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Research Article

Resource use efficiency and profitability of potato production in Syangja district, Nepal

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ABSTRACT

Potato (*Solanum tuberosum* L.) is an important cash crop and a key contributor to food security in Nepal, but its productivity is limited by inefficient input use and low adoption of improved practices. This study seeks to bridge that research gap by examine the factors of potato production on farms of varying sizes in Syangja district of Nepal. Field survey was conducted from April 2024 to June 2024 in the Galyang, Bhirkot, Waling, and Chapakot municipalities of Syangja district. Primary data was collected from 91 potato farmers, who were then categorized into small scale and large scale farmers according to their area under potato cultivation. The Cobb-Douglas production function and regression analysis were applied. To ensure the validity of the results, t-tests, chi-square tests, and multicollinearity diagnostics using the variance inflation factor (VIF < 5) were conducted. Large-scale farmers demonstrated a 9% lower variable cost (NRs. 18,232 vs. 19,969/Ropani), but comparable profitability (Benefit-cost ratio: 2.09 vs. 1.86). This may be due to the higher bargaining power of small-scale farmers. The presence of overused inputs like seeds, labor, and fertilizer, where (Marginal Value Product/Marginal Factor Cost < 1), lowered efficiency, while transport ($\beta = 0.24$), and post-harvest costs ($\beta = 1.09$), were revenue drivers. Semi-commercial and commercial systems of agriculture increased production by 237 to 293 kg/ropani ($p < 0.05$) over traditional agriculture. Among the commonly cultivated varieties, Khumal Ujjwal exhibited the highest production, with average yield of 940.10 kg/ropani. Return to scale was found to be 1.40, indicates thescaled inputs led to higher productivity in potato production. Therefore, it is suggested to provide training and extension supports on proper utilization of inputs, increase scale of production and post-harvest management.

Keywords: Cobb-Douglas production function, economic analysis, farm commercialization, input allocation, potato production

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is the fourth most widely cultivated crop in Nepal, following rice, maize, and wheat in terms of area coverage, and ranks second in total production, after rice. It provides food and income, which are among the basic sources of livelihood for different groups of people, especially in settler agriculture (Subedi *et al.*, 2019). Potatoes are grown in more than 150 countries, making them a staple of the diet (Timsina *et al.*, 2013; Subedi *et al.*, 2019). Nepal ranks among the top 20 countries in which potatoes play a fundamental role in meeting dietary requirements, thereby its importance in alleviating food

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insecurity in this region (Haverkort & Struik, 2015). Despite of their good yield potential, potato productivity in Nepal remains far below than attainable level due to inefficient resource use, , and limited access to quality agricultural inputs (Upadhyay, 2024).

Potatoes have also been cultivated in Nepal for more than two centuries in all agro-ecological zones, ranging from 100 masl in the southern plains to 4000 masl in the mountainous regions of the north. Beyond 2000 masl, the potato has emerged as a major staple (Sapkota *et al.*, 2019). Owing to their adaptability, production potential, and market demand, potatoes have become an essential ingredient of agricultural economy, accounting for 6.57% of Agricultural Gross Domestic Product (AGDP) and 2.17% of Gross Domestic Product (GDP) of the country (Chauhan *et al.*, 2022). Though its total production in 2022 was recorded at 3.41 million metric tons, with an average productivity of 17.2 t ha^{-1} (MoALD, 2022), it does not meet the increasing demand, resulting in annual imports of over 300,000 metric tons.

Previous researchers found that potato production was five times more profitable than cereal crops (DoAD, 1992). However, the agricultural sector faces challenges of low productivity and inefficient resource use, mainly due to conventional agricultural practices and limited technology adoption (Bajracharya & Sapkota, 2017; Paudel *et al.*, 2019;). Although past research has focused on profitability and yield, very little work has been done on the efficient use of resources, their effectiveness, and economic issues of potato production across varying farm sizes in Nepal. This research work is based on production theory, which holds that agricultural production specifies the optimal employment of factors. The Cobb-Douglas production function provides a reliable method for estimate the factor elasticity and economies of scale. At the same time, the ratio of Marginal Value Product to Marginal Factor Cost allows assessment of the level of input utilization. This methodological approach enables the identification of whether factors are under or overutilized. This also suggests the optimal use of resources to increase the profitability of the agricultural enterprise.

The reason of why Syangja district was purposively chosen for the study is that it epitomizes a general mid-hill potato production region. The district significantly shapes the overall potato supply chain in Gandaki Province. However, productivity is decreasing annually due to the unavailability of better inputs, a shortage of farm labor resulting from youth migration, pests, and a lack of marketing facilities (Kandel *et al.*, 2024). This research proposes to examine the efficiency of input utilization, the scale of returns, and the profitability of potato production among small and large scale farmers in the Syangja district. Furthermore, this study aims to examine the critical factors that shape productivity and resource use efficiency. This information is intended to help policymakers provide necessary interventions to improve efficiency, lower production costs, make informed decisions, and support the commercialization of potato production in Nepal. of. The scope of this study is limited by its purposive sampling design within four municipalities of Syangja, which is not universally generalizable., and by the possibility of recall bias in data collected through a cross-sectional survey.

METHODOLOGY

Syangja district is one of the central potato-producing districts of Nepal, and its geographic coordinates are 28°4'60" North latitude and 83°52'0" East longitude. Four municipalities, namely Galyang, Bhirkot, Waling, and Chapakot were chosen as a research site with consideration of the superior production level of those districts.

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To select participants, a purposive sampling method was used to identify the 91 households who were active potato producers, as the study intended to select the key producers. The sample was distributed across the municipalities (Galyang: 26, Bhirkot: 19, Waling: 26, Chapakot: 20) based on the relative density of potato farmers.

Conducting face-to-face interviews, the research used an interview schedule to gather primary data through a structured, pre-tested questionnaire. The household survey was conducted between 15 April 2024 and 3 June 2024. The time frame allowed incorporation of the potato harvesting and marketing season in the region. This favored the precision of the recall method with respect to production, cost of production, and sales. The descriptive and inferential analyses of the data obtained were executed using Microsoft Excel 365 and IBM SPSS version 25. The respondents were stratified into small-holder and large-holder groups according to whether their potato landholding is below or above 5.82 ropani per household, respectively which corresponded to the average potato landholding of the surveyed farmers. These groups are used to conduct the independent-samples t-test on economies of scale. The key features of research participants in this study are reflected in Table 1.

Table 1: Characteristics of the participants in the study area

Parameter	Value
Study site	Galyang, Waling, Bhirkot and Chapakot Municipalities of Syangja
Sample size	91
Farm size categories	Small holders (56) and Large Holders (35)
Gender distribution	56% male and 44% female
Major religions	95.6% Hindu and 4.4% Christian
Major ethnicities	82.4% Brahmin/Chhetri, 6.6% Janajati and 11% Dalit
Training access	59.3% Yes and 40.7% No

Source: Field survey, 2024

Gross margin analysis

Gross margin was calculated as:

Gross margin: Gross return – Total variable cost………..(1)

where, Gross return: Total production (kg) × Price (NRs./kg)

Total variable cost: summation of all variable costs such as seed, labor, machinery, Farmyard manure (FYM), chemical fertilizer, plant protection, transportation, and postharvest handling costs.

Benefit cost ratio (BCR) analysis

Benefit cost ratio was calculated as, BCR: Gross return/Total variable cost……….(2)

Production function analysis

The Cobb-Douglas Production Function (CDPF) is the most frequently used method for analyzing the technology association between different inputs and income derived from cash crops (Bajracharya & Sapkota, 2017; Upadhyay, 2024; Sapkota *et al.*, 2019). Expenses for farmyard manure (FYM), labor, fertilizer, and seeds are shown to affect gross income from potato cultivation significantly (Upadhyay, 2024).

The following form of CDPF was used:

$$Y= aX_1^{b1}X_2^{b2} X_3^{b3} X_4^{b4}X_5^{b5}X_6^{b6} X_7^{b7} X_8^{b8}e\mu \quad (3)$$

where Y is the gross return from potato production in a ropani (NRs.), Where X_1 is the seed cost(NRs.), X_2 is the labor cost(NRs.), X_3 is the machinery cost(NRs.), X_4 is the FYM cost(NRs.), X_5 is the chemical fertilizers' cost(NRs.), X_6 is the cost of plant protection(NRs.),

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X_7 is the cost of transportation and X_8 is the postharvest handling cost(NRs.), e is the error term, a is the intercept and b_1, b_2, b_3, b_4, b_5, b_6, b_7 & b_8 are the coefficients to be estimated. The above equation was linearized by log transformation as follow:

$$ln\ Y = ln\ a + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 + b_4 \ln X_4 + b_5 \ln X_5 + b_6 \ln X_6 + b_7 \ln X_7 + b_8 \ln X_8 + \mu \ldots\ldots (4)$$

Where 'ln' is the natural logarithm, 'a' is a constant, and 'μ' is the random disturbance term.

Return to scale analysis

Returns to Scale (RTS) measures how the total output of a production process changes when all the input factors are increased or decreased proportionally. In the context of a CDPF, RTS is determined by summing the output elasticities of each input. Mathematically, it is expressed as:

$$RTS = b_1 + b_2 + b_3 \ldots\ldots + b_n \ldots\ldots (5)$$

This sum indicates whether the production process exhibits increasing (RTS>1), constant (RTS=1), or decreasing (RTS<1) returns to scale.

Variance Inflation Factor (VIF)

The variance inflation factor (VIF) quantifies how much the variance of an estimated regression coefficient increases due to multicollinearity, and is calculated as

$$VIF = 1/(1-R^2) = 1/Tolerance \ldots\ldots (6)$$

The tolerance was also calculated, which is the inverse of the VIF. A lower tolerance (higher VIF) indicates stronger multicollinearity for that predictor.

Resource use efficiency analysis

Resource use efficiency reflects the maximization of production by optimizing resource use in the production process. Optimal utilization of a resource entails maximizing output (Thapa *et al.*, 2025). The efficiency of resource utilization can be measured using the equation below:

$$\text{Efficiency Ratio}(r) = MVP/MFC \ldots\ldots (7)$$

Where, Marginal Value Product (MVP) represents the monetary value of the additional output (additional revenue (NRs.)) generated by utilizing one more unit of a specific input cost.
MVP = Coefficient × (Geometric mean of output/Geometric mean of input)
Marginal Factor Cost (MFC) denotes the incremental cost incurred by acquiring an additional unit of input cost (NRs.). Since the input variables (X1 to X8) are already expressed in monetary cost (NRs.), the Marginal Factor Cost (MFC) for an additional unit of cost is assumed to be 1.
This ratio evaluates how efficiently resources are allocated in production as:
r = 1: Optimal efficiency
r > 1: Underutilization of inputs; Increase it to gain more profit.
r < 1: Overutilization of inputs; Decrease it to gain more profit.
By comparing MVP and MFC, this metric identifies whether inputs are used in a manner that maximizes economic returns.

The inefficiency index (D value) measures the percentage deviation of the marginal value product (MVP) of a resource from its marginal factor cost (MFC), thereby indicating the

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extent to which the existing level of resource utilization deviates from the profit-maximizing condition. D value of zero denotes optimal resource use, whereas larger absolute values reflect increasing levels of inefficiency. Absolute D values were used to assess the extent or magnitude of inefficiency, while the r value is used to determine the direction of resource use. The inefficiency index value can be calculated as follows:

D value = $\left|\frac{1-r}{r}\right| \times 100$ …………………(8)

Multiple linear regression analysis

The general equation for multiple linear regression is:

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + e$…………(9)

where, Y is the production (kg/ropani) (dependent variable); β_0 is the intercept (constant); X_1, X_2, and X_3 are the independent variables (dummy variables for agriculture type); β_1, β_2, and β_3 are the regression coefficients, and e is the error term.

RESULTS AND DISCUSSION

Demographic and socioeconomic status of the respondents

Tables 2 and 3 compare smallholder and large holder farmers across various socioeconomic variables. For continuous data, an independent t-test was performed, and for categorical data, a chi-square test was used to assess significance.

Table 2: Comparison of continuous socioeconomic condition of respondents in the study area

Variables	Total (N=91)	Small holders (N_1=56)	Large holders (N_2=35)	Mean difference	t-value	P value
	Mean(SD)	Mean(SD)	Mean(SD)			
Age (years)	46.98(9.16)	45.5(9.04)	49.43(8.93)	-3.98**	-2.05	0.04
Family size	5.64(2.16)	5.46(2.26)	5.91(2.01)	-0.45	-0.96	0.34
Economic members	4.00(1.50)	3.80(1.54)	4.31(1.39)	-0.51	-1.56	0.11
Dependency ratio	0.51(0.59)	0.55(0.62)	0.45(0.53)	0.04	0.82	0.42
Annual income (NRs./year)	832857.14 (1196982.58)	833392.86 (1406203.50)	832000.00 (770629.23)	1392.86	0.005	0.99
Landholding (ropani)	13.90 (13.74)	12.84 (12.77)	15.57 (15.20)	-2.72	-0.92	0.36
Irrigated land (ropani)	9.44 (11.30)	7.43 (8.20)	12.66 (14.57)	-5.23**	-2.19	0.03
Potato area (ropani)	5.82(6.83)	2.47(1.40)	11.23(8.47)	-8.76***	-7.62	0.00

*** Significant at 5% level, ***Significant at 1% level* *Source: Field survey, 2024*
Values in parentheses present the mean standard deviation (SD)

The mean age of the surveyed farmers was 46.98 years, the same as that reported by Sapkota and Bajracharya (2018), and large-scale farmers were significantly older than small farmers. Mean family size, dependency ratio, annual income (NRs.), and landholding (ropani) of farmers were found to be 5.64, 0.51, 832,857.14, and 13.90 respectively, but there was no significant difference in those variables between small and large farmers. However, large farmers tend to possess significantly ($p<0.05$) larger irrigated land areas by 5.23 ropani and allot a larger area to potato crops by 8.76 ropani ($p<0.01$) compared to small farmers.

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The χ^2 test indicated that the gender distribution differed significantly between small and large holders. The dominant ethnicity in the studied area is Brahmin/Chhetri (82.40%), as reported by both small- and large-holders. Most respondents had a certificate level of education (36.30%) and followed agriculture (54.90%) as their dominant economic activity, which did not vary significantly between small and large holders. This result supports the findings of Pradhan *et al.* (2023) that agriculture is the dominant economic activity in Syangja, practiced by 60% of households.

Table 3: Comparison of categorical socioeconomic condition of respondents in the study area

Variables	Categories	Total (N=91)	Small holders (N_1=56)	Large holders (N_2=35)	Chi-square (χ^2) statistic	P value
		Mean	Mean	Mean		
Gender	Male	51(56)	26(46.40)	25(71.40)	5.46**	0.019
	Female	40(44)	30(53.60)	10(28.60)		
Ethnicity	Brahmin/Chhetri	75(82.40)	44(78.60)	31(88.60)	1.77	0.41
	Janajati	6(6.60)	4(7.10)	2(5.70)		
	Dalit	10(11)	8(14.30)	2(5.70)		
Education level	Illiterate	6(6.60)	5(8.90)	1(2.90)	3.09	0.68
	Literate	15(16.50)	9(16.10)	6(17.10)		
	Primary level	9(9.90)	7(12.50)	2(5.70)		
	Secondary level	23(25.30)	12(21.40)	11(31.40)		
	Certificate level	33(36.30)	20(35.70)	13(37.10)		
	University level	5(5.50)	3(5.40)	2(5.70)		
Major economic activity	Agriculture	50(54.90)	29(51.80)	21(60)	0.69	0.87
	Foreign employment	22(24.20)	14(25)	8(22.90)		
	Service	16(17.60)	11(19.60)	5(14.30)		
	Business	3(3.30)	2(3.60)	1(2.90)		
Agriculture type	Subsistence	20(22)	18(32.10)	2(5.70)	14.06***	0.003
	Semi-commercial	46(50.50)	28(50)	18(51.40)		
	Commercial	22(24.20)	10(17.90)	12(34.30)		
	Entrepreneurial	3(3.30)	0(0)	3(8.60)		
Experience in potato cultivation	0-5 years	28(30.80)	19(33.90)	9(25.70)	15.29***	0.004
	6-10 years	10(11)	3(5.40)	7(20)		
	11-15 years	10(11)	3(5.40)	7(20)		
	16-20 years	15(16.50)	14(25)	1(2.90)		
	>20 years	28(30.80)	17(30.40)	11(31.40)		

** Significant at 5% level, ***Significant at 1% level Source: Field survey, 2024

Values in parenthesis present mean percentage

However, statistical variations existed in the types of agriculture practiced (p = 0.003), as more of the small holders practiced subsistence (32.10%) and semi-commercials (50%); contrarily, large holders practiced semi-commercials (51.40%) and commercial (34.30%); thus, leaving subsistence agriculture in the rear. This result indicates that large holders are more progressive and income-oriented than small holders. The level of experience in potato production varied significantly across farm sizes (p = 0.004). A larger proportion of smallholders (33.90%) had only 0 to 5 years of experience, suggesting that greater farming experience may contribute to farm expansion and production advancement.

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Production cost analysis

Table 4 presents a comparative analysis of input costs per ropani for potato production between smallholder and large-holder farmers, highlighting the variations in resource allocation and expenditure patterns. Seed cost per ropani varied significantly ($p = 0.018$) by NRs. 758.25 among small and large farmers. Even the numerical differences of labor, machinery, FYM, transportation, and postharvest handling costs were prominent, the differences were not statistically significant across farm sizes. The difference fertilizers and plant protection costs between small and large holder farmers were significant. Large farmers spent more on FYM and postharvest handling, while small farmers spent more on the remaining inputs, thereby increasing total variable cost. Economies of scale favored the large farmers.

Table 4: Inputs cost comparison of potato production by farm size in the study area

Inputs cost (NRs./ropani)	Total ($N=91$)	Large holders ($N_1=35$)	Small holders ($N_2=56$)	Mean difference	t-value	P value
	Mean(SD)	Mean(SD)	Mean(SD)			
Seed cost	7533.33 (1492.82)	7241.70 (1638.46)	7999.95 (1091.83)	-758.25**	-2.42	0.018
Labor cost	4113.18 (1269.50)	3960.09 (1009.62)	4358.13 (1586.46)	-398.04	-1.46	0.14
Machinery cost	1243.06 (393.37)	1237.50 (310.75)	1251.96 (503.25)	-14.46	-0.17	0.86
FYM cost	3363.18 (1037.99)	3403.12 (1015.52)	3299.28 (1084.86)	103.84	0.46	0.64
Fertilizer's cost	1093.76 (524.85)	938.18 (529.52)	1342.68 (414.70)	-404.50***	-3.84	0.00
Plant protection cost	584.10 (305.00)	499.93 (275.43)	718.77 (305.24)	-218.84***	-3.53	0.001
Transportation cost	629.30 (262.03)	607.14 (247.06)	664.76 (284.45)	-57.62	-1.02	0.31
Postharvest handling cost	340.95 (164.78)	345.22 (184.60)	334.11 (129.11)	11.10	0.31	0.75

*** Significant at 5% level, ***Significant at 1% level* *Source: Field survey, 2024*
Values in parenthesis present standard deviation (SD)

Economic determinants analysis

Economic indicators of potato production including total variable cost (TVC), yield, selling price, gross return, gross margin, and benefit–cost ratio (BCR) was estimated and compared between small and large holding farmers (Table 5). The mean differences in these variables between small and large holding farmers did not differ significantly, except for TVC, which showed a significant difference in NRs. 1736.77($p < 0.001$). A slightly higher selling price for small farmers indicates stronger negotiating capacity, as they can store during market saturation and sell during the off-season. In contrast, large ones tend to sell earlier (usually at harvest), even at a lower cost. Although it is insignificant, a slightly higher yield for large-holding farmers could be justified by the increased use of better-quality inputs and advance techniques. Profit of more than NRs. 3,000 per ropani was realized by large-holding farmers compared to smallholders. The mean BCR was 2.01, like Subedi *et al.* (2019) and Noonari *et al.* (2016), and was higher by 0.23 for large holders, though not statistically significant. Hence, the findings indicated that though, largescale farming enjoys some production cost advantages, these are not always translated into significantly higher profitability. Policies aimed at enhancing cost efficiency, input access, and smallholders' productivity can further improve their economic viability.

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Table 5: Comparison of economic determinants of potato production by farm size in the study area

Variables	Total (N=91)	Large holders (N_1=35)	Small holders (N_2=56)	Mean difference	t-value	P value
	Mean (SD)	Mean (SD)	Mean (SD)			
Total variable cost (NRs./ropani)	18900.88 (2994.16)	18232.90 (2896.87)	19969.66 (2871.41)	-1736.77***	-2.79	0.00
Yield (kg/ropani)	789.76 (367.18)	805.45 (411.13)	764.67 (287.04)	40.77	0.51	0.60
Selling price (NRs.)	48.02 (10.93)	47.68 (11.13)	48.57 (10.75)	-0.89	-0.37	0.70
Gross return (NRs./ropani)	38360.66 (21268.73)	39024.40 (23799.57)	37298.67 (16711.29)	1725.73	0.375	0.71
Gross margin (NRs./ropani)	19459.78 (20391.05)	20791.51 (22700.07)	17329.01 (16108.26)	3462.50	0.786	0.43
BCR	2.01 (1.02)	2.09 (1.14)	1.86 (0.78)	0.23	1.05	0.29

*** Significant at 5% level, ***Significant at 1% level.   Source: Field survey, 2024*
Values in parenthesis presents standard deviation (SD)

Production function and resource use efficiency analysis

Table 6 presents the results of the Cobb-Douglas production function analysis for potato production in the study area. The model was estimated with revenue/ropani as the dependent variable and input costs as independent variables to assess their contribution to production efficiency. This result identified the key factors influencing potato productivity, with an R^2 of 0.7489, signifying that about 74.89% of the variation in revenue is explained by the selected cost inputs. According to Upadhyay (2024), an adjusted R^2 value of more than 75% indicates a very good model, 50%-75% indicates a good model, 25%-50% indicates a fair model, and less than 25% indicates a poor model. The F-statistic was greater than 30, with a p-value less than 0.01, confirming the model's overall significance and indicating its explanatory power. Among the different components of costs, postharvest cost (β = 1.088, $p < 0.01$) and transportation cost (β = 0.243, $p < 0.01$) had a significant impact on revenue. This implies that efficient postharvest handling and market accessibility significantly contribute to the revenue. In contrast, seed cost (β = 0.077, $p > 0.1$), machinery cost (β = 0.080, $p > 0.1$), and plant protection cost (β = 0.39, $p > 0.1$) had statistically insignificant positive impacts, reflecting that expenditure on these inputs under prevailing conditions may not enhance revenue. More interestingly, FYM cost (β = -0.115, $p > 0.1$), labour cost (β = -0.179, $p > 0.1$), and cost of fertilizers (β = -0.102, $p > 0.1$) had negative coefficients, indicating that higher expenditure on these inputs is more likely to result in lower revenue, possibly due to inefficient application; however, this relationship is not statistically significant**.** The RTS value was 1.40, indicating increasing returns to scale. That is, a 1% rise in the cost of all inputs led to a 1.4% rise in output value, reflecting production efficiency and possible economies of scale.

These findings agree with Sapkota *et al.* (2019) but disagree with Bajracharya and Sapkota (2017). The VIF values, ranging from 1.17 to 1.80, indicated no serious multicollinearity among the variables, confirming that the estimated coefficients were stable and reliable. The independent variables are often retained in regression analysis if their VIFs remain below 5, because higher values may indicate problematic multicollinearity among predictors.

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Table 6: Production function analysis of potato production in the study area

Variables	β coefficients	Standard error	t value	P value	Collinearity statistics	
					VIF	Tolerance
Ln(Seed cost)	0.077	0.180	0.04	0.966	1.540	0.649
Ln(Labor cost)	-0.179	0.165	-1.08	0.281	1.801	0.555
Ln(Machinery cost)	0.080	0.110	0.72	0.473	1.171	0.853
Ln(FYM cost)	-0.115	0.127	-0.91	0.366	1.541	0.648
Ln(Che. fertilizer's cost)	-0.102	0.633	-1.61	0.112	1.177	0.849
Ln(Plant protection cost)	0.3854	0.677	0.57	0.571	1.200	0.832
Ln(Transportation cost)	0.2430***	0.091	2.67	0.009	1.272	0.785
Ln(Postharvest cost)	1.088***	0.082	13.26	0.000	1.575	0.634
Constant	4.8677**	2.027	2.40	0.019		
R^2	0.7489					
Adjusted R^2	0.7244					
F statistics (8,82)	30.58***					
Prob>F	0.000					
RTS	1.40					

*** Significant at 5% level, ***Significant at 1% level* *Source: Field survey, 2024*

Table 7: Resource use efficiency analysis in the study area

Variables (NRs.)	Geometric mean	Beta Coefficient	Efficiency ratio (r)	D-value	Efficiency
Revenue	32725.66				
Seed cost	7359.00	0.077	0.342	192.40	Overutilized
Labor cost	3955.82	-0.179	-1.48	167.56	Overutilized
Machinery cost	1182.20	0.080	2.215	54.85	Underutilized
FYM cost	3200.00	-0.115	-1.176	185.03	Overutilized
Chemical fertilizer's cost	950.00	-0.102	-3.514	128.49	Overutilized
Plant protection cost	510.39	0.3854	24.711	95.95	Underutilized
Transportation cost	579.32	0.2430	13.727	92.71	Underutilized
Postharvest cost	302.22	1.088	117.813	99.15	Underutilized

The result of resource use efficiency analysis of potato production in study area is presented in Table 7. The β-coefficients measure the partial elasticities of production, which measure the contribution of each input to the outputs. The D-value measures the percentage divergence of actual input use from the optimal use, where a higher D-value implies a wider divergence and therefore a higher potential to improve. The findings revealed that the actual costs of seed, labor, FYM, and chemical fertilizers is over the optimal use, which implies that the cost of these factors can be reduced to improve the financial viability of the farm, whereas the use of machinery, plant protection, transport, and postharvest can be increased to improve the financial performance of the farm. However, only transportation and postharvest costs significantly impacted revenue, as indicated by the statistically insignificant β-values for other inputs in Table 6, implying that, also the efficiency analysis for these other inputs might be non-significant. Overall, optimizing input use by reducing overused inputs and increasing underused inputs, as indicated by the D-values, can improve production efficiency and farm profitability.

Regression analysis of agricultural type on yield

Table 8 presents the results of a one-way ANOVA analyzing the average yield (kg/ropani) across different types of agriculture, namely semi-commercial, commercial, and entrepreneurial, with subsistence agriculture serving as the reference category. Analysis of the data revealed that potato yield is increased by 292.56 kg/ropani and 236.92 kg/ropani respectively in semi-commercial (p = 0.003) and commercial agriculture (p = 0.033), compared to subsistence agriculture. However, the output in entrepreneurial agriculture, compared to subsistence agriculture, is statistically insignificant. However, the F value of 3.28 with p-value < 0.05 indicated overall significance of models, while the R^2 value of 0.10, and the Adj R-Squared of 0.07 indicated that models are not explaining significant variation in output; after all, there could be other factors also contributing to the output, having nothing to do with the type of agriculture.

Table 8: Yield comparison of potato in different agricultural type in the study area

Yield (kg/ropani) Agriculture type	Mean diff. (Coefficient)	St. error	t-value	P value	Interval (95%) Lower bound	Lower bound
Semi commercial	292.56***	94.814	3.09	0.003	104.103	481.0105
Commercial	236.92**	109.37	2.17	0.033	19.53	454.30
Entrepreneurial	127.28	219.17	0.58	0.563	308.35	562.91
Constant (Subsistence)	580.40***	79.16	7.33	0.000	423.07	737.73
R^2	0.10					
Adjusted R^2	0.07					
F statistics (3, 87)	3.28**					
Prob>F	0.024					

*** & *** represents significance at 5% & 1% levels.* *Source: Field survey, 2024*

Regression analysis of potato variety on yield

Table 9 presents the results of the regression analysis in ANOVA form, conducted to assess the influence of different potato varieties on yield (kg/ropani). The comparison of yields across different varieties relative to the Janakdev variety was performed. The Khumal Ujjwal variety had a significantly higher yield by 264.34 kg/ropani compared to Janakdev variety (p = 0.001), with a confidence level of 116.40-412.28 kg/ropani. On the other hand, the Sajita variety does not show a statistically significant difference in yield compared with the Janakdev variety; therefore, the yield is the same for both varieties. The R-squared of 0.13 and the adjusted R-squared of 0.11 indicate that the model explains a tiny portion of the variation in yield. On the other hand, the F-statistic of 6.42, with a p-value of less than 0.01, indicated overall significance. In conclusion, the farmers cultivating the Khumal Ujjwal variety achieved higher yields than those of other varieties.

Table 9: Yield comparison of common potato varieties in the study area

Yield (kg/ropani) Potato variety	Mean diff. (Coefficient)	St. error	t-value	P value	Interval (95%) Lower bound	Lower bound
Khumal Ujjwal	264.34***	74.44	3.55	0.001	116.40	412.28
Sajita	21.46	206.32	0.11	0.917	-388.57	431.48
Constant (Janakdev)	675.77***	49.56	13.64	0.000	577.28	774.25
R^2	0.13					
Adjusted R^2	0.11					
F statistics (2, 88)	6.42***					
Prob>F	0.002					

**** represents significance at 1% level.* *Source: Field survey, 2024*

CONCLUSION

The potato sector is important for food security, but it still faces challenges due to inefficient use of inputs. This study found that, although input costs are lower in large-scale production because of economies of scale, wastage in seed, labor, and fertilizer management continues to

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reduce cost efficiency. In contrast, costs related to transportation, post-harvest handling, and marketing play a key role in generating revenue, indicating that better management of these areas is necessary to improve profitability and support food security. The adoption of improved varieties like Khumalujjwal and the shift from semi-commercial to commercial production, though still at an early stage, has already shown positive effects on revenue, reflecting the benefits of technological innovation. Therefore, to strengthen the sector, efforts should focus on optimum utilization of resources, reducing input wastage, improving postharvest and marketing practices, and promoting the wider adoption of improved varieties and modern production technologies.

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Authors' contribution
Bibas Chaulagai: Project administration, conceptualization, methodology, data collection, data entry, investigation, formal analysis, writing the original draft, review, and editing
Poonam Sapkota: Supervision, formal analysis, methodology, review, and editing
Narayan Prasad Tiwari: Supervision, formal analysis, methodology, review, and editing
All three authors have read and approved the final version of the manuscript.

Conflicts of Interest
The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Ethics Approval Statement
This study involved human participants who provided informed consent. All procedures were conducted in accordance with institutional ethical guidelines, and necessary approvals were obtained from the relevant authorities.

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