Research Article

Economic Returns and Obstacles of Potato (*Solanum tuberosum*) Production in Karnali Province, Nepal

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Abstract | Potato is a nutritionally rich major non-grain cash commodity consumed as a staple food in the hills and subsidiary food in the terai of Nepal. It is one of the extensively traded commodities with annual global and domestic production of 375.91 and 3.48 million tons, respectively. Crop has the potential to substitute expensive cereal imports, eradicate poverty, and ensure food security. However, there is a lack of adequate scientific studies on demographic and socio-economic characteristics determining crop production, productivity, and profitability. Therefore, a household survey was conducted in the Gurans rural municipality of Dailekh (n = 60) and the Baghchaur municipality of Salyan (n = 60) using a pretested semi-structured questionnaire, and various demographic and socio-economic characteristics were recorded. Primary data were thoroughly cleaned and wrangled, and statistical techniques such as univariate, i.e., mean and bivariate, i.e., t and chi-square tests, and econometric tools such as production function and probit regression analysis were employed to derive meaningful insights. Results revealed that the average variable cost of potato production was NRs 245242.19 per hectare with annual production and productivity of 2106.61 Kg per household and 10.02 metric tons per hectare, respectively. The benefit-cost (BC) ratio of potato production was 1.81, indicating that potato production is a profitable business with a return of NRs 1.81 per Re 1 investment. The cost of planting materials, chemical fertilizers, animal labor, and human labor was found to influence the return significantly. Similarly, annual revenue of the crop, land holdings, access to training, and credit were the major factors determining the large-scale production of potatoes. Collaborative efforts to develop and implement targeted policies, particularly in mechanization, input supply, technology dissemination, and establishing a sustainable value chain for potato-based agro-industries, are of utmost importance for the province.

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Introduction

Potato is one of the major non-grain food commodities with a global production of 375.91 million metric tons per year (FAO, 2022), and has the potential to substitute expensive cereals imports. It is highly nutritious, grows quickly and about 85% of the plant body is consumable while in the case of cereals, merely 50% is edible. Potato is consumed as a subsidiary food in terai and as a staple food in the

mountainous region of Nepal (Joshi and Joshi, 2017) it also can play a role in eradicating poverty, ensuring food security (Lutaladio and Castaldi, 2009) and supports to achieve sustainable development goals (SDGs). Potato is cultivated in 203,812 hectares of land with the production of 3,487,816 metric tons and productivity of 17.11 tons per hectare, which contributes about 6.56% of AGDP (MOALD, 2024). Every 100 gm (grams) of fresh potato has 81.08 gm of water, 2.0 gm of proteins, and 16.1 gm of carbohydrates including traces of minerals and vitamins (Murniece *et al.*, 2011), so can be consumed for better body functions. In Nepal, potato is grown from the lower plains of Terai of 100 masl to upper mid-hills up to 4000 masl (Bajracharya and Sapkota, 2017). It can be consumed as cooked vegetables, fries, chips, mashed, and canned (Farvin *et al.*, 2012; Tierno *et al.*, 2016), and has a large scope to create employment opportunities, especially for small farmers including women. It is fast-growing, and responsive to low input supply (Wijesinha *et al.*, 2019) and provides direct access to adequate nutrition and income reducing food shortage and income poverty (Devaux *et al.*, 2014).

Karnali province is located in the region of the Hindu Kush Himalayas with inaccessible, infertile, and slopy lands, and prone to poverty and food insecurity (Thapa & Hussain, 2021) with an insecurity score of 7.94 and almost third-quarter households being afraid of uncertain food supply (Bhandari, 2018). Farmers of the province have fewer crop choices due to harsh climatic conditions, lack of irrigation, and marginality of soil and depend on locally adapted barley, beans, maize, and potatoes. Despite of these constraints, the productivity of potato in the province was recorded to be 17.20 mt Ha^{-1} which is slightly higher than the national average productivity (17.11 mt Ha^{-1}) (MOALD, 2024), this might be due to edaphic and climatic suitability and crop adaptability; however, the supply is still deficit in the region (Thapa, 2020). Crop holds then potentiality to reduce poverty by generating employment opportunities, ensuring household food security, substituting imports, and even promoting export if scientific production packages with applicable technologies are disseminated to the farmers. Although, several plans and policies have been formulated to promote agricultural commercialization and establishment of stable value chain for sustainable agro-based industries, those efforts have remained as paperwork without their rigorous implementation (Sapkota *et al.*, 2017). Therefore, scientific planning of programs, acts, policies, and regulations with their effective implementation for rapid technology distribution is needed to commercialize potato production in the province. Therefore, this study will help to understand the present scenario of production, productivity, and profitability of potato production along with their determinants in Karnali province of Nepal.

Methodology

Selection of study site

Potato is the major staple and cash-generating tuber crop in most of the districts of Karnali province including Salyan and Dailekh (Table 1). Thus, these two districts were selected purposively as the

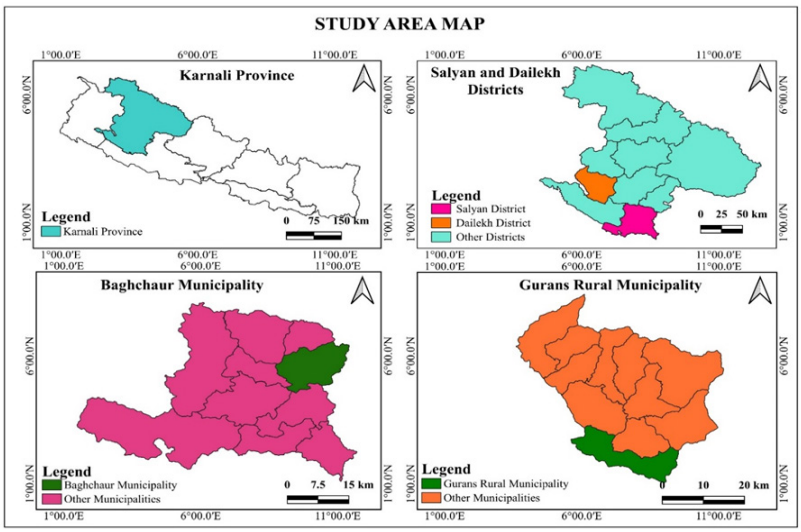

Figure 1: *Map of study area indicating Gurans rural municipality (Dailekh) and Baghchaur municipality (Salyan) districts of Karnali province, Nepal. Source: Department of Survey, 2023.*

production area and production are higher than other districts (Key informant interview with DADO and PMAMP). For this study, Gurans rural municipality of Dailekh and Baghchaur municipality of Salyan district were selected based on production and production area (Figure 1). These municipalities have the following topo-geographical characteristics.

Table 1: *Characteristics of districts with authors illustrations.*

Parameters	Dailekh	Salyan
Coordinates	28.75°N 81.633333°E	28.4511° N, 82.2851° E
Altitude	2,157 masl	1,320 masl
Major ethnic groups	Bhramin, Chhetri, Magar	Bhramin, Chhetri, Magar
Crop duration	June - October	February - June
Extension services	Relatively better	Poor
Access to road	Good	Good
Irrigation	Very poor	Good

Masl: Meters above sea level.

Sampling frame and sample size

Purposive sampling method was employed to select the study areas i.e., Gurans rural municipality of Dailekh district and Baghchaur municipality of Salyan district based on their relatively higher numbers of growers and larger production areas. Within each local level, two wards were selected following same sampling criteria. Gurans (ward 4 and 5) and Baghchaur (ward 11 and 12) comprised 243 and 352 potato growers out of which 60 growers from each local level were selected using random sampling method making 120 samples in the province.

Selected sample respondents were used for face-to-face interviews to collect primary data on production, productivity, profitability, and determinants.

Data collection

The prepared questionnaire was pretested with 5 potato growing farmers of Baghchaur municipality to assess the efficiency, relevancy, and farmers' understanding, and necessary modifications were made. The household heads or their spouse who are responsible for the farm decision-making process were considered to be the informants for the interview. The interview process was conducted fully voluntarily by respondents without any conflicts of information sharing. Focus group discussion was done with informally gathered farmers group in the community during the interview process while key informant interview was conducted with local agriculture technicians of municipalities and agriculture officers of the Integrated Agriculture and Livestock Development Office (IALDO) to triangulate the collected data. Various demographic and socio-economic characteristics were recorded during the primary data collection process. Secondary data were accessed from books, reports, scientific journals, and websites of related organizations.

Data analysis

Collected data were encoded in MS Excel version 2021. Data quality was assured by cleaning and checking for missed and misplaced data. Statistical software for data science (STATA) version 15 was used to derive the required inferences on descriptive statistics, mean comparisons, production function analysis, and probit model and marginality.

Cost of production

Both variable and fixed costs of potato production were calculated but total variable cost was taken for calculation of profitability of the enterprise as mentioned by Bajracharya and Sapkota (2017) and Mandal (2022).

$$\text{Total variable cost of potato production} = VC_{seed} + VC_{organic\ manure} + VC_{fertilizers} + VC_{irrigation} + VC_{pesticides} + VC_{transportation} + VC_{animal\ labor} + VC_{human\ labor} \quad \text{.....Equation (1).}$$

where, $VC_{seed;}$ is the cost of seeds in NRs per hectare, $VC_{organic\ manure;}$ cost of organic manure in NRs per hectare, $VC_{fertilizers}$; cost of chemical fertilizers in NRs per hectare, $VC_{irrigation}$; cost of irrigation in NRs per hectare, $VC_{pesticides}$; cost of pesticides in NRs per hectare, $VC_{transportation}$; cost of transportation in NRs per hectare, $VC_{animal\ labor}$; cost of animal labor (bullock) in NRs per hectare, $VC_{human\ labor}$; cost of human labor in NRs per hectare.

Similarly, fixed cost includes the following headings as employed by Bajracharya and Sapkota (2017) and Cotter (2022).

$$\text{Total fixed cost} = FC_{interest} + FC_{machineries} + FC_{depreciation} \quad \text{.....Equation (2).}$$

where, $FC_{interest}$; is the total fixed cost for annual interest, $FC_{machineries}$; cot of agricultural machineries, $FC_{depreciation}$; cost of depreciation of agricultural

machineries.

Gross margin

Gross margin was calculated as suggested by Kay *et al*. (2012).

Gross margin = Gross Return –Total variable cost .....Equation (3).

where Gross Return = Price of potato × Total potato production.

Total variable cost = Summation of all variable costs

Variable costs = Cost of seeds, organic manure, fertilizers, animal labor, human labor, irrigation, pesticides, transportation cost and other costs.

Benefit cost ratio

The benefit cost ratio is the easiest way of determining the profitability of any farm business (Dhakal *et al*., 2015). It aims to determine whether the farm enterprise will provide reasonable return or not.

Benefit cost ratio of potato production was computed by using following formula as suggest by Cotter (2022)

$$Benefit\ cost\ ratio = \frac{Gross\ return}{Total\ variable\ cost}$$

.....Equation (4)

Decision rule:

BCR > 1: positive net present value

BCR< 1: negative net present value

Econometric models

Cobb-Douglas production function

Cobb-Douglas production function is the most widely used linear regression model, which is used to determine the relationship between inputs used for the production of a commodity and its output produced. The regression coefficients of CDPF indicate how the elasticity of each input changes the output of the production process. The following linear regression model suggested by Zellner *et al*. (1966) was used to determine the technological relationship between inputs and output of the production process.

$$Y = aX_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4} X_5^{b_5} X_6^{b_6} e^{u}$$.....Equation (5)

where, Y is the total revenue generated by potato production in NRs. X_1 is the cost of seeds/tuber, X_2 cost of organic manure, X_3 cost of fertilizers, X_4 cost of transportation, X_5 cost of animal labor, X_6 cost of human labor incurred for cultivation of potato per hectare during one crop cycle, e is the error term and b_1, b_2, b_3.....b_6 represents the coefficients of respective inputs to be calculated.

Logarithmic transformation was done to obtain the data in normal distribution form which changes the above equation into following linearized equation.

$$ln\ Y = a + b_1 ln\ X_1 + b_2\ ln\ X_2 + b_3 ln\ X_3 + b_4\ ln\ X_4 + b_5 ln\ X_5 + b_6 ln\ X_6 + u$$.....Equation (6).

where, ln is the natural logarithmic, a is the constant and u is the random distribution term.

Probit model

Probit is dichotomous econometric model with binary responses of dependent variables where inverse standard normal distribution of probability is modeled in linear forms of independent variables (Muthén, 1979) . This regression model was used to identify the determinants of high scale potato production in Karnali province of Nepal.

$$Pr\ (Y=1) = f\ (b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7$$.....Equation (7).

where, Pr (Y=1, farmer cultivate potato in more than 0.25 hectare otherwise 0) is the probability of adoption of high scale potato production, X_1 is age of the household head (years), X_2 gender of household (1 if male otherwise 0), X_3 is access to agricultural credit family type (1 if yes otherwise 0), X_4 previous year revenue in, X_5 is access to trainings (1 if yes otherwise 0), X_6 is total land holdings (hectare), X_7 is experience of household head (years), b_1, b_2, b_3.....b_7 are regression coefficients.

Indexing

Indexing technique was employed to determine the rank orders of major diseases and insects of potato crop based on the experience of each respondent. Scaling technique when used properly provides the direction and extremity of respondents towards any problems or situation (Miah, 1993). Index ranks were computed by using following equation as used by (Poudel *et al*., 2022).

$$I_{prob} = \in \frac{S_i F_i}{N}$$ ..... Equation (8).

Table 2: *Distribution of socio-economic and demographic characteristics (continuous variables) of potato farmers in Karnali province.*

Variables	Mean (n=120)	Dailekh (n=60)	Salyan (n=60)	Mean difference	t value	p value
Age of HH	50.08(1.25)	49.00(1.63)	51.17(1.89)	-2.17	-0.87	0.39
Number of schoolings	3.79(0.39)	4.83(0.56)	2.75(0.52)	2.08***	2.72	0.01
Male members	3.08(0.13)	3.10(0.21)	3.07(0.17)	0.03	0.13	0.90
Female members	3.03(0.14)	2.82(0.19)	3.25(0.20)	-0.43	-1.56	0.12
Total members	6.12(0.22)	5.92(0.31)	6.32(0.32)	-0.40	-0.90	0.37
EA males	2.07(0.10)	2.23(0.17)	1.90(0.12)	0.33	1.63	0.11
EA females	2.13(0.09)	2.08(0.12)	2.17(0.14)	-0.08	-0.44	0.66
EA total	4.19(0.16)	4.32(0.24)	4.07(0.23)	0.25	0.76	0.45
Dependency ratio	0.53(0.04)	0.43(0.06)	0.64(0.07)	-0.21**	-2.38	0.02
Upland area Ha	0.42(0.04)	0.44(0.07)	0.40(0.05)	0.04	0.47	0.64
Low land area Ha	0.03(0.01)	0.05(0.02)	0.02(0.01)	0.03*	1.67	0.10
Total Area Ha	0.45(0.04)	0.49(0.07)	0.42(0.05)	0.07	0.86	0.39
Irrigated land Ha	0.22(0.03)	0.11(0.04)	0.32(0.04)	-0.21***	-3.34	0.00
Unirrigated land Ha	0.24(0.04)	0.38(0.06)	0.10(0.04)	0.27***	3.75	0.00

Source: Field survey, 2023.
EA: Economically Active
*Notes: ***, **, * represents significant at 1%, 5% & 10% level of significance respectively.*
Values in parenthesis are standard errors.
Table format adapted from Dahal et al., (2023).

Where,
I_{prob}: Index value of problem intensity.
ϵ: Summation
S_i: Scale value of i^{th} intensity.
F_i: Frequency of i^{rh} response.
N: Total number of respondents.

Results and Discussion

Demographic characteristics of potato growers

Various demographic characteristics of households were studied during the field survey (Tables 2 and 3). The average age of the respondents was 50.08 years in the study area which was found similar in Dailekh (49.00 years) and Salyan (51.17 years) with a statistically non-significant mean difference. The educational non-significant mean difference. The educational qualification of the household head was estimated in the number of years went for formal education. The average schooling of household head was 3.79 years in the province. Schooling of household heads was significantly higher in Dailekh (4.83 years) than Salyan district (2.75 years) with a statistically significant mean difference (2.08 years, p = 0.01). The family size of the respondents in the province was 6.12 family members with almost equal numbers of male (3.08) and female (3.03) members. Dailekh had a family size of 5.92 members (male: 3.10 and female: 2.82) whereas Salyan had 6.32 members in the family (male: 3.07 and female: 3.25) with a statistically non-significant mean difference. Similarly, potato cultivating households of Karnali province had 4.19 (male: 2.07 and female: 2.13) economically active members on average. However, the mean total numbers of economically active members per household in Dailekh and Salyan districts were 4.32 (male: 2.08 and female: 2.23) and 4.07 (male: 1.90 and2.17) respectively with a statistically non-significant mean difference. The dependency ratio of the province was 0.53 indicating almost equal numbers of economically dependent and independent members in the household. The mean dependency ratio of the Salyan district was found significantly higher (0.64, p = 0.02) which is higher than that of the Dailekh district (0.43). This might be due to the higher number of dependent members per household in Salyan district.

The average land holdings of the potato cultivating households in Karnali province was 0.45 hectares per household. Such holdings of households were comprised of upland (0.42 Ha per household) and lowland (0.30 Ha per household). The average land

Table 3: *Description of socio-economic, demographic and institutional characteristics (categorical variables) with potato production.*

Variables	Overall	Gurans (Dailekh)	Baghchaur (Salyan)	Chi-square	p value
Access to trainings					
Yes	36.00(30.00)	42.00(70.00)	42.00(70.00)	0.00	1.00
No	84.00(70.00)	18.00(30.00)	18.00(30.00)		
Access to loan					
Yes	11.00(9.20)	10.00(0.17)	1.00(0.02)	8.12***	0.00
No	109.00(90.80)	50.00(0.83)	59.00(0.98)		
Membership on cooperatives					
Yes	69.00(57.50)	50.00(0.83)	19.00(0.32)	32.77***	0.00
No	51.00(42.50)	10.00(0.17)	41.00(0.68)		
Gender of household head					
Male	91.00(75.80)	50.00(0.83)	41.00(0.68)	3.68**	0.05
Female	29.00(24.20)	10.00(0.17)	19.00(0.32)		
Family type					
Nuclear	43.00(35.80)	24.00(0.40)	19.00(0.32)	0.91	0.34
Joint	77.00(64.20)	36.00(0.60)	41.00(0.68)		
Seed source					
Formal	68.00(56.67)	40.00(66.67)	29.00(48.33)	5.62**	0.02
Informal	52.00(43.33)	20.00(33.33)	31.00(51.67)		
Seed treatment					
Yes	30.00(25.00)	10.00(8.00)	21.00(35.00)	8.53**	0.01
No	90.00(75.00)	55.00(92.00)	39.00(65.00)		
Use of chemical fertilizers					
Yes	101.00(84.20)	42.00(0.70)	59.00(0.98)	18.07***	0.00
No	19.00(15.80)	18.00(0.30)	1.00(0.02)		
Crop rotation					
Yes	35.00(29.20)	24.00(40.00)	11.00(18.30)	6.82**	0.01
No	85.00(70.80)	36.00(60.00)	49.00(81.70)		
Irrigation facility					
Irrigated	79.00(65.83)	35.00(58.33)	44.00(73.33)	2.19	0.14
Rainfed	41.00(34.17)	25.00(41.67)	16.00(26.67)		
Earthing up					
Yes	97.00(80.83)	43.00(71.67)	54.00(90.00)	4.74**	0.03
No	23.00(19.17)	17.00(28.33)	6.00(10.00)		
Weeding					
Yes	105 (87.50)	48.00 (80.00)	58.00 (96.67)	6.52**	0.01
No	15 (13.50)	12.00 (20.00)	2.00 (3.33)		

Source: Field survey, 2023.
*Notes: ***, ** represents significant at 1% & 5% % level of significance respectively.*
Values in parenthesis are percentages.

holdings of potato farmers in Dailekh district were recorded to be 0.49 hectares per household (upland: 0.44 Ha and lowland: 0.05 Ha) while Salyan district had mean land holdings of 0.42 Ha per household (upland: 0.40 Ha and lowland: 0.02 Ha) with a statistically non-significant mean difference. The mean irrigated land in the province was 0.22 hectares per household while 0.24 hectares land per household was deprived of irrigation facilities. The average irrigated land holding of potato farmers in Salyan

district was 0.32 hectares per household with 0.10 hectares of unirrigated land area. On the other hand, farmers of Dailekh district were found to be deprived of irrigation facilities with a mean irrigated land of 0.11 hectares per household with 0.38 hectares of unirrigated land per household. The mean difference between irrigated land (0.21 Ha per household, p =0.00) and unirrigated land (0.27 Ha per household, p = 0.00) was found statistically significant.

Cropping pattern

Cropping pattern is the sequence of crops grown in the same piece of land per year. Cropping patterns may differ due to the economic, climatic, and socio-economic conditions of the community (Yadav *et al*., 2015). The cropping pattern that prevailed in Karnali province is given below (Table 4).

Cost of production

The mean total cost of potato production in the province was estimated to be NRs 256496.60 per hectare (Table 5). Out of which total variable cost and total fixed cost were found to be NRs 245242.19 per hectare and 11254.41 per hectare respectively. The

Table 4: *Prevalence of cropping patterns associated with potato in Karnali province, Nepal.*

Gurans (Dailekh)	Reasons	Baghchaur (Salyan)	Reasons
Potato – fallow	Limited crop suitability due to agroclimatic constraints (drought, snowfall)	Potato – fallow	Limited crop suitability due to agroclimatic constraints (drought, snowfall)
Potato + Maize – Fallow	Food and income diversification, prolonged drought, lack of irrigation	Potato – Maize – Potato	Crop suitability
Potato – Beans	Limited crop suitability due to agroclimatic constraints (drought, snowfall)	Potato – Maize – Vegetables	Irrigated land, food and income diversification.
Potato – Barley		Potato -Finger millet	Limited crop suitability due to agroclimatic constraints (drought, snowfall)

Source: FGD and KII, 2023.

Table 5: *Distribution of cost components of potato cultivation in Karnali province.*

Variables	Mean (N=120)	Dailekh (n=60)	Salyan (n=60)	Mean difference	t value	p value
Variable costs Ha^{-1}						
Seed/Tuber	148975.04(10558.88)	137969.45 (16068.77)	159980.64(13690.43)	-22011.19	-1.04	0.30
Organic manure	37163.17(5101.51)	29136.13 (5286.22)	45890.21(8651.90)	-16054.08	-1.58	0.12
Fertilizer	12093.11(1516.61)	10159.84 (2287.74)	14026.38 (1979.39)	-3866.54	-1.28	0.20
Irrigation	965.52 (643.15)	109.22 (109.22)	1821.83 (1277.42)	-1712.60	-1.34	0.19
Pesticide	4205.54 (1701.30)	3453.35 (808.61)	4957.73 (3317.05)	-1504.38	-0.44	0.66
Transportation	3229.37 (994.84)	4608.51 (1776.92)	1850.22 (877.76)	2758.29	1.39	0.17
Animal labor	9654.07(1208.88)	7803.12 (1717.81)	11505.01 (1681.69)	-3701.89	-1.54	0.13
Human labor	28956.36 (3713.64)	41347.58 (6815.41)	16565.15 (1994.32)	24782.43***	3.49	0.00
Total variable	245242.19(15544.74)	234587.20(24601.66)	255897.18(19122.17)	-21309.98	-0.68	0.49
Fixed costs Ha^{-1}						
Annual interest	7468.98 (4385.25)	14937.96 (8699.56)	0.00 (0.00)	14937.96*	1.72	0.09
Farm machineries	3605.17 (2334.94)	7210.35 (4642.42)	0.00 (0.00)	7210.35	1.55	0.13
Depreciation	180.26 (116.75)	360.52 (232.12)	0.00 (0.00)	360.52	1.55	0.13
Total fixed cost	11254.41 (4985.06)	22508.82 (9795.52)	0.00 (0.00)	22508.82**	2.30	0.03
Total cost Ha^{-1}	256496.60(16173.32)	257096.02 (26258.39)	255897.18(19122.17)	1198.84	0.37	0.97

Source: Field survey, 2023.
*Notes: ***, **, * represents significant at 1%, 5% & 10% level of significance respectively.*
Values in parenthesis are standard errors.
Table format adapted from Dahal et al., (2023).

mean difference across the Dailekh (NRs 257096.02 Ha^{-1}) and Salyan (NRs 255897.18 Ha^{-1}) was statistically non-significant. The average total variable cost in Dailekh (NRs 234587.20 Ha^{-1}) and Salyan (NRs 255897.18 Ha^{-1}) were on par with a statistically non-significant mean difference. In contrast, the mean fixed cost was significantly higher in Dailekh (NRs 22508.82 Ha^{-1}, p =0.03) than in Salyan (NRs 0.00 Ha^{-1}) at a 5% level of significance.

Out of the various variable costs incurred during the production of potatoes in the province, the maximum (60.75%) cost was incurred for planting materials i.e., either seed or tuber which indicates seed cost as the major input required (Figure 2). This was followed by organic manure cost (15.15%), human labor cost (11.81%), fertilizer cost (4.93%), animal labor cost (3.94%), plant protection materials (1.71%), transportation (1.32%) and irrigation cost (0.369%) in the province. The average cost of planting materials was NRs 148975.04 per hectare in the province while the mean difference across Dailekh (NRs 137969.45 Ha^{-1}) and Salyan (NRs 159980.64 Ha^{-1}) was non-significant. The average expenditure on organic manure and fertilizers in the province were estimated to be NRs 37163.17 and NRs 12093.11 per hectare were respectively. The expenses on organic manure and chemical fertilizers in Dailekh were NRs 29136.13 and NRs 10159.84 per hectare while that of Salyan had NRs 45890.21 and NRs 14026.38 per hectare, however differences were statistically non-significant. Similarly, costs incurred for irrigation management, pesticides, transportation, and animal labor in Karnali province were estimated to be NRs 965.52, NRs 4205.54, NRs 3229.37, and NRs 9654.07 per hectare respectively. However, the mean differences across the districts were statistically non-significant. Furthermore, the average human labor cost in the province was NRs 28956.36 per hectare. The expenditure on human labor was higher in Dailekh (NRs 41347.58 Ha^{-1}) than in Salyan (NRs 16565.15 Ha^{-1}), the mean difference was statistically significant at a 1% level of significance. In the case of fixed costs, annual interest, cost for machines purchase, and depreciation were calculated. The mean annual interest per hectare was estimated to be NRs 7468.98 which was significantly higher in Dailekh (NRs 14937.96 Ha^{-1}, p = 0.09) than in Salyan (NRs 0.00 Ha^{-1}). Similarly, the cost of machinery and their depreciation were estimated to be NRs 3605.17 and NRs 180.26 per hectare in the province. Farmers of Dailekh were found to spend NRs 7210.35 and NRs 360.52 per hectare for the purchase of machines and their depreciation respectively. However, farmers of Salyan do not spend any money on interest, machine purchase, and their depreciation with statistically non-significant mean differences.

Production, productivity and profitability

Both the Dailekh and Salyan districts of Karnali province are considered to be feasible for commercial potato production due to climatic suitability and soil conditions (Table 6). It is the major staple crop of the people for domestic consumption and commercial purposes. The mean production of potatoes was estimated to be 2106.61 Kg per household annually. Households of the Salyan district were found to produce more potatoes (2679.47 Kgs per household) than the Dailekh district (1533.75 Kgs per household) with a statistically significant mean difference (1145.72

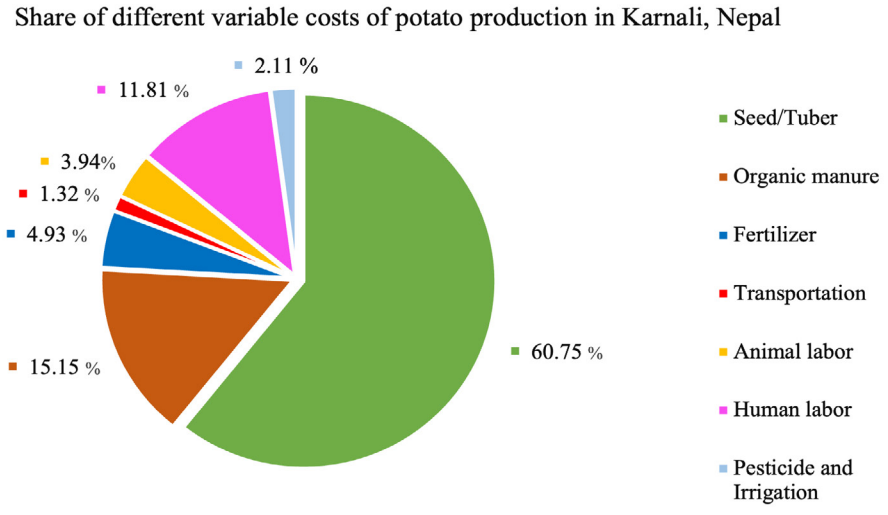

Figure 2: *Percentage share of different variable costs of potato production in Karnali, Nepal.*

Kgs HH^{-1}, p = 0.00). The productivity of potatoes in the province was estimated to be 10.02 per hectare. Salyan had shown significantly higher productivity (10.11 tons Ha^{-1}, p = 0.09) than Dailekh (8.64 tons Ha^{-1}). Although the production and productivity of potato was found to be significantly higher in Salyan district, the mean annual revenue generated by each household was estimated to be similar in the overall province (NRs 78791.58 HH^{-1} or NRs 386574.90 Ha^{-1}) and both of the districts Dailekh (NRs 73234.17 HH^{-1} or NRs 409711.24 Ha^{-1}) and Salyan (NRs 84349.00 HH^{-1} or NRs 363438.50 Ha^{-1}) mean difference being statistically non-significant. This might be due to differences in the market price of potatoes.

Benefit cost analysis

The average cost incurred for the production of unit Kg of potato in the study area was NRs 33.31 which was NRs 36.54 per kilogram in Dailekh and Salyan NRs 21.01 per kilogram with a statistically non-significant mean difference. The average price per unit Kg of potato was estimated to be NRs 38.42 in the province. However, the price per unit Kg of potato received by farmers of Dailekh was higher (NRs 45.92 Kg^{-1}) than that of Salyan (NRs 30.93 Kg^{-1}) with a statistically significant mean difference (NRs 14.99 Kg^{-1}, p = 0.00). The profitability of the potato production in Karnali province was estimated to be NRs 5.11 per kilogram. Similarly, the profitability of potato production in Dailekh (NRs 9.37 Kg^{-1}) and Salyan (NRs 0.85 Kg^{-1}) had a statistically non-significant mean difference. The average benefit-cost ratio of potato cultivation in the province was estimated to be 1.81indicating a profitable business yielding revenue of NRs 1.81

Table 6: *Production, productivity and profitability of potato in Karnali province.*

Variables	Mean (n=120)	Dailekh (n=60)	Salyan (n=60)	Mean difference	t value	p value
Production in Kgs	2106.61 (166.12)	1533.75 (191.91)	2679.47 (251.73)	-1145.72***	-3.62	0.00
Productivity Ha	10.02 (0.85)	8.64 (1.08)	10.11 (1.34)	-2.94*	-1.73	0.09
Total Revenue HH^{-1}	78791.58 (6582.93)	73234.17 (10138.41)	84349.00 (8424.64)	-11114.83	-0.84	0.40
Revenue Ha^{-1}	386574.90(37042.66)	409711.24(60982.19)	363438.50(42404.90)	46272.74	0.62	0.53
Cost per Kgs	33.31 (2.40)	36.54 (3.93)	21.01 (2.71)	6.47	1.35	1.78
Price in Kgs	38.42 (0.98)	45.92 (1.37)	30.93 (0.36)	14.99***	10.60	0.00
Profit per Kgs	5.11(2.56)	9.37 (4.26)	0.85(21.53)	8.52	1.67	0.97
BCR	1.81(0.17)	2.04 (0.25)	1.59 (0.22)	0.46	1.37	0.17

Source: Field survey, 2023.
*Notes: ***, * represents significant at 1%, & 10% level of significance respectively.*
Values in parenthesis are standard errors.
Table format adapted from Dahal et al., (2023).

Table 7: *Cobb Douglas production function of honey production in Karnali province.*

Explanatory variables	Coefficient	Standard error	t value	p value
Log seed cost	0.470***	0.061	7.64	0.000
Log organic manure cost	0.030	0.039	0.76	0.448
Log fertilizer cost	0.092***	0.027	3.44	0.001
Log transportation cost	-0.011	0.023	-0.48	0.630
Log animal labor cost	0.039*	0.019	2.02	0.046
Log human labor cost	0.218**	0.089	2.46	0.015
Constant	1.476***	0.286	5.16	0.000
F statistic	41.03***			
R square	0.747			
Adjusted R square	0.734			
Return to scale	0.838			

Source: Field survey, 2023.
*Notes: ***, **, * represents significant at 1%, 5% & 10% level of significance respectively.*
Table format adapted from Dahal et al., (2023).

in the province was estimated to be 1.81 indicating a profitable business yielding revenue of NRs 1.81 at investment of every NRs 1 making the profit of NRs 0.81. BC ratio of Dailekh (2.04) and Salyan (1.59) shows that potato production is a profitable enterprise, however, the difference across districts was statistically non-significant. (Bajracharya and Sapkota, 2017), (Dahal and Rijal, 2019) and (Sapkota *et al*., 2019) also found potato production a profitable enterprise with benefit-cost ratios of 1.44, 1.71 and 1.35 Baglung, Nuwakot and Achham districts of Nepal.

Table 8: *Determinants of potato production in Karnali province.*

Variables	Coefficients	Standard Error	p value	dy/dx
Log age of household head	-0.229	1.213	0.850	-0.052
Gender	-0.130	0.340	0.703	-0.030
Access to agricultural credit	-0.290	0.492	0.558	-0.066
Log annual revenue	1.963***	0.509	0.000	0.458
Access to trainings	-0.013	0.378	0.973	-0.003
Log total land holdings	1.670***	0.494	0.001	0.382
Log experience	1.069	0.600	0.074	0.244
Constant	-7.514***	3.179	0.001	
Number of observations = 120				
Log likelihood = -47.21				
LR chi^2(12) = 67.68***				
Prob > (chi^2) = 0.000				
Pseudo R^2 = 0.418				

Source: Field survey, 2023.

*Notes: ***, ** represents significant at 1% level of significance.*

Production function analysis

The result showed that the F statistic value (41.03, p = 0.00) was found to be statistically significant at a 1% level of significance indicating the high explanatory power of the model (Table 7). The dependent variable was found to be well explained by the explanatory variable as shown by the R square value of 0.747 (Adjusted R^2: 0.734) which indicates that 74.7% of the response of the dependent variable was due to independent variables.

Other variables keeping constant, increasing the investment in planting materials by 1% would increase the income from potatoes by almost 0.470% this was statistically significant at a 1% level of significance. The finding was in line with those (Bajracharya and Sapkota, 2017) who found the increasing returns from potato with increased investment on plating materials. Similarly, expenses on chemical fertilizers when increased by unit percentage would yield 0.092% more return which was significant at the 1% level. Since the potato is a heavily feeding crop, nutrients supplied through chemical fertilizers would increase crop production and productivity (Ghosh, 2014). Keeping all other variables constant, expenses on animals and humans when increased by 1% would increase the return by 0.039% and 0.218% which were found statistically significant at 10% and 5% level of significance respectively. The finding on human labor cost was inline and animal labor cost was in contrast with the findings of (Bajracharya and Sapkota, 2017) and (Sapkota *et al*., 2019) who found that increments in the cost of human labor would significantly increase the return from potato production but animal labor cost decrease. On the other hand, increasing investments on organic manure and transportation by unit percentage had statistically non-significant impacts on crop revenue.

Determinants of potato production by using probit model.

The log-likelihood ratio chi-square (LR-chi^2) of the model was statistically significant at a 1% level of significance which indicates the higher explanatory power of the probit model (Table 8). Results revealed that explanatory variables such as access to training, access to loans, annual revenue and total land holdings were the major factors determining the commercialization of potato production in Karnali province. When the annual household revenue is increased by 1%, the probability of large-scale production of potatoes would increase by 45.80%. This relationship was statistically significant at a 1% level of significance. The result indicates that those who had higher annual revenue from potatoes last year are likely to expand their area of cultivation in the following year. This might be due to increased capital availability would increase the power to purchase farm resources. The finding was in line with (Sapkota *et al*., 2017) who revealed that the probability of adopting foundation seed production of maize would increase with increasing household income. Similarly, if farmers own higher landholdings, their probability

of expanding the area for potato cultivation would also increase by 38.20% and was found statistically significant at 5% level of significance.

Since the farmers of Karnali province cultivate different crops and raise livestock in their limited land resources, larger landholdings will help them to allocate a larger land area for potato cultivation. The age of the household head when increased by 1 year, the probability commercializing potato production would increase by 0.2%. Interestingly, if the household head is male, the probability of increasing the area of production would decrease by almost 3.6%, this might be because most of the male members are involved in off-farm jobs and prefer not to increase their area of production while females are usually homemakers and prefer to expand their farm enterprises. But the result was in contrast to (Sapkota *et al.*, 2017).

If the agricultural credit is accessible to farmers the probability of increasing their area of potato production would increase by 1.0% as farmers need agricultural loans to purchase their farm inputs. Likewise, the probability of commercializing potato production was found to increase by 3.3% when the farmers took the training as compared to those who did not take the training which was supported by Dahal and Rijal (2019).

Major diseases and pests

Diseases

Various diseases were recorded to infest the potato crop in Karnali province (Table 9). The ranking of the five different diseases that prevailed in the province using a scale/indexing procedure revealed that the

Table 9: *Ranking of major diseases occurred in potato field of study area.*

Disease	Mean (n=120)	Rank	Dailekh (n=60)	Rank	Salyan (n=60)	Rank
Late Blight (*Phytophthora infestans*)	0.90	I	0.40	II	0.50	I
Early Blight (*Alternaria solani*)	0.47	V	0.30	III	0.20	IV
Potato Scab (*Streptomyces scabies*)	0.61	II	0.50	I	0.10	V
Viral Diseases	0.51	III	0.10	IV	0.40	II
Black Heart	0.50	IV	0.20	V	0.30	III

Table 10: *Ranking of major insects occurred in potato field of study area.*

Insect	Mean (n=120)	Rank	Dailekh (n=60)	Rank	Salyan (n=60)	Rank
Red Ant (*Solenopsis spp*)	0.90	I	0.50	I	0.40	II
Potato Tuber Moth (*Phthorimaea operculella*)	0.40	IV	0.10	V	0.30	III
White Grub (*Holotrichia spp*)	0.89	II	0.40	II	0.50	I
Leaf Miner (*Liriomyza spp*)	0.50	III	0.30	III	0.20	IV
Cut Worm (*Agrotis spp*)	0.30	V	0.20	IV	0.10	V

Table 11: *Distribution of potato productivity according to agronomical practices and seed source.*

Variable	Overall Mean	Yes	No	Mean difference	t value	p value
Earthing up (Yes=95/No=25)	10.11 (0.85)	10.91 (1.01)	7.07 (1.36)	3.83**	2.26	0.03
Irrigation (Yes=79/No=41)	10.11 (0.85)	12.92 (1.15)	4.68 (0.49)	8.24***	6.57	0.00
Crop rotation (Yes=35/No=85)	10.11 (0.85)	13.20 (2.20)	8.84 (0.77)	4.36*	1.87	0.07
Fertilizer application (Yes=101/No=19)	10.11 (0.85)	10.92 (0.96)	5.76(1.39)	5.16***	3.05	0.00
Seed treatment (Yes=30/No=90)	10.11 (0.85)	13.04 (2.11)	9.04 (0.88)	4.26*	1.86	0.07
Weeding (Yes=105/No=15)	10.11 (0.85)	10.69 (0.95)	6.01 (1.27)	4.68***	2.96	0.01
Seed source (Formal=68/informal=52)	10.11 (0.85)	10.69 (0.95)	6.01 (1.27)	4.68***	2.96	0.01

Source: Field survey, 2023.
*Notes: *** represents significant at 1% level of significance.*
Values in parenthesis are standard errors.

most frequently occurring disease was late blight which was followed by potato scab, viral diseases, and black heart. The potato growing areas of Dailekh was deprived of irrigation facilities, potato scab was most prevalent as potato scab is most likely to occur in rainfed area with higher salinity problems. Late blight was ranked second, viral diseases as third, black heart as fourth, and early blight as fifth major disease in the Dailekh district. Similarly, late blight was ranked as a major disease prevailing in the Salyan district. Following this, viral diseases, black heart, early blight, and late blight were ranked as the second, third, fourth, and fifth major diseases in the district.

Insects

As reported by the farmers, the potato was highly infested by red ants in Karnali province which was immediately, followed by white grub, leaf miners, potato tuber moth, and cut worm (Table 10). The potato fields of Dailekh were highly infested by red ant while white grub, leaf miner, cutworm, and tuber moth were ranked in sequential order. Furthermore, farmers of Salyan reported white grub as their major problematic insect which was followed by red ant, potato tuber moth, leaf miner, and cut worm in descending rank order.

Distribution of potato productivity according to agronomical practices and seed source.

The agronomical practices such as earthing up, irrigation, crop rotation, fertilizer application, seed treatment, weeding and seed source had noticeable impacts on potato crop productivity of the province at varied level of significance (Table 11). The average productivity of potatoes was higher in the earthed-up condition (10.91 tons Ha^{-1}) as compared to the unearthed-up field condition (7.07 tons Ha^{-1}) with a statistically significant mean difference (3.83 tons Ha^{-1}, p = 0.03). The result depicts earthing up the soil at least once during the vegetative growth of potatoes would promote productivity. This might be due to the reason that earthing up stimulates and provides a favorable environment for tuber formation and development (Gutema *et al.*, 2016), controls the weeds, protects the tuber from sunlight (Tafi *et al.*, 2010), and increases the number and size of tubers (Getachew *et al.*, 2012).

Similarly, mean productivity of potatoes was higher under irrigated conditions (12.92 tons Ha^{-1}) than in rainfed conditions (4.68 tons Ha^{-1}) with a statistically significant mean difference (8.24 tons Ha^{-1}, p = 0.00) It shows the positive response of irrigation on the productivity of potato particularly during its critical stages due to shallow root system (Djaman *et al.*, 2021) and 'drought stress results into suppressed growth, production and even crop failure (Kashyap *et al.*, 2003; Camargo *et al.*, 2015). Likewise, productivity of potatoes was significantly higher under crop rotation (13.20 tons Ha^{-1}) as compared to no rotation (8.84 tons Ha^{-1}) with a statistically significant mean difference (4.36 tons Ha^{-1}, p = 0.07). Rotational growing of dissimilar crops helps to break the disease cycle such as late blight (Kessel *et al.*, 2018), improves soil fertility (Hooper *et al.*, 2000), and conserves the agroecosystem (Smith *et al.*, 2008).

Chemical fertilizers also had significantly enhanced productivity of potatoes (10.92 tons Ha^{-1}) as compared to no fertilizers (5.76 tons Ha^{-1}) with a statistically significant mean difference (5.16 tons Ha^{-1}, p = 0.00), the result supported that macronutrient supplied through high analytical fertilizers help to meet the heavy nutrient demand of the crop (Kumar *et al.*, 2017). Furthermore, productivity was significantly higher under seed treated conditions (13.04 tons Ha^{-1}) as compared to no seed treatment (9.04 tons Ha^{-1}) with a statistically significant mean difference (4.26 tons Ha^{-1}, p = 0.07) indicating that treating seeds or tuber prior to sowing is crucial as it helps to suppress severalfungal diseases including *Fusarium spp* (Duellman *et al.*, 2021) and *Phytophthora infestans* (Wharton *et al.*, 2012).The potato productivity was significantly higher under properly weed-managed conditions (10.69 tons Ha^{-1}) as compared to no-weeding (6.01 tons Ha^{-1}) with a statistically significant mean difference (4.68 tons Ha^{-1}, p = 0.00) as weeding reduces competition for soil nutrients, space, water and sunlight with weed species (Skiba *et al.*, 2021). Similarly, the use of formal seeds/tubers resulted higher productivity of potatoes (11.49 tons Ha^{-1}) as compared to informal seeds (8.30 tons Ha^{-1}) with a statistically significant mean difference (3.18 tons Ha^{-1}, p = 0.05) which indicates that genuine planting materials have higher potentiality of withstanding pathogens.

Conclusions and Recommendations

The study was conducted to understand the economics and commercialization dynamics of potato production in two different districts with varied topo-

geographical characteristics. The total cost of potato production in the province was NRs 256496.60 per hectare with total variable and fixed costs of NRs 245242.19 and NRs 11254.41 per hectare respectively, indicating enterprise as high-input intensive agri-business. The planting materials, organic manure, human labor and fertilizers shared 60.75%, 15.15%, 11.81% and 4.93% of the total variable costs respectively. The average BC ratio in the province was 1.81 indicating the potato cultivation as a profitable agri-business, however there is a huge potentiality of increasing production and productivity. The CDPF analysis shown that increasing investments on several variable inputs including planting materials, chemical fertilizers and labor would significantly increase the crop revenue. Similarly, the probit regression analysis shown that land holdings of the household and crop revenue are key determinants for commercialization of the potato enterprise in the province. In order to enhance the production, productivity and profitability of potato enterprise in the province, several resources and supports should be provided to the growers. All three government stakeholders including federal, provincial and local should work collaboratively on development and implementation of targeted policies to commercialize the crop production and developing profitable potato-based agro-industries such as chips, starch, fries and frozen products thereby creating a stable value chain of the raw potato and marketable value-added products. Also, dissemination of technical know-how, technology including high-yielding resistant cultivars, irrigation facilities, and storage facilities are still lacking and need to be considered for bumper production. Similarly, emphasis should be given to introduce and promote farm machineries to reduce drudgery, cost of production. Furthermore, interventions are also needed to overcome the influences of middlemen on price determination, risk, and uncertainty management and to ensure on-time input supply.

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Novelty Statement

This study provides a comprehensive assessment of socio-economic, agronomical and environmental factors determining commercialization of potato production at the farm level. The findings will support evidence-based recommendations for enhancing resource efficiency, farm income and policy interventions in potato based cropping system.

Author's Contribution

Shishir Dahal: Survey and questionnaire design, data collection, curation, statistical analysis and manuscript writing.
Bijaya Dangi: Data collection, statistical analysis and manuscript writing.
Aarjal Bhandari, Raman Kumar Dangi, Shriya Oli and Prajwal Adhikari: Data collection.

Generative AI and AI-assisted technology statement
None of the generative AI and AI-assisted technologies were employed during this study.

Conflict of interest
The authors have declared no conflict of interest.

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