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Factors affecting the adoption of ecological intensification practices: A case study in vegetable production in Chile

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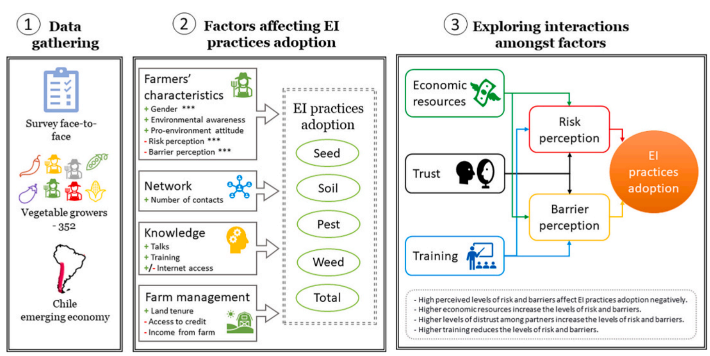
HIGHLIGHTS

- We analyse EI practices adoption as a gradual process, encompassing different farming practices and production stages.
- The study is based on an extensive survey amongst vegetable farmers in the central regions of Chile.
- Factors were analyzed individually and between them in a systematic way to measure the impact on EI adoption.
- Women in rural communities prove to play a crucial role when it comes to foster EI practices adoption.
- Economic resources, trust and training influence farmers' perception of risk and barriers when it comes to EI adoption.

GRAPHICAL ABSTRACT



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ABSTRACT

Context: Vegetable production is highly dependent on chemical fertilisers and pesticides, but the intensive use of these inputs negatively impacts the environment and human health. Ecological Intensification (EI) has the potential to counter the adverse effects of agricultural intensification and improve sustainability. Despite the potential benefits of EI for the environment, the adoption rate of EI in vegetable production is low. Moreover, most studies on EI adoption focus on implementing a single farming practice or a single production stage.
Objective: This article aims to empirically analyse what factors influence the simultaneous adoption of various EI practices in different vegetable crop production stages by farmers in the context of an emerging economy such as Chile. Further, since the literature on EI practices adoption mainly analyses these factors as separate from each other, we aim to explore the interactions between factors and how these jointly impact the application of EI practices.
Methods: We collected data via a survey to vegetable growers in the central zone in Chile. First, we measure EI practices adoption through a farm-level index that reflects the sustainability of farming practices in five production stages. Second, we identify which factors affect EI practices adoption through multiple linear regressions. Third, based on the results of the previous steps, we carried out a literature review to see how the factors predicting the adoption of EI could interact. This analysis was performed using structural equation modelling.
Results and conclusions: Our results show that being a woman, receiving training on EI practices, and being pro-environment positively affect EI practices adoption. Contrarily, obstacles include the perception of risk and

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barriers, better access to credit and higher income from farm activities, all of which negatively affect EI practices adoption. With reference to the interaction amongst the factors, we found that economic resources, trust and training are the major factors affecting the perception of risk and barriers amongst Chilean farmers when it comes to adopting EI practices.

Significance: Embracing a broad perspective, including different farming practices and production stages, allowed us to offer insights into the complex processes of adopting EI practices. Identifying which factors are important and how these factors interact with each other, contributes to the debate on whatpolicymakers and scholars need to focus in order to increase the use rate of EI practices.

1. Introduction

Agricultural Intensification (AI) is characterised by the intensive use of agrochemicals and monocultures (Tscharntke et al., 2005). AI has multiple detrimental consequences for ecosystems such as biodiversity loss (Plue et al., 2018), reduction of environmental quality (Cánovas et al., 2018), soil degradation (Bardgett and van der Putten, 2014) and adverse social and cultural effects (Horlings and Marsden, 2011). This has encouraged governments, farmers and scientists to explore alternative agricultural practices that have fewer negative effects on agroecosystems. A promising alternative to counter the adverse effects of AI is ecological intensification (EI) (Bommarco et al., 2013). EI is defined as "the means to make intensive and smart use of the natural functionalities of the ecosystem (support, regulation) to produce food, fiber, energy and ecological services in a sustainable way" (Tittonell, 2014, p. 58). EI embraces the complexity of the rural landscape and local management interventions (Bommarco et al., 2013); EI includes concepts such as agroecology and organic, bio-diverse and restorative agriculture. These concepts differ in the degree they internalise diversity, ecosystem services, social movements among other elements. However, they share the principles of biodiversity and natural regulation (Tittonell, 2014).

The goals of EI practices are to achieve more environment-friendly crop production (Bommarco et al., 2013), while at the same time improving food security and farm-product quality (Martin-Guay et al., 2018). To achieve these goals EI practices include different farming practices such as soil structure management, water conservation, crop diversification, and the use of organic fertilisers and pesticides (Astier et al., 2011). The benefits of EI practices are context-dependent (Geertsema et al., 2016), and several experiments around the world have shown their benefits. Recent EI applications on co-culture practice in cauliflower-aquaculture (Wan et al., 2019), soil transformation in maize crop (Ullah et al., 2020), plant diversity (Wan et al., 2020), intercropping maize, bean, and squash (Novotny et al., 2021), and livestock farm redesign (Ruggia et al., 2021) found that EI enhances ecosystems services, crop yields and economic value, and that it reduces the use of insecticides. However, despite the goals of EI and its potential benefits, the use rate of EI practices in developed and developing countries is still low (Pannell et al., 2006; Tey et al., 2017).

In Latin America, the negative impact of AI on society and the environment, and the higher demand for sustainable[1] products has triggered the emergence of alternative farming and agri-food systems (Le Coq et al., 2020). In the literature, various examples of alternative models to AI are given, such as: organic agriculture, agroecology, and sustainable agriculture in general (Giraldo and McCune, 2019; Le Coq et al., 2020; Schiller et al., 2020). Organic agriculture is characterised as such if it is certified according to international and/or national organic production standards. However, in large parts of Latin America the organic certification model seems to be only accessible and affordable for large-scale farmers who mostly deliver to international markets (IICA, 2020; Le Coq et al., 2020; Parrott and Marsden, 2002). Agroecology proposes a whole new business model, as opposed to the export-oriented business model based on AI. The agroecology approach encompasses an integral vision combining social, environmental, economic and cultural characteristics (Gaitán-Cremaschi et al., 2020; Le Coq et al., 2020). This model is usually promoted by rural or new urban agriculture movements. Moreover, some governments have institutionalised agroecology, and they have even included it in the law (e.g. Brazil, Nicaragua) (Giraldo and McCune, 2019; Schiller et al., 2020). Further, there are other sustainable agriculture approaches that promote the adoption of specific production techniques aimed to provide or conserve environmental services. However, this model does not pronounce against all chemical inputs, GMOs or multinational trading systems (Le Coq et al., 2020). Sustainable agriculture has been promoted by policies in some countries (e.g. Costa Rica, Chile and Mexico) to encourage conventional farmers to produce more environmentally friendly (Le Coq et al., 2020). Although agroecology and sustainable agriculture models have been mostly promoted from bottom-up work, with the intervention of social movements and NGOs, and governments have tried to institutionalise these models, the low adoption rates of environment-friendly practices are still a challenge (Le Coq et al., 2020; Schiller et al., 2020). Until now, the top-down support and public policies on behalf of AI and agri-export models evidence the asymmetrical balance of power between the conventional and the alternative models in Latin America (Le Coq et al., 2020; Schiller et al., 2020; Loch et al., 2021; López-García et al., 2021).

EI practices adoption is a dynamic process that depends on factors such as environmental challenges, farmers' and farms' characteristics and government policies (Daloğlu et al., 2014). For example, Pannell et al. (2006) argue that EI practices adoption depends on a range of farmers' personal, social, cultural and economic characteristics. Knowler and Bradshaw (2007) argue that financial factors and farmers' knowledge of farming practices, amongst others, might explain their adoption. However, the literature concludes that there are no universal factors that explain EI adoption and that factors differ according to the context. In a developed country context, for example, Prokopy et al. (2008) and Baumgart-Getz et al. (2012) find that factors such as access to information, capital and networking are positively related to EI practices adoption. In a developing country context, Tey et al. (2017) also find that EI practices adoption is positively related to gender, education level, farm size and land tenure.

Most of the studies on EI practices adoption refer to a 'yes or no' decision and focus on the implementation of a single farm practice, such as conservation tillage, the use of cover crops and compost, contour barriers, integrated pest management or water conservation (Tey et al., 2017) or on a single production stage (e.g., planting, manuring or weeding) (Kassie et al., 2013). Similarly, these studies do not consider possible interactions amongst EI practices, although some have to be adopted simultaneously during different production stages to be effective. Moreover, these research approaches may underestimate the interaction between natural, technological, and social factors on farmers' adoption decision (Darnhofer, 2021; Kassie et al., 2013). In addition, (Serebrennikov et al., 2020) suggest utilising standardised surveys to better study factors influencing farmers' adoption decision.

Therefore, this article aims to analyse which factors influence the simultaneous adoption of various EI practices in different vegetable production stages, by farmers in an emerging economy such as Chile.

[1] Throughout the paper we use the term "sustainable" to refer to any product or practice that could be framed within ecological intensification.

Additionally, since most of the literature on the adoption of EI practices analyses factors separately (e.g., age, education, received training, risk behaviour, income), this paper aims to explore the interactions between factors and how these jointly impact the application of EI practices. Although there is an extensive body of literature on experiments supporting the adoption of EI, this paper is one of the first to report, based on a survey amongst farmers, on the adoption of EI practices in different vegetables production stages. We argue that such an approach is crucial for designing policies that improve the adoption rate of EI practices.

Our paper is organised as follows. Section 2 presents the characteristics of the vegetable farming sector in Chile. Section 3 details the methods of our study, and section 4 describes the results of our data collection and analysis. This is followed by the discussion in section 5. Section 6 presents our conclusions, including implications for policy.

2. Case study: vegetable production in Chile

Emerging economies as Chile, are considered as economies that neither meet all the standards of a developing economy nor fully meet the standards of a developed economy. Usually, these are growing economies that are attractive for foreign investors (Meyer, 2004) but also open to innovative developments in specific sectors, such as modern agriculture. According to the (Worl Bank, 2021), Chile has improved economically and has reduced poverty levels in the last few decades. Moreover, it has a fast-developing agricultural export sector next to strong domestic calls for more sustainable agricultural production. These dual challenges make a country like Chile an excellent case for the study of opportunities and tensions in the development towards more sustainable agriculture.

Vegetable production is socially and economically significant in Chile. The main vegetables produced are tomatoes, sweet corn (known locally as *choclo*), lettuce, onions and pumpkin. Vegetable production is one of Chile's main agricultural activities and is the source of work for 34,000 farmers (ODEPA, 2017). Most of these farmers are smallholders with less than five hectares who mainly supply the local market (Núñez and Osses, 2014; ODEPA, 2017). From 2007 to 2018, 75,000 ha were dedicated to vegetable production on average every year. Vegetables are produced all over Chile, and the largest production regions are Coquimbo, Valparaiso, Metropolitana, O'Higgins and Maule, contributing 85% of national production volumes (ODEPA, 2017).

However, vegetable production in the country makes intensive use of chemical inputs (e.g., fertilisers and pesticides) in order to increase production and reduce costs (Altieri and Rojas, 1999; David et al., 2000). The intensive use of these inputs threatens the sector's sustainability through soil erosion, biodiversity loss and water pollution (Riquelme-Garcés et al., 2013). Additionally, it has negatively impacted human health. Research in rural areas in Chile has indicated that farmers exposed to pesticides have cognitive deficits (Corral et al., 2017) and that pesticides may affect the intellectual capacity of children living near agricultural activity areas (Muñoz-Quezada et al., 2016). Additionally, consumers are affected by the high residue levels of pesticides found in vegetables (Muñoz-Quezada, 2011).

To counterbalance these effects, two types of ecological farmers have emerged in Chile: those with organic[2] certifications (certified through a participatory guarantee system[3] (PGS) or a third-party organisation) and those without certifications, also known as 'agroecological farmers' (Gaitán-Cremaschi et al., 2020). In 2017, less than 1% of vegetables in Chile were sold with an organic certification (ODEPA, 2017), and around 1.4% of the farmers (approximately 1800 smallholders) self-recognised themselves as 'agroecological' (INDAP, 2017). The limited presence of organic certifications and low number of agroecological farmers – together with evidence of the negative effects of intensive agriculture – indicate the need for a better understanding of what influences EI practices adoption in the vegetable sector in Chile.

3. Methods

3.1. Data collection

We collected data for our study by conducting manual face-to-face interviews with vegetable growers in Chile. The questionnaire was designed based on literature review with the aim to gather information related to factors that could explain farmers' adoption of EI practices (Appendix A). Before conducting the interviews, a pilot test with 13 farmers and a group discussion with three members of the Pontificial Catholic University of Valparaiso were carried out to test the survey. After the pilot, some questions were modified, some questions were reordered, and some words were changed according to the rural slang. Together with two enumerators, the lead author surveyed a total of 352 farmers. Each interview lasted 30 to 40 min. All the fieldwork was conducted in Chile's official language Spanish. Vegetable growers were visited in the field, at their home or at fairs, and were randomly sampled. We implemented the questionnaire from October 2018 to April 2019 in four regions in central Chile: Valparaiso, Metropolitana, O'Higgins and Maule (Fig. 1). These four regions include 50,000 ha dedicated to vegetable production, which represents 70% of vegetable production in Chile (Valparaiso 11%, Metropolitana, 31%, O'Higgins 14% and Maule 14%) (ODEPA, 2017). The sample is representative only for the central region in Chile, due to the differences in agroecological and socio-economic conditions between regions. However, the sample represents the regions with a major concentration of vegetable farmers and vegetable production.

The survey gathered information on five data categories (details in Table 2) related to EI practices adoption: 1) Type of farm practices (e.g., organic or conventional practices), measured through a farm-level index (explained in Section 3.2); 2) farmers' characteristics, including socio-economic traits, perceptions, attitudes and beliefs related to the adoption of EI practices (Leite et al., 2014); 3) network, including indications of trust in people (e.g., farm labourers, input suppliers and neighbours), personal links and membership in farmers' organisations (Baumgart-Getz et al., 2012) –being a beneficiary of the Chilean INDAP[4] was also included in this category as has been used in other Chilean studies (Jara-Rojas et al., 2013)–; 4) knowledge, including information on farmers' education level, training, technical assistance, access to internet and attending technical agricultural talks (Prokopy et al., 2008; Tey et al., 2017); and 5) farm management, including information regarding land tenure, income from the farm, land size, use of a greenhouse, number of assets, number of animals, access to credit and total household income (Baumgart-Getz et al., 2012). For analysis, the interviews were tabulated to build a digital database.

[2] Organic products, "are those coming from holistic production management systems in agricultural, livestock or forestry sector, which promotes and improves the health of the agroecosystem and, in particular, biodiversity, biological cycles and the biological activity of the soil" (SAG, 2019).

[3] PGS is a certification where farmers organise themselves into organic farmers' associations. These associations have internal control systems to comply with organic regulations and to grant the organic certifications to their members. The associations are audited and registered by the Servicio Agricola Ganadero (SAG) which is an institute within the Chilean Ministry of Agriculture (SAG, 2019).

[4] The Institute of Agricultural Development (INDAP), within the Chilean Ministry of Agriculture, provides assistance to family farmers (INDAP, 2020).

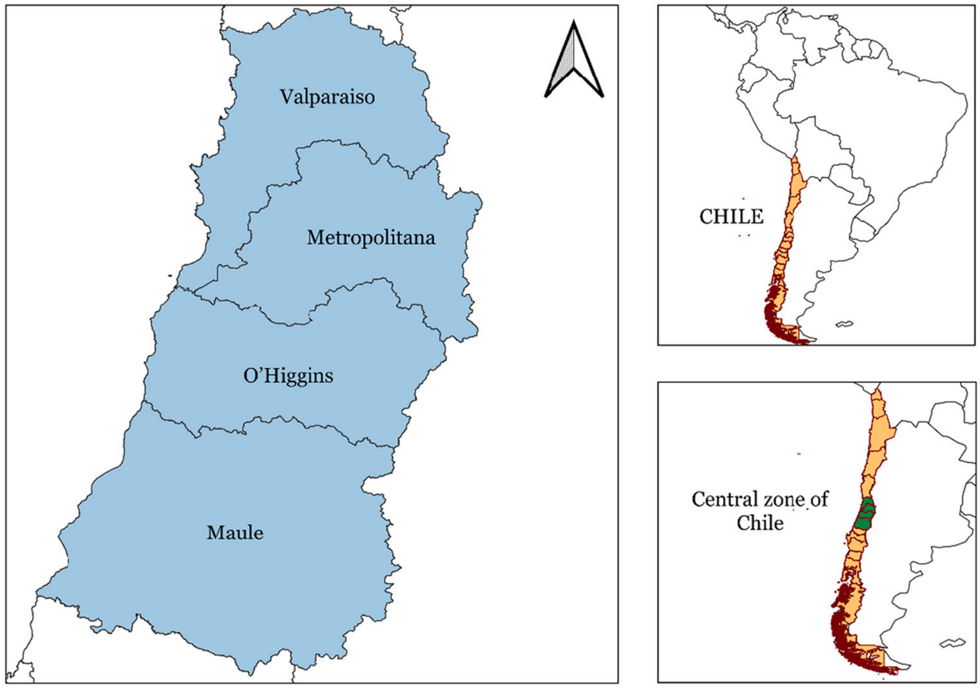

Fig. 1. Research area.

3.2. Measurement of EI practice adoption: a farm-level index

A large number of studies have proposed indexes and developed frameworks for measuring the adoption of EI practices (Lefroy et al., 2000; Astier et al., 2011). However, there is no single, universally accepted index to measure EI practices due to the complexity of farm-level practices. To measure EI practices adoption, we used a farm-level index, which builds on the work of Rigby et al. (2001) (Table 1) and encompasses organic and conventional farming practices. Moreover, this index serves three purposes. First, it allows a comparison among diverse agricultural practices by their sustainability dimensions. Second, it supports detailed comparative assessments for large samples. Third, it is a versatile index which can be modified according to the research needs. It is possible to exclude/include components (e.g., use of technology, type of irrigation systems) or modify the weighting of the components (Rigby et al., 2001).

Rigby et al.'s (2001) index reflects the level of EI practices adoption in five agricultural production stages: seed sourcing, soil fertility, pest

Table 1
Scoring EI practices.

Production stage		Sustainability dimensions				Total
		Minimises off-farm inputs	Minimises non-renewable inputs	Maximises natural biological processes	Promotes local biodiversity	
Seed sourcing						
1	Conventional seed					0
2	Organic seed		1			1
3	Reused	1				1
4	Traditional	1				1
Soil fertility						
1	Conventional synthetic	−1	−1	−1		−3
2	Organic fertiliser purchased		1	1		2
3	Prepared organic fertiliser	2	2	1	3	8
Pest/disease control						
1	Chemical pesticides	−1	−1	−3	−3	−8
2	Organic pesticide purchased		1	1		2
3	Prepared organic pesticide	1	1	1	1	4
4	Preventive practices without chemicals	2	2	2	2	8
Weed control						
1	Chemical herbicides	−1	−1	−1	−1	−4
2	Organic herbicides purchased		1	1		2
3	Mechanic control	1	0.5	1	0.5	3
4	Preventive practices without chemicals	1	1	1	1	4
Crop management						
1	Crop rotation	0.5	0.5	1		2
2	Intercropping	1	1	1	1	4
3	Crop rotation + intercropping	1.5	1.5	2	1	6

Source: Based on Rigby et al. (2001).

control, weed control and crop management. The index scores of the farming practices used in each production stage, were based on four sustainability dimensions: minimisation of off-farm inputs; minimisation of non-renewable inputs; maximisation of natural biological processes; and promotion of local biodiversity. These dimensions are scored from −1 to 3 points according to the following scheme: −1 indicates the practice has a negative impact on the specific sustainability dimension; 0 indicates it has no significant impact; and 3, a strong positive impact. The index is the sum of each sustainability dimension's scores per farming practice used and is shown in the "Total" column in Table 1. The scores of the total index are interpreted from -3 to +3. Where ±3 indicates strong negative/positive impact, ±2 indicates medium negative/positive impact, ±1 moderate negative/positive impact, and 0 has no significant impact. The total scores are transformed between the range of -3 to +3 using a rule of three, considering that the lowest possible value is -8 and the highest possible value is 8.

Once we obtained the production stage index and in order to adapt it to the local context, we multiplied the index by the percentage of farm area on which that farming practice was used. For instance, if a farmer used chemical herbicides on 80% of her fields, the final index for weed control would be the result of multiplying −4 (the total sustainability score associated with the use of chemical herbicides as in Table 1) by 80%, obtaining a final score of −3.2. Rigby et al. (2001) calculate five indexes (SEEDX, SOILX, PESTX, WEEDX and CROPX). We add a final one to group all the previous indexes (TOTALX).

3.3. Data analysis methods

To identify the factors that influence EI practices adoption, we estimated a multiple linear regression model. Building on the results of this regression, we applied a structural equation model (SEM) to inspect the interaction amongst the factors, allowing us to explore the causes of adoption and potential policy actions to enhance the latter.

3.3.1. Multiple linear regression

The multiple linear regression technique serves to analyse whether a set of independent variables (and which ones, in particular) is a significant predictor of a dependent variable.

A linear regression model for p independent variables is as follows:

$$Yi = \beta 0 + \beta 1X1 + \beta 2X2 + \ldots + \beta pXp + \varepsilon$$

Table 2
Descriptive statistics.

Variable name	Description	Type of variable	Min.	Mean	Max.
Dependent variables					
Farm practices					
SEEDX	Type of seed used	Continuous variable, index	0.00	0.20	1.00
SOILX	Type of fertiliser used	Continuous variable, index	−3.00	0.30	8.00
PESTX	Type of pesticide used	Continuous variable, index	−8.00	−3.30	8.00
WEEDX	Type of herbicide used	Continuous variable, index	−4.00	−0.19	4.00
CROPX	Strategy for crop management	Continuous variable, index	0.00	2.58	6.00
TOTALX	Average of the farming practices indexes SEEDX, SOILX, PESTX, WEEDX and CROPX	Continuous variable	−15.00	−0.40	26.00
Independent variables					
Farmer characteristics					
Age	Age of the farmer (years)	Continuous variable	24.00	52.68	91.00
Experience	Numbers of years working in agriculture	Continuous variable	1.00	29.07	78.00
Gender	Gender of the farmer	Dummy, 1 woman, 0 man	0.00	0.21	1.00
Awareness	Environmental awareness (three statements)	Likert scale from 1 (disagree) to 7 (agree)	1.00	6.62	7.00
Motivations	Motivations to preserve the land (two statements)	Likert scale from 1 (disagree) to 7 (agree)	1.00	6.14	7.00
Pro-environment	Easiness to act in favour of the environment	Likert scale from 1 (disagree) to 7 (agree)	1.00	4.46	7.00
Risk perception	Risk perception to adopt EI practices	Likert scale from 1 (disagree) to 7 (agree)	1.00	4.05	7.00
Barrier perception	Barrier perception to adopt EI practices (three statements)	Likert scale from 1 (disagree) to 7 (agree)	1.00	4.06	7.00
Network					
Trust	Farmers' trust in farm labourers, input suppliers and neighbours (two statements)	Likert scale from 1 (disagree) to 7 (agree)	1.00	5.57	7.00
Contacts	Number of contacts to reach out in case of problems	Continuous variable	0.00	4.12	80.00
Coop-Mem.	Membership in farmers' organisations	Dummy, 1 yes, 0 no	0.00	0.20	1.00
INDAP-benef.	Beneficiary of INDAP, farmers who have access to training and funding.	Dummy, 1 yes, 0 no	0.00	0.71	1.00
Knowledge					
Education	Level of formal education	Categorical variable from 1 to 7	1.00	4.56	7.00
Tech. visits	Number of visits by an agricultural technician per year	Continuous variable	0.00	9.10	72.00
Talks	Agricultural technical talks attended per year	Continuous variable	0.00	3.98	90.00
Training	Participation in training programmes related to EI practices	Dummy, 1 yes, 0 no	0.00	0.28	1.00
Internet	Internet access	Dummy, 1 yes, 0 no	0.00	0.59	1.00
Farm management					
Vegi-size	Total area of land exploited (ha)	Continuous variable	0.01	10.23	600.00
Tenure	If the farmer owns the land	Dummy, 1 yes, 0 no	0.00	0.57	1.00
Animals	Number of the animals on the farm	Continuous variable	0.00	11.92	271.00
Credit	Ability to get credit	Likert scale from 1 (disagree) to 7 (agree)	1.00	4.88	7.00
Greenhouse	Use of greenhouses	Dummy, 1 yes, 0 no	0.00	0.49	1.00
Income-farm	Percentage of income that comes from the farm	Continuous variable in %	0.00	0.80	1.00
Assets	Number of assets related with the farm	Continuous variable	0.00	1.87	5.00
Total income	Total household income	Categorical variable from 1 to 8	1.00	2.95	8.00

Note: we acknowledge that there are two schools of thought, one only allowing to consider the Likert scale as ordinal and the other as interval, for analysis purposes (Joshi et al., 2015). However, most of the literature agrees on using mean values of Likert scale to give indicative information about the data.

In this model, Y is the estimated dependent variable; $X1, X2, \ldots Xp$ are the independent variables; $\beta_0, \beta_1, \ldots, \beta_p$ are the parameters indicating the magnitude of the influence of the independent X variables on the dependent one; and, finally, ε is a statistically independent error term normally distributed with mean 0 and variance σ.

The dependent variables in this study are the practices described in the previously calculated indexes (SEEDX, SOILX, PESTX, WEEDX, CROPX and TOTALX), whereas the independent variables are divided into four categories as per our survey: farmers' characteristics, network, knowledge and farm management (see Table 2).

Some variables, such as "awareness", "motivations", "barriers" and "trust" were created as a composite factor of two or more variables that were designed to measure these concepts. In fact, we used different items (or statements) in the survey to help us to identify these variables. We measured the reliability of each of these constructs we created using Cronbach's alpha, where values above 0.5 indicate that consistency was achieved (Taber, 2018).

We performed a descriptive statistics analysis using IBM SPSS Statistics 25 on the variables to check for normality, correlations and outliers, thus avoiding overfitting and multicollinearity in our model. We adjusted some variables (logarithm 10 and winsorizing) to achieve normal distribution and eliminate outliers.

We estimated six multiple linear regression equations (one for each dependent variable) with RStudio version 3.6.0. using all the independent variables in Table 2.

3.3.2. SEM

The main objective of performing a SEM is to identify how the factors affecting EI practices adoption interact. The SEM test used the output of the multiple linear regressions to identify indirect effects and interactions amongst the independent variables.

This process comprised three steps. First, we derived the design of the structural equation model from the outputs of the linear regressions. We then complemented these outputs with a literature review to identify which variables could initially be grouped to form a construct and how these constructs could interact with each other.

Second, we carried out a confirmatory factor analysis (CFA) with RStudio version 3.6.0 (Lavaan package). CFA allows checking wether the variables can be grouped in the identified constructs. CFA also checks for unidimensionality, internal consistency and convergent and discriminant validity for each construct.

We measured the validity of the CFA model through goodness-of-fit indexes. Unidimensionality checks whether the set of variables grouped together measures only one construct (Danes, 1984). In addition, unidimensionality is evaluated by checking the values of the variables' completely standardised loadings (>0.5) and their significance (p-value >0.05) in the constructs (Hair et al., 2014). We removed variables that did not present loadings above 0.5 or had a p-value higher than 0.5 from the construct. Internal consistency explores whether the variables measure the intended construct (Vaske et al., 2016). We tested the internal consistency of the construct with Cronbach-α and composite reliability (CR), where values above 0.5 indicated that the internal consistency of the construct was achieved (Taber, 2018). Convergence of the construct examines how strong the relationship between the variables measuring a given construct is (Lee et al., 2005). We measured this convergence by the average variance extracted (AVE) in which values should be 0.5 or higher (Hair et al., 2014). Finally, discriminant validity examines whether the variables measuring a given construct are not related to the variables measuring another construct (Lee et al., 2005). We tested for this discriminant validity by looking at the modification indexes. These illustrated whether there was a strong relationship amongst variables from different constructs.

In the third step, the SEM was estimated in RStudio version 3.6.0 (Lavaan package) with a maximum likelihood estimator. SEM tested the interactions amongst observed variables through unobserved latent constructs. We checked the model's goodness-of-fit using two types of indexes (absolute and incremental) which provide sufficient basis for model evaluation. Finally, we evaluated the model's operational relevance, checking the regression coefficients of the linear relationships between constructs (Hair et al., 2014).

4. Results

We organise the results of the paper into the following steps: 1) descriptive results, where we present an overview of the farmers surveyed summarising the information of the farm practices, farmer characteristics, network, knowledge and farm management; 2) factors affecting EI practices adoption, where we present the factors that predict the adoption of EI practices in each stage of production (seed sourcing, soil fertility, pest control, weed control and crop management); and 3) exploring interactions amongst variables. Because the SEM used in 3) is based on the results of 2), we present a literature review to support the structure of the SEM, and then we present the outcomes from the SEM, notably the interactions between factors.

4.1. Descriptive results

The distribution of the farmers surveyed in each region was: Valparaiso 45%, Metropolitana 26%, O'Higgins 13% and Maule 16%. Table 2 provides details of the surveyed farmers' descriptive statistics. The index scores for the farm practices reflect the heterogeneity of farming practices (namely, conventional and EI practices) used in Chile. Some of the applied EI practices registered during the survey range from endemic seeds, humus, compost, nettle tea as biofertilizer, manure, insect traps, biological pest control, chilli pepper tea, intercropping and crop rotation. From the 352 farmers surveyed, 225 farmers present an index score below 0 (i.e., use of conventional practices), 1 farmer presents an index score equal to 0 (i.e., balanced mix of conventional and EI practices) and 126 farmers present an index score above 0 (i.e., use of EI practices). The overall impact (TOTALX) of vegetable production shows a negative effect on the environment, with a mean of −0.40.

The average age of the sample is 53, with an average 29 years of experience in agriculture. Only 21% of the sample comprises women. Most of the farmers are aware that the use of agrochemical inputs is negative for the environment; farmers scored 6.62 out of 7 in the environmental awareness statements. Moreover, the majority of them are motivated to produce vegetables until the end of their lives and to bequeath the land to their children (6.14). However, the majority of farmers do not seem to have a clear position in terms of their perception of which actions they can take to preserve the environment. They are actually neutral in terms of the statement that describes whether they consider it easy to take actions to preserve the environment, with a score of 4.46. When it comes to the perception of risk and barriers regarding EI practices adoption, farmers also take a neutral position (4.05 and 4.06, respectively). Most farmers consider that people are opportunistic (5.57), so they do not trust them. Most farmers also perceive difficulty in obtaining credit (4.88). On average, vegetable producers indicate they rely on four contacts to reach out in case of problems. The majority of farmers (80%) are not members of any farmers' associations; however, nearly all farmers (71%) receive training or have access to credit via INDAP.

Half of the farmers surveyed completed high school, while the other half started high school but did not finish. Farmers receive nine technical visits per year on average and attend four technical talks per year. Only 28% of farmers have participated in a specific training programme related to sustainable production practices during the last five years, and a small majority of the farmers have access to internet.

Although the average size of land exploited is 10 ha, there are farmers with 100 m^2 and farmers with 600 ha. A small majority of the farmers (57%) own their land. The average number of animals that farmers have is 12. Almost half of the farmers surveyed (49%) use greenhouses to produce vegetables. The average percentage of income derived from farming activities is 80%. On average, farmers score 1.87 out of 5 on asset ownership, including tractors, trucks, pick-ups, cars and motorcycles. On average, the total monthly income of the households surveyed is 560,000 Chilean pesos (±700 USD).

4.2. Factors affecting EI practices adoption

The choice of sustainable seeds (SEEDX) for vegetable production only seems to be explained by gender: women farmers seem to be the ones most likely to use sustainable seeds (e.g., traditional or reused seeds) compared to men (Table 3). Further, perceived barriers such as the availability or accessibility of organic inputs, the fact that conventional production is adopted in their surroundings and the time required to transition to EI practices, all seem to negatively influence the use of sustainable seeds. When it comes to preserving soil fertility (SOILX), the use of organic fertilisers positively correlates with gender (namely, being a woman); in addition, those considering it easy to take actions to preserve the environment (pro-environment variable) and with a network of contacts to reach out to in case of problems are more likely to adopt such practices. However, farmers who perceive the adoption of EI practices as risky and those who perceive barriers to their adoption are less likely to use organic fertilisers.

When it comes to a practice such as pest and disease control (PESTX), we found that awareness of the impact agrochemicals have on the environment together with attending agricultural technical talks and participating in training programmes related to EI practices all positively influence the use of organic pesticides or preventive practices without chemicals, in particular, amongst women. In contrast, farmers who perceive barriers for the adoption of EI practices, who see the adoption of EI practices as risky and those who also have better access to credit are less likely to apply EI practices for pest and disease control. Regarding weeding practices (WEEDX), farmers who believe that taking action to preserve the environment is easy, who participate in training programmes related to EI practices and who have access to internet are more likely to adopt more sustainable practices such as using chemical-free organic herbicides, control mechanisms and preventive practices. On the other hand, farmers who perceive EI practice adoption as risky and who derive a higher percentage of their income from farming activities use sustainable weeding practices less.

Regarding crop rotation and intercropping practices (CROPX), we found that having a safety network, namely, relying on close contacts in case of problems, participating in training programmes related to EI practices and owning the cultivated land all positively influence the use of crop rotation and intercropping techniques. In contrast, farmers with more experience in agriculture, those who perceive the adoption of EI practices as risky, those who perceive great barriers and those with access to internet are negatively inclined to use crop rotation and intercropping practices.

Finally, the dependent variable, TOTALX, which groups all the farming practices mentioned before, represents the average adoption of EI practices by farmers. We found that being a woman, considering it easy to take actions to preserve the environment, having a network with contacts to reach out to in case of problems and having participated in training programmes related to EI practices all positively influence the use of EI practices (e.g., organic fertilisers, chemical-free preventive practices and crop rotation). On the other hand, farmers who perceive EI practice adoption as risky, those who perceive numerous barriers, have better access to credit and derive a higher percentage of their income from farming activities are less likely to use EI practices.

The linear regressions undertaken provide information on which variables are important for EI practice adoption during each production stage. What is particularly relevant from these results is that variables such as the perception of risk and barriers show significance for EI practice adoption during all production stages. Regardless of the practice (or stage) analysed, they maintain their negative influence on the decision to adopt that practice or not. Hence, we assume that knowing

Table 3
Linear regression results.

Variables	SEEDX		SOILX		PESTX		WEEDX		CROPX		TOTALX	
Intercept	0.145		−0.422		−10.442		0.295		3.275		−7.150	
Farmers' characteristics												
Age	0.004		0.016		0.026		−0.032		0.011		0.025	
Experience	−0.002		0.016		−0.031		0.017		−0.024	*	−0.024	
Gender	0.185	*	2.699	***	2.236	*	0.821		0.520		6.461	***
Awareness	0.043		0.278		1.546	*	0.246		0.161		2.274	
Motivations	−0.024		−0.114		0.122		0.018		−0.020		−0.018	
Pro-environment	0.000		0.263	*	0.198		0.238	*	0.036		0.736	*
Risk perception	−0.011		−0.524	***	−0.791	***	−0.269	**	−0.216	***	−1.812	***
Barrier perception	−0.050	**	−0.358	*	−0.509	*	0.086		−0.227	**	−1.059	*
Network												
Trust	0.000		−0.019		−0.026		−0.099		0.137		−0.006	
Contacts	0.007		0.162	*	−0.013		0.031		0.092	*	0.278	
Coop-Mem.	0.031		0.273		1.173		0.355		0.225		2.056	
INDAP-Benef.	−0.107		0.048		−0.342		−0.574		−0.086		−1.062	
Knowledge												
Education	0.012		0.288		0.460		−0.002		−0.002		0.757	
Tech. visits	−0.001		−0.026		−0.063		0.025		−0.022		−0.086	
Talks	0.001		0.032		0.224	*	0.087		−0.010		0.334	
Training	0.106		0.900		1.787	*	1.211	**	0.697	*	4.700	**
Internet access	−0.017		−0.501		−0.043		1.402	**	−0.611	*	0.230	
Farm management												
Vegi-size	−0.010		−0.077		−0.054		−0.084		−0.022		−0.246	
Tenure	0.037		0.748		0.718		0.292		0.606	*	2.401	
Animals	0.001		0.004		0.003		0.000		0.002		0.010	
Credit	0.002		−0.149		−0.656	***	−0.130		−0.071		−1.004	**
Greenhouse	0.005		0.515		0.639		0.776		−0.399		1.536	
Income-farm	−0.069		−1.377		−1.455		−1.466	*	−0.912		−5.278	*
Assets	−0.015		−0.027		0.062		−0.033		−0.044		−0.057	
Total income	0.008		−0.041		0.180		−0.205		0.095		0.037	
Adjusted R2	0.276		0.501		0.542		0.421		0.437		0.638	
p-value	0.276		0.000		0.000		0.000		0.000		0.000	

Significance: *$P < 0.05$, **$P < 0.01$, ***$P <$ 0,001.

which factors affect these perceptions of risk and barriers could potentially predict EI practices adoption not just in each separate production stage but, in particular, overall, across all the different production stages. To examine this further, in the next section we explore interactions amongst the independent variables by applying the SEM model.

4.3. Exploring interactions amongst variables

Our structural equation model (SEM) is based on our linear regression results, which identified the perception of risk and barriers as the factors influencing the adoption of EI practices across all production stages. The aim of this analysis is to disentangle which factors influence or drive these two variables. To understand how factors could interact with these two variables we conducted a literature review focused on these relationships.

In line with our findings, the literature shows that risk perception is a key factor explaining EI practice adoption (Ghadim et al., 2005). Perceived risk represents a real concern of a person (Aven and Renn, 2010); it can be defined as the cognitive representation and evaluation of the chance that an investment (e.g., time and money) will generate gains or not (Vignola et al., 2010). The cognitive representation and evaluation of risk will be limited by the human mind capacity (Thaler, 1980). Literature has identified an extensive list of factors (e.g., socio-economic characteristics, attitudes, beliefs) that affect farmers' risk perception. However, economic resources (Flaten et al., 2005), trust (Dovey, 2009) and training (Leeuwis, 2004) have been identified as the most relevant factors by multiple sources. Further, Mekoya et al. (2008) and Sewell et al. (2017) found that, even if farmers perceive low levels of risk to adopt EI practices, their adoption may be impeded by their perception of barriers. The latter can be seen as perceiving challenges to overcome and could derive from different factors such as resource constraints, the lack of information, social infrastructure and technology (Leite et al., 2014; Kernecker et al., 2021).

Based on our literature review and acknowledging that the perception of risk and barriers can be affected by diverse factors, our SEM tested if any of the independent variables (Table 2) had an indirect effect on EI practices adoption due to these perceptions. To design the SEM, we grouped the independent variables into constructs (e.g., economic resources and training) according to what was found in the literature. During the validation of the SEM, variables such as pro-environment, credit, and income-farm (identified as significant for some practices in the regression analysis) did not fit the SEM model and were thus discarded. Contrarily, other variables (e.g., trust and assets) which were not identified as having a significant (direct) impact on EI practices adoption in the regression analysis, were still included in the final set of variables for the SEM, indirectly impacting the adoption of EI practices. The SEM's final configuration is illustrated in Fig. 2.

The SEM model analyses how farmers' perceptions of risk and barriers directly affect the adoption of EI practices, and how economic resources, trust and training affect those perceptions in terms of EI practices adoption. Table 4 describes the set of variables used to build the constructs presented in the SEM model (Fig. 2).

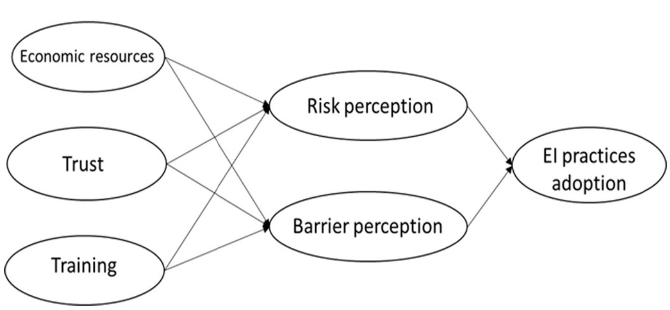

Fig. 2. Structural equation model (SEM).

Although this model has two constructs (training and risk perception) expressed by only one variable, the model helps us to systematically investigate the interaction amongst factors that affect EI practices adoption, forming the basis for future discussion and research.

Table 4
Variables that compose the SEM.

Constructs	Variable	Variable ID	Question/Statement
Economic resources	Vegi-size	E1	How much of your land is dedicated only to vegetable production?
	Assets	E2	Do you have the following assets? (Multiple answers) Tractor ☐ Truck ☐ Pick-up ☐ Car ☐ Motorcycle ☐
	Total-income	E3	In which monthly income bracket is your household income?
Trust	Trust	T1	Most people only look after their own interests
		T2	Given the opportunity, most people would try to take advantage of me
Training	Training	K1	During the last five years, have you participated in any training programme related to sustainable production?
Risk perception	Risk	R1	The adoption of agricultural practices without agrochemicals represents a risk to me
Barrier perception	Barriers		A main barrier for the adoption of EI practices is…
		B1	* Availability and/or accessibility of organic inputs
		B2	* Surroundings with conventional production practices
		B3	* The time required for the transition
EI practices adoption	SEEDX	A1	What type of seed do you use? / In what percentage of your property do you use this seed?
	SOILX	A2	What type of fertiliser do you use? / In what percentage of your property do you use this fertiliser?
	PESTX	A3	How do you control pests and diseases? / In what percentage of your property do you use this practice?
	WEEDX	A4	How do you control weeds? / In what percentage of your property do you use this practice?
	CROPX	A5	What strategy do you use for crop management? / In what percentage of your property do you use this strategy?

Table 5
Factor loadings and construct reliability measures.

Constructs	Variables ID	Factor loading	P-value	Cronbach α (cut-off 0.6)	CR (cut-off 0.6)	AVE (cut-off 0.5)
Economic resource				0.672	0.674	0.412
	E1	0.747	0.000			
	E2	0.552	0.000			
	E3	0.610	0.000			
Trust				0.531	0.538	0.372
	T1	0.685	0.000			
	T2	0.524	0.000			
Barrier perception				0.674	0.636	0.368
	B1	0.612	0.000			
	B2	0.560	0.000			
	B3	0.646	0.000			
EI practices adoption				0.862	0.862	0.560
	A1	0.680	0.000			
	A2	0.890	0.000			
	A3	0.814	0.000			
	A4	0.625	0.000			
	A5	0.703	0.000			

Moreover, the set of variables used in our model is supported by the results of the SEM's goodness-of-fit (Table 5). The values of the factor loadings and *p*-values in each construct met the conditions for unidimensionality, being above the cut-off value of 0.5 and significant at p-value 0.000. Regarding internal consistency, the construct's economic resources and barrier perception presented values of Cronbach-α and CR higher than 0.6, indicating good internal consistency (Taber, 2018). The trust construct presented the lowest value for Cronbach-α and CR. However, both were above the cut-off value of 0.5, indicating that the set of variables are internally consistent and can be grouped in the construct (Taber, 2018).

The EI practice adoption construct showed robust consistency because the Cronbach-α and CR values were higher than 0.8. Regarding the convergence of the constructs, AVE values for the economic resources and barrier perception constructs were below the 0.5 cut-off. However, due to their CR values above 0.6, the validity of the constructs is still adequate (Fornell and Larcker, 1981). The trust construct presented a value of AVE below the 0.5 cut-off, which means that less than 50% of the variance is explained or, in other words, the variables poorly measure the trust construct (Fornell and Larcker, 1981). Finally, the EI practice adoption construct explained more than 50% of the variance with a value of AVE above 0.5.

To evaluate the model's goodness-of-fit, we started with the absolute indexes (Table 6). The *p*-value of the chi-square was significant at 0.000, but, according to Hair et al. (2014), for a sample with more than 250 observations, significant *p*-values are expected. The value of RMSEA is 0.07, which showed an acceptable level of fit. GFI showed an acceptable fit with a value of 0.91. Based on the absolute indexes, it seems that the model specified in the conceptual framework fits the sample data well. The values of the TLI and CFI incremental indexes should be close to the cut-off value of 0.90 for an acceptable fit. The value of TLI is 0.88, and CFI is 0.91. Thus, both showed an acceptable fit, which means that the proposed model has an acceptable fit in comparison to an alternative baseline model.

Fig. 3 shows the results of the proposed model. It reveals that risk perception (p-value 0.00) and barrier perception (p-value 0.00) have a significant negative effect on EI practice adoption. In other words, farmers who perceived higher levels of risk and barriers are less willing to adopt EI practices. Moreover, the model showed that, in the Chilean case, farmers with more land, assets and monthly income (economic resources) perceive higher levels of risk and barriers. In addition, the model showed that trust has a significant positive effect on risk and barrier perceptions. Hence, farmers who have less trust in the people around them will perceive higher levels of risk and barriers for EI practice adoption. Finally, training has a significant negative effect on risk and barrier perceptions. Consequently, farmers with more training related to EI practices seem to perceive lower levels of risk and barriers, and are more likely to adopt EI practices.

Table 6
Fit indexes and their acceptable thresholds.

Indexes		Acceptable fit	Good fit	Results
	Chi-square	p-value above 0.05		0.00
	Root mean square error of approximation (RMSEA)	≤0.07	≤0.05	0.07
Absolute fit indexes	Goodness-of-fit statistic (GFI)	≥0.90	≥0.95	0.91
	Tucker-Lewis index (TLI)	≥0.90	≥0.95	0.88
Incremental fit indexes	Comparative fit index (CFI)	≥0.90	≥0.95	0.91

References: Brown (2006) and Hair et al. (2014).

5. Discussion

5.1. Factors affecting EI practices adoption

The linear regression equations identified the factors that affect EI practices adoption in the Chilean vegetable production sector. In each stage of production and for each dependent variable (SEEDX, SOILX, PESTX, WEEDX and CROPX) we found different factors influencing EI practices adoption. However, we will only discuss the results of the dependent variable which groups all the production stages (TOTALX). We found seven factors having a statistically significant effect on the adoption of EI practices. Three factors had a positive effect: a) being a woman; b) perception about the ease of acting in favour of the environment; c) participating in training programmes related to EI practices. However, the following factors had a negative effect on the use of EI practices: d) perception about the risk of adopting EI practices; e) perception about the barriers of adopting EI practices; f) access to credit; and g) high percentage of income deriving from the farming activities.

Regarding the factor being a woman, these results could be explained by women farmers having stronger attitudes towards conserving the environment than male farmers (Karami and Mansoorabadi, 2008), and women being in the frontline of agroecology transition in Latin America (Mestmacher and Braun, 2020). According to Karami and Mansoorabadi (2008), these stronger attitudes of women may be due to women's lack of access to economic resources and gender-based division of labour, mainly for women's role in caring for family and household needs. A study that confirms women's attitude is by (Peredo-Parada et al., 2020), who highlighted the aptitude of women in establishing an agroforestry system using agroecological principles in southern Chile. The positive effect of the pro-environment variable, which reflects whether farmers consider it easy to take actions to preserve the environment, is in line with Kollmuss and Agyeman (2002) who argue that pro-environmental behaviour affects EI practices adoption. However, the easiness perceived by individuals to take actions in a way that protects and preserves the environment could be influenced by socio-cultural constraints beyond individuals' control (Kaiser et al., 1996). In addition, our results show that formal training on EI practices positively affects the adoption of EI, confirming the findings of Rajendran et al. (2016), who carried out a literature review on factors influencing the adoption of sustainable agricultural practices.

Our results also support evidence from previous studies which state that perceptions of risk (Rolfe and Gregg, 2015) and barriers (Kheiri, 2015; Kernecker et al., 2021) affect EI practice adoption. Another finding of our study was that access to credit is not a determinant factor for the adoption of sustainable practices per se. This contrasts with Jara-Rojas et al. (2012), who argue that access to credit has a positive influence on EI practice adoption. Rather, what seems to be predominant is a risk-adverse behaviour: even with resources at hand, Chilean farmers still prefer to avoid the perceived risks of adopting EI practices for their vegetable production. We also found that farm income has a negative effect on EI practice adoption, contradicting Baumgart-Getz et al.'s (2012) findings. This might be explained by the fact that Chilean farmers who derive a lower percentage of income from their farming activity are less economically dependent on the farm itself and feel more inclined to experiment with vegetable production (e.g., adopting EI practices) than if farming were their households' main economic activity. Finally, in the Chilean case, being an INDAP beneficiary has no significant effect on EI practice adoption. This is in line with Le Coq et al. (2020) and López-García et al. (2021), who argue that in Latin America, governments and urban actors strongly support agricultural intensification while agroecology still faces problems such as access to land, training, and the implementation of administrative tools.

5.2. Exploring interactions amongst variables

Concerning the SEM results, we found that risk perception is an

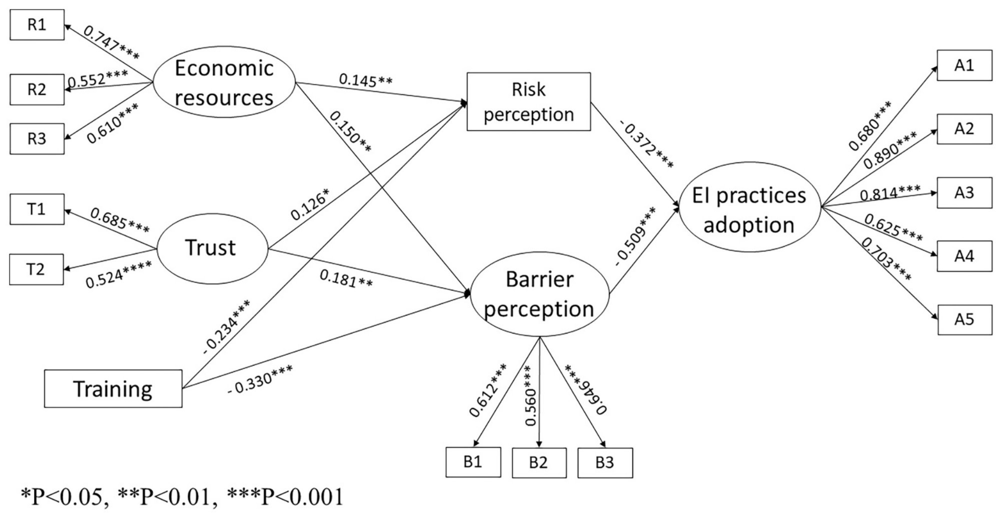

Fig. 3. SEM regression - Farmers' perceptions of EI adoption practices.

important factor in EI practices adoption, confirming previous researchers' findings (Lee, 2005; Shiferaw et al., 2009). In the Chilean context, several of the farmers we interviewed indicated two main risk perception dimensions. The first is related to uncertainty at the crop production level. Most of the farmers believe that adopting EI practices entails lower crop production and quality. The second dimension is related to the farmers' health benefits. They believe that they can avoid diseases or improve their health if they use fewer synthetic fertilisers, herbicides and pesticides. In this context, the uncertainty regarding crop production and crop quality increases the perceived risk, while the perceived improvement in their health decreases the perceived risk of adopting EI practices. However, in the end, most of the farmers assign more importance to production, and that is why they perceive EI practices adoption as risky. In Chile, the reasons why farmers tend to find the uncertainty of production levels more important may be related to the fact that they not only need to compete in the local market but, also, they need income to afford credit payments, rent payments, and family education. On the other hand, one possible explanation why farmers give less importance to improving health-related circumstances may be so-called 'risk denial' (Sjöberg, 2000). Risk denial could be explained by people's overconfidence; in this case, farmers seem unrealistically optimistic about their health (e.g., amongst peers, a farmer believes that the harmful effect of pesticides on his own health will always be lower) (Dunning et al., 2004).

Our research also shows that barrier perception is an important factor in EI practices adoption. The results uncovered, that farmers perceive three main barriers to EI practices adoption: 1) the availability and/or accessibility of organic inputs; 2) being surrounded by others adopting conventional production methods; and 3) the time required to transition to these practices. Most of the farmers in our sample have never tried to adopt EI practices; that is why we define the barriers as hypothetical. The low availability and/or accessibility of organic inputs and the long time required to a transition are in line with Valdivia et al. (2012) who found that a major component of these barriers are transaction costs related to information access and establishment costs. On the other hand, being surrounded by others adopting conventional production techniques has not been identified as a barrier in any other study. Farmers are aware that the synthetic fertilisers, herbicides and pesticides that neighbouring conventional farms use might contaminate their farms. Although the prior barriers are not directly linked to governmental policies, the adoption rate of EI practices could be influenced when farmers are supported by policies (e.g., financing programmes for transition farmers).

Our study found that having economic resources does not alleviate the perceived levels of risk and barriers. We found that those who have the most economic resources (e.g., land and income) perceive higher levels of risk and barriers when they consider adopting EI practices. In contrast, previous researchers found that farmers who lacked assets, capital and land would not invest in activities that they perceived as risky (e.g., EI practices) (Baumgart-Getz et al., 2012). And, on the other hand, farmers with more economic resources are better able to adopt EI practices because they can bear the risk (Shiferaw et al., 2009; Baumgart-Getz et al., 2012). Our findings could be explained by Tversky and Kahneman (1973) who argue that individuals whose wealth status is sufficiently high will prefer to maintain their status quo if the process of changing implies transition costs. In other words, if a farmer is wealthy or more economically stable, he will not risk his economic patrimony. However, it could also be explained by the local context of organic product consumption and vegetable production in Chile. Although organic product consumption in Chile has tended to increase, the growth rate is low, and Chile is still a net exporter of organic products (IICA, 2020). Unlike the agro-export sector (e.g., fruits), vegetables for the local market are not supported by the government (Altieri and Rojas, 1999; David et al., 2000). As a result, vegetable production in Chile faces competitive and unfavourable conditions. We believe that, under current market conditions, farmers perceive vegetable production in Chile as risky; even farmers with greater wealth are afraid of potentially low economic returns as a consequence of transitioning to EI production methods.

Our research offers insights in the interaction between trust and the perception of risk and barriers for EI practices adoption. This study uses the term trust as the belief that a partner is reliable and benevolent (Ganesan, 1994). We found that farmers with low levels of trust in farm labourers, input suppliers and neighbours perceive high levels of risk and barriers. These findings are in line with the work of Small et al. (2016) and Hunecke et al. (2017) who argued that trust in networks has a positive impact on the adoption of new practices. From another perspective, our results are also confirmed by (Wossen et al., 2015), who found that farmers who do not trust their social network will probably perceive higher risk levels of adopting EI practices. According to Corsten and Kumar (2005), trust results in greater knowledge and appreciation between partners. Hence, if farmers trust actors in their social network who are already involved in EI practices, the adoption will be facilitated (Vanclay, 2004; Lee, 2005). On the contrary, if conventional agriculture is predominant in the social network, farmers feel more social pressure not to adopt EI practices, which has been identified as a barrier (Rodriguez et al., 2009; Home et al., 2019). Overall, when people trust each other, the process of cooperating, collaborating and creating social networks is easier (Nilsson et al., 2012).

Lastly, training is a way to acquire particular knowledge (Leeuwis, 2004). Through this lens, our results show that a lack of knowledge increases the perceived levels of risk of adopting EI practices. These results corroborate Greiner et al.'s (2009), who found that improving knowledge and human capacity is fundamental to manage risk regarding EI practices adoption. According to O'Connor et al. (1999), knowing the causes of a problem (e.g., soil degradation) and its possible meliorative solutions could lead to promote pro-environmental actions. An Individual with more knowledge about a topic will be able to estimate the risk more objectively (Tversky and Kahneman, 1974; Knight et al., 2003). Similar to our results, Kernecker et al. (2021) identified the lack of training for managing complex agroecological systems as a barrier for EI practices adoption. In general, and in terms of the influence knowledge has on perceived barriers, many studies have shown that a lack of knowledge is a key barrier for the adoption of new practices or technologies (Grothmann and Patt, 2005; García de Jalón et al., 2015). We thus assume that farmers who have participated in training programmes related to EI practices have been provided relevant information and have the knowledge to implement EI practices.

6. Conclusion

Our study aimed to analyse which factors influence the simultaneous adoption of various EI practices in different vegetable production stages by farmers in the context of an emerging economy such as Chile. We identified that, depending on the production stage, various factors have a different effect on EI practices adoption (e.g., awareness of the impact agrochemicals have on the environment only has a positive effect on the use of organic pesticides). In general, the most significant factors positively or negatively affecting the adoption of EI practices are gender, the degree of farmers' pro-environment attitude, their perception of risk and barriers, access to training and credit, and farm income. Further, we found that factors pertaining to economic resources, trust and training influence the perception of risk and barriers and, therefore, have an indirect effect on EI practices adoption. This study also highlights the potential role of women fomenting EI adoption and indicates the appearance of farmers' health dimension within risk perception in adopting EI.

The exploratory nature of this study allows obtaining new insights into how factors interact and it contributes to the debate on which factors should be prioritised by policymakers and scholars in order to improve the adoption rate of EI practices. Overall, our study offers insights on sustainable vegetable production from a broad perspective, taking into account different farming practices and production stages, all of which contributes to the discussion on the complex processes at farm level.

We acknowledge that our research has some limitations related to methodology and data measurement. Although our model does not comply with all of the cut-off criteria suggested in the literature on SEM methodology, our results open the way for further investigating the relationships as exposed by our model, and for theory building. Regarding the data measurement limitations, we acknowledge that other factors not currently considered may also determine EI adoption. Because the survey used in this study did not include measurement on the two risk dimensions (crop production and farmers' health), this would be an interesting topic for further research. Moreover, future studies analysing the interactions between risk and barriers could provide more insights, likewise analysing why farmers integrate EI practices in one production stage but not in another. In addition, further investigation on the measurement of farmers' trust in farm labourers, input suppliers and neighbours would help to establish a larger degree of accuracy on this matter. Finally, future research should also focus on how farmers obtain knowledge and what motivates them to increase their knowledge related to EI practices.

Our results also have implications for practitioners and policymakers. Knowing which factors affect EI practice adoption and how these factors interact can support governments to prioritise and focus policies. One strategy to increase adoption rates is offering technical assistance programmes related to EI practices in Chile. For instance, as results show that women seem to be more inclined to use agroecological practices, these programmes could start with women farmers and then progressively incorporate other farmers. Moreover, the low levels of trust perceived by farmers in farm labourers, input suppliers and neighbours highlighted in our study should be taken into account by the Chilean government when designing programmes to promote EI practices adoption. These programmes could provide farmers with guidance on shared decision-making and co-governance, and offer non-specific support that stimulates community connectedness, thereby building trust (Jagosh et al., 2015; Fretwell et al., 2018).

Disclosure statement

No potential conflict of interest was reported by the author(s).

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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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2021.103283.

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