Heliyon 10 (2024) e30225

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Good agricultural practices (GAP) adoption intensity and production constraints in apple orchards of western Nepal

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A R T I C L E I N F O

Keywords:
Adoption
Food security
GAP
Negative binomial regression
Severity index
Sustainability

A B S T R A C T

The declaration of 'Fruits Decade 2016/17–2026/27' and the enaction of the 'NepalGAP Scheme' by the Government of Nepal has redirected increased public investments to promote apple production and marketability in the western high hills of Nepal. This study explores major good agricultural practices (GAP) related to orchard management, factors influencing their adoption intensity, and key underlying constraints to production using cross-sectional survey data from apple growers in Dolpa district, Nepal. The results showed that farmers mostly adopted GAP such as frequent weeding, intercropping, and nutrient management in apple orchards. Based on the negative binomial regression estimates, household characteristics such as gender of the orchard owner, experience, and number of literate household members were found influential in determining the GAP adoption intensity. The analysis of the problem severity index implied that apple production is mostly constrained by limited access to production inputs and transportation. The findings provide useful insights to the farmers and policymakers regarding the current scenario of GAP adoption along with the diversity of barriers that severely limits the realization of apple production potential in western Nepal.

1. Introduction

Apple (*Malus domestica*) is one of the most popular fruits globally with an annual production of over 85 million metric tons [1]. The widespread production of apples is attributed to their multiple health benefits, culinary versatility, and adaptability to a wide range of temperate climatic conditions [2–4]. Although apples have been domesticated for more than 4000 years in Asia, their commercial production in Nepal began only in the 1960s. Despite short production history in Nepal, apple remains one of the major temperate fruits with an annual production of ∼49,000 metric tons [5]. Apple farms cover ∼13,500 ha in more than 40 districts and are

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https://doi.org/10.1016/j.heliyon.2024.e30225
Received 1 June 2023; Received in revised form 13 April 2024; Accepted 22 April 2024
Available online 25 April 2024

predominantly present between 2000 m and 3000 m elevation in western Nepal, including major production hubs such as Jumla and Mustang [6]. The major varieties grown include Red Delicious, Royal Delicious, Golden Delicious and McIntosh, but currently there is also increasing preference for Fuji, Gala and Red Jonaprince varieties [7–9]. Popular apple rootstocks used are M-9, *edimayal* (*Pyrus pashia*), and crab apple. Although the temperate climate (i.e., 21°C – 24°C average temperature and 200–250 mm rainfall) and soil are favorable in the northern high hills (1500m – 3000m elevation) of the country, apple production previously received limited attention due to poor transportation and market infrastructures [6]. However, the declaration of the "Fruits Decade 2016/17–2026/27" by the Government of Nepal has prioritized expanding fruit orchard areas, including apples, in the western hilly districts. This has led to increased assistance from the local, provincial, and federal governments to facilitate apple production and marketing.

Commercial fruit farming is emerging as a promising alternative to cereal crop production, particularly in response to problems posed by out-migration and labor shortages in hilly areas. Strong domestic demand for apples also led to an increase in investment by farmers in apple farming. In the late of the 2010s, apple area, production, and productivity in Nepal grew by 2.35%, 11.65%, and 5.18%, respectively (Fig. 1). However, it remains insufficient to meet the strong national demand, despite the high quality of the fruits compared to imported ones. More than the double quantity of apples, compared to the national production estimate, is imported to meet the Nepali market demand for apples [10].

Despite the significance of apple cultivation for the livelihoods and rural economy of western Nepal's high hills, research on apples, specifically focusing on cultivation, cultivar development, yield enhancement, and value chains, has not received considerable attention. There are only a few studies regarding apple production in Nepal, and most of the existing studies have focused on benefit-cost analysis [9], climate change impacts [11], suitability of cultivation [12], landscape sustainability [13], profitability and allocative efficiency [14], and value chains [15]. An analysis of these existing studies on apples suggests that research in this area is still in its early stages, and considerable efforts are required to support apple growers and marketers in making apple production a more promising enterprise in the future.

Starting in 2015, alongside the conventional planting system, a high-density planting (HDP) system was introduced in Nepali apple orchards. With increasing emphasis on commercial apple production from both farmers and the government, concerns have arisen regarding production practices and their implications for the existing 'organic by default' label, production efficiency, environmental sustainability, food quality, and food safety have been in the limelight. The growing public concern about these issues has prompted the adoption of good agricultural practices (GAP) in apple orchards.

According to the FAO [16] – "GAP is a collection of principles to apply for on-farm production and post-production processes, resulting in safe and healthy food and non-food agricultural products, while taking into account economic, social and environmental sustainability." GAP is a voluntary standard aimed at assuring food quality while also addressing environmental management issues surrounding farmland [17]. GAP offers many benefits to farmers, such as reduced input usage, high-quality production, and increased farm income [18]. GAP fosters food safety and sustainable agriculture through its three pillars: social equity, sustainability, and food security [16]. While GAP has been extensively adopted by industrialized countries for pests and nutrient management for at least two decades, it is a relatively new topic in Nepal. Nepali farmers are adopting GAP, especially after the enaction of the 'NepalGAP Scheme' by the Government of Nepal in October 2018, with a particular focus on integrated plant nutrient and pest management. Different farmers' field schools (FFS) have been organized by the government across the country to generate awareness and facilitate GAP adoption.

The adoption of GAP is in a nascent phase in Nepal, which is reflected in the limited literature available on this topic. Existing literature on GAP in Nepal is mostly related to farm performance and input usage [18], awareness determinants [19], adoption determinants [20] and yield impacts [21]. GAP encompasses a wide range of measures, from simple to complex, spanning from production to post-harvest stages. Therefore, it is essential to identify key factors influencing their adoption along with the constraints, which can inform GAP policy planning. To our knowledge, there are no studies that explore factors influencing the adoption intensity (i.e., frequency of adoption) of GAP in fruit orchards. We aim to fill this void by examining GAP related to orchard management among apple growers and exploring the factors that are likely to influence GAP adoption intensity in apple orchards.

Furthermore, apple production in Nepal is primarily concentrated in rural settings, where orchard owners face a myriad of

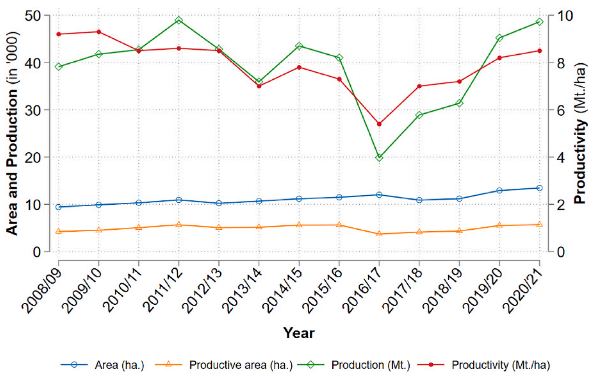

Fig. 1. Apple area, production, and productivity in Nepal from 2008/09 to 2020/21 (Data source: MoALD, 2022).

challenges such as unavailability of adequate inputs (i.e., quality seedlings/saplings, irrigation, fertilizers), lack of proper storage and marketing channels for produce owing to poor transportation facility in the rugged hilly terrains, and invasions from diseases and pests. Given the array of problems and the limited availability of public spending, it is crucial to prioritize these challenges based on severity rank so that farmers achieve the highest marginal benefits by addressing the most prominent problem through the use of public funds. However, the task of prioritizing the pressing concerns of apple orchard owners based on the actual on-ground scenario has often been overlooked, which this study takes into account.

The objectives of this study are twofold: (*i*) to explore the adoption status of various GAP and assess the factors influencing the intensity of their adoption, and (*ii*) to identify and rank the key constraints related to apple production and marketing. To accomplish these objectives, we collect data through face-to-face surveys of apple growers in Dolpa, Nepal, and employ two approaches. First, the factors influencing GAP adoption intensity are assessed using the negative binomial regression model. Second, the key constraints related to apple production and marketing are identified and ranked using the severity index calculated from responses on a 5-point Likert scale. The results show that factors such as the gender of the orchard owner, the number of literate household members, and apple-growing experience are influential in determining the intensity of GAP adoption in apple orchards. Furthermore, the study highlights prominent challenges for apple growers, including issues such as the lack of irrigation, insect pests and diseases (e.g., woolly aphids, papery bark), and inadequate transportation facilities.

This study adds to the existing literature on apples and GAP by Reganold et al. [22], Peck et al. [23], Busdieker-Jesse et al. [24], Leong et al. [25], Orpet et al. [26], and Piñeiro et al. [27]. The findings from this study could serve as a useful reference for farmers and policymakers aiming to increase GAP adoption and prioritize resource use with implications for product marketability, economic profitability, efficient public spending, food safety, and environmental sustainability. The knowledge of factors influencing GAP adoption intensity along with the major constraints of production can guide GAP adoption planning and support ongoing efforts to expand apple orchard acreage and production in Nepal.

The next section explains the data and methods. Section 3 presents the results and discussion. Section 4 concludes the paper with suggestions for future research.

2. Data and methods

2.1. Study area

This study was conducted in the lower region of the Dolpa district in Karnali province, Nepal (Fig. 2). We chose Dolpa, the largest district in Nepal, as our study area because it is one of the nine major districts for commercial apple production in the country and is

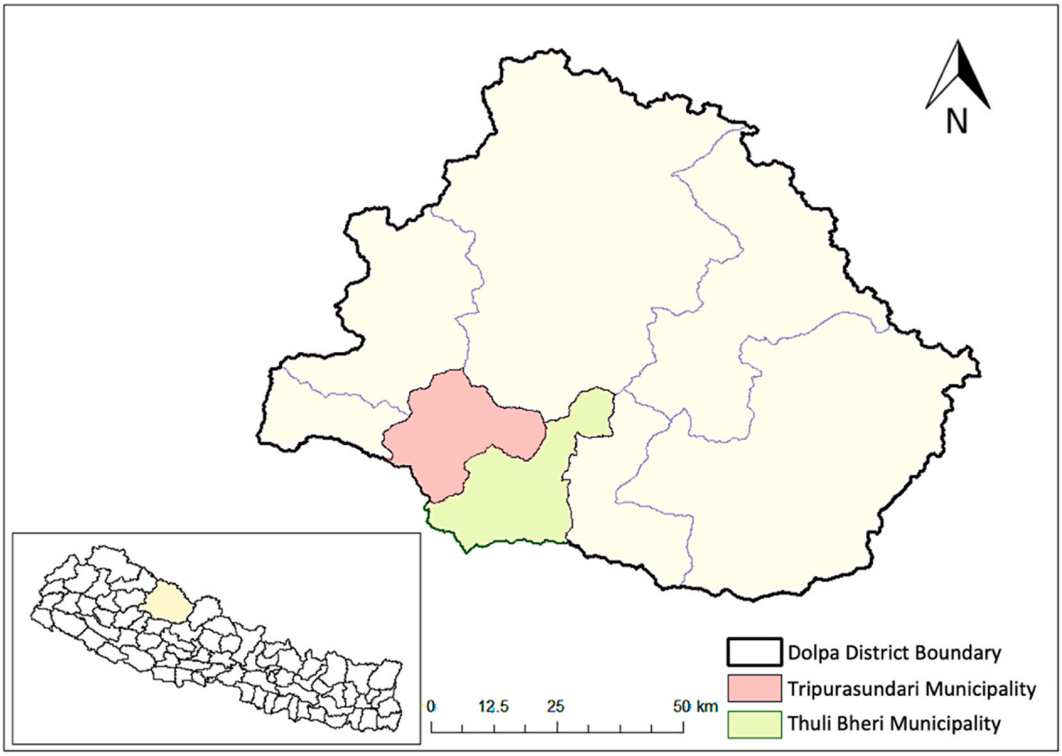

Fig. 2. Map of the study area in the Dolpa district. The inset map shows Dolpa in the map of Nepal.

renowned for growing organic apples. Notably, Dolpa was connected to the national road network only in 2018, which facilitated transportation and distribution of apple nursery trees to the farmers [28]. Dolpa boasts a mountainous terrain, with elevations ranging from 1525 m to 7754 m above sea level. The temperate climate (in 5.1% of total area) in lower Dolpa provides a suitable growing environment for fruits such as apple, peach, pear, plum, and hazelnut among others. The trend of apple production in Dolpa is shown in Fig. 3.

2.2. Data collection

We identified apple growers from the farmers' database maintained by the local governance unit (i.e., municipality). All the apple growers enlisted in the farmers' profile maintained by Tripurasundari Municipality and Thuli Bheri Municipality constituted the sampling frame of our study. Out of the eight (rural)municipalities in this district, we purposively chose Tripurasundari and Thuli Bheri municipalities for this study (Fig. 2) because they include the command areas of the Apple Zone in Dolpa, as part of the Prime Minister Agriculture Modernization Project (PMAMP). Altogether 100 survey respondents were randomly selected from the sampling frame. Due to the extreme remoteness of Dolpa, it was challenging to conduct household surveys with additional farmers in the project area. We used a structured questionnaire to collect socioeconomic, demographic, and farm-related information. Before the formal survey, we pre-tested the interview schedule with 10 households to ensure the questionnaire's efficacy and validity.

The household survey was conducted from March to April 2020, during which farmers were visited in person. Verbal consent was obtained from each respondent before formally asking questions. There were not any tangible rewards for respondents participating in our study. Participants were allowed to stop responding and opt-out at any point during the survey. Each face-to-face interview lasted around 20 minutes. A good rapport was built before starting the interview to ensure that the information given by them is reliable and unbiased. Besides the household survey, we also conducted ten key informant interviews (KII) and five focus group discussions (FGD) with progressive farmers, ward representatives, leaders of farmer groups, and members of the Apple Zone Management Committee to cross-validate the survey data. All survey responses were anonymized and subjected to standard procedures for data entry, cleaning, and analysis using MS Excel and RStudio (v. 1.4.1717).

2.3. Variables

The dependent variable in our study is GAP adoption intensity, which we define as the total number of GAP adopted by apple growers on their farms. We specifically focus on GAP related to orchard management (Table 2) that are likely to contribute to the quality and quantity of apple produce. Examples of orchard management-related GAP include the use of certified planting materials from government authorities (often based on phytosanitary certificate issued by sapling-exporting country), intercropping practices, and nutrient and irrigation management systems. GAP unrelated to orchard management (e.g., post-harvest practices) were excluded in the study. The independent variables include the gender of the apple orchard owner (*Gender*), the number of literate members in the household (*NumEduc*), experience in apple farming (*Exp*), the area of the apple orchard (*FarmSize*), agricultural income (*AgInc*), institutional involvement (*Insti*), distance to the nearest road (*DistRoad*), and access to technical assistance and extension services (*TechSer*). The details of the variables used in our study are presented in Table 1.

In developing countries, gender plays a special role in farming and partly determines access to productive resources (e.g., land, labor, finance) that are crucial to farm success [29]. The number of literate members within households is important in driving GAP uptake, as the adoption of innovations is influenced by literacy levels [30]. Experience is another key factor likely to influence the adoption of GAP [31,32]. Multiple years of experience in farming could provide insights into the prospective costs and benefits of adopting new practices. Moreover, farmers with more experience witness both benefits and pitfalls of different methods of production. Farm size is another variable that may influence GAP adoption intensity because of prospective benefits from reduced input usage in larger farms (i.e., economies of scale) and increased revenue through the premium price of products [33,34]. Agriculture is the major source of income in the study area with more than 77% of people earning their living from it. We also consider variables like

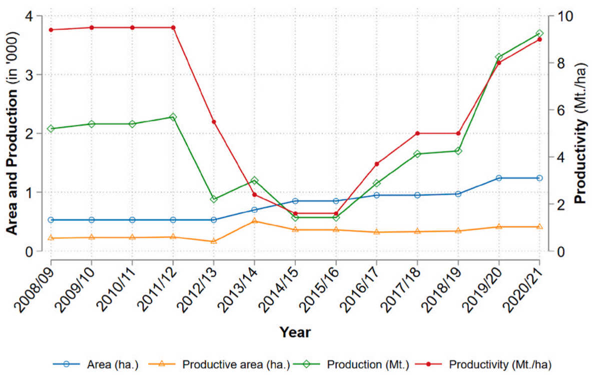

Fig. 3. Apple area, production, and productivity in the Dolpa district from 2008/09 to 2020/21 (Data source: MoALD, 2022).

Table 1
Descriptive statistics.

Variables	Description	Mean ($N = 100$)	SD
GAP	Number of GAP adopted by apple grower	5.28	1.48
Gender	Gender of the orchard-owner (*Male = 1, 0 otherwise*)	0.76	0.43
NumEduc	Number of literate members in the household	1.89	1.07
Exp	Experience in apple farming (*years*)	6.38	3.97
FarmSize	Area of apple orchard (*ropani*)[a]	7.84	6.03
AgInc	Agricultural income (*NRs./year*)[b]	81376	50051
Insti	Institutional involvement (*Yes = 1, 0 otherwise*)	0.78	0.42
DistRoad	Distance to road (*km*)	2.31	1.67
TechSer	Access to technical assistance and extension services (*Yes = 1, 0 otherwise*)	0.53	0.50

Notes: SD = Standard Deviation; GAP = Good Agricultural Practices.
[a] 1 ha = 19.65 *ropani* = 2.47 acre.
[b] US $1 = 0.936 Euro = NRs. 123.99 (as of May 25, 2022).

agricultural income and market access, whether regional or national, in our study as they are important factors influencing GAP adoption [35,36]. Institutional involvement could foster efficient use of production inputs, improving technical efficiency and economic performance [37,38]. Given that efficient input usage is one of the objectives of GAP, we include the institutional affiliation status variable (e.g., cooperatives, community groups, producers' group) in the study due to its likely positive effect [39]. Distance to the nearest road is a good proxy of market access [40]. In addition, the availability of technical assistance and extension services may not only influence the uptake of GAP but also its continued implementation in a way that benefits farmers, consumers, and the environment [27].

2.4. Econometric model

We consider an apple grower as an adopter of GAP if she is implementing at least one GAP in her apple orchard. Our primary interest is to explore the relationship between various independent variables and GAP adoption intensity. Since GAP adoption intensity is a count data taking only non-negative integer values, Poisson regression is a preferred modeling option. However, Poisson regression assumption that mean equals variance does not always hold due to overdispersion problem resulting inefficient parameter estimates [41]. This issue can be tackled using negative binomial regression model, which is robust to distributional misspecifications. When dispersion parameter is known and variance function is correctly specified, negative binomial regression is a widely used approach for modeling count data and offers a good alternative by accounting for the shortcomings of Poisson regression [32]. The negative binomial regression model is represented as [41]:

$$P(y_i|\boldsymbol{x}_i) = \frac{\Gamma(\theta + y_i) r_i^{\theta} (1 - r_i)^{y_i}}{\Gamma(1 + y_i)\Gamma(\theta)}, \quad y_i = 0, 1, 2, \ldots, \theta > 0, \quad r_i = \frac{\theta}{(\theta + \mu_i)} \tag{1}$$

In equation (1), y is the frequency of GAP, $\boldsymbol{x}_i$ is a vector of explanatory variables, $\Gamma(.)$ is the gamma integral, θ is the index or precision parameter, and μ_i is the mean parameter denoting the expected number of events (i.e., GAP adoption intensity). The mean and variance terms are expressed in equations (2) and (3) as:

$$\mu_i = E[y_i|\boldsymbol{x}_i] = exp(x_i'\beta), i = 1, \ldots, N \tag{2}$$

$$\text{Var}\ [y_i|\boldsymbol{x}_i] = \mu_i[1 + (1/\theta)\mu_i] \tag{3}$$

The parameters of the negative binomial regression are estimated using the maximum likelihood estimation method.

2.5. Severity index

Besides studying GAP adoption intensity and factors influencing its adoption, we are also interested to rank various problems in apple orchards based on the severity index obtained via responses to a closed-ended Likert rating scale. We elicited the problems in apple orchards by posing the question: "What are the major problems related to apple production, post-production, or marketing?" Additionally, we asked farmers to rank their problems within each category (i.e., production, post-production, or marketing) using a Likert scale with ratings ranging from 1 to 5, where 1 denotes the least severe and 5 denotes the most severe problem. This scale allows us to rank the problems under consideration based on their severity when other explicit ordinal ranking measures are not readily applicable. The severity index is calculated as:

$$I_{severity} = \sum \frac{S_i F_i}{N}, \tag{4}$$

In equation (4), $I_{severity}$ denotes the severity index for the problem, S_i is the severity scale value for a problem i based on a 5-point rating scale. S_i is considered as the constant denoting weight assigned to each response ranging from 1 to 5. F_i is the frequency of a particular scale value for the ith problem, and N is the number of respondents. The severity index helps to rank the problems facing orchard owners. The higher value of the index denotes higher severity and vice-versa. This facilitates both government agencies' and farmers' decision-making by prioritizing the problems to make judicious use of available limited resources for uplifting the livelihood of fruit growers.

3. Results and discussion

3.1. Descriptive statistics

The summary statistics of the variables under investigation are presented in Table 1. The results reveal that, on average, farmers adopt around five GAP in their apple orchards. The low standard deviation of GAP adoption intensity indicates that there is relatively little variability in the frequency of GAP adoption among apple orchards in Dolpa. Most of the apple orchards (>75%) are male-owned. This is not uncommon in rural areas of developing countries like Nepal, where women are mostly limited to household chores. Additionally, the majority of apple farmers in the study area seem to be new growers, with an average experience of only 6.38 years. The average farm size is 7.84 *ropani*, equivalent to 0.40 ha, implying that apple farms are mostly small to medium-sized due to land fragmentation. The average annual income from agriculture is approximately Rs. 81,000 (equivalent to US $ 653 or € 611, as of May 25, 2022). Moreover, institutional involvement is also seen as more common, with farmers mostly associated with farmers' groups, cooperatives, or producers' groups. The average distance to the nearby road is around 2.3 km, highlighting the rurality of apple farms and the limited market access for apple growers. Furthermore, only around 50% of the apple growers have access to technical services emphasizing the need for extension and outreach efforts are necessary in the study area.

The distribution of adoption intensity of GAP is given in Fig. 4, showing that respondent farmers were typically adopting at least two GAP in their apple farms. This distribution further resembles that implementing GAP is common among apple growers. However, whether farmers have successfully realized the benefits offered by GAP remains a subject for further investigation.

The details regarding the adoption frequency of different GAP are provided in Table 2. The quality of seedlings or saplings largely determine apple yield. We found that farmers use planting materials from both seed source and vegetative grafting techniques. Certified planting materials are primarily sourced from the Temperate Horticulture Development Center, other government farms, or private nurseries. However, it is worth noting that only about half of the farms used certified planting materials. Several studies have shown that land facing southwest direction are conducive to apple growth due to adequate exposure to sunlight [42] and effective air drainage. In our study, more than two-thirds of the farms were facing southwest. For planting saplings, a recommended pit size is 3 feet (around 1 m) in diameter. We found that around 69% of the farmers adopted this recommended pit dimension. Intercropping is very important for apple cultivation as it increases the efficiency of land use and economic returns [43]. Farmers commonly intercropped with vegetables like peas, beans, radish, cabbage, onion, garlic, soybean, potato, and mustard. The benefits of intercropping have been realized by more than 70% of apple growers in the study area.

Irrigation plays a crucial role in ensuring the quality and size of apples [44]. Although drip irrigation is the recommended method of irrigation in apple orchards, it is not widely practiced among Nepali apple producers. As an alternative, pipeline and ring method of irrigation is recommended to prevent the spread of disease in apple orchards [45]. Typically, apple orchards require irrigation at 15-day intervals [45], but in the Dolpa district, this pattern is not followed by any farmer. The Fruit Development Directorate suggests that more than 10 times irrigation per year is required for good apple production. However, the recommended irrigation frequency appears to be the least adopted GAP, possibly due to the reliance on seasonal precipitation and limited access to good alternative irrigation sources. The recommended planting density for medium-sized apple tree ranges from 15 to 25 trees per *ropani* [46]. However, more than half of the farmers did not follow this recommended planting density. Weeds are problematic mostly in young plantations. Weeding protects from competing vegetation and insect pests. Weeding more than twice is beneficial for apple production [42]. Notably, recommended weeding is the most widely adopted GAP, likely due to its relative ease of implementation. Farmyard manure (FYM) is important for sustainable soil management, as it enhances soil aggregates formation and maintains soil drainage and aeration. The recommended dose of FYM during planting is 15–25 kg per plant. This is also well-practiced by the farmers because

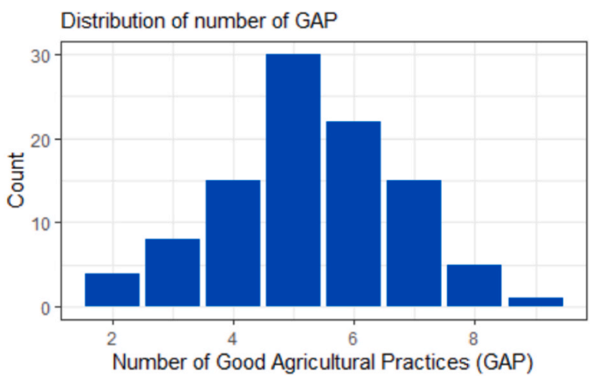

Fig. 4. Distribution of GAP adoption intensity.

Table 2
Distribution of respondents based on the adoption of GAPs ($N = 100$).

Good agricultural practices (GAPs)	Adopter (%)	Non-adopter (%)
Use certified planting materials	53	47
Direction of farm (Southwest facing)	68	32
Dimension of pit (1 m diameter)	69	31
Intercropping	71	29
Method of irrigation (Ring and pipeline)	48	52
Irrigation interval (>10 per year)	10	90
Planting density (15–25 trees per *ropani*)	49	51
Frequency of weeding (>2 times)	89	11
FYM application at planting time (15–25 kg per plant)	71	29

Source: Field survey (2020)

livestock is an important component of Nepali farming practice due to which most of the farmers are able to supply adequate FYM to their orchards.

3.2. Econometric results

We present the results obtained from the negative binomial regression regarding the influence of different factors on GAP adoption intensity in Table 3. The parameters in Model 1 of Table 3 were estimated ignoring all observations that consisted of missing values. In Model 2, parameter estimation was done after replacing missing values through mean imputation method. The results of the negative binomial regression show that gender, number of literate members in the household, and years of apple farming experience are highly influential in determining GAP adoption intensity. Specifically, female farmers are expected to have around 19% fewer GAP in their apple orchards. In other words, female owners are predicted to have about one less GAP in their orchard compared to their male counterparts, all other factors being equal. Similarly, having one more literate member in the household is associated with around 4.5–6.7% more GAP in apple orchards. Furthermore, each additional year of experience in apple farming is associated with the adoption of around 2% more GAP. The positive relation between GAP adoption and farming experience may be attributed to the accumulated knowledge about the prospective resiliency and better marketing opportunities provided by GAP to the farm. The estimated coefficients and marginal effects in both Model 1 and Model 2 are not drifting much and the results are still consistent suggesting that missing values do not bias our parameter estimates in Model 1. However, it should be noted that we failed to reject the null hypothesis that data are missing completely at random using the Little's test (χ^2 (15) = 54.4; p-value = <0.001). The coefficient of agricultural income is negative and that of access to technical services is positive, as per our expectations. However, both variables are found to be statistically insignificant. The results in Table 3 further show that household characteristics are seen as influential in determining GAP adoption levels in apple orchards. Although we did not find any significant influence of institutional involvement, distance to road, and access to technical service in this study, the actual effect of these variables is subject to further investigation.

Table 3
Estimated coefficients and marginal effects from the negative binomial regression model.

Variables	Negative binomial regression			
	Model 1		Model 2	
	Coefficients	*dy/dx*	Coefficients	*dy/dx*
Gender (*Male = 1*)	0.193* (0.106)	0.986	0.188** (0.086)	0.945
Number of literate HH members	0.067* (0.039)	0.362	0.045** (0.019)	0.239
ln(Agricultural income (*NRs.*))	−0.051 (0.043)	−0.276	−0.035 (0.040)	−0.183
Apple farming years	0.019** (0.009)	0.100	0.018** (0.008)	0.096
Area of apple cultivation (*ropani*)	−0.001 (0.005)	−0.002	0.002 (0.004)	0.009
Institutional involvement (*Yes = 1*)	−0.115 (0.098)	−0.644	−0.033 (0.071)	−0.177
Distance to road (*km*)	0.009 (0.020)	0.047	0.003 (0.016)	0.015
Access to technical support and extension service (*Yes = 1*)	0.049 (0.070)	0.262	0.006 (0.055)	0.031
Constant	1.910*** (0.499)	–	1.699*** (0.459)	–
Wald χ^2	68.67		114.27	
Deviance	19.31		34.89	
Log-likelihood	−114.97		−192.00	
N	60		100	

Notes: The dependent variable is good agricultural practices (GAP) adoption intensity. Numbers in the parentheses denote robust standard error. *ln* denotes natural logarithm. *, **, and *** denote significance at 10 %, 5 %, and 1 % respectively. *dy/dx* denotes average marginal effects. The coefficients represent semi-elasticities. Model 1 estimates parameters by omitting missing observations. In Model 2, parameter estimation is done after replacing missing values using mean imputation technique. HH denotes household. The mean variance inflation factor (VIF) for the variables under consideration is 1.23, implying that multicollinearity is not a problem in our model.

3.3. Problems and their severity in apple orchards

Besides factors influencing GAP adoption, we also explored major problems faced by apple farmers in relation to production and marketing, including issues related to diseases and insects. The ordinal ranking of the major problems faced by apple growers is presented in Table 4. Using the weighted-index ranking method, we found that lack of irrigation is the prominent problem followed by insect pests. Moisture stress, especially during the apple growth period, severely affects fruit size and fruit number is also impacted as a result of the June drop – i.e., immature fruit drop in the spring. Irrigation in the study region is mostly dependent on seasonal precipitation, with more than 70% of cultivated land deprived of alternative irrigation sources. Other notable problems include lack of nutrient inputs and shortage of quality planting materials. When it comes to apple marketing, poor transportation infrastructure stands out as a significant limitation. Ironically, lack of certification poses another hurdle for farmers. Without a proper provision for GAP certification, farmers cannot secure the price premium which is really a disadvantage to the growers. Unless the certification process is unconstrained, the essence of GAP is not well realized both by the farmers and the consumers.

In terms of diseases, papery bark stands out as the most problematic disease, followed by collar rot and powdery mildew. Root rot is comparatively seen as a less problematic disease. These diseases are responsible for declining orchard quality through reduced fruit size and quality. In the realm of insect-related challenges, wooly aphid is the major problem, followed by *Zygaena* moth and San Jose scale. The major problems identified in this study align with the previous findings of Adhikari and Thapa [20], Ojha et al. [47] and Atreya and Kafle [48]. This alignment corroborates the fact that apple farms across different regions face multiple similar problems in terms of production and marketing. The diverse range of problems being faced by apple farmers needs to be duly addressed by redirecting future investments of government agricultural agencies to promote input access and market linkage in a way that would benefit both farmers and consumers. This is essential to promote sustainability of apple production, profitability, and marketability in the long run while also capitalizing the tremendous production potential of high-quality apples in the western hills of Nepal.

On another note, less uptake of agricultural insurance and inadequate consideration for land planning during orchard establishment are additional problems in apple-growing areas. These aspects have important implications for the development of the apple zone in the long term and need due consideration in future program planning.

4. Conclusion

Fruit production is receiving considerable attention in Nepal recently, driven by increased investments from both government and farmers. Additionally, GAP are being increasingly emphasized to address concerns related to production efficiency, marketability, food safety, and environmental sustainability. Our paper analyzed the adoption status of GAP in apple orchards, the factors influencing adoption intensity, and the prominent challenges associated with apple production and marketing. We found that farmers are more inclined to adopt GAP related to management practices during production. Thus, devising programs focused on capacity-building of farmers to promote (post)production-related GAP are suggested to harness the potential of apple orchards for increased marketability and revenue from apples. The results from the negative binomial model underscore the importance of factors such as gender, experience, and number of literate household members in determining the adoption intensity of GAP. Therefore, prioritizing future programs based on household characteristics could improve the GAP adoption intensity. GAP adoption is still fledgling and realigning existing programs to address the pressing problems in production and marketing could help promote GAP in a wide range of fruits and vegetables. The findings of this article could supplement the effort of government agencies to expand apple orchards by addressing the key constraints.

There are a few caveats to our analysis that should be acknowledged. First, our dataset is relatively small and limited to two municipalities in the Dolpa district due to the extreme remoteness of the study area. Extending this analysis with a larger sample size, including multiple apple-growing regions across the country, may yield more promising results. Second, we conducted this analysis assuming that variables in our negative binomial model are exogenous, which might be a subject for further investigation. Third, we focused primarily on GAP associated with cultivation practices in this study, while excluding those related to post-production events which are equally important in meeting GAP standards. Further analysis incorporating GAP ranging from production operations to post-harvest operations could provide more comprehensive information about GAP adoption in apple value chains. Future research on relative returns of GAP adoption, GAP price premiums, dynamics of GAP benefits, and how GAP improves the sustainability of orchards, resilience to climate change and orchard performance could provide valuable insights for the scale-up of GAP in the country.

Data availability statement

Data and code used in this study are included as supplementary materials in the article.

CRediT authorship contribution statement

Dinesh Bajgain: Writing – review & editing, Writing – original draft, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Injila Tiwari:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Hema Joshi:** Writing – review & editing, Writing – original draft, Validation, Resources, Formal analysis, Data curation. **Kabita Kumari Shah:** Writing – review & editing, Writing – original draft, Validation, Resources, Investigation, Formal analysis, Data curation. **Jiban Shrestha:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project

Table 4
Major problems in apple production with their severity indices and ranks.

Problems in apple orchards	Severity Index	Rank
Production problems		
Lack of irrigation	0.83	I
Insect pest problem	0.70	II
Lack of nutrient inputs	0.60	III
Lack of quality planting materials	0.46	IV
Lack of technical knowledge	0.43	V
Marketing problems		
Higher transportation cost	0.90	I
Lack of collection center	0.78	II
Lack of packaging materials	0.66	III
No certification	0.39	IV
Lack of market information	0.28	V
Major diseases		
Papery bark	0.78	I
Collar rot	0.67	II
Powdery mildew	0.46	III
Apple scab	0.39	IV
Root rot	0.28	V
Major insects		
Woolly aphid	0.86	I
Zygaena moth	0.73	II
San Jose scale	0.60	III
Apple borer	0.43	IV
Tent caterpillar	0.39	V

Source: Field Survey (2020)

administration, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors extend gratitude to the editor and two anonymous reviewers for their invaluable feedback and insightful suggestions on the earlier versions of this paper. Dinesh Bajgain would like to acknowledge the profound support received from Udit Prakash Sigdel and respondents in the Dolpa district, which significantly contributed to the success of this study. Special thanks to the officials of the Prime Minister Agriculture Modernization Project (PMAMP) in the Apple Zone, Dolpa and the Agriculture and Forestry University (AFU) for facilitating this study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30225.

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