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Enhancing agricultural value chains through technology adoption: a case study in the horticultural sector of a developing country

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Abstract

Background The development of agricultural value chains in developing countries has been the focus of much international interest, prompting the exploration of technology adoption strategies. These strategies hinge upon a multitude of factors like farmer characteristics, farm structure, location, organizational and institutional elements, as well as information-related factors.

Purpose In this study, we delve into the influential social and productive factors that underpin technology adoption among small horticultural producers in Chile.

Design/methodology/approach Data pertaining to the five primary horticultural crops in Chile—namely, corn, lettuce, tomato, cucumber, and onion—were collected, considering their respective cultivated areas. A comprehensive evaluation of 13 technologies encompassing cultural practices, crop improvement, and irrigation was conducted. The methodological approach comprised two stages. Initially, an ordered probit model was employed to analyze the adoption intensity of cultural practices, crop improvement, and irrigation. Subsequently, a Kruskal–Wallis test was utilized to compare the means across technology adoption groups.

Results The findings reveal a positive correlation between technology adoption intensity and the level of education, composition of the family nucleus, and investment intensity. Moreover, the production system's location emerged as the most critical determinant for technology adoption.

Conclusions The factors under scrutiny furnish direct and indirect evidence of their impact on the productivity and competitiveness of agricultural value chains. Thus, this paper significantly contributes to comprehending the role of technology adoption in designing and executing rural development strategies within developing countries.

Keywords Adoption strategies, Technology, Supply chain, Horticulture, Chile

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Introduction

Today's agricultural sectors are confronted by a multitude of challenges, including the need to address climate change's adverse impact on production factors, cater to the demands of expanding populations, and foster market-oriented production opportunities [11]. Consequently, developing countries have turned to technology adoption strategies to propel the growth of agricultural value chains [8, 34]. The horticulture sector, in particular, faces technological constraints compared to non-perishable products, resulting in higher transaction costs throughout the value chains [21]. Consequently, the sector grapples with significant inefficiencies in managing various phases of production and marketing [27], hindering its overall development. Unveiling the motivating factors behind farmers' adoption of such strategies is of great interest to producers, educators, extension agents, and policymakers.

Implementing an appropriate technology adoption strategy at the farm level generates synergistic effects along the entire agricultural value chain [22, 34]. It is crucial to recognize that technology adoption is a gradual process, contingent upon several factors, such as farmers' characteristics, farm structure, location, organizational and institutional elements, and information-related factors [12, 32, 33]. From the farmers' perspective, the efficacy of a technology adoption strategy is determined by its ability to align with their economic, social, and environmental objectives, as well as enhance the physical productivity and economic profitability of their production systems [12, 14, 15].

Designing suitable technology adoption strategies holds immense importance in developing agricultural value chains and enhancing the welfare of farmers [18]. Despite this significance, the analysis of factors influencing technology adoption in developing countries remains relatively underexplored. Some exceptions include the approaches by [5] and [9], which yielded varied results on adopting sustainable practices in different national contexts. Notably, the most studied independent variables in technology adoption studies encompass education, age, farm size, family size, gender, extension services, owned land, and farming experience. Additionally, [22] introduced territorial and regional distribution aspects in analyzing the different productive and economic variables influencing technology adoption.

Whereas these studies offer valuable insights into the multifaceted dynamics of technology adoption, they do not specify crucial aspects of developing agricultural value chains in developing countries. Hence, this paper addresses this gap in the existing literature by focusing on three highly relevant aspects of the process. Firstly, it presents a case study of a highly atomized horticultural sector in a developing country, predominantly composed of small and medium-scale farmers. Secondly, it meticulously analyzes the most influential social and productive factors driving technology adoption. Lastly, it categorizes different adoption intensity groups based on the average number of practices each producer adopts.

The paper's organization is as follows: Sect. "Theoretical frameworks" provides a comprehensive review of factors impacting technology adoption in agriculture to establish the groundwork for our research. Section "Materials" offers a description of the research data, and Sect. "Methods" outlines the methodologies utilized. The results and analysis are covered in Sect. "Results". Finally, in Sect. "Discussion", we delve into the main implications for both theory and practice, and in Sect. "Conclusions", we present our concluding remarks.

Theoretical frameworks

The determinants of technology adoption have been extensively explored by scholars in the field []. These factors can be broadly classified into four main groups []. Firstly, the contextual factors—encompassing the political environment, market dynamics, and climate—in which the significance of extension agency services in skill development and technology transfer cannot be overstated. Such services foster innovation at the level of family farms, which constitute the predominant form of agriculture in developing countries [2, 19, 20]. Moreover, in this regard, a study by [25] examined the impact of microcredit policies on technology adoption and productivity in rice farming. The study concluded that additional access to credit alone may not suffice to enhance technology adoption, agricultural productivity, and the welfare of smallholder farmers. Indeed, various policy tools may complement technology adoption in rural settings.

The second category pertains to farmer characteristics, including intrinsic, socioeconomic, educational, and value motivations. For instance, a study by [32] found higher levels of adoption among younger farmers, those with higher levels of education, increased information intensity, larger farm sizes, and higher labor intensity. Similar results were observed by [30], which showed that beginning farmers were more likely to adopt advanced technologies in rice cultivation compared to more experienced farmers. Additionally, [6] demonstrated that farm size, farmer education, and technical assistance significantly influence the adoption of precision sugarcane farming technologies.

Thirdly, the characteristics of agricultural practices, farm management, associativity, and producer contact networks also play a crucial role. Indeed, [5] identified that coffee farmers belonging to cooperatives exhibited increased adoption of sustainable practices and technologies, likely due to the support networks based on social capital (trust and human capital) provided by such cooperatives. In this regard, [16] highlighted the role of social capital in predicting farmer decisions to adopt technology and irrigation scheduling in vineyards in Central Chile. Within social capital, formal networks and their size are among the main influencing components.

The last group of factors for technology adoption revolves around farmer perceptions of the benefits derived from using these technologies. One finding [12] demonstrated that farm size significantly impacts the perception of technology adoption, with larger farms typically having better access to capital and credit, enabling them to invest in technology at the farm level. On the other hand, small farms require more incentives due to lower profitability, lack of external incentives, limited resources, or lack of economies of scale for implementing good management practices or adopting conservation practices in productive systems [22].

In sum, while the above studies discussed several factors that influence technology adoption strategies among rural farmers, most did not specifically focus on developing countries, nor explore the impact of the process of technology adoption. In the horticultural sector, it has been reported that the successful adoption and utilization of any agricultural technology by small scale farmers positively impact farmers 'practices, as well as reduces the risks and uncertainties associated with the commercialization process [35, 38]. Therefore, our analysis will focus on the social and productive factors driving technology adoption, encompassing the dimensions described in this section.

Materials

Geographic area of study

Chile, situated in southwestern South America between 17°30' and 90°S latitude, is comprised of 16 regions, with horticultural production predominantly concentrated (92%) between the III and VIII Regions, i.e., between Atacama and Biobío (see Fig. 1), including the Metropolitan Region (RM). The region enjoys a Mediterranean climate throughout the production area, except for the high peaks of the Andes, where colder weather prevails due to altitude. In this area, the four seasons—spring, summer, fall, and winter—follow one another regularly. Each has its own light, temperature, and weather patterns that repeat yearly. The distinct is characterized by warm springs, dry summers and cold falls followed by rainy winters. According to estimates from the Chilean Office of Agricultural Studies and Policies (*Oficina de Estudios y Políticas Agrarias de Chile-ODEPA)* [26], the horticulture area in Chile expanded to 67,993 hectares in 2021, reflecting a 6.3% increase compared to 2020.

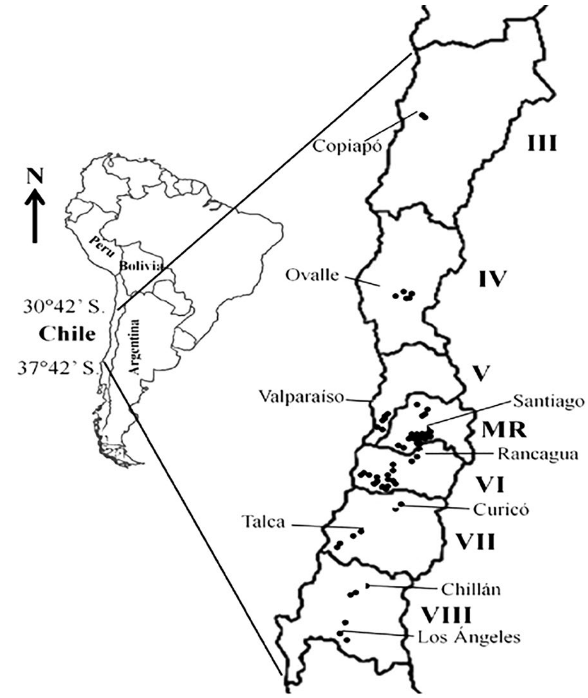

Fig. 1 Chiles's main agricultural regions

In the horticulture area 50% of cultivated land is dedicated to corn, lettuce, tomato, squash, onion, carrot, and melon, which—taken with artichoke, beans, watermelon, and asparagus—make up 80% of the domestic vegetable production area, highlighting a relative concentration of cultivated species.

From a commercial standpoint, the distribution of fruit and vegetable products primarily occurs through regional wholesale markets, accounting for over 70% of domestic sales [17]. According to the latest Agricultural Census in 2007, this segment is supplied by approximately 196,000 horticultural farms, each with productive areas of less than one hectare per producer. Specifically, 75% of farmers in this sector fall within the subsistence, small, and medium categories [26].

Study population

This study is regional in scope, gathering primary information through various methodological instruments to offer an integrated view of small-scale agriculture in the central region of the country. Regarding the selected variable, our study focuses on small-scale horticultural producers in the central region of the country. These farmers typically face limited access to technological advancements and cultivate small plots of land under various ownership regimes. Their characteristics include low productivity, limited bargaining power, sporadic use of wage labor, and inadequate storage infrastructure. In

Chile, they are mainly supported by the National Institute for Agricultural Development (INDAP), which depends on the Ministry of Agriculture. Indeed, the selection criteria were established was established in conjunction with the Chilean Ministry of Agriculture for beneficiaries of production development programs, aiming to match each producer's productive profile and not to serve as an evaluative tool for a specific policy. The program considered was the Local Development Program (PRODESAL). PRODESAL aims to build technical and productive capacity among low-income, subsistence and family farmers and their families, with the goal of increasing their participation in revenues along the value chain [26]. PRODESAL is the most important extension program in terms of coverage and number of beneficiaries in Chile today [26]. One of its main characteristics is its comprehensive approach. In addition to supporting farmers on technical issues, the program focuses on socio-economic concerns, such as the health and human capital of the family farm. The criteria to be selected do not include mean farm-plot income, but rather focus on factors such as land area, asset volume, and land tenure. The target group consists of producers with a cultivated area of up to 12 hectares of Basic Irrigation, assets not exceeding the equivalent of 3,500 UF (1 UF = 43 USD), primary income from agricultural activities, and direct involvement in land cultivation, regardless of land tenure arrangement.

For this study, pertinent data were gathered through a standardized survey conducted with 84 farmers cultivating the five primary horticultural crops (corn, lettuce, tomato, cucumber, and onion) located in six peri urban districts in the Valparaíso, Metropolitan, and Maule regions between January and Dezember 2022. The questionnaire was divided into three general sections: (i) personal characteristics of the farmers: age, gender, level of education, employment status, type of land tenure and participation in associations; (ii) technical and production features: land size, use of fertilization and irrigation, and access to credit to finance investments; and (iii) farm income and farming system.

Next, Table 1 presents the descriptive statistics of the independent variables included in the model, as described in subsect. "Study population".

To identify the variables with the most significant impact on designing and implementing technology adoption strategies, researchers consulted the farmers on the application of 13 technologies relating to cultural practices, crop improvement, and irrigation. These technologies are: (a) the employment of certified seed purchase (produced under strict seed certification standards to maintain varietal purity), (b) deep water for production (which provides controlled and less ecologically impactful methods of food production), (c) utilization of production records, (d) technified irrigation (which maximize irrigation efficiency by reducing water waste, while maintaining plant health and quality), (e) adoption of new crop varieties (more resilient and productive varieties that consumers want to eat, that are nutritious and tasty, and that are adapted to local preferences, environments and challenges), (f) utilization of machinery for planting and harvesting (which can help to optimize land use by preparing the soil more effectively, leading to increased crop yields per unit area), (g) fertigation (injection of fertilizers, used for soil amendments, water amendments and other water-soluble products into an irrigation system), (h) waste management, (i) integrated pest management (which combines the use of biological, cultural and chemical practices to control insect pests in agricultural production), (j) protection systems for fruit trees (mainly of three types: irrigation, heat application and, mixing of the air), (k) meadows with fertilization and planting, (l) use of sensors for temperature, humidity, and others (to predict weather conditions and can be used in heating systems, ventilation systems, and even

Table 1 Descriptive statistics of the independent variables used in the study

Variable	Abbrev.	Description	Continuous variables				Categorical variables (%)	
			Avg	S.D	Min	Max		
Education	*educ*	Level of formal education (farmer years of schooling)	8.70	3.56	0	17		
Family size	*for*	Number of persons in the family group	3.98	1.35	1	8		
Productive area	*sup*	Productive area of the farm (ha)	2.65	2.57	0.40	12		
Permanent labor	*trab_per*	Number of employees working on the farm permanently	1.25	0.53	0	3		
Investment[1]	*inv*	Number of items in which investments are made	1.75	0.98	0	4		
Community	*commune*	Community where the farm is located (1 = Quillota, 0 = otherwise)	0.61	0.49	0	1	0 = 0.39	1 = 0.61
Associativity	*asoc*	Associated head of household (1 = if belonging to an agricultural association, 0 = otherwise)	0.23	0.42	0	1	0 = 0.77	1 = 0.23

[1] This discrete variable was constructed as the sum of the items the farmers have invested in across machinery, equipment, buildings, vehicles, or none of the above

air conditioning systems), (m) fruit tree practices such as pruning and thinning (to promote air circulation and light penetration by thinning out branches. Also, to remove dead, damaged, or diseased branches).

Based on the average number of practices adopted ($\overline{x}$) and the standard deviation (s) [22], the sample was classified into four groups of adoption intensity: Group A (Very low), $A \leq \overline{x} - s$; Group B (Low), $\overline{x} - s < B \leq \overline{x}$; Group C (High), $\overline{x} < C \leq \overline{x} + s$; and Group D (Very high), $\overline{x} + s < D \leq max$.

The study considered socioeconomic and demographic aspects as independent variables, alongside farm characteristics. For instance, the productive area (*sup*) was utilized as a continuous variable to assess the influence of farm size dedicated to production on technology adoption, generally yielding a positive effect. Additionally, farmer characteristics were examined as factors likely to influence the likelihood of adopting new technologies. These encompassed years of schooling (educ), which previous studies have found to have both positive and negative influences, and in some cases, not significantly [4, 5, 29, 37, 38]. The study also integrated the dichotomous variable association (*asoc*), indicating whether the farmer belonged to some form of association. Past research has studied associativity [4], organic markets [35], or various agricultural organizations like cooperatives or trade-related entities [3, 5]. Furthermore, the study gathered data on family size (*per*)—a recurrent variable in this type of model with diverse outcomes [3, 29]—represented here as the number of individuals comprising the family, including adults and minors. Additionally, the study incorporated the number of people working permanently on the farm (*trab_per*). Associated with formal work, previous studies [23] have found a significant relationship between the owner's formal employment and the likelihood of adopting climate-smart agricultural practices. The rapid adoption of new technologies is often associated with reduced labor use, and technology adoption is unlikely to be linked to job creation [32]. The farm's location is also a significant variable. Some studies have analyzed the farm's distance from crucial reference points, such as markets or sales points [7, 29], or urban areas and access to extension services [11]. In this study, we adopt a similar approach [29], dichotomizing the farm's location to account for its inherent effect. We include the community (*commune*) as a variable to analyze the differences between the two most representative communities in the sample. Lastly, the study examines the discrete variable investment (*inv*), which takes values from 0 to 4, based on respondents' answers regarding the number of investments made in machinery, equipment, buildings, or vehicles.

Methods

Ordered Probit model (OP)

Adoption intensity (categorized as very low, low, high, or very high) serves as the dependent variable in this study. While regression models like Poisson can be used for such ordinal variables, they assume equal probabilities of adoption for each technology. However, considering the objectives of our study, this assumption is not valid. Therefore, we employ an ordered probit model (OP) [3, 29, 37, 38], to assess the factors influencing the level of technology adoption among small producers engaged in horticultural value chains in central Chile.

The model is defined in [13] as:

$$y_i^* = \boldsymbol{x'}_i\beta + u_i \tag{1}$$

where $\boldsymbol{x}_i^{'}$ is a vector comprising household, plot, and location characteristics; β, the vector of parameters to be estimated; and u_i, the unobserved characteristics. As y_i^* is usually unobserved, we assume the following:

$$y_i = j if : \alpha_{j-1} < y_i^* \leq \alpha_j \tag{2}$$

where the α's are unknown parameters to be estimated alongside β. The probability that producer i belongs to group j is:

$$\begin{aligned} p_{ij} &= p\left(y_i = j\right) = p\left(\alpha_{j-1} < y_i^* < \alpha_j\right) \\ &= F\left(\alpha_j - \boldsymbol{x'}_i\beta\right) - F\left(\alpha_{j-1} - \boldsymbol{x'}_i\beta\right) \end{aligned} \tag{3}$$

Here, F denotes the standard normal cumulative distribution function. The marginal effects of an increase in the independent variable (x_r) on the probability of belonging to group j are calculated as:

$$\frac{\partial p_{ij}}{\partial x_{ri}} = \left\{F'\left(\alpha_{j-1} - x_i'\beta\right) - F'\left(\alpha_j - x_i'\beta\right)\right\}\beta_r \tag{4}$$

Comparison of means and chi tests of independence

Next, for the comparison of means and tests of independence, we utilized analysis of variance (ANOVA) to contrast the means among the four groups of technology adoption used (very low, low, high, very high) for the quantitative variables related to the production unit and the responsible individual (both included in the model), as well as additional variables associated with labor, productive area, and crop diversification. To verify the normality of errors and homogeneity of variances, we applied the Shapiro–Wilk test and Levene test, respectively, both analyzed at a significance level of 5%. As the assumptions were not met, we opted for the Kruskal–Wallis test, a non-parametric alternative to one-way analysis of variance.

Table 2 Adoption intensity categories

Group	Percentage	Practices adopted	
		Average	S.D
A (very low)	9.52	1.88	0.35
B (low)	39.29	3.52	0.51
C (high)	38.10	5.88	0.79
D (very high)	13.10	9.00	1.18
Total	100.00		

Table 3 Estimated coefficients of the ordered probit (OP) model and their average marginal effects

Variables	Coefficients	Marginal effects			
		P(Y = 1|X)	P(Y = 2|X)	P(Y = 3|X)	P(Y = 4|X)
Education	0.0637*	−0.0089*	−0.0096*	0.0085*	0.0100*
	(0.0368)	(0.0053)	(0.0057)	(0.0049)	(0.0059)
Family size	0.1717*	−0.0239*	−0.0259*	0.0229*	0.0269*
	(0.0976)	(0.0144)	(0.0151)	(0.0132)	(0.0157)
Productive area	0.0366	−0.0051	−0.0055	0.0049	0.0057
	(0.0519)	(0.0072)	(0.0079)	(0.0068)	(0.0082)
Permanent labor	0.3905	−0.0542	−0.0590	0.0520	0.0612
	(0.2604)	(0.0382)	(0.0395)	(0.0362)	(0.0403)
Investment	0.3054**	−0.0425**	−0.0461**	0.0407**	0.0479**
	(0.1374)	(0.0208)	(0.0218)	(0.0191)	(0.0221)
Community	−1.2306***	0.1710***	0.1858***	−0.1639***	−0.1929***
	(0.2974)	(0.0548)	(0.0461)	(0.0394)	(0.0527)
Associativity	0.0376	−0.0052	−0.0057	0.0050	0.0059
	(0.3191)	(0.0443)	(0.0483)	(0.0425)	(0.0501)
LR chi^2(7)	40.76				
Prob > chi^2	0.0000				
Log likelihood	−82.5092				
Pseudo R^2	0.1981				

10% significance (*); 5% significance (**); 1% significance (***). Standard error in parentheses

Furthermore, we examined the association of technology adoption groups with qualitative variables, such as access to extension services, investment in specific items (machinery, equipment, infrastructure, and vehicles), farm location, and belonging to an association (all included in the model). To evaluate these associations, independence tests were conducted using contingency tables and Pearson's Chi-square test at a significance level of 5%, and the relationships between variables were analyzed using Cramer's V coefficient.

Results

The adoption intensity among farmers—indicated by the most prevalent technologies—reveals that 88% employ certified seed purchase, followed by: deep water for production (64%); utilization of production records (64%); technified irrigation (52%); adoption of new crop varieties (51%); utilization of machinery for planting and harvesting (44%); fertigation (40%); waste management (29%); integrated pest management (21%); protection systems for fruit trees (13%); meadows with fertilization and planting (13%); use of sensors for temperature, humidity, and others (8%); and finally, fruit tree practices such as pruning and thinning (8%). On average, farmers adopted 4.98 practices, with a standard deviation of 2.18. Table 2 presents the adoption intensity categories.

As previously mentioned, the application of an ordered probit model allowed us to examine the extent of the impact of the independent variables on the intensity of technology adoption and to calculate the marginal effect of each variable on the probability of belonging to each adoption intensity group. These findings are of utmost significance, as they facilitate the formulation of more targeted and tailored technology adoption strategies. Detailed results of this model are presented in Table 3.

The results indicate that the chi-square of the likelihood ratio test is 40.76 and highly statistically significant ($p = 0.0000$), rejecting the joint test for coefficients with a slope equal to zero. The model exhibits a pseudo R^2 of 0.1981, with four out of seven variables significant at the 10% level. Notably, the factors most influencing the intensity of technology adoption are farmer level of

Table 4 Kruskal–Wallis test for variables related to production and farmers among the adoption intensity groups

Variable	Statistic (H)	Intensity of adoption			
		Very low (A)	Low (B)	High (C)	Very high (D)
Education	8.1127**	5.8750[a]	8.7273[b]	8.8125[b]	10.3636[b]
Family size	10.8346***	3.7500[ab]	3.9697[a]	3.6563[a]	5.0909[b]
Permanent labor	5.5452*	0.8750[a]	1.1212[a]	1.4063[a]	1.4545[a]
Temporary labor	2.8120*	0.5000[a]	0.0303[a]	0.1250[a]	1.0000[a]
Productive area (ha)	0.6392	2.3125[a]	2.6803[a]	2.8688[a]	2.1545[a]
Farm size (ha)	0.7912	2.6875[a]	3.1227[a]	3.5609[a]	3.1818[a]
Owned land area (ha)	1.6641	2.6875[a]	3.0924[a]	3.1859[a]	2.2727[a]
Irrigated area (ha)	2.2585	0.8125[a]	1.7379[a]	2.1438[a]	1.9727[a]
Investment	8.9057**	1.3750[ab]	1.4242[a]	1.9688[b]	2.3636[b]
Diversification	3.4538	1.5000[a]	1.9697[a]	2.3438[a]	2.1818[a]

10% significance (*); 5% significance (**); 1% significance (***). According to the nonparametric mean comparison test, the means with a common letter are not significantly different ($p > 0.05$)

formal education, family size, investment intensity, and the community where the farm is situated. For the first three variables, the evidence suggests a positive effect on the probability of adopting more practices.

To facilitate interpretation, average marginal effects have been included, explaining the percentage impact on the dependent variable when the covariates increase by one unit, while keeping other variables constant. The evidence suggests that the probability of adopting a greater number of practices increases with each additional year of formal education of the farmers, with a positive impact of approximately 1% for each additional year. Similarly, an increase in family size reduces the probability of belonging to the lowest adoption group by about 2.4%, while increasing the probability of belonging to the very high adoption group by approximately 2.7%. Notably, the variable representing investment exhibits an even more substantial impact: farmers reporting a higher number of investment items are more likely to apply a greater number of technologies on their farms, with marginal effects ranging from approximately 4% to 5%.

The dichotomous variable representing the community, which evaluates geographic location, is significant and negatively associated. This suggests that farms located far from marketing centers are approximately 17% more likely to have a very low level of adoption and about 19% less likely to belong to the highest adoption category.

Furthermore, to contrast the means of quantitative variables related to the production unit and the person in charge or owner, analyses of variance under the Kruskal–Wallis nonparametric test were performed, as presented in Table 4.

Schooling (education) exhibits significant differences, with the very low adoption group having an average of approximately 5.88 years of schooling or incomplete basic education. Family size also varies among adoption groups, with the highest level having the highest average number of members per household (5.09 persons). However, it is not significantly different from the group with the lowest level of adoption. Although group B has a higher average than this group, the test considers ranges, and groups A and D have the highest range. Accordingly, there is no direct relationship between family size and adoption intensity.

As the data on investment in machinery, equipment, infrastructure, and vehicles were mainly estimates, this category showed biases and inconsistencies. To analyze the investments made, we quantified the number of items in which farmers claim to have acquired assets. This discrete variable shows differences between groups, with those having a higher level of adoption forming one group and those with a lower level forming another, overlapping in group A.

The sample analyzed consisted of 28 vegetable types, with lettuce and tomato being the most prevalent. However, the number of crops per production unit varied from one to up to 8 products, leading to diverse diversification levels. This diversification, measured as a discrete variable indicating the number of crops produced for commercial purposes on the farm, was analyzed.

Next, the discrete items for each quantifiable investment case were compared with adoption intensity to identify possible associations between them. As shown in Table 5, only investment in infrastructure is significant among all the investment categories. According to Cramer's V, the relationship between investment in this area and the level of technology adoption is moderate—similar to findings in [10]. This coefficient rarely exceeds

Table 5 Pearson's Chi test for variables related to production and head of household among the adoption intensity groups

Variable 1	Variable 2	Statistic (Chi)	gl	Cramer's V
Intensity of technology adoption (very low, low, high, very high)	Community	19.4806***	3	0.3405
	Associativity	3.5855	3	0.1461
	Investment in machinery	4.0322	3	0.1549
	Investment in equipment	3.8952	3	0.1523
	Infrastructure investment	16.0214***	3	0.3088
	Investment in vehicles	0.9441	3	0.0750
	Access to local development program	2.8558	3	0.1304
	Access to technical advisory services	9.0554**	3	0.2322

values higher than 0.6, so values close to 0.3 are considered moderate or of intermediate association.

Technology adoption serves as a crucial strategy for promoting the development of agricultural value chains. In Chile, the Ministry of Agriculture, through the Agricultural and Fishing Development Institute (INDAP, *Instituto de Desarrollo Agropecuario*)—provides support and incentives for forestry, fishing, and agricultural activities, including the Local Action Development Program (Prodesal, *Programa de Desarrollo de Acción Local*) the Technical Assistance Service (SAT, *Servicio de Asesoría Técnica*). The participants in these programs demonstrated a significant and moderate relationship between their access to INDAP's technical assistance services and the intensity of technology adoption. However, contrary to previous findings, this study did not find any relationship between belonging to organized groups and technology incorporation. Notably, the most highly significant variable in the ordinal probit model was the geographic location, exhibiting a moderately related association, with the highest value of Cramer's V.

Discussion

The aim of this research was to examine the most relevant social and productive factors influencing technology adoption among small horticultural producers in Chile. Our study sheds light on how the relationship between social and productive variables influences the development of agricultural value chains through technology adoption. The results from the ordered probit model revealed that the location of the farm had the most significant impact on adopting the analyzed practices. Consistent with previous studies [1, 3, 7, 28], our findings highlight that the greater the distance of the production unit from strategic points, such as markets, extension services, or urban areas, the less likely technology adoption is. Hence, technology adoption strategies should account for the distance effect from marketing centers to enhance the efficiency of agricultural value chains.

We found a positive and significant relationship between the number of items with investments and the probability of having a high level of technology adoption. This underscores the importance of studying these investments, as overcoming barriers to adoption becomes vital. From a policy perspective, targeted investment programs should be established to support farmers in overcoming this barrier.

Among the sociodemographic characteristics, our analysis revealed that the adoption of practices increases as more household members, especially farmers, have access to formal education. This finding is consistent with research by [35] on the intensity of adopting soil conservation practices among basic grains and coffee producers in Honduras. The education variable is of great relevance and has been included in similar models by many authors. Farmers with higher levels of formal education can more easily acquire technical information, as their capacity to assimilate information from various sources is assumed to be greater [11], thus leading to a positive relationship. While in most cases, this variable is found to have significant effects [5], there have also been instances where it is not statistically significant [10, 37].

The effect of membership in organizations, such as cooperatives or associations, has been previously studied [29, 31, 35]. The relationship between associativity and technology adoption highlights the critical role that agricultural organizations play in building the capabilities of smallholder farmers. Our results did not find a significant relationship between this variable and technology adoption. The perception of the relevance and benefits of membership in these organizations may be influenced by various factors, which would explain why some producers may not feel motivated to be associated. Motivation to join may be diminished because these producers are part of an INDAP incentive program that may offer them some benefits they would obtain from producer groups. Some studies have indicated that the impact of cooperatives in promoting farmers' adoption of sustainable technologies is limited or unclear. Previous works [31, 36] found that participation in cooperatives did not contribute significantly to adopting some sustainable practices due to the maturity of these cooperatives and differences in opinions that diminished the degree of farmers' participation in the decision-making process. These results are in line with previous research findings, which have concluded that some variables may show different behaviors in different contexts or populations where intrinsic motivations [4, 18] as well as socio-psychological factors of producers may play a crucial role in this adoption process [38].

The productive area is often used as an indicator of economic status, and it is generally expected that larger farms are more likely to adopt more technologies. However, in the literature, this variable usually presents mixed results. For example, in [6], the productive area was statistically significant and negative, indicating that larger farms were less likely to adopt most agricultural technologies evaluated in that study. On the contrary, [24] found a positive correlation with the intensity of adoption, e.g., improved seeds, as well as with efficiency and economies of scale. In our study, the correlation between productive area and technology adoption was not statistically significant. Even when analyzed through Chi tests, we found no relationship between total area, owned area, and area under irrigation, and the level of adoption of the practices evaluated. One of the reasons for this could be the high degree of productive intensity present in horticultural plantations. These farms are not mainly extensive in surface area, so the effect of farm size loses relevance when controlled by the use of technology. This means that producers with small areas can be large users of technologies to the detriment of producers with larger productive areas. In this regard, other authors such as [5] have reached similar conclusions.

Another variable that was not statistically significant was the amount of permanent labor employed on the farm, included as another indicator of income or economic status. Despite the average number of full-time employees generally increasing with technological adoption, the comparison of means tests did not detect significant differences. A similar case occurred with temporary labor.

Extension or technical assistance is often used as a proxy for access to agricultural information and is expected to positively influence technology adoption strategies. Our study found a significant relationship between adoption intensity and access to support incentives.

Overall, the different dimensions that influence technology adoption processes provide direct and indirect evidence of their effects on the development of agricultural value chains, promoting productivity and competitiveness. Technological adoption, i.e., the rate at which a given technology is incorporated into a production process, emerges as one of the most critical factors in advancing the development of agricultural value chains. Therefore, understanding the most relevant factors is crucial in designing public policies for the successful implementation of technologies in the rural sectors of developing countries.

Conclusions

This research examined the primary factors contributing to technological adoption among small horticultural farmers. The study categorized adoption intensity based on the average and standard deviation of employed practices, shedding light on the barriers and favorable conditions for adopting cultural practices, crop improvement, and irrigation in this agricultural sector. Factors such as farmers' characteristics, family, productive unit, and environment were found to be crucial in shaping technology adoption decisions. Additionally, the farm's location was shown to significantly influence the number of technologies utilized, with farms farther from marketing centers adopting fewer practices.

Understanding the relationships between social and productive variables that impact agricultural value chain performance is essential for designing effective technology adoption strategies. The findings herein should be taken under consideration by decision-makers, organizations, and institutions, enabling them to plan approaches to producers with greater efficiency and efficacy in technology transfer methodologies. Expanding the study of this variable can further evaluate improvements in access to markets, communication routes, frequency, and perceived quality of extension services, among other factors. Such insights can enhance extension processes and agricultural policy by facilitating the design and implementation of more efficient technology adoption strategies for small and medium-sized producers.

Abbreviations

ANOVA	Analysis of variance
INDAP	Agricultural and Fishing Development Institute of Chile
ODEPA	Chilean Office of Agricultural Studies and Policies
OP	Ordered probit model
PRODESAL	Local action development program
SAT	Technical assistance service

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Author contributions

RV secured and managed the funding for this research, devised the methodology, collected and analyzed the data. DQ and LB contributed equally to conceptualizing the work, interpreting the results, and writing the manuscript. All authors have reviewed and approved the final version.

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Availability of data and materials
The datasets utilized in this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics and Bioethics Scientific Committee at Pontificia Universidad Católica de Valparaíso, code: BIOEPUCV-H173-2018.

Consent for publication
All authors consent to the publication of the manuscript, should the article be accepted by the Editor-in-chief after completion of the refereeing process.

Informed consent
Informed consent was obtained from all subjects involved in the study.

Competing interests
The authors declare no competing interests.

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