected from dairy cattle farmers through face-to-face interviews using a structured questionnaire that included both closed-ended and open-ended questions. The questionnaire was designed and administered using the mWater Surveyor mobile application to facilitate digital data collection. Data collection was carried out by the principal author with the support of two enumerators. Before the main survey, the interview schedule was pretested to evaluate its clarity, relevance, and overall suitability. Feedback from the pretest was used to refine the questionnaire by addressing identified gaps and making the necessary revisions to improve its quality and effectiveness.

The sampling frame comprised 420 dairy farm households from dairy cooperatives in three municipalities. The sample size was determined using Yamane's formula (Yamane, 1967):

$$n = \frac{N}{1+N(e)^2}$$

where, n = sample size, N = population size, and e = margin of error

Applying this formula, a sample size of 204 dairy cattle farmers was obtained at 5% margin of error. However, during the data cleaning process, six observations were removed because of incomplete sampling, resulting in a final sample size of 198 for the analysis. The specific ward location of respondents, along with corresponding municipalities and districts are presented below.

Table 1. Distribution of respondents across selected municipalities and districts

District	Municipality	Location	Sampling frame	Sample size
Chitwan	Khairahani	Khairahani 2, 5, 12	142	67
Dhading	Dhunibesi	Dhunibesi 3, 4, 5	140	65
Makwanpur	Makwanpurgadhi	Makwanpurgadhi 3, 6	138	66

2.3 SCORING SYSTEM

Climate friendly practices related to dairy production were identified from the literature and from recommendations of organizations such as the Food and Agriculture Organization of the United Nations (FAO), the Department of Livestock Services (DLS), and the National Dairy Development Board (NDDB). In total 20 practices were grouped into five management domains and assessed during the field survey. For transparency and replicability, the authors should ensure that the number of listed practices in Table 2 fully matches the number used in the adoption score and subsequent categorization.

Table 2. Description of CFPs used in dairy cattle farming

Variable	Description	Reference
Breed and reproduction management	-Use of high-yielding or improved breeds -Use of artificial insemination -Regular vaccination of cattle for disease prevention -Reduction of age of first calving	(Dall et al., 2019) (Gastelen et al., 2019) (Gerber et al., 2013) (Hawkins et al., 2022)
Feed management	- Provision of balanced feed to the cattle -Use of chopped fodder in the diet - Feeding silage in lean period -Use of mineral and supplements in diet	(Balehegn et al., 2020) (Bhusal et al., 2020) (Kataria, 2016) (Van Middelaar et al., 2014)
Cattle shed management	-Presence of proper ventilation and air circulation -Presence of insulated roofing -Comfortable bedding for cattle -Biosecurity measures followed	(Rotz, 2018)
Manure management	-Frequent removal of manure -Use of cover materials to cover the manure -Composting manure -Collection of urine for fertigation -Use of bio-gas plant	(Afotey & Sarpong, 2023) (Bhusal et al., 2020.)
Milking management	-Maintain consistent milking schedule and frequency -Use of proper milking techniques -Use of low emission or eco-friendly method for milk transportation	(D'Urso & Arcidiacono, 2021) (Mech et al., 2023)

A binary scoring method was used for each identified CFP, assigning a score of 1 if adopted and 0 otherwise. Individual scores were summed to generate gross adoption score (AS), for each household. This score represented the total number of CFPs adopted by a respondent. Assuming the adoption scores are roughly normally distributed, the method ensures that the medium category encompasses the central M ± SD of the sample, while the low and high categories capture the respective tails. This distribution aligns with the theoretical expectations in Rogers (2003) diffusion of innovations framework, where early adopters and laggards each represent relatively small proportions of the overall population.

Table 3. Methods of estimation of adoption score and adoption category

Category	Estimate Threshold
A (Low adoption)	AS ≤ M – SD
B (Medium adoption)	M – SD < AS ≤ M +SD
C (High adoption)	M+SD<AS ≤ Max

Notes: AS= Adoption score; SD= Standard deviation; M= Mean; Max= Maximum

2.4 ANALYTICAL TECHNIQUES

Socio-demographic characteristics such as age, sex, family size. education level, ethnicity, cattle size, and land allocated to cattle farming were included in the analysis. The study also examined farmers' awareness of climate change and their perceptions of its effects on dairy farming. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were used to summarize the data. Data analysis was performed using Microsoft Excel Spreadsheet 2024 and IBM SPSS version 26 for tabulation and graphical presentation.

3. RESULTS AND DISCUSSION

This section presents the socio-demographic characteristics of the respondents. It also discusses farmers' awareness of climate change and their perceptions of its impacts on dairy farming. Finally, it highlights the adoption status of climate-friendly practices (CFPs) among dairy cattle farmers.

3.1 SOCIO-ECONOMIC PROFILE OF RESPONDENT

The socio-economic assessment of the respondents is illustrated in Table 1. The average age of respondents was 45.11 years, with a minimum of 18 years and a maximum of 78 years, indicating that both young and older farmers were engaged in dairy farming. The mean farming experience of households was 8.70 years, suggesting that most families had moderate experience in cattle rearing. The average household size was 5.31 members, ranging from 3 to 15, which is comparable to the national average family size reported in rural Nepal. On average, respondents owned 6.01 cattle, of which 4.02 were lactating, showing a considerable focus on milk production. Landholding patterns indicated that farmers allocated on average 0.30 ha of land specifically for cattle rearing, while the total mean landholding was 0.84 ha, highlighting small-scale land ownership.

In terms of categorical characteristics, the majority of respondents were male (69.70%), while females accounted for 30.30%. Regarding ethnicity, Hill Brahmin/Chhetri households dominated the sample (87.88%), followed by Hill Janajati (10.10%), Hill Dalit (1.52%), and Terai Janajati (0.50%). Educational status revealed that 19.10% of respondents were illiterate, while 22.72% had attained primary education. A larger share (43.43%) had completed secondary education, whereas only 14.64% had studied beyond secondary level. These findings indicate that while most respondents had at least some level of education, higher education was less common among dairy cattle farmers. Regarding institutional support, 39.90% of respondents reported having received training related to dairy cattle farming, indicating that a majority still lacked access to capacity-building opportunities. Similarly, 39.90% of households had benefited from subsidies for dairy operations, reflecting limited but important policy support for the sector. A very high proportion of farmers (96.46%) had insured their cattle, suggesting widespread recognition of insurance as a risk management tool against climate- and disease-related uncertainties. Meanwhile, only 34.34% of respondents had accessed credit specifically for dairy operations, highlighting the financial constraints faced by many farmers in scaling up or modernizing their production practices.

Table 4. Socioeconomic characteristics of respondent household

Continuous variable (n=198)

Variable	Description	Mean	Standard deviation	Maximum	Minimum
Age	Age of respondent	45.11	9.99	78	18
Farming experience	Number of years family had involved in cattle rearing	8.70	3.70	20	3
Family size	Total family members	5.31	2.01	15	3
Lactating cattle	Total number of lactating cattle	4.02	2.89	22	2
Cattle size	Total number of cattle	6.01	4.61	35	2
Land for cattle	Total land under cattle rearing in ha	0.30	0.32	2.33	0.01
Total land	Total land holding	0.84	0.78	8.66	0.13

Categorical variable

Variable	Description	n	Frequency	Percentage
Sex	Male	198	138	69.70
	Female		60	30.30
Ethnicity	Hill Brahmin/Chettri	198	174	87.88
	Hill Janajati		20	10.10
	Hill Dalit		3	1.52
	Terai Janajati		1	0.50
Education status	Illiterate	198	38	19.10
	Primary level		45	22.72
	Secondary level		86	43.43
	Higher level		29	14.64
Training	1= Yes	198	79	39.90

Variable	Description	n	Frequency	Percentage
Subsidy	1= Yes	198	79	39.90
Cattle insurance	1= Yes	198	191	96.46
Credit utilized for dairy operation	1=Yes	198	68	34.34

3.2 CLIMATE CHANGE PERCEPTION BY CATTLE FARMERS

A total of 59.60% of cattle farmers reported being aware of climate change, compared to 40.40% who were not. Regarding the impact of climate change, 92.42% of respondents perceived an effect, while 7.58% reported no effect. Responses on the impact of climate change were collected after explaining the concept to farmers, including examples of changes in agroclimatic variables such as temperature, rainfall, and humidity. These results indicate that, although 40.40% of farmers were not familiar with the term “climate change,” a significant majority (92.42%) were able to perceive its impact on their livelihoods. (Figure 2).

The gender-disaggregated analysis revealed notable differences in farmers’ awareness and perception of climate change. Among male respondents, 67.40% reported having heard of climate change, compared to 41.70% of female respondents. Similarly, a higher proportion of males (91.30%) perceived that climate change had an impact on their farming activities, while 95.00% of females also reported experiencing its effects. Despite lower awareness of the term climate change among women, the vast majority recognized its impacts, with only 5.00% reporting no perceived effect compared to 8.70% of men. These findings suggest that although female farmers were less familiar with the concept of climate change, they were equally, and even slightly more, likely than male farmers to perceive its effects on their livelihoods and farming systems (Figure 2).

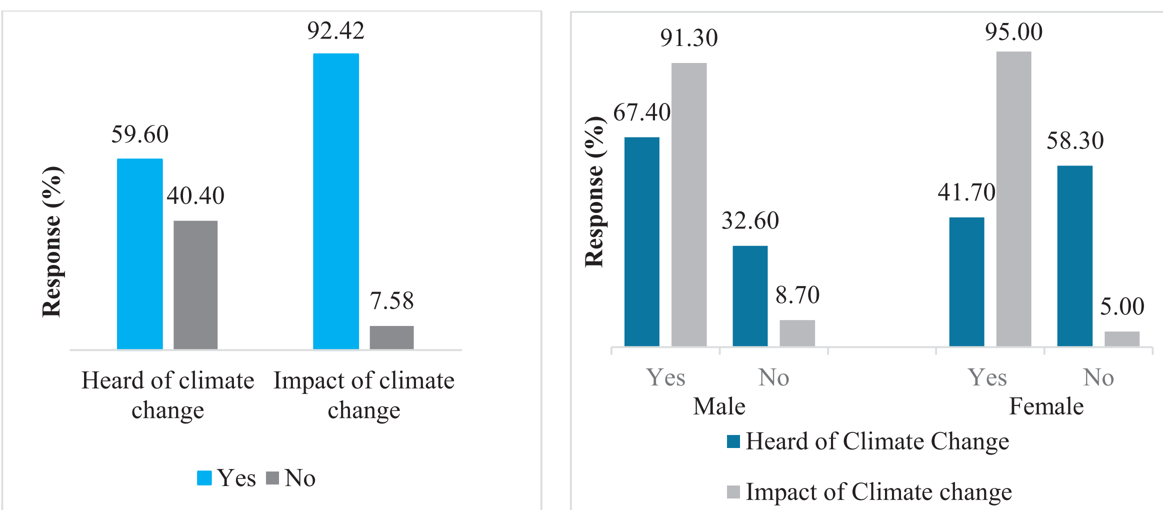

Figure 2. Farmers awareness on climate change and perceived experience of its impact (n=198, Male =138, Female = 60)

3.3 ADOPTION RATE OF CLIMATE-FRIENDLY PRACTICES

This section presents the observed adoption rates of 20 CFPs across five different management domains. The findings provide a descriptive overview of which practices were more commonly adopted in the samples households and which practices remained less common.

3.3.1 Breed and reproduction management

All households (100.00%) had adopted the improved or high-yielding breed in the study area. The cattle breeds on their farms were Holstein cross, Jersey cross, and Sahiwal cross. About 96.46% of farmers were using artificial insemination (AI) for the purpose of breeding. The success of improved breeds and AI is a result of decades of government and cooperative-led programs in Nepal that made superior genetics accessible and affordable (Gautam et al., 2017). Similarly, 94.45% of farmers provided vaccination to their cattle in regular interval. Likewise, 29.29% of households were involved in reducing age at first calving by providing enough dietary requirements to growing calves (Figure 4). The reduction of age at first calving requires sophisticated understanding of animal nutrition and requires long-term investment where economic return is delayed (Thorpe et al., 2010). These findings align with the findings of Montes de Oca Munguia et al. (2021) that farmers adopt technologies due to clear relative advantages.

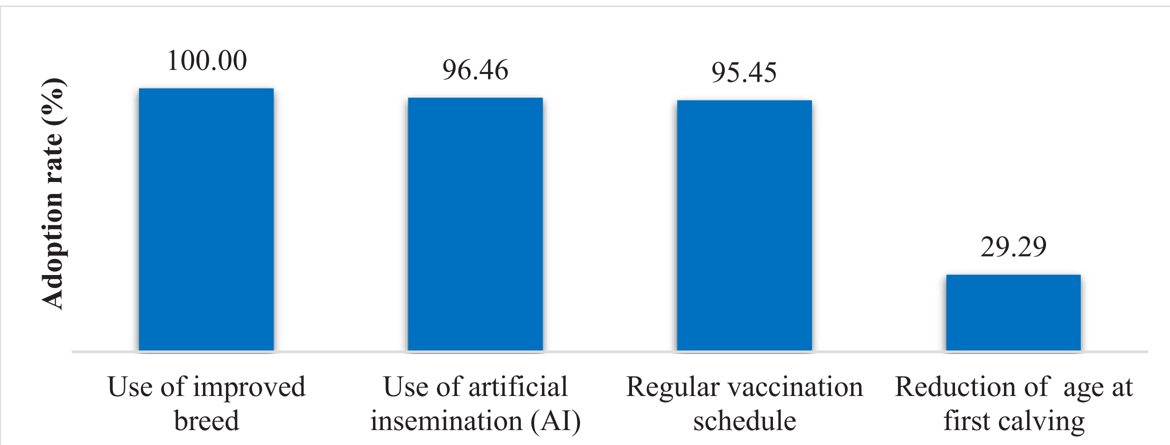

Figure 3. Adoption of breed and reproduction management practices among dairy cattle farmers (n=198)

3.3.2 Feed management

About 67.67% of household provided the balanced proportion of feeds to the cattle. This includes the provision of green roughage, dry roughage and concentrates in appropriate amount as recommended by the Department of Livestock Services. Similarly, 55.05% of sampled households provided chopped fodder to the cattle. Likewise, 31.31% used additional minerals and supplements in the cattle diet. The low uptake of mineral supplements is a persistent issue in smallholder dairy system across South Asia (Garg & Bhanderi, 2016). The use of silage for feeding the cattle in lean period was practices by only 14.65% of households (Figure 5). Farmers may have limited knowledge and skills to adopt technologies such as silage making (Kirimi et al., 2024).

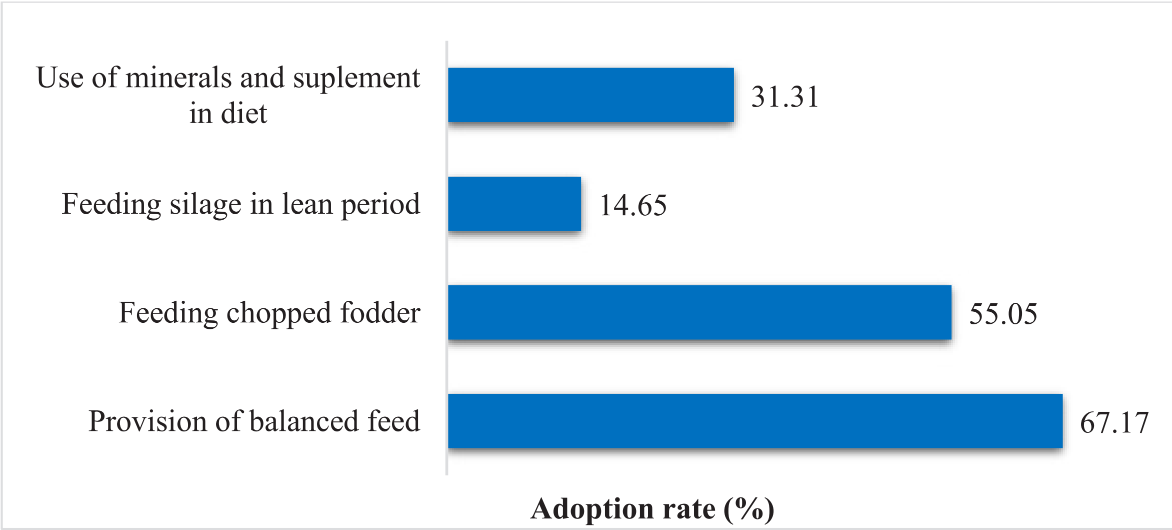

Figure 4. Adoption of feed management practices among dairy cattle farmers (n= 198)

3.3.3 Cattle shed management

Proper ventilation or air circulation in the farm was present in 50.51% of the households. Likewise, the presence of comfortable bedding was reported by 50.00% of the respondents. Practices like improved ventilation and bedding are crucial climate adaptation strategies to mitigate heat stress in dairy cattle under rising temperature (Sejian et al., 2015). Around 46.46% of households followed biosecurity measures to prevent disease transmission and to maintain cattle overall wellbeing. Similarly, 45.96% of cattle farms had insulated roofing to maintain the overall cattle shed temperature (Figure 6). The findings align with study by Shilpakar et al. (2021), who noted that the Nepalese farmer perceive high upfront cost of shed improvements as barrier to adopt these management practices. The partial adoption of biosecurity measures implies a more targeted training, as these practices are often low-cost but require a clear understanding of disease transmission pathways.

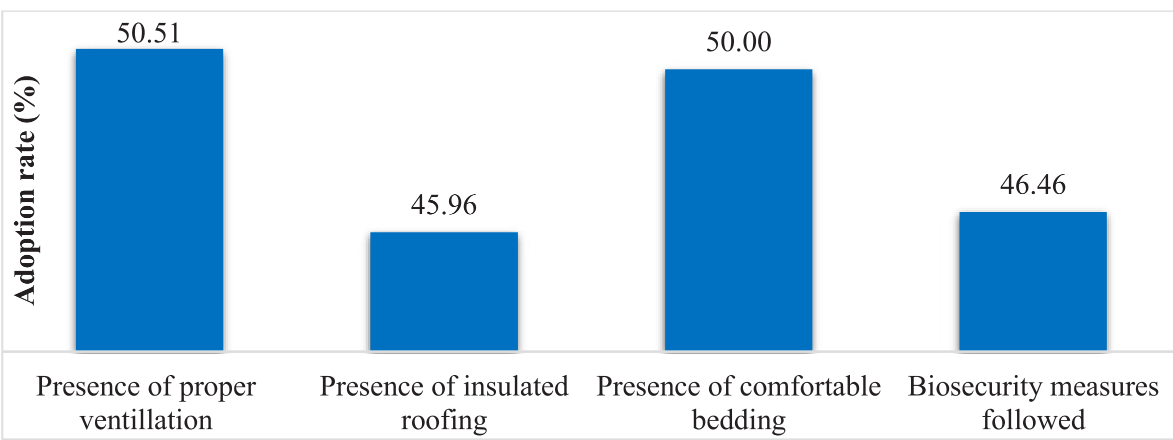

Figure 5. Adoption of cattle shed management practices among dairy cattle farmers (n= 198)

3.3.4 Manure management

All sampled households (100%) practiced the frequent removal manure from cattle shed. The 31.82% of households reported covering of manure to reduce the nutrient loss and odor. Similarly, 24.24% of farmers used biogas technology in their farm. The use of improved urine pits was reported by 18.18% of households. Likewise, 8.59% of the household was engaged in composting the manure (Figure 7). The climate-friendly practices like composting and biogas production reduces GHG emissions contributing to a circular farm economy (Sapkota et al., 2019). The barriers of adoption of these particular CFPs include high initial costs, as approaches like biogas technology is costly to set up (Munidasa et al., 2021).

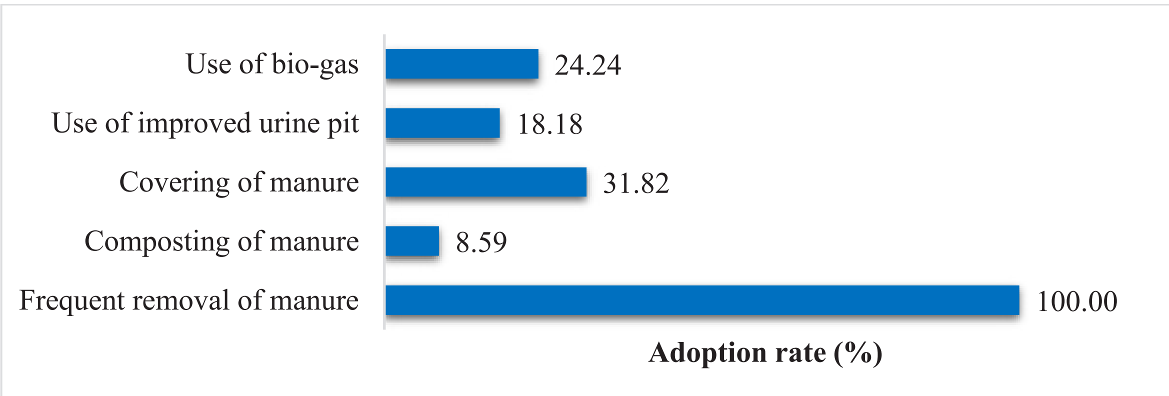

Figure 6. Adoption of manure management practices among dairy cattle farmers (n= 198)

3.3.5 Milk management

All sampled household (100.00%), maintained the consistent milking schedule. The 50.00% of household followed the clean milking practices. This finding is consistent with study of Adebe et al. (2013), which show that while farmers are aware about hygiene, limited technical knowledge and limited access to proper disinfectants hinder the uptake of this practice. Improving the adoption of clean milking is essential, as it not only enhances milk quality and safety but also reduces the incidence of costly diseases like mastitis. Similarly, 47.47% of household stated the use of low emission of eco-friendly mode for transportation of milk to the milk collection centers (Figure 8).

Figure 7. Adoption of milk management practices among dairy cattle farmers (n= 198)

3.4 CATEGORIZATION OF CATTLE FARMERS BASED ON ADOPTION OF CFPS

The classification of dairy farmers into low, medium, and high adoption categories provides a descriptive summary of the adoption status of CFPs in the study area. Of the 198 respondents, 110 were categorized as medium adopters, 49 as low adopters and 39 as high adopters. The observed distribution indicates that many farmers had adopted some CFPs, but the extent of adoption varied across households. These results may be useful for identifying groups that could benefit from the targeted technical support, but they should not be interpreted as evidence of adoption determinants because of no inferential analysis was conducted.

Table 5. Categorization of dairy cattle farmers based on their level of adoption of CFPs

Category	Description	Number of household (%)
Low adopter	Farmer adopting 1-7 CFPs	49 (24.75)
Medium adopter	Farmers adopting 8-14 CFPs	110 (55.35)
High adopter	Farmers adopting 15-20 CFPs	39 (19.70)

Note: Figures in parentheses indicate percentage.

LIMITATIONS OF THE STUDY

This study has several limitations that should be considered when interpreting its findings. First, the cross-sectional research design captures adoption status at a single point in time, which limits the ability to examine changes over time or establish causal relationships. Second, the sample was drawn from active members of dairy cooperatives in selected local units, which may restrict the generalizability of the findings to non-member farmers and to other regions of Nepal. Third, much of the information was based on self-reported responses, which may introduce recall bias or social desirability bias. Finally, the analysis was largely descriptive in nature and did not explore deeper explanatory relationships between adoption behavior and household or institutional factors. These constraints should be considered when interpreting the results and drawing policy or programmatic implication.

CONCLUSION

This study described the adoption of climate-friendly practices (CFPs) among sampled dairy cattle farmers in Bagamati Province, Nepal. Practices closely associated with herd productivity and animal health such as improved breeds, artificial insemination, and regular vaccination were widely adopted, whereas practices requiring greater technical knowledge, labor, or initial investment such as silage preparation, manure composting, and biogas use were less common. More than half of the respondents were categorized as medium adopters, suggesting partial uptake of the recommended practices. The findings indicate scope for extension support, practical training, and policy measures that address barriers to the adoption of less frequently used CFPs.

FUNDING INFORMATION

This research was supported by the Feed the Future Innovation Lab for Livestock Systems (LSIL), University of Florida.

ETHICAL STATEMENT

Ethical approval for the study was obtained from the Institutional Review Board (IRB) of Agriculture and Forestry University (AFU) prior to data collection. Before the commencement of each interview, verbal informed consent was obtained from all respondents.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Feed the Future Innovation Lab for Livestock Systems (LSIL), University of Florida, for the financial and technical support that made this research possible. The authors are thankful to the Department of Agricultural Economics and Agribusiness Management, the Directorate of Research and Extension (DoREX), and the Faculty of Agriculture, Agriculture and Forestry University (AFU), for providing a conducive environment for conducting this study, Finally, the authors extend their appreciation to all the participating dairy farmers whose cooperation was essential to the successful completion of this research.

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SEED YIELD POTENTIAL OF FODDER OATS (*Avena sativa* L.) TO THE DATE OF SOWING AND DEFOLIATION MANAGEMENT

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ABSTRACT

Optimizing sowing date and assessing defoliation responses are crucial for enhancing the seed yield of fodder oats (Avena sativa L.), particularly in the case of both seed and straw yields. A two-year field study on fodder oats was done at the National Pasture and Fodder Research Program, Khumaltar, Lalitpur, Nepal, to determine optimum date of sowing and the effect of defoliation on seed production. In the first experiment, the fodder oats cultivar Netra was sown on six dates (October 1, October 15, November 1, November 15, December 1 and December 15) using recommended agronomical practices. The experiment was conducted in Randomized Complete Block Design (RCBD) The second experiment was done to evaluate seed yield of two defoliation regimes, Zero-cut and One-cut at 45 days after sowing by using four fodder oat cultivars) in RCBD. The results revealed that the date of sowing significantly ($p<0.001$) influenced growth and seed yield parameters. Accordingly, sowing on November 1 produced the highest ($p<0.001$) seed yield, associated with superior ($p<0.05$) tillering, indicating early November as the optimum sowing time for seed production. Defoliation significantly ($p<0.05$) reduced plant height, number of effective tillers plant^{-1} and seed yield across all cultivars.

Keywords: Cultivar, Defoliation management, Number of effective tillers, Number of leaves, Straw yield

INTRODUCTION

Oat (*Avena sativa* L.) is an important multipurpose cereal crop globally, valued not only for its grain but also as a highly nutritious fodder for livestock. Within crop-livestock systems, high quality roughage like oat fodder is vital for sustainable animal production (Russelle *et al.*, 2007). Although, it is primarily cultivated for grain, its utility as a dual-purpose crop, where early growth can be grazed or cut for forage before the crop is left to regenerate for grain harvest, offers an effective strategy to enhance farm profitability and resource use efficiency (Bharati *et al.*, 2023; Ghimire, 2025).

The successful cultivation of oat, whether for single or dual purposes, is highly dependent on agronomic management, and the sowing date being a critical determinant of productivity. The phenological development of oat is exquisitely sensitive to environmental parameters such as temperature and photoperiod (Ghimire *et al.,* 2026). Sowing at an optimal time ensures

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that critical growth stages, including tillering, panicle initiation and grain filling; coincide with favourable climatic conditions thereby maximizing yield potential. On the otherhand, suboptimal sowing dates can expose the crop to abiotic stresses like terminal heat or moisture deficit that leads to significant yield reduction (Basu *et al.*, 2009). Identifying the appropriate date of sowing is therefore essential for optimizing seed yield, particularly in specific agro-ecological zones like the mid-hills of Nepal. For dual-purpose systems, defoliation management is another important factor. The practice of harvesting oat for fodders at a vegetative stage, followed by regrowth for seed, involves a multifaceted phenomenon. In general, while it provides the forage the defoliation acts as a physiological stressor, removing photosynthetic tissue and apical meristems, which can compromise the ability of the plant to accumulate biomass and ultimately reduce grain yield (Zhang *et al.*, 2021). The magnitude of yield reduction is influenced by the timing and severity of defoliation, as well as the genetic potential of the cultivar for regrowth and compensatory growth (Ferraro & Oesterheld, 2002). Cultivars with greater tolerance to defoliation, capable of maintaining satisfactory seed yields after a cutting are crucial for the economic viability of dual-purpose systems (Baron *et al.*, 1994).

In the context of growing importance of oat as the winter forage crop and the increasing research emphasis on optimizing its seed production in Nepal, the information particularly on the date of sowing and the feasibility of dual-purpose use remains limited. Therefore, the study was done to determine the optimum sowing dates for seed production of oats and to assess the effect of defoliation on the seed yield production of promising fodder oat cultivars.

MATERIALS AND METHODS

Experimental site

The study was conducted at the research field of the National Pasture and Fodder Research Program under Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur (27°39'18" N 85°19'29" E, altitude 1335 masl) during September 2018 to May 2020. The site experiences a humid subtropical climate. The weather parameters recorded at the station during the study period are presented in Figure 1.

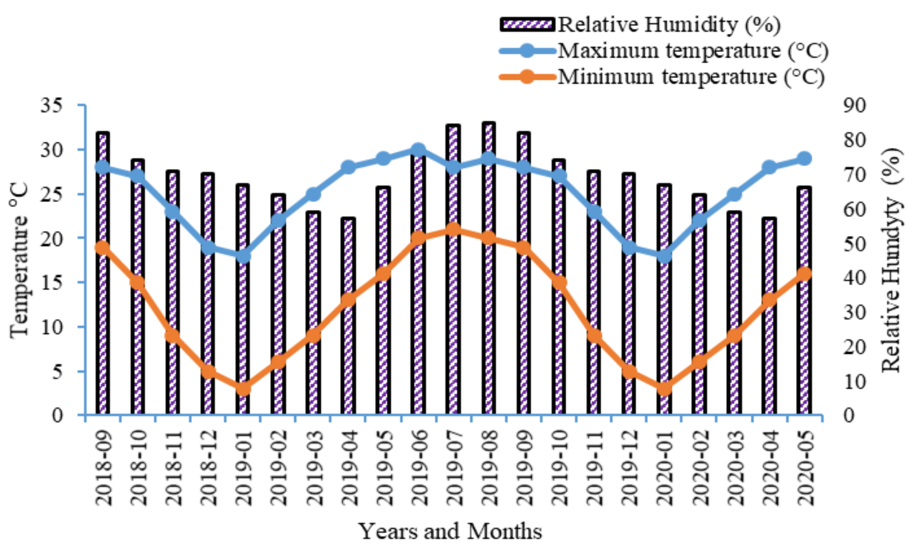

Figure 1. Monthly temperatures and Relative Humidity during September, 2018 to May 2020 at Khumaltar, Lalitpur, Nepal

The soil physicochemical properties of the experimental fields for both experiments were analysed prior to sowing (Table 1). The soil was moderately acidic with medium to high levels of organic matter, nitrogen, phosphorus and potassium contents (Table 1).

Table 1. Physicochemical properties of the soil at the experimental sites at Khumaltar, Lalitpur, Nepal

Parameters	Date of sowing experiment (Mean±SD)	Defoliation management experiment (Mean±SD)
pH	5.4±0.04	5.8±0.98
Total N (%)	0.2±0.01	0.2±2.02
P2O5 (kg ha^{-1})	79.0±7.22	80.4±0.71
K2O (kg ha^{-1})	317.36±40.86	338.56±32.84
OM (%)	3.12±0.38	3.37±0.39

Experimental details

The first-year experiment on date of sowing was laid out using Randomized Complete Block Design (RCBD) with four replications for each treatment compromising six dates of sowing (October 1, October 15, November 1, November 15, December 1 and December 15). Netra cultivar of fodder oats was used and the plot size was maintained for 12 square-meter as an experimental unit. The seed rate of 80 kg ha^{-1} was used. Fertilizer was applied at 80:60:40 kg ha^{-1} N:P_2O_5:K_2O. A basal dose of 40 kg ha^{-1} N along with the full dose of P and K was applied at the time of sowing. The remaining 40 kg ha^{-1} N was top-dressed after irrigation at 45 days after sowing (DAS). Weeding, irrigation and other crop management practices were carried out as per the recommendations of Nepal Agricultural Research Council (NARC).

The second-year experiment on defoliation management was done using a RCB Design with five replications for each treatment. The treatments were Zero-cut (not defoliated) and One-cut (defoliated once at 45 DAS) in four fodder oat cultivars were evaluated. Each experimental plot measured 12 m^2. The defoliation height was maintained at 5 cm above ground level. The seed rate of 80 kg ha^{-1} and a fertilizer dose of 80:60:40 kg ha^{-1} N:P_2O_5:K_2O was applied. Basal dose of 40 kg ha^{-1} N and the full dose of P and K was applied at the time of sowing and the remaining nitrogen was top-dressed. The top-dressings for the Zero-cut plots were done after an irrigation application at 45 DAS, while it was applied after the defoliation followed by irrigation in case of the defoliated plots. Weeding, irrigation and other crop management practices were uniformly maintained for all plots as per the NARC recommendation.

Data Collection

For both experiments, agronomic data were collected at seed maturity. Plant height, number of leaves tiller^{-1} and number of effective tiller plant^{-1} were measured from five randomly selected plants in every plot. The seed yield and straw yield were collected by harvesting the central three rows of each plot. The harvested materials were threshed, winnowed and dried to 12% moisture content for seed yield determination. The yields were calculated to kg m^{-2} by using the following equation, and then converted to t ha^{-1}.

$$\text{Seed yield, kg m}^{-2} = \frac{\text{Seed yield of three central rows, kg}}{\text{Row to row distance, m } \times \text{Row length, m } \times \text{Number of sample rows}}$$

Similarly, the following equation was used to estimate the straw yield per m^2 and converted to t ha^{-1}.

$$\text{Seed yield, kg m}^{-2} = \frac{\text{Seed yield of three central rows, kg}}{\text{Row to row distance, m } \times \text{Row length, m } \times \text{Number of sample rows}}$$

Statistical Analysis

The data from date of sowing experiment conducted during first year were analysed using one-way Analysis of Variance under RCBD. The treatment means were separated by using the Tukey's HSD Test at a 5% level of significance. For the defoliation experiment conducted in second year, the primary objective was to assess the effect of defoliation on seed yield components, seed yield and straw yield within each cultivar. Therefore, a paired sample t-test (2-tailed) was employed to evaluate the effects of defoliation on these parameters for each cultivar separately. The statistical analyses were performed using the jamovi™ (The jamovi project, 2020) software.

RESULTS

Date of sowing

Sowing date had a significant influence ($p<0.001$) on all measured growth and yield parameters of fodder oats (Table 2). Plant height differed markedly across sowing dates, with crops sown from October 1 to November 15 producing statistically similar ($p>0.05$) and comparatively taller plants (128.85-139.68 cm). In contrast, plant height declined substantially when sowing was delayed to December, with the reduced plant height (78.19 cm) recorded on December 15 (Table 2).

The number of effective tillers $plant^{-1}$ was also affected by sowing date. The highest tiller number (7.45 $plant^{-1}$) was obtained from the November 1 sowing, which was significantly higher ($p<0.001$) to all other treatments. Tiller production declined with both earlier (October) and later (December) sowings.

Seed yield followed a similar trend, with November 1 sowing producing the maximum seed yield (4.576 t ha^{-1}), which was significantly higher than all other dates ($p<0.001$). Sowing on November 15 followed the November 1 for seed yield, while the lowest yield was recorded for December 15 sowing. Straw yield showed comparable responses, with the highest value (13.352 t ha^{-1}) from the early November sowing and pronounced reductions in December sowings.

The results showed that optimal crop growth, tillering and seed production were achieved when oat was sown in early November, while substantial yield penalties occurred with delayed sowing.

Table 2. Seed yield and yield components of fodder oats (cv. Netra) under different dates of sowing at Khumaltar Lalitpur, Nepal

Date of sowing	Plant height (cm)	No of leaves tiller^{-1}	No of effective tillers plant^{-1}	Seed yield (t ha^{-1})	Straw yield (t ha^{-1})
October 1	139.68^{a}	6.28^{b}	5.22^{cd}	2.306^{d}	11.317^{bc}
October 15	136.60^{a}	5.88^{bc}	6.25^{b}	3.084^{c}	12.083^{ab}
November 1	128.85^{a}	6.83^{a}	7.45^{a}	4.576^{a}	13.352^{a}
November 15	131.60^{a}	5.63^{c}	6.50^{b}	3.671^{b}	11.951^{b}
December 1	107.63^{b}	5.67^{c}	5.69^{c}	2.835^{c}	10.654^{c}
December 15	78.19^{c}	4.85^{d}	5.10^{d}	1.508^{e}	7.523^{d}
Significance (F-test)	***	*	***	***	***

Defoliation management

Defoliation at 45 DAS had a significant impact on plant height, tillering, seed and straw yield across all four oat cultivars evaluated (Tables 3 and 4). Plant height was consistently reduced ($p<0.05$) in defoliated plants of each cultivar, with decreases ranging from 18 to 31 cm depending on cultivar. Significant reductions ($p<0.05$) in the number of leaves tiller^{-1} were observed in Amritdhara and Kamadhenu, while the effect was non-significantly different ($p>0.05$) in Ganesh and Parbati (Table 3).

Defoliation significantly decreased the number of effective tillers plant^{-1} in all cultivars. Zero-cut plants produced 6.80-8.56 tillers plant^{-1}, whereas one-cut plants produced only 6.00-6.16 tillers plant^{-1}, reflecting their incomplete compensatory ability after removal of photosynthetic and meristematic tissues.

Seed yield was significantly reduced in all cultivars following defoliation ($p<0.01$). Under zero-cut management, seed yield ranged from 3.63 t ha^{-1} (Amritdhara) to 4.62 t ha^{-1} (Parbati). Defoliation reduced seed yield by 43%, 24%, 37% and 31% in the case of Amritdhara, Kamadhenu, Ganeshand Parbati cultivars, respectively. Straw yield exhibited similar declines ($p<0.05$) across cultivars. Among the tested cultivars, Kamadhenu showed the least proportional reduction in seed yield, indicative of its comparatively higher tolerance to defoliation and better suitability for dual-purpose use (Table 4), although the statistical significances of the reduction in seed yield were yet to be analyzed.

Table 3. Seed components of different fodder oats cultivars under defoliation treatments at Khumaltar, Lalitpur, Nepal

Defoliation	Amritdhara			Kamadhenu			Ganesh			Parbati		
	Plant height (cm)	No of leaves tiller^{-1}	No of effective tillers plant^{-1}	Plant height (cm)	No of leaves tiller^{-1}	No of effective tillers plant^{-1}	Plant height (cm)	No of leaves tiller^{-1}	No of effective tillers plant^{-1}	Plant height (cm)	No of leaves tiller^{-1}	No of effective tillers plant^{-1}
Zero-cut	136.26	3.93	6.80	130.20	4.46	8.56	122.33	3.73	6.64	102.20	3.60	6.93
One-cut	104.73	3.53	6.00	103.53	3.86	6.13	102.53	3.93	6.16	87.53	3.20	6.00
Significance$^{\lambda}$	**	*	*	*	*	**	*	ns	**	**	ns	*

$^{\lambda}$Paired differences significance in t-test (2-tailed), * significance at p<0.05, ** significance at p<0.01.

Table 4. Seed and straw yield (t ha^{-1}) of different fodder oat cultivars under defoliation treatments at Khumaltar, Nepal

Defoliation	Amritdhara		Kamadhenu		Ganesh		Parbati	
	Seed yield	Straw yield	Seed yield	Straw yield	Seed yield	Straw yield	Seed yield	Straw yield
Zero-cut	3.625	14.636	4.163	13.350	3.930	13.600	4.617	15.702
One-cut	2.068	9.297	3.182	10.583	2.480	11.245	3.182	12.887
Significance$^{\lambda}$	**	**	**	**	**	*	**	*

$^{\lambda}$Paired differences significance in t-test (2-tailed), * significance at p<0.05, ** significance at p<0.01.

DISCUSSION

The marked variation in growth and yield components across different sowing dates demonstrates the strong influence of seasonal temperature and photoperiod on fodder oat phenology. The superior seed yield obtained from the November 1 sowing is consistent with the well-established principle that fodder oat performs best when vegetative growth, panicle initiation and grain filling coincide with moderate temperatures and favorable day lengths. Although early October sowings produced taller plants, they generated comparatively fewer effective tillers and lower seed yields, likely because crop establishment occurred under relatively warmer conditions and less favorable photoperiods during the initial stages of development (Ko *et al*., 2022; Trevaskis *et al*., 2022). In contrast, delayed sowing, particularly in December, exposed seedlings to low temperatures and shortened day lengths, conditions that can accelerate phenological development, reduce tillering, shorten the vegetative growth period and ultimately limit biomass accumulation and reproductive potential (Devi *et al*., 2023). The substantial decline in seed yield under December sowing agrees with the findings of Dhakal *et al*. (2023), who reported considerable yield penalties when oat sowing was delayed beyond mid-November under mid-hill environments of Nepal.

The results clearly indicate that early November provides the most suitable combination of environmental conditions for oat seed production at Khumaltar condition. Sowing during this period allows adequate vegetative growth, optimal tiller development and grain filling under favorable temperatures, thereby avoiding both early-season heat stress and late-season cold stress. Consequently, sowing oat around November 1 can be considered as the optimum planting date for seed production in agro-ecological conditions similar to those of central Nepal.

Previous studies have consistently demonstrated the effects of forage defoliation on growth and seed yield potential in oat genotypes (Devkota *et al*., 2015; Ghimire *et al*., 2026). The second experiment was designed to evaluate the effects of defoliation on the seed production performance of recently developed oat cultivars rather than to re-establish the response of a widely adopted check cultivar used in sowing date experiment. Therefore, the emphasis of the second experiment was on assessing whether newly released cultivars possess comparable or superior tolerance to defoliation stress. From a breeding and cultivar evaluation perspective, understanding the relative resilience of new cultivars is more important than repeatedly validating responses that have already been well established in a benchmark cultivar.

The significant reduction in seed yield following forage harvesting in all cultivars highlights the inherent compromise associated with dual-purpose oat management. Removal of photosynthetically active biomass during the stem elongation stage (45 DAS) reduces the assimilatory capacity of the crop and limits the accumulation and translocation of carbohydrates required for floret development, grain set and grain filling (Ferraro & Oesterheld, 2002; Bell *et al*., 2020; Ko *et al*., 2022). Although partial compensatory growth through additional tillering was observed, it was insufficient to fully offset the loss of assimilate-producing tissues, resulting in a measurable decline in final seed yield. Similar responses have been reported in oats and other small-grain cereals, where defoliation after the commencement of stem elongation generally reduces reproductive productivity because the capacity for compensatory growth becomes progressively restricted (Bell *et al*., 2020; Ferraro & Oesterheld, 2002). Studies conducted in Nepal have likewise shown that forage harvesting can substantially increase total biomass production while causing varying levels of seed yield reduction, depending on genotype, cutting stage and environmental conditions (Devkota *et al*., 2015; Ghimire *et al*., 2026).

Notably, cultivars differed in their response to defoliation. Kamadhenu exhibited the least proportional reduction in seed yield (24%) following forage harvest, indicating comparatively greater tolerance to defoliation stress. However, the statistical significance of cultivar differences in defoliation response was not evaluated in this study. Such genotypic variation in response to defoliation has been widely reported in fodder oat, with yield losses ranging from approximately 20% to 45% depending on cultivar characteristics and timing of defoliation (Yang *et al*., 2019). The comparatively superior performance of Kamadhenu, although statistically not tested, suggests greater regrowth capacity, enhanced recovery following biomass removal, and more efficient partitioning of assimilates to reproductive structures after stress. These attributes are particularly desirable for dual-purpose cultivars because they allow the production of valuable forage without incurring excessive reductions in seed yield (Baron *et al*., 1994). Future studies incorporating economic analyses that compare the value of harvested forage with the associated reduction in seed yield would provide a more comprehensive assessment of the profitability and practical feasibility of dual-purpose oat production systems in Nepal.

CONCLUSION

The findings demonstrated that both sowing date and defoliation management significantly influence seed yield of fodder oat under the mid-hill valley conditions of Nepal. For maximizing seed production, early November sowing (November 1) without defoliation was the most effective strategy, producing the highest seed yield and superior yield components. A single defoliation at 45 DAS reduced seed yield by 24-43% across cultivars, indicating a clear trade-off between forage harvest and seed production. However, where both forage and seed are desired from the same crop, further comprehensive study incorporating biological and economic analysis of forage and seed yields following a single forage harvest are needed to assess the feasibility and profitability of dual purpose production system.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICAL STATEMENT

The manuscript is original work of the authors and has not been published previously, nor submitted, nor is it under consideration for publication elsewhere.

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WTO COMMITMENTS AND COMPLIANCE IN NEPALESE AGRICULTURE: IMPLICATIONS FOR THE TEA SECTOR

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ABSTRACT

Despite more than two decades of Nepal's membership in the World Trade Organization (WTO), limited empirical evidence exists regarding the implementation of its agricultural commitments and their implications for strategic export commodities such as tea. This paper examines the commitments of Nepal under the WTO system and assesses how these obligations have been implemented and their impact on the agricultural sector and specifically on tea. To assess the implications of WTO accession at the institutional and policy level, it focuses on three pillars of the AoA, namely market access, domestic support, and export competition. Moreover, it also examines the obligations and challenges of the Sanitary and Phytosanitary (SPS) and Technical Barriers to Trade (TBT) agreements. The analysis is performed using WTO notifications, national budgetary data, and industry-specific information to assess the tariff bindings along with intensity of domestic support and export incentives. The findings suggest that Nepal has maintained the applied tariffs much lower than the bound rates and utilized Green Box and Special and Differential Treatment with domestic support that is considerably low. Export incentive measures implemented during the study period were modest in scale. The evidence related to SPS and TBT challenges indicates that there are several capacity and compliance issues. Overall, the study concludes that Nepal has implemented its WTO commitments conservatively and recommends utilising the policy space available for supporting domestic producers.

Keywords: Agricultural trade, Nepal Tea, SPS, TBT, WTO

1. INTRODUCTION

As the first Least Developed Country (LDC), Nepal's accession to the World Trade Organization (WTO) in April 2004 was an important event in its economic and trade policy history. Upon joining the WTO, Nepal undertook several binding commitments to implement the Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS), the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) and the Agreement on Technical Barriers to Trade (TBT) with limited transitional periods, including in agriculture (Adhikari et al., 2008). This shift from a largely protectionist and state-controlled trade regime to a liberalized and rule-based multilateral system was not

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merely a legal shift, but a fundamental transformation in how Nepal positioned itself in the global trading system (GC, 2018).

The accession was preceded by a decade-long preparation, during which Nepal restructured its tariff schedules, revised several trade laws, and committed to transparency, non-discrimination, and market-oriented reforms. The country made a sequence of commitments under key WTO agreements, including General Agreement on Tariffs and Trade (GATT), Agreement on Agriculture (AoA), SPS and TBT agreements (WTO, 2003).

The WTO accession process and its implications for trade have attracted considerable attention in the literature. Some researchers such as Campos et al. (2024) found that being a member of the WTO has generally contributed positively to international trade, but the benefits are different from one country to another and from one sector to another. In the Nepalese context, researchers have also examined the implications of WTO membership for agricultural development and trade competitiveness (Adhikari et al., 2008; Awasthi & Adhikary, 2004). Specific to the tea sector, Shrestha (2010) had highlighted the structural challenges affecting the tea trade in the international market, while Luitel et al. (2025) documented the evolution of Nepalese tea during the post-WTO era and emphasised the challenges in market access, standards compliance and export competitiveness. Similarly, Dembatapitiya (2015) demonstrated the growing significance of product standards and technical regulations in shaping agricultural export performance in South Asia.

Despite these contributions, there remains limited empirical evidence on how Nepal has implemented its WTO commitments in agriculture and how these commitments have affected the tea sector. Most of the existing studies have primarily focused on trade performance, export trends and standard compliance. However, a comprehensive assessment of Nepal's obligations and implementation under the AoA, SPS and TBT agreements remains largely unexplored. This knowledge gap is particularly important because agricultural trade policy is increasingly shaped by multilateral commitments, while tea remains one of Nepal's most important high-value export commodities.

Accession to the WTO marked the beginning of a new phase of trade liberalization, transparency and institutional reform. For agriculture, the implications have been wide-ranging, extending from the changing market access opportunities to significant regulatory and compliance challenges in meeting international standards. As Nepal prepares to graduate from LDC status by 2026, a clear understanding of the effects of such commitments, especially for high-value agricultural exports like tea is crucial.

Such assessment is very important because of the strategic necessity to make effective use of its policy space through WTO regulations, as well as the enhancement of the competitiveness of Nepalese agricultural exports. The knowledge about compliance levels and the extent of flexibility in the WTO agreement can assist in policy reform efforts and the development of sectors in a manner consistent with the evidence provided by this assessment. Thus, this research will attempt to: (i) assess Nepal’s compliance with the WTO Agreement on Agriculture; (ii) analyze the measures taken for market access, domestic support and export competition within Nepalese agriculture; and (iii) assess the remaining policy space for agricultural and tea sector development under WTO regulations.

In addition, the study seeks to provide insights into potential policy reforms that could strengthen the competitiveness of Nepalese tea exports while remaining consistent with WTO obligations.

2. METHODOLOGY

2.1 SOURCES OF DATA

The empirical assessment of Nepal's WTO commitments and compliance in the agricultural and tea sector of Nepal is based primarily on secondary data sources. The study adopts a documentary and secondary-data-based analytical approach and does not involve primary surveys or stakeholder interviews. The analysis combines the information from WTO sources and from national budgetary sources. "Table 1. Indicators and data sources used for WTO commitments and compliance analysis" Table 1 summarises the key variables used in the analysis along with their data sources. While WTO accession documents, tariff schedules and notification records were referred for the assessment of Nepal's commitments, the external regulatory data from United States Food & Drug Administration [FDA] (2025) and national data sources like Ministry of Finance [MoF] (2025), Line Ministry Budget Information System [LMBIS] (2025) and Nepal Rastra Bank [NRB] (2024) were consulted for evaluating the compliance and associated challenges. The analysis utilizes the most recent data available from the respective sources at the time of the study.

Table 1. Indicators and data sources used for WTO commitments and compliance analysis

Analytical Component	Indicators	Data Source
Market access commitments	Tariff bound and MFN applied rates	World Tariff Profiles
Domestic support commitments	Green Box and SDT measures	Notification portal of WTO (2025)
Domestic support implementation	Agricultural expenditure and support intensity	MoF (2025) and LMBIS (2025)
Product-specific domestic support in tea	Tea development expenditure and tea support intensity	LMBIS (2025)
Export competition measures	Export incentive payments by product	NRB (2024) dataset on export incentives
SPS and TBT implementation	Import refusal frequency by product category	United States FDA (2025)

2.2 ANALYTICAL APPROACH

The market access commitments were examined through a comparison of bound tariff rates and the Most Favoured Nation (MFN) applied tariffs in the agricultural sectors with a particular focus on the tea sector. The analysis focuses on Nepal's market access commitments under the

WTO framework rather than market access conditions faced by Nepalese tea exports in foreign markets. This analysis aimed to identify the gap between the bound and the applied tariffs, which indicates the extent of Nepal's underutilized tariff policy space.

Similarly, domestic support commitments and implementation were analysed by categorizing the support measures in accordance with the WTO's Green Box and Special and Differential Treatment (SDT) provisions. To estimate the level of domestic support, the intensity indicators were calculated. In the agricultural sector, the support intensity is measured as the ratio of total agricultural expenditure to the agricultural GDP, which is calculated by using Equation (1).

$$Agriculture\ Support\ Intensity = \frac{Agriculture\ Expenditure}{Agricultural\ GDP} X\ 100\% \qquad \text{Equation (1)}$$

For the product-specific support in tea, the support intensity was calculated using Equation (2).

$$Product\ Specific\ Support\ Intensity\ in\ tea = \frac{Tea\ Developement\ Expenditure}{Value\ of\ tea\ production} X\ 100\% \qquad \text{Equation (2)}$$

In *Equation (1)* and *Equation (2)*, the agriculture expenditure and the tea development expenditure data were drawn from LMBIS expenditure report as reported by Ministry of Agriculture and Livestock Development (MoALD) and National Tea and Coffee Development Board (NTCDB), respectively. This approach is consistent with the methodologies employed in several studies (Awasthi & Adhikary, 2004; Brink, 2007; Sharma, 2016).

Furthermore, the export competition measures were assessed by examining the historical export incentives schemes provided by the Government of Nepal to the exporters of specific products. Since the export incentive programme has subsequently been discontinued, the analysis is intended to assess the nature and magnitude of these measures during the period in which they were implemented and their relevance to WTO compliance. The implementation challenges related to the SPS and TBT agreements were evaluated using proxy indicators of export refusal by FDA.

3. RESULTS AND DISCUSSION

The AoA constitutes one of the core WTO legal agreements negotiated during the Uruguay Round and has been instrumental in transforming global agricultural trade. Before the establishment of the WTO in 1995, trade in agricultural products was heavily distorted by domestic subsidies, export subsidies and tariff & non-tariff barriers, particularly in industrialized countries (Anderson & Martin, 2005). The AoA introduced a three-pillar framework, namely market access, domestic support and export competition, which was aimed to gradually reduce these trade-distorting measures.

3.1 MARKET ACCESS COMMITMENTS UNDER THE AOA

At the global level, the market access pillar of the AoA is aimed at improving the transparency and predictability in agricultural trade through tariff bindings and reductions in border protection. While the Uruguay Round introduced tariffication for many WTO members, Nepal's accession commitments primarily involved binding agricultural tariffs at negotiated levels. Under this provision, Nepal committed to bind its agricultural tariffs at relatively high levels at the time of WTO accession. The slight decline in average bound tariffs presented in World Tariff Profiles reflects changes in the composition and reporting of tariff schedules over time rather than renegotiation of Nepal's WTO commitments.

For agriculture, the final bound tariff rate stood at 41.4 per cent in Fiscal Year (FY) 2004/05 and declined slightly to 39.6 per cent in FY 2018/19 ("Figure 1. Nepal’s tariff bound and MFN applied for agriculture"). In contrast, the MFN applied rates remained significantly lower, ranging between 12.5 to 14.9 % throughout the period. This significant gap between bound and applied tariffs suggests that Nepal has not fully utilised its policy space under AoA within its WTO commitments, thereby retaining the flexibility to adjust applied tariffs in response to domestic market conditions.

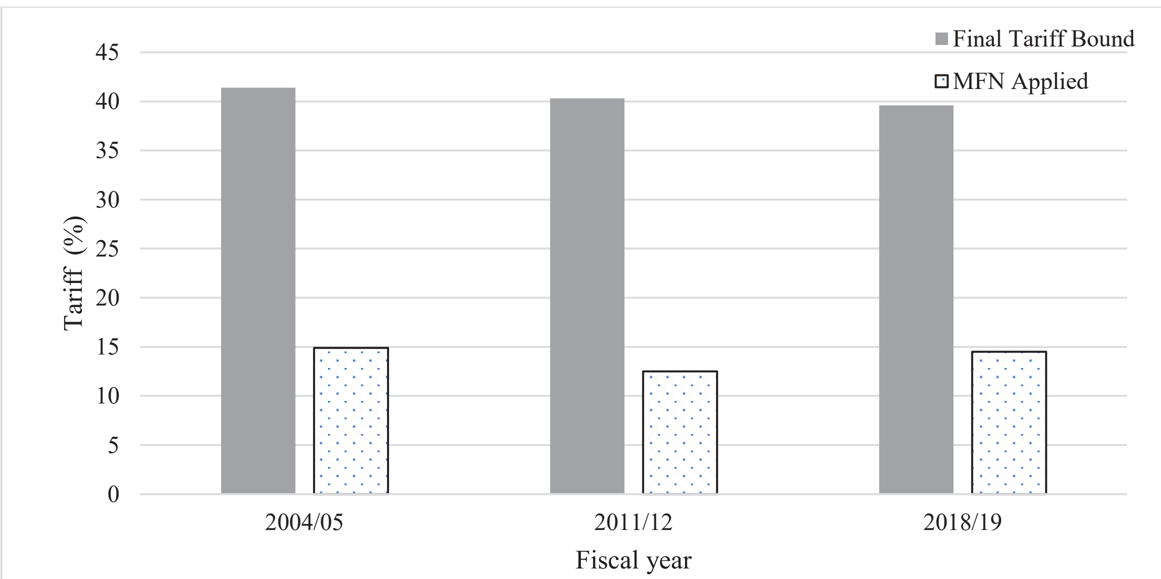

Figure 1. Nepal’s tariff bound and MFN applied for agriculture

Source: Compiled from World Tariff Profiles (2005, 2012 and 2019)

A similar pattern can be observed in the tea sector. The bound rate for tea has remained constant at 40.8 per cent over the years, while MFN rates are in the range of 23 to 24 per cent (Figure 2. Nepal’s tariff bound and MFN applied for tea). This gap indicates that Nepal has the scope to adjust the tariffs on tea imports without breaching the WTO commitments.

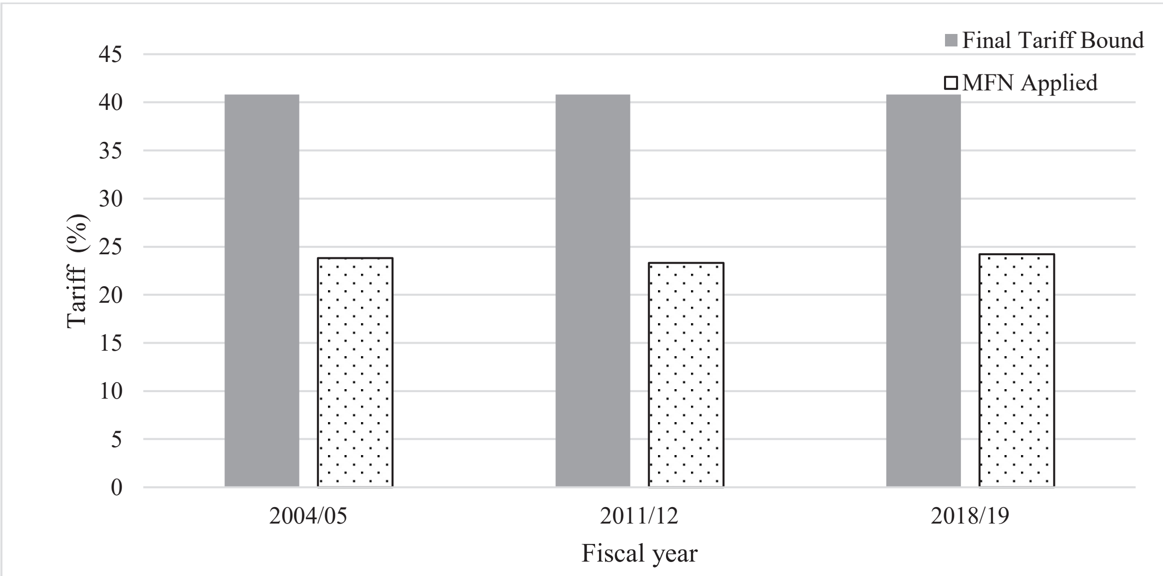

Figure 2. Nepal's tariff bound and MFN applied for tea

Source: Compiled from World Tariff Profiles (2005, 2012 and 2019)

3.2 DOMESTIC SUPPORT COMMITMENTS UNDER THE AOA

The second pillar of the AoA is domestic support, which refers to the governmental interventions providing financial assistance to agricultural producers. In recognition of the developmental needs and structural constraints faced by the developing and LDCs, the AoA allows a certain level of domestic support to be exempted from the reduction commitments. These exemptions are provided under the Green Box and SDT measures. While Green Box supports include the public spending on research, extension, infrastructure, pest and disease control, food security and environmental programmes, the SDT measures allow flexibility for the government to support low-income or resource-poor farmers by supporting them with input and investment subsidies.

Being a developing country, Nepal is committed to providing domestic support below the *de minimis* level, which is 10 per cent of the total value of agricultural production (Awasthi & Adhikary, 2004). Within this threshold, product-specific and non-product-specific support is exempted from reduction commitments. However, Nepal has reported zero Aggregate Measurement of Support to the WTO during the study period. This further indicates that Nepal has adequate policy space under the AoA to provide domestic support to its agricultural sector within the permitted level.

Table 2 summarizes the composition of domestic support provided by Nepal to its farmers and agricultural producers. The input subsidies, primarily provided for chemical fertilizers, provided under SDT provisions account for nearly half of the total exempt support, while Green Box expenditures are largely concentrated on extension and advisory services (21.23%) and infrastructural investments (11.88%). Interestingly, less than five per cent of the total domestic support in agriculture is allocated to research, suggesting relatively limited emphasis on knowledge generation and innovation. Overall, Nepal's domestic support is dominated by Green Box and SDT measures, indicating underutilization of available policy space within the AoA provision.

Table 2. Average annual domestic support notified by Nepal under WTO-exempt categories

Category	Average Annual Value (Million NPR)	Share of Total Exempt Support (%)
Green Box Measures		
Extension and advisory services	5,240.76	21.23
Infrastructural services	2,932.72	11.88
Regional assistance programmes	1,115.32	4.52
Research	1,079.66	4.37
Pest and disease control	700.08	2.84
Domestic food aid	534.81	2.17
Payments for relief from natural disasters	487.13	1.97
Other direct payments	408.55	1.66
Inspection services	266.86	1.08
Marketing and promotion services	242.71	0.98
Environmental programmes	141.33	0.57
Training services	139.21	0.56
Public stockholding for food security	79.68	0.32
Total Green Box Measures	**12,351.61**	**50.15**
Special and Differential Treatment Measures		
Input subsidies to low-income/resource-poor producers	12,307.19	49.66
Investment subsidies (agricultural loan interest subsidy)	47.13	0.19
Total SDT Measures	**12,316.61**	**49.85**
Grand Total (Green Box + SDT)	**24,668.22**	**100.00**

Source: Compiled from the notification portal of WTO (2025)

3.3 DOMESTIC SUPPORT IN NEPALESE AGRICULTURE

The domestic support structure of Nepal considerably relies on the Green Box and SDT measures. As already presented above, the Green Box support is primarily composed of extension and advisory services, infrastructure development and research expenditure. Similarly, the SDT measures are mainly concentrated in input subsidies for small farmers in the form of chemical fertilizers subsidies. These approaches suggest that Nepal's domestic support is targeted towards developmental intervention rather than direct price or production support.

Although the structure of domestic support complies with WTO requirements, size of the monetary value of support still remains small compared to the value of production. The total domestic support intensity of the Nepalese agricultural sector is presented in Table 3. It shows that despite 21% contribution to the national GDP, the public expenditure on agriculture has remained below 4% of the aggregate value of agricultural production, which indicates that Nepal has underutilized the policy space permitted under the AoA.

Table 3. Agricultural domestic support intensity in Nepal from FY 2020/21 to 2023/24.

Particulars	2023/24	2022/23	2021/22	2020/21	Data source
GDP Current Price (million NPR)	5704840	5348528	4976558	4352550	MoF (2025)
Agriculture GDP (in million NPR) (A)	1216648	1133329	1040816	958495	MoF (2025)
Agriculture Contribution in GDP (%)	21.33	21.19	20.91	22.02	
Agriculture expenditure (in million NPR) (B)	38836	45222	30399	23007	LMBIS (2025)
Agriculture Support Intensity (%) (B/A x 100)	3.19	3.99	2.92	2.40	

Source: Authors' calculation

3.4 DOMESTIC SUPPORT IN THE NEPALESE TEA SECTOR

The Nepalese tea sector has received very little product specific domestic support. Majority of the support in tea is indirect and is embedded within the non-product-specific Green Box measures. Even the SDT provisions of the input subsidies on chemical fertilizers are mostly oriented towards food crop and resulting the tea farmers are marginally benefited from this.

Table 4 shows the intensity of product-specific domestic support in tea, expressed as a percentage of the estimated value of tea production. The results are based on the analysis of budgetary expenditures made through the NTCDB. It reveals that the government expenditure, in the form of public investment for the development of tea sector is a very small in relation to the total value of tea production. The product-specific support in tea was less than two percent throughout the observed period. The findings indicate that product-specific support to the tea sector remains limited relative to the value of tea production and considerably below the level of support permitted under WTO provisions.

Table 4. Product-specific domestic support intensity for tea in Nepal from FY 2020/21 to 2023/24.

	2023/24	2022/23	2021/22	2020/21	Data source
NTCDB expenditure for tea/coffee development (thousand NPR) (A)	105738	99357	103599	107698	LMBIS (2025)
Tea production (kg) (B)	26983175	26401942	26379493	23745902	NTCDB (2025)
Price of Tea (NPR) (C)	260.49	237.26	237.26	318.53	DoC (2023)
Value of tea production (thousand NPR) (D=B*C)	7028894	6264057	6258730	7563838	
Product-specific support intensity in tea (%) (A/D*100)	1.50	1.59	1.66	1.42	

Source: Authors' calculation

3.5 EXPORT COMPETITION COMMITMENTS UNDER THE AOA

The third pillar of the AoA is export competition, which is concerned with limiting the trade policies which directly or indirectly subsidise the agricultural exports. Historically speaking, the developed economies in the past used export subsidies to dispose of their excess production. This lowered the prices in the international market at the expense of the producers in developing countries. To address the price distortions, the AoA introduced binding of the commitment to reduce and ultimately eliminate the export subsidies while also allowing some flexibility to the developing countries.

As an LDC, Nepal was not required to take any reduction commitments on export subsidies at the time of its accession to the WTO. At the same time, it was also committed not to introduce any new export subsidies programme that is not permitted under the agreement. However, Nepal has instrumentalized the export incentives and trade-facilitation measures as a part of its export promotion strategy, which are designed to support exporters being compliant to the AoA commitments.

3.6 COMPLIANCE WITH EXPORT COMPETITION RULES

As explained in previous sections, Nepal does not provide export subsidies to domestic producers. However, it provides some product-specific export incentives to selected products like tea, coffee, handicrafts, leather, herbs, essential oil, nettle fibres, jewels, turmeric, vegetables, honey, black cardamon and ginger. Exporters of these products are provided 5% cash back provided that they can prove that their domestic value addition is more than 30%. The domestic value addition is determined based on the free-on-board price minus the value of imported materials used for the production of that product.

It should be noted that the export incentive programme discussed in this section reflects the policy framework that existed during the study period. Subsequently, the Government of Nepal discontinued the export incentive scheme citing fiscal constraints. Therefore, the analysis is intended to evaluate the nature and magnitude of these measures during their period of implementation rather than describe the current export promotion regime.

Tea is one of the products that was receiving 5% export incentives. However, these measures are employed as national export support measures, and not as product-specific export subsidies. "Figure 3. Export incentives in tea and other products from FY 2021/22 to 2023/24." presents the cash incentives given to tea and other products from FY 2021/22 to 2023/24. It shows that incentives provided to the tea exports are relatively small in comparison to the total export incentives. Even in years when the overall export incentives distribution was high, the allocation for tea exports remained lower compared to other exports.

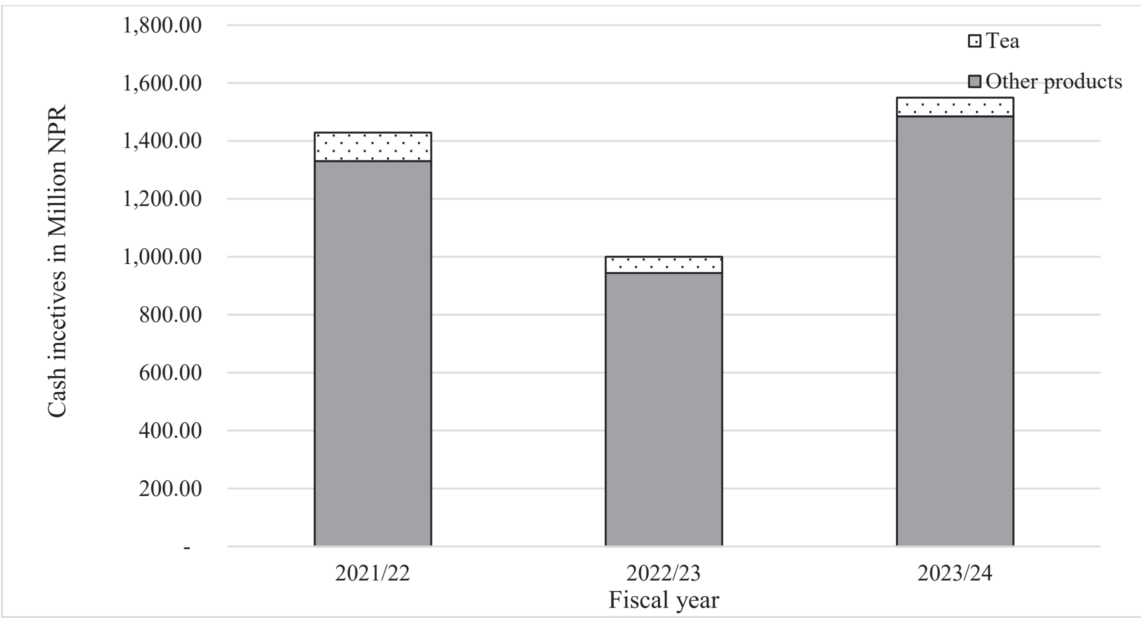

Figure 3. Export incentives in tea and other products from FY 2021/22 to 2023/24.

Source: Compiled from NRB (2024) dataset on export incentives

From the compliance perspective, the structure of Nepal's export incentive schemes is in line with the WTO rules regulating export competition. However, their role in addressing structural issues for tea exports, such as high production costs, compliance with quality standards and other logistics challenges remain limited. In the meantime, it is worthwhile to note that the Government of Nepal has discontinued the export incentive program citing fiscal constraints.

3.7 SPS COMMITMENTS AND IMPLEMENTATION CHALLENGES

Under the SPS Agreement, Nepal is required to ensure that sanitary and phytosanitary measures are based on scientific evidence and consistent with international standards where appropriate. Compliance with SPS obligations is particularly important for tea exports because importing countries increasingly regulate pesticide residues, contaminants and other food safety parameters.

However, implementation remains constrained by limited laboratory infrastructure, insufficient risk-assessment capacity and the shortage of internationally accredited testing facilities (Acharya et al., 2021). Because of the limited internationally accredited testing laboratories, Nepal currently lacks the capacity for testing the residues of pesticides, heavy metals and other quality parameters mandated by the importing countries. As a result, the tea exporters are affected and they are compelled to conduct required tests in neighbouring countries, particularly India, thereby causing the delayed shipment process and increased transaction costs.

3.8 TBT COMMITMENTS AND IMPLEMENTATION CHALLENGES

The TBT Agreement addresses technical regulations, standards, labelling requirements and conformity assessment procedures. In the tea sector, these requirements increasingly include traceability systems, packaging specifications, sustainability standards, organic certification and product documentation. For Nepal's predominantly smallholder-based tea industry, compliance with these requirements remains challenging because certification, auditing, record keeping and conformity assessment costs are relatively high. Previous studies have also highlighted the growing importance of standards and certification in determining tea export competitiveness (Pradhani et al., 2024).

As a proxy indicator of compliance constraints, the United States FDA import refusal data was analysed to provide insight into these challenges faced by the Nepalese tea growers and exporters. "Figure 4. Refusal of Nepalese imports by the United States FDA" illustrates that the Nepalese exports to the US across multiple product categories have been repeatedly refused by the FDA. The highest number of refusals is seen in human food products, drugs and biologics, cosmetics and animal feed. Tea classified as a human food is directly governed by SPS and TBT measures for food safety, pesticide residues, contamination, labelling and documentation. The import refusals concentrated in this category serve as an indicator of the challenges in complying with the SPS and TBT requirements in high-end markets.

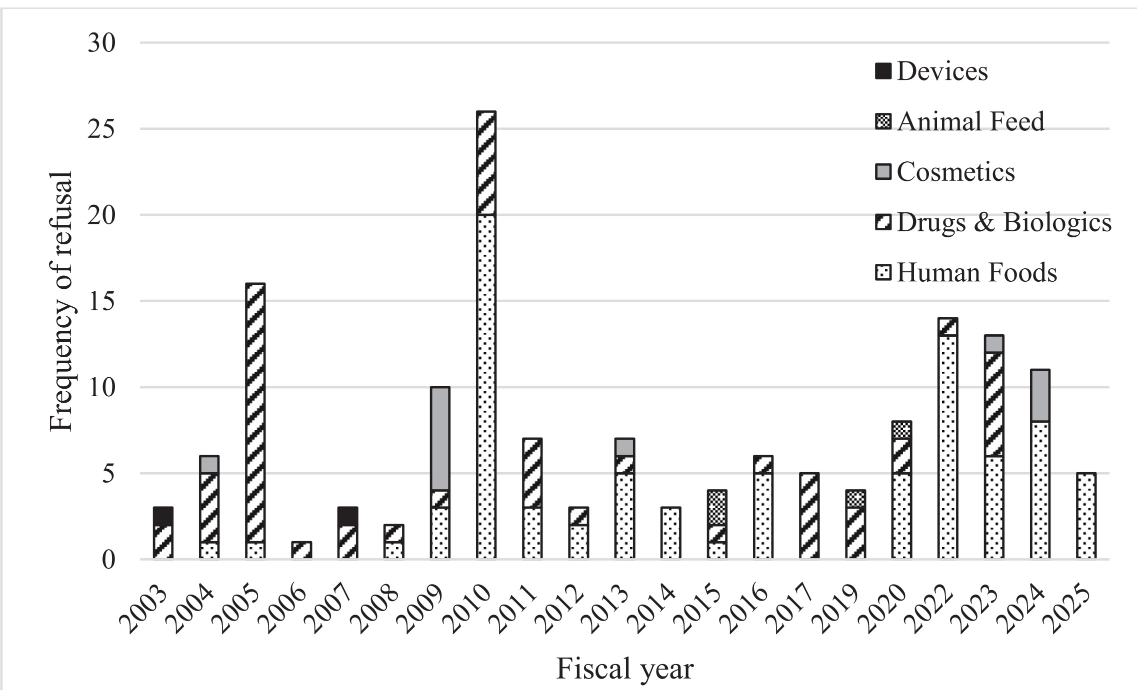

Figure 4. Refusal of Nepalese imports by the United States FDA

Source: Compiled from the database of the United States FDA (2025)

These findings are broadly consistent with previous studies that identify standards compliance, certification requirements and quality assurance systems as emerging determinants of competitiveness in international tea markets (Luitel et al., 2025; Pradhani et al., 2024; Shrestha, 2010). Although Nepal has formally adopted WTO-consistent SPS and TBT frameworks, institutional and technical capacity constraints continue to affect effective implementation and compliance.

This study relied primarily on secondary data sources and documentary evidence. The estimates of agricultural and tea-sector support intensity are based on expenditures reported by MoALD and NTCDB and may not fully capture support provided through other ministries, provincial and local governments, or donor-funded programmes. Similarly, the analysis of SPS and TBT implementation uses FDA import refusal data as a proxy indicator of compliance challenges and may not represent all export destinations. In addition, the tea sector is analysed at an aggregate level rather than by individual product categories and tariff lines. Therefore, the findings should be interpreted as indicative of broad policy trends and implementation patterns rather than exhaustive estimates of WTO-related support and compliance.

4. CONCLUSIONS

In conclusion, this study indicates that Nepal has generally complied with its WTO commitments while maintaining substantial policy space within the existing rules. It suggests that Nepal's WTO commitments have been implemented conservatively and have not significantly constrained the government's ability to support agricultural development. Rather, the available evidence indicates that substantial policy space remains under existing WTO provisions. Greater utilization of WTO-consistent Green Box and SDT measures, increased investment in research, extension services, quality infrastructure and testing facilities, and strengthened support for standards compliance and certification could enhance the competitiveness of Nepalese agriculture and tea exports while remaining fully compliant with international trade obligations. As Nepal approaches graduation from LDC status, a strategic use of the remaining policy space, coupled with strengthened institutional capacity for SPS and TBT compliance, will be essential for improving export competitiveness and maximizing the benefits of participation in the multilateral trading system.

FUNDING INFORMATION

This research was funded by University Grant Commission of Nepal (Grant number: PhD-80/81-Ag&F-02).

DECLARATION

The authors have no competing interests to declare.

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GROWING DEGREE DAY: AN ESSENTIAL COMPONENT FOR SUSTAINABLE MANAGEMENT OF *Spodoptera frugiperda* (J E SMITH): A REVIEW

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ABSTRACT

Insects are exothermic organisms. Their phenology and behavior are affected by temperature. An amount of total heat unit accumulated to develop insect from one stage to another is expressed as growing degree day. Growing degree day has immense importance in integrated pest management which helps in predicting insect pest emergence, population growth and its distribution. Spodoptera frugiperda (J.E. Smith) *is a migratory invasive pest of maize which neither hibernates nor survive during winter in the hill of Nepal. Insect population survived in terai during winter season multiply in spring and migrate to hills of Nepal. Study in growing degree day required for different stages of S. frugiperda helps in forecasting the pest incidence aiding timely and sustainable management of this pest during maize cultivation in hill and terai regions. The objective is to summarize the available data on thermal constant and threshold temperature, synthesize degree day calculation methods and to develop strategic framework for management of S. frugiperda.*

Keywords: Growing degree days, polyphagous, poikilothermic, *Spodoptera frugiperda*, temperature

INTRODUCTION

Insects are poikilothermic as their body temperature vary in relation to the temperature of their surroundings. Therefore, any fluctuations in environmental temperature directly influence their survival (Skendzic et al., 2021). Fluctuation in environmental temperature exert both direct and indirect influences on insect population. The direct effects occur through alterations in physiological activity across developmental stages, dispersal dynamics, biological and phonological processes, and overall survival rate. Whereas the indirect effects are mediated through modifications in host plant phenology and activity, abundance, and efficacy of natural enemies within the ecosystem.

Accumulated heat energy required for development of ectothermic organism like insect is measured in a unit called growing degree day. More than 250 years ago, researcher stated the relationship between degree day and duration of development related to temperature, which

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helps to understand how poikilothermic organisms evolve as they rely on external temperature to regulate their body temperature affecting biochemical reaction. Therefore, studying how developments changes with temperature gives the idea of biology, ecology and evolution (Pedigo, 1996). Growing degree day helps to estimate the total amount of heat require to complete its each life cycle. It helps to calculate the number of generations in future as well as forecasting different stage which support in integrated pest management.

The objective for this narrative review paper is to summarize the available data on thermal constant and threshold temperature of each life stage of *S. frugiperda*. Synthesize different calculation methods of growing degree day and thermal units within agricultural meteorology. Support to develop the strategic framework for growing degree day driven pest forecasting and sustainable integrated pest management intervention of *S. frugiperda* in Nepal.

METHODOLOGY

The relevant information related to degree day, growing degree days, methods for their calculations was collected thorough the study of published literature in the national and international journals, proceedings, books, reports, factsheets, and bulletins. Literature search was conducted using academic database including Google Scholar, Research Gate, Oxford Academia, SPRINGER NATURE, Science Direct, Nep Jol, ELSEVIER, Indian journals, PlOS One, books. Search study involved use of relevant keyword. The source was evaluated on the basis of credibility and related to research objective. The research findings were systematically summarized in both tabular and textual formats. It is a narrative review based on a qualitative summary of literature research on growing degree day. It serve as background for research paper and provide a review of a topic, integrating theoretical perspective.

RESEARCH DESIGN

This study outline as a comprehensive narrative review paper which include historical data, mathematical formula framework and entomological research finding. It relies on systematic compilation and collection of previously published peer- reviewed literatures. It lacks primary field experiment data or raw meta-analytical statistical testing.

KEYWORD

Primary keyword used during literature search include growing degree day, GDD, thermal unit, heat accumulated, *Spodoptera frugiperda*, Faw, fall armyworm, Lower development threshold, LDT, pest forecasting, climate change, temperature, insect migration, maize crop, insect phenology, history, insect development, insect stages and other keywords related to the study.

LITERATURE SEARCH PROCESS AND DATABASE

The literature on growing degree day and related topics was conducted over a period of six months till 2026. Literature review focused on examining research throughout a period of time, starting with the first time an issue, concept emerged in the literature, then tracing its evolution within the discipline till 2026. Relevant literature published between 1855 and 2026 were reviewed to gather information related to growing degree day. In order to maintain the quality of work peer-reviewed journal articles and book chapters were included and information from predatory journals, opinion pieces and unpublished raw data were not included.

RESULTS

DEGREE DAY AND GROWING DEGREE DAY

Global warming has increased the average surface temperature by $0.74 \pm 0.18^{0}C$ in the time of 100 years, which has impacted both human activities and natural ecosystems (IPCC, 2007). Degree days are expressed as heating degree day (HDD), cooling degree day (CDD) (Moustris et al., 2011), and growing degree day (GDD) (Sadiq et al., 2025). Heating degree day and cooling degree day helps in analyzing weather related energy consumption (Lee at al., 2014). Heating degree day and cooling degree day represents the cumulative difference between the base temperature and outdoor air temperature over a specified period, used in the energy sector to estimate energy required for heating and cooling buildings (Moustris et al., 2011). Growing degree days and growing degree unit are synonyms and frequently used to assign a heat value accumulated in each day to relate growth and development of living organism (Fraisse et al., 2010; Sadiq et al., 2025). The French scientist Rene A. F. de Réaumur introduced the concept of growing degree days related to growth and development with respect to air temperature in 1730 (McMaster and Wilhelm, 1997). Since then, growing degree day has been used in biological system to predict the different growth stages of living organism (McMaster and Smika, 1988). According to Tarun and Bhanu (2022) degree day is a unit that combines temperature and time to predict the growth and development of an organism from one stage into another stage of its life cycle. Linear relationship is used to determine the relationship between development rate and temperature (Chander et al., 2023). Linear regression helps to calculate lower development threshold. Lower development threshold (LDT) is the temperature at which development of insects stops (Honek, 1996). One degree-day represents, one degree above the lower developmental threshold in 24 hours of period (Tarun and Bhanu, 2022).

HISTORY OF GROWING DEGREE DAY

Growing degree day has served as the foundation for calculating heat units to describe the relationship between temperature and development rate. Various models to predict the effect of temperature on plant growth and development came into existence soon after introduction of concept on thermal unit by French scientist Reaumur in 1730. Subsequently several methods for calculating heat units were successfully applied in agricultural sciences (McMaster and

Wilhelm, 1997). Traditionally, farmers often used the calendar based prediction of plant development for management decision which has limitations in predicting the accurate stage of plant growth. Growing degree day is an effective tool which measures heat accumulation over time, calculated using daily temperature data. Because plant development is directly driven by temperature rather than calendar dates, growing degree day models provide a much more accurate prediction of crop stages viz, emergence, flowering, maturity, harvesting. Thus, the growing degree day calculated from actual temperature data provides accurate tool for predicting the timing of accurate growth stage (Miller et al., 2001). Emphasis was given to temperature and degree day calculation methods based on weekly temperature developed during 19th and 20th centuries, although conflict existed among researchers on role of other weather parameters on degree day calculations in addition to temperatures (Gregory, 1954). Cooling and heating were also used to calculate energy requirement for cooling and heating in building sector based on hourly air temperature data (Moustris et al., 2011). Later on, De Candolle (1855) introduced this concept into geobotany, geographical distribution of climate related with temperature. Gregory (1954) mentioned about the use of degree day calculation in agricultural meteorology. In the early 1950's a growing degree day concept was widely adopted by canning industry to predict crop development rate on the basis of accumulated thermal rate (Neild and Seeley, 1977).

USES OF GROWING DEGREE DAY IN AGRICULTURE

Growing degree day has been used in predicting plant stages (Miller et al., 2001). It helps in the prediction of insect development and its activity which helps in the pest management (Herms, 2004). Degree day models help to predict the effect of climate change on the intensity, distribution and timing of the transmission of infectious diseases (Moore et al., 2012). It helps to forecast pest emergence and population growth (Abduljaleel et al., 2025). It also supports in time specific crop management decisions such as nutrient and pesticide applications and weed control (Sadiq et al., 2025). According to Miller et al. (2001), accumulated degree day is calculated from the starting date from a specific point in time known as biofix. Biofix is chosen based on key biological events that signal the beginning of the organism development. Selecting an appropriate biofix allows for more accurate prediction of developmental stages and improves the timing of management decisions. Degree day helps to estimate the developmental timing of an organism to schedule field activities more efficiently. It minimizes conflict between temporal overlap of cultural operations such as irrigation and pesticide application for the pest management. Coordinated cultural practice minimizes operational conflicts and improves overall pest management efficiency. It helps to forecast the pest, it determines the best time to apply the control measures, monitoring the pest activity over the season. Pest data collected along with degree day information helps to quantify pest biology under different temperature condition and its relationship to crop yield (Zalom et al., 1983). Calculating the insect development time with respect to time become the important tools in predicting insect for pest management (Roy et al., 2002). Although the growing degree day has many uses in agriculture, its study is limited in Nepal. A study was conducted to develop a model to predict different growth stages in grapevine (Acharya et al., 2025). So far study based on growing degree day focusing insect pest and management is lacking in Nepal.

GROWING DEGREE DAY AND EFFECTS IN INSECT PESTS

Temperature can easily change the phenotypic character affecting the various life history traits of insects (Atkinson, 1994). According to Kuo et al. (2006) elevated temperature influences the longevity, population dynamics and fecundity rate of insects. Proper amount of heat units can provide a reliable means to growth and development of many insect pests (Marchioro and Foerster, 2011). Biochemical and physiological process such as enzyme activity, tissue function operates most efficiently in the optimal temperature in most of the insects enzyme activity is also influenced by temperature for example digestive enzymes has maximum activity at 35-45^{0}C temperature. Beside that thermoregulatory behavior of insects (Chapman, 1969) also known to be affected by temperature.

RELATION OF TEMPERATURE AND DEGREE DAY

A rational relationship between temperature and degree day statistics is need to understand in order to use it; the heating degree day. Degree day cannot be obtained by applying arithmetical procedure because of heterogenous nature of temperature (Thom, 1954). Calculation of degree day is affected by the frequency of temperature measured over time. Higher temporal resolution more accuracy while lesser resolution has less accuracy. Degree day calculation based on hourly temperature provides better estimates than the daily and monthly temperature (Mourshed, 2012). According to Schoenau and Kehrig (1990) degree day calculation is based on assumption that the daily average temperature distribution is in a normal pattern over a month. According to Thom (1954) mean degree days cannot be derived from mean temperature alone, instead the standard deviation of temperature must also be considered because temperature variability strongly influences the frequency and magnitude of degree days. His study provided a reliable method for converting temperature normal into degree-day normal, forming a foundation for consistent climatological analysis. Different methods of degree day developed based on degree day probability are derived from the temperature distribution.

FALL ARMYWORM (*Spodoptera frugiperda*) INVASION

The fall armyworm (FAW) *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a destructive global pest which causes serious threat to agriculture. It is a polyphagous pest, and maize is a preferred host (Prasanna et al., 2018). The fall armyworm is native to American continents (Luginbill, 1928). The insect was reported for the first time out of American continent Africa in 2016 (Goergen et al., 2016) and subsequently form Asia Karnataka, India in May 2018 (Sharanabasappa et al., 2018). The pest was recorded for the first time in Nepal from Gaindakot of Nawalpur district in May 2019 (Bajracharya et al., 2019). Since then, it has spread in most parts of Nepal causing havoc to maize production and plant infestation recorded up to 56% in winter and spring maize (Bajracharya et al., 2020).

ECONOMIC IMPACT OF FALL ARMYWORM (*Spodoptera frugiperda*)

Fall armyworm, *S. frugiperda* has been reported to cause substantial yield losses in maize. The pest can attack all stages of maize crop from vegetative to reproductive phase, with higher damage in vegetative stage (Prasanna et al., 2018). Hruska and Gladstone (1988) reported a yield reduction up to 45% due to *S. frugiperda* infestation in maize. Chimweta et al., (2020) observed that damage caused by second and third instar larvae of *S. frugiperda*, affecting leaves, silks, and tassels at infestation levels of 25-50%, resulted in a 58% reduction in maize grain yield. Furthermore, yield losses ranging from 15 to 73% were observed when 55-100% of plants were infested during the mid to late whorl growth stages (Hruska and Gould, 1997).

FALL ARMYWORM (*Spodoptera frugiperda*) IN MAIZE GROWING REGIONS

Nepal consists of three ecological regions, high-hills, mid-hills and terai based on topographical perspective. Maize producing areas consists of flat land of the terai (up to 800 m), mid-hill (800-1800 m) and high-hills (above 1800 m). Maize is produced in areas up to 2500 m. Temperature also varies in these three ecological regions in different period, on an average mid-hills are 5-8^{0}C cooler than the terai and 3-8^{0}C warmer than the high hills (Paudyal et al., 2001). *S. frugiperda* recognized as economically important pest of maize which could survive well in temperature 28-30^{0}C. Climate change can cause significant influence in geographic spread of insect pest. *S. frugiperda* took long distance seasonal migration moving in response to the temporal availability of favorable habitat that emerge at different time along its migration route (Gao et al., 2025). Maize cultivation across varying elevations and planting schedules creates a temporal and spatial continuum of host availability, which facilitates *S. frugiperda* migration by providing successive food resources along its migratory range. According to Bajracharya et al. (2020) fall armyworm can survive in winter season in terai and inner terai districts of Nepal where maize crop is cultivated. Foster and Cherry (1987) reported eggs of fall armyworms were most tolerant to cold temperature even surviving at -10^{0}C. The average minimum temperature during winter in high-hill and mid-hills of Nepal is recorded as -0.2^{0}C and 5.8^{0}C respectively, which is quite below developmental threshold (10.9^{0}C) of *S. frugiperda*. However, average minimum temperature during winter in terai region (10.3^{0}C) is quite comparable to the developmental threshold of *S. frugiperda*. Thus, fall armyworm could easily survive in terai region of Nepal during winter season and which could multiply as soon as the spring starts as average minimum temperature during spring is recorded 19.5^{0}C in terai which is quite higher than developmental threshold (DHM, 2017). Thus, adult population of fall armyworm from terai could migrate to hilly regions of Nepal as soon as the temperature become suitable for its growth and survival in hilly areas.

DEGREE DAY REQUIREMENT OF FALL ARMYWORM (*Spodoptera frugiperda*)

The biological development of *S. frugiperda* in relation to degree day accumulation provides information about the key physiological events from egg hatching to adult emergence. *S. frugiperda* requires accumulation of 462.43 growing degree days for emergence of adult from egg stage. Once 462.43 growing degree days reached effective monitoring can be scheduled for its management (Ashok et al., 2022). For the survival of *S. frugiperda* air temperature plays a vital role in regulating its life cycle and development rate is faster in warmer weather (Sumila et al., 2004). *S. frugiperda* does not survive in cold temperature and adult stage are more susceptible to cool temperature (Foster and Cherry., 1987). Adult survival decreases when exposed to temperature 9^0C or below. Indirect chilling began after reaching temperature of 15^0C (Tanaka and Matsukura, 2023). So, it migrates from unfavorable condition to favorable condition as it has strong migratory capacity (Prasanna et al., 2018). It lacks diapause behavior so temperature exerts a great influence on its population dynamics by regulating the metabolic activity and development rates and determines the degree of crop damage (Yan et al., 2022). Degree day required for each stage of life cycle of *S. frugiperda* were calculated as 35.68± 0.22 degree day for eggs, 204.60±123 degree days for larva, 150.54±0.93 degree days for pupa and 391.61±1.42 degree days for egg to adult development (Plesis et al., 2020).

GROWING DEGREE DAY REQUIREMENT FOR OTHER INSECT PESTS

Insect development is influenced by the temperature they exposed. Each species has a specific temperature below which no noticeable development takes place is its threshold development. The total amount of heat required over time for an insect to complete a stage of development is referred as its thermal constant (Andrewartha and Birch, 1954; Bursell, 1964). Threshold development and the thermal constant considered as useful indicators of an insect's potential distribution and abundance (Messenger 1959; 1970). Wilson and Barnett (1983) studied the thermal requirements for completion of cotton bollworm (*Heliothios zea*, Boddie) larval development at four constant temperatures of 60, 65, 70, and 80^0F and estimated as 572, 539, 622, and 583 degree-days, respectively.

Similarly, Jallow and Matsumura (2001) studied the effect of constant range of temperature 13.3 to 32.5^0C on the development of all life stage of *H. armigera* reared on tomato plant. The duration of the different stage of the life cycle decreased as temperature increased from 13.3 to 32.5^0C. The reported egg development required a thermal constant of 51 degree-days above threshold of 10.5^0C, while for the larval and pupal stages needed 215.1 and 151.8 degree days above their respective development threshold of 11.3^0C and 13.8^0C.

Ali et al. (1990) studied the effect of temperature on *S. frugiperda* reared in artificial diet at seven constant temperatures ranging between17-38^0C. They found variations in developmental rates, survival, pupal weights, and number of instars among different diets and temperatures. Eggs hatched in all temperature and larvae completed development except at 38^0C temperature. Larval and pupal development rate declined at temperature between 33 and 35.5^0C. Number of instars found to be increased when temperature was dropped below 25^0C simultaneously, increasing development time with increase in number of instars.

ACCUMULATED DEGREE DAY AND THERMAL CONSTANT

Different studies were conducted over a range of temperatures to estimate the threshold temperature and degree-day requirements for various developmental stages of *S. frugiperda* on maize, its major host crop, as well as on other host plants. Research has also been carried out to determine the threshold temperature of *Spodoptera litura* (Fab.) on groundnut and jute. In these studies, threshold temperature and thermal constants (degree days) were calculated using a linear regression model expressed as y = a + bx. From this equation, the lower developmental threshold temperature (t_0) was derived as –a/b (^{0}C), and the thermal constant (K) was subsequently calculated. Growing degree days required for various development stages of *S. frugiperda* and *S. litura* has been calculated by different researches, some of the research findings are presented in Table 1.

Table 1: Accumulated degree day and thermal constant of *S. frugiperda and S. litura*

S N	Insect	Crop	Temperature (^{0}C)	Threshold temperature (t_o)	Growing degree day				Reference
					Egg	Larva	Pupa	Adult	
1	*S. frugiperda*	Maize (*Zea maize*)	32	10.9	63	247.08	214.38	232.52	Ashok et al., 2022
2	*S. frugiperda*	Maize (*Zea maize*)	20-30	Egg:15.79 Larva:10.39 Pupa:14.05	30	360.2	129		Dahi et al., 2020
3	*S. frugiperda*	Turnip (*Brassica campestris*)	15 - 35	Egg: 11.14 Larva: 10.50 Pupa:10.90	55.76	225.50	133.31		Ouda et al., 2022
4	*S. frugiperda*	Maize (*Zea maize*)	18 - 36	Egg: 12.59 Larva: 12.33 Pupa: 12.67	45.45	333.33	166.67		Aggarwal. Et al., 2023
5	*S. frugiperda*	Sweet corn (*Zea maize*)	21 - 32	Egg:13.01 Larva: 12.12 Pupa:13.06	35.73	202.60	150.29		Plessis et al.,2020
6	*S. litura*	Jute (*Corchorus alitorius)*	18-32	Egg:11.93 Larva:10.68 Pupa:9.54	34.48	344.82	163.93		Thakur et al.,2017
7	*S. litura*	Groundnut (Arachis hypogea)	15 - 37	Egg:8.2 Larva:10 Pupa:10	64	303	155		Rao et al., 1989

Accumulated growing degree day has importance in development of maize to attain various stages of vegetative and reproductive stages. Early and full season maize varieties are known to differ in their duration and accumulated growing degree days (GDD). Generally, early- season, mid-season and full season maize varieties maturity days and accumulation GDD are presented in Table 2 and 3. Normally, maize plant develops above the threshold of base temperature 50^0F (10^0C) in warm season field corn (Ralph and James, 2026). Similar threshold temperature of *S. frugiperda* (10.9^0C) has been reported (Ashok et al., 2022). The minimum threshold temperature for development of maize as well as *S. frugiperda* is quite similar. Hence, accumulated heat units for both maize and *S. frugiperda* are nearly similar during maize growing season, thereby, *S. frugiperda* infestation occurs few days after maize seed emergence. *S. frugiperda* damage starting from early leaf initiation up to the tasseling/silking stage is considered to reduce yield significantly. *S. frugiperda* hatch eggs after accumulation of 30 GDD, and one complete generation of FAW requires about 500 GDD (Dahi et al., 2020). Maize remains in the field for a long duration and *S. frugiperda* begins damaging the crop soon after egg hatching. Since maize accumulates 2100–3200 GDD to mature the crop depending upon the variety, *S. frugiperda* could complete more than one generation during vegetative stage and multiple overlapping generations could occur during single maize growing season.

Table 2: Hybrids corn representing days and GDD from planting to harvesting of the central part of cornbelt of U.S. (Ralph and James, 2026)

SN	Corn	Days	GDD
1	Early season	85-100	2100-2400
2	Mid season	101-130	2400-2800
3	Full season	131-145	2900-3200

Table 3: Growth stage of corn with approximate GDDs and Cumulative GDDs (CFAES, 2026)

	Growth stage	Approximate GDDs	Cumulative GDDs
-	Planting	0	0
VE	Emergence	100	100
V3	Three -leaf collar	246	346
V6	Six -leaf collar	246	592
V9	Nine-leaf collar	246	838
V12	Twelve -leaf collar	182	1020
V15	Fifteen -leaf collar	150	1170
V19	Nineteen- leaf collar	50	1370
VT	Tasseling	50	1420
R1	Silking	-	1420
R2	Blister	266	1686

	Growth stage	Approximate GDDs	Cumulative GDDs
R3	Milk	144	1830
R4	Dough	151	1981
R5	Dent	343	2324
	Dent-$^{1/2}$ milk line	-	-
R6	Black layer	326	2650

METHODS OF DEGREE DAY CALCULATION

Temperature changes from year to year over an entire growing season, there may be either increase or decrease in temperature than the normal during any period of growing season. Growing degree day is a method of assigning heat value of each day. Summation of value of each day gives an estimate of total heat required by an organism for their development and growth (Miller et al., 2001). Generally, three methods are applied for calculating degree day, they are the average method, the modified average method, and the triangle and sine wave methods (Herms, 2004).

Average method: The simplest method of calculating the number of daily degree day. It is calculated by subtracting the lower threshold temperature from the average daily temperature. The basic equation for the calculation of degree days is given by McMaster and Wilhelm (1997).

$$DD = \frac{T_{max}+T_{min}}{2} - t_o$$

Whereas,

DD = degree days

T_{max} = daily maximum temperature

T_{min} = daily minimum temperature

t_o = lower threshold temperature

One of the drawbacks of this method is, it neglects the daily minimum temperature that fall below the species lower temperature threshold. This situation mainly occurs in spring which results in underestimation of degree days accumulated by insects as not all hourly temperature during a day are above the threshold level. During this period also insect development continues but heat accumulation systems fail to account for it.

Modified average method: This method corrects the weakness of the average method; daily minimum temperature is substituted with lower threshold temperature. This method is used when the minimum temperature drops below the lower threshold temperature. Thus, this approach approximates reality more closely by calculating the daily temperature accumulation between the maximum temperature and lowest threshold related to the species,

$$DD = \frac{T_{max}+t_o}{2} - t_o$$

Whereas,

DD = degree days

T_{max} = daily maximum temperature

t_o = lower threshold temperature

This shows higher number of degree days by including the development taken during the short periods in which temperature is slightly above the lower development threshold.

Triangle and sine wave method: Above two methods of growing degree day calculation do not consider the daily fluctuation of temperature within 24 hours. In order to correct the problem of daily temperature fluctuation and pattern some methods were proposed by various workers viz. simple triangle, double triangle, simple sine and double sine methods. These methods assume that the minimum daily temperature occurs at midnight and daily maximum temperature occur at noon. These methods also allow incorporation of upper threshold temperature above which insects do not develop.

Triangle method: In this method degree day is estimated as the area within the triangle and between the lower and upper threshold temperatures. There are two types of triangle methods proposed by various workers:

a. *Single triangle method*: Lindsey and Newman (1956) calculated degree day estimating the area under the temperature curve using as simple triangle. This method is based on assumption the temperature curve is symmetrical around the maximum temperature within 24 hours.

b. *Double triangle method*: Sevacherian et al. (1977) made some modification in single triangle method, that the difference between the first and second daily minimum temperature may not be the same. As a result, it calculates the area under the curve on a half day basis as double triangle. The degree day are estimated as the areas within the triangles and between the thresholds which is the sum of the degree days for the two halves.

Sine wave method: Baskerville and Emin (1969) modified the triangle approach and calculated the degree including the value of development maximum and estimate using simple sine. This method assumes a sine wave pattern using daily maximum and minimum temperature with temperature fluctuation allowing both lower and upper threshold temperatures. This method represents the daily temperature pattern as sine wave, representing the gradual rise and fall of temperature over time. The area under the sine wave curve used to calculate the temperature accumulation. Later, Allen (1976) modified the technique and presented formulas and a computer program for its use. According to him formulas may vary to specific relationship between the daily minimum and maximum temperature and lower and upper threshold. According to his opinion, data could be classified into six possible situations, they are:

1. The minimum temperature is higher than the lower threshold and the maximum temperature is higher than upper threshold.
2. The minimum temperature is lower than the lower threshold and maximum temperature is higher than upper threshold.
3. Both maximum and minimum temperatures are within thresholds.
4. The minimum temperature is lower than lower threshold and maximum temperature is lower than upper thresholds.
5. Both minimum and maximum temperature are higher than the upper threshold.
6. Both minimum and maximum temperature are lower than lower threshold.

Generally, sine method produces a sine curve using the minimum and maximum temperature of the day. This method could be classified as:

a. Single sine method: In this method minimum temperature is same for both halves of the day and estimated heat accumulation in the area under the sine curve and between thresholds.

b. Double sine method: In method degree day is estimated by fitting two different sine curves for each half using minimum and maximum temperature (UC, IPM 2005).

According to Baskerville-Emin (1969), growing degree days could be calculated in different three cases with different methods which are as follows:

Case 1: If maximum temperature is less than base temperature

Growing degree day (GDD) for the day =0

Case 2: If minimum temperature is greater or equal to base temperature

Average Temperature (T_{AVE}) is calculated then,

GDD = Average Temperature (T_{AVE}) – Base Temperature (BASE)

Which is similar to average method calculation.

Case 3: If minimum temperature is lower than base temperature and base temperature is lower than maximum temperature

$$GDD = ((W*COS(A)) - ((BASE-T_{AVE}) * ((3.14/2)-A)))/3.14$$

Whereas,

$$W = \frac{T_{max} - T_{min}}{2}$$

$$A = \text{Arcsin}((BASE - T_{AVE})/W)$$

$$T_{AVE} = \frac{T_{max}+T_{min}}{2}$$

T_{min} = minimum temperature

T_{max} = maximum temperature

BASE=.Base temperature

CALCULATION OF DEVELOPMENTAL THRESHOLD AND DEGREE DAY IN INSECT

Degree day in insect is generally calculated on the basis of lower developmental threshold and accumulated heat units at constant temperature. According to Dahi et al. (2020) theoretical development thresholds (t_o) and the accumulated thermal units (K) is calculated using the regression formula:

$y = a + bx$

$t_o = - a/b$

$K=1/b$

Whereas,

y = development rate of a given stage

x = temperature in degree centigrade

a = constant term

b = regression coefficient

t_o= lower threshold of development and

K =Thermal unit

While the mean number of degree days (^{0}D) required for the development of the egg, larval, pupal and pre-embryogenic period at constant temperature can be estimated using the equation proposed by Jackson and Elliott (1988) as follows:

GDD (^{0}D) = $T(C-T_o)$

Whereas,

GDD = Growing degree day

^{0}D = unit of degree day

T = number of days taken to complete development at a constant temperature

C= constant temperature

t_o = minimum developmental threshold temperature

Previously Campbell et al. (1974) proposed simple linear regression analysis to determine the relationship between temperature and the development rate. The lower threshold temperature and the number of degree days required to complete the development of each of the stages, as well as their standard errors, were calculated using the equation:

$y = a+bx$

Whereas,

y=1/days, x= temperature, a= intercept and b= slopes

In this method lower threshold temperature was estimated by setting y = 0 and solving x from the regression equation. Similarly, the lower temperature threshold was calculated as $t_o = -a/b$ and the thermal constant for development in number of degree days (^{0}D): k=1/b.

The degree day required for different stages under field condition can be calculated on the basis of thermal summation scheme proposed by AliNiazee (1976). The daily minimum and maximum temperature recorded at field condition is used along with previously determined lower threshold temperature in this procedure:

$$DD = \frac{\text{Daily max. temperature + daily min. temperature}}{2} - \text{lower threshold temperature}$$

Time required for development decreased with increasing temperature, the total amount of heat needed to complete the development remains approximately same (Wilson and Barnett, 1983). According to them degree days (^{0}D) is the heat accumulation between the temperature and the lower threshold multiplied by total days to develop which can be expressed mathematically:

$^0D = (C-t_o)$ X days to develop

C = Constant temperature

t_o = Lowe threshold temperature

IMPLICATION OF GROWING DEGREE DAY IN FALL ARMYWORM *(SPODOPTERA FRUGIPERDA)* MANAGEMENT

S. frugiperda life cycle is strongly dependent on temperature, degree day model estimates the amount of heat required to complete each life cycle. Growing degree days helps to determine the number of generation of *S. frugiperda* (Sumila et al., 2024). *S. frugiperda* start damaging from early leaf initiation upto silking /tasseling stage and reduce the maize yield. *S. frugiperda* require about 500 degree day (Dahi et al., 2020) while maize accumulates 2100-3200 degree days (Ralph and James, 2026) to mature. So *S. frugiperda* complete more than one generations during vegetative stage and multiple generation could occur during single maize growing season. The study of growing degree day in *S. frugiperda* helps in understanding the biological development of insects over a period of time and physiological events like scouting, placement of traps and timing for damage observation in addition to the control of damaging larval stage by scheduling the insecticide spray. Degree day study support in predicting the different life stages of *S. frugiperda* which helps in planning pest management operations like release of biological control agents and application of microbial insecticides for effective management of the pest which helps in reducing the unnecessary chemical hazard, minimize environmental impact and cost of cultivation.

DISCUSSION

Insects are exothermic organism so its physiological processes are largely depended on temperature. Growing degree day helps to quantify heat accumulation for insect development. *S. frugiperda* development is regulated by thermal accumulation thus degree day could be used to predict its occurrence and seasonal activity which ultimately helps in management. It also supports in crop management decision such as pesticides application (Sadiq et al., 2025).

Linear relationship between temperature and insect development rate which form the basis for estimating lower development threshold and thermal constants of insect. On the basis of various literatures reviewed lower development threshold of different developmental stages of *S. frugiperda* ranged from 10.4^{0}C to 15.8^{0}C. Similarly, thermal requirement to develop FAW eggs into adult ranged between 390 to 500 degree days. Such findings indicate that *S. frugiperda* required a predictable amount of heat to complete its development. Insect stages occurred in the fields could be predicted, if developmental threshold and thermal requirement could be determined for *S. frugiperda* in Nepal. Insect management tactics could be chosen based on stage of insect which differs in feeding habits and vulnerabilities. Such method to predict insect developmental stage based on degree day and its management at appropriate time had been successfully used by Hems (2004). Aggarwal et al. (2023) calculated the degree day for planning the most effective period for monitoring and effective suppression to reduce the losses occurred by *S. frugiperda*.

Despite of increasing damage and losses caused by fall armyworm in Nepal, information on degree day accumulation, thermal requirement and seasonal generation dynamics under Nepalese agro-ecological conditions still lacking. Nepal has diverse topography and variation in temperature in different topographic region play a crucial role in determining population dynamics and geographical distribution of *S. frugiperda*. The pest can tolerate wide range of temperature but its development is constrained when temperature fall below the lower development threshold of approximately 10.9^{0}C as mentioned by Ashok et al. (2002). In Nepal average winter temperature in hilly region are below threshold, which limits the continuous development and survival of the pest but in terai region temperature remains close to the development threshold, creating favorable condition for its survival and serve as inoculum source for hills (Bajracharya et al., 2020). Growing degree day model could be valuable tool for predicting temperature driven migration and population development of *S. frugiperda* which helps in development of pest forecasting system. Location specific degree day forecasting model could also provide an effective decision support tool for integrated *S. frugiperda* management program and contribute to sustainable production of maize Nepal.

CONCLUSION

Degree days and thermal constant required for the growth and development of the pest can be exploited for effective integrated management of *S. frugiperda* by predicting its occurrence in the field. Despite its importance, application of growing degree day for insect pest management remain unexplored area of entomological studies in Nepal. Studies on degree day calculation including thermal constant and developmental threshold for *S. frugiperda* or any other insect pests under laboratory and field conditions within the country is lacking. Thus, scientific study on growing degree day of fall armyworm need to be conducted in future for its efficient management through early prediction and timely implementation of appropriate management practices for sustainable production of maize in Nepal.

FUNDING

No funding was received for this study.

ETHICAL STATEMENT

The author declare that they do not have conflict of interest that could influence the publication of this article.

ACKNOWLEDGEMENTS

We would like to acknowledge management team of National Entomology Research Center, Nepal Agriculture Research Council and Institute of Agriculture and Animal Science, T.U. for proving opportunity to conduct this research.

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