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RESEARCH

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The Moringa value chain in Ethiopia and the socio-economic impact of pests and diseases

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Abstract

Background: Moringa is a multipurpose tree, and the demand for Moringa products is growing significantly. It has gained popularity in southern Ethiopia, where the tree is cultivated for its nutritious food, medicinal properties, cultural significance, and economic value. However, there is limited research examining how pests and diseases affect the Moringa value chain. The aims of this study were to examine the socio-economic factors influencing the level of pest severity among Moringa growers and to estimate the impact of Moringa production on the income of value chain actors. *Methods*: The study used primary data collected from Moringa value chain actors in the Arba Minch and Derashe districts of the southern Ethiopia Region, encompassing 507 households involved in the Moringa value chain. The study employed value chain mapping to analyse the entire chain and applied a multinomial endogenous switching regression model to address selection bias and assess the impact of Moringa production on the income of value chain actors. *Results*: Results show that younger individuals, women, singles, and cooperative members are more likely to participate in distribution and processing, while larger households with land and more Moringa plants tend to remain growers. Pest severity varies by location and household age, with Arba Minch growers more likely to experience medium pest severity, likely due to lower insecticide use than in Derashe. Distributors earn significantly less than growers, while processors earn similar incomes. Pest impacts on income were not statistically significant, likely because infestation periods were brief and Moringa is mainly grown for household consumption. *Conclusions*: The findings provide new insights into the impact of pests and diseases on the Moringa value chain and on the income of actors. The results identify key socio-economic and locational factors associated with pest severity among growers and estimate income differences across value chain actors. This highlights how participation in different stages of the value chain and pest dynamics influence economic outcomes in Moringa production systems. Given Moringa's importance as a staple vegetable for food security, employment opportunities, and medicinal and cultural benefits, support from the government and NGOs is essential to strengthen the Moringa value chain. In addition, raising awareness of the impacts of insecticides and promoting integrated pest management is crucial for sustainable and resilient Moringa production and should inform policy and technical interventions.

Keywords: Moringa, pest and disease, value chain, impact, multinomial endogenous switching regression

Introduction

Moringa, commonly known as the "miracle tree" has gained significant attention globally due to its multifaceted socio-economic benefits (Arshad *et al*., 2025). *Moringa oleifera* Lam. and *Moringa stenopetala* Bak. f. (Cufodontis) are the two most widely cultivated species of the Moringaceae family, which comprises 13 species (Kumssa *et al*., 2017). In Ethiopia, *M. stenopetala* is the most common species of Moringa grown (Demisse *et al*., 2024) and is locally widely known as Halako or Aleko and by some as Shiferaw (Tafesse *et al*., 2020). Moringa has grown in popularity

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in southern Ethiopia, where the tree is cultivated as a source of nutritious food and for its medicinal, cultural, and economic values. Its ability to thrive in drought-prone areas makes it an essential resource for sustainable agriculture (Kidane *et al*., 2024). The tree is widely grown in home gardens and farmlands and is consumed daily. This practice is not driven by food insecurity but rather by the community's preference for Moringa as its primary vegetable source.

The demand for Moringa products has substantially increased in various parts of Ethiopia, and the supply of products from different areas is also growing (Tafesse *et al*., 2020; Meskel *et al*., 2020). Moringa is a nutritional powerhouse, providing a source of essential proteins, vitamins, and minerals. Moringa leaves, seeds, and pods are parts of the Moringa plant that contain valuable dietary supplements (Birhanu and Fitamo, 2015; Derbo and Debelew, 2024). Moringa is not only valuable nutritionally but also has medicinal value that is recognised in both traditional and modern medicine (Anwar *et al*., 2007; Kumssa *et al*., 2017), treating several diseases, such as cancer, high blood pressure, diabetes, cough, and other ailments (Agedew *et al*., 2022; Tesfaye *et al*., 2022; Jikah and Edo, 2023; Thakur *et al*., 2024). The tree is also widely used as an animal feed (Demisse *et al*., 2024; Lungu *et al*., 2024), serves as a source of organic fertiliser in vegetable production (Karthiga *et al*., 2022; Marie *et al*., 2025), and can be used as a natural preservative (Abera *et al*., 2022; Orcho *et al*., 2023) and for pest control (Hordzi, 2024; Regasa and Shiberu, 2024).

Moringa is also culturally significant in some parts of Ethiopia and is often seen as a symbol of security and prosperity. For example, a person with many Moringa trees in their garden or on their farmland is considered to have a higher social status, and when a man proposes marriage, the first question from the woman's family is often about how many Moringa trees he has (Birhanu and Fitamo, 2015; Demisse *et al*., 2024). Moringa also has a cultural value as it is inherited or transferred from generation to generation.

Despite the many benefits of Moringa, it remains underutilised in Ethiopia, and the value chain is poorly understood (Seifu, 2014). A value chain is defined as a financial system that encompasses a series of production, distribution, and supply chains, with the product flowing from production to consumption or back from the consumer to the producer. According to Kelemu and Alemu (2013), the Moringa value chain in Ethiopia comprises several actors, each playing a vital role throughout the production and consumption stages. At the initial stage, there are input suppliers, who are responsible for collecting quality seeds, raising seedlings, and distributing them to growers. The next group is the growers, who cultivate Moringa either at the household level for subsistence purposes or on a commercial scale for the market. Processors are the next group, who add value by transforming Moringa into a variety of products, such as dry leaves, powders, oils, teas, and capsules, to increase its economic and nutritional values once the fresh Moringa leaves or seeds are harvested. The other actors are distributors, which include wholesalers, retailers, and exporters, who facilitate the flow of fresh Moringa and value-added products within domestic markets as well as to international buyers. Finally, the chain concludes with consumers, who use Moringa in various forms for food, health, and other purposes. However, the Moringa value chain remains underdeveloped and is constrained by numerous challenges, including limited market access, inadequate processing capacity, and production constraints such as pests and diseases (Kumssa *et al*., 2017; Tesfaye *et al*., 2022; Demisse *et al*., 2024; Lungu *et al*., 2024).

Pests (e.g., insects) and diseases of Moringa can reduce crop yields, thereby affecting different actors in the Moringa value chain. However, the actual impact of pests and diseases on the agribusiness value chain remains unknown. According to Kumssa *et al.* (2017), pest attacks have been reported as a significant challenge in Moringa production in Ethiopia and Kenya, particularly during the dry season and at the beginning of the rainy season. One of the more important pests is the Moringa moth, *Noorda blitealis*, whose larvae mainly affect the leaves and sometimes bore into the pods (Bedane *et al*., 2013). Larvae consume leaves, reducing leaf biomass and quality, thereby affecting human food consumption (Anjulo, 2009; Kumssa *et al*., 2017).

Most previous studies have primarily examined the medicinal value of Moringa (Anwar *et al*., 2007; Kumssa *et al*., 2017; Agedew *et al*., 2022; Tesfaye *et al*., 2022; Thakur *et al*., 2024), its contribution to income (Shonde, 2017; Meskel *et al*., 2020), its use as animal feed (Demisse *et al*., 2024; Lungu *et al*., 2024), its role as a source of organic fertiliser in vegetable production (Karthiga *et al*., 2022; Marie *et al*., 2025), as well as its application as a natural preservative (Abera *et al*., 2022; Orcho *et al*., 2023) and for pest control (Hordzi, 2024; Regasa and Shiberu, 2024). However, there is limited research focusing on the impact of pests and diseases on the Moringa value chain. In this study, we aimed to (i) examine the socio-economic factors influencing the level of pest severity among Moringa growers and, (ii) assess the impact of Moringa production on the income of value chain actors. The findings of the study contribute to the existing literature by providing new insights into the impact of pests and diseases on the Moringa value chain and on policy-relevant management practices.

Methods

DESCRIPTION OF THE STUDY AREA

The study was conducted in the Gamo and Gardula Zones, South Ethiopia Regional State, in Ethiopia (Fig. 1). The South Ethiopia Regional State is a newly formed region, established in August 2023 from the southern part of the former Southern Nations, Nationalities, and Peoples' Region (SNNPR). The Gamo and Gardula Zones are among the primary Moringa-growing zones (Tafesse *et al*., 2020; Demisse *et al*., 2024). Gamo Zone contains 14 rural districts and six town administrations, and Gardula contains one district (Derashe), and each district contains many kebeles (the lowest administrative structure).

SAMPLING AND DATA COLLECTION

The study used primary data collected through individual surveys, key informant interviews, and focus group discussions. Semi-structured questionnaires were used to collect the individual data.

Multi-stage sampling techniques were employed to identify the study areas and select respondents for primary data collection. In the first stage, the Gamo and Gardula zones were selected due to their extensive production and consumption of Moringa. In the second stage, two districts (Arba Minch Zuria from the Gamo zone and Derashe from the Gardula zone) were selected based on the availability of more active value chain actors. In the third stage, 12 kebeles were selected from the two districts based on the availability of more producers and consumers. The kebeles were from Arba Minch Zuria (Arba Minch City, Chanomile, Kola Shele, Lante, Shelemela, and Wezaqa) and from Derashe (Arguba, Holte, Onato, Shilile, Walessa, and Wolite). In total, there were 507 households representing different actors in the value chain (Table 1). The proportions of people involved in the different components of the value chain varied, and therefore, the sample sizes for the different actors were unequal. Most actors in the value chain are growers, as the majority of farmers in the study area cultivate Moringa primarily for household consumption. Only a small proportion of farmers participate as input suppliers, processors, or distributors.

Data collection was conducted in accordance with the University of Pretoria's ethical guidelines and was approved accordingly (NAS040/2025). All respondents provided informed consent before each interview. Well-trained enumerators collected the data between March and April 2025. The enumerators received

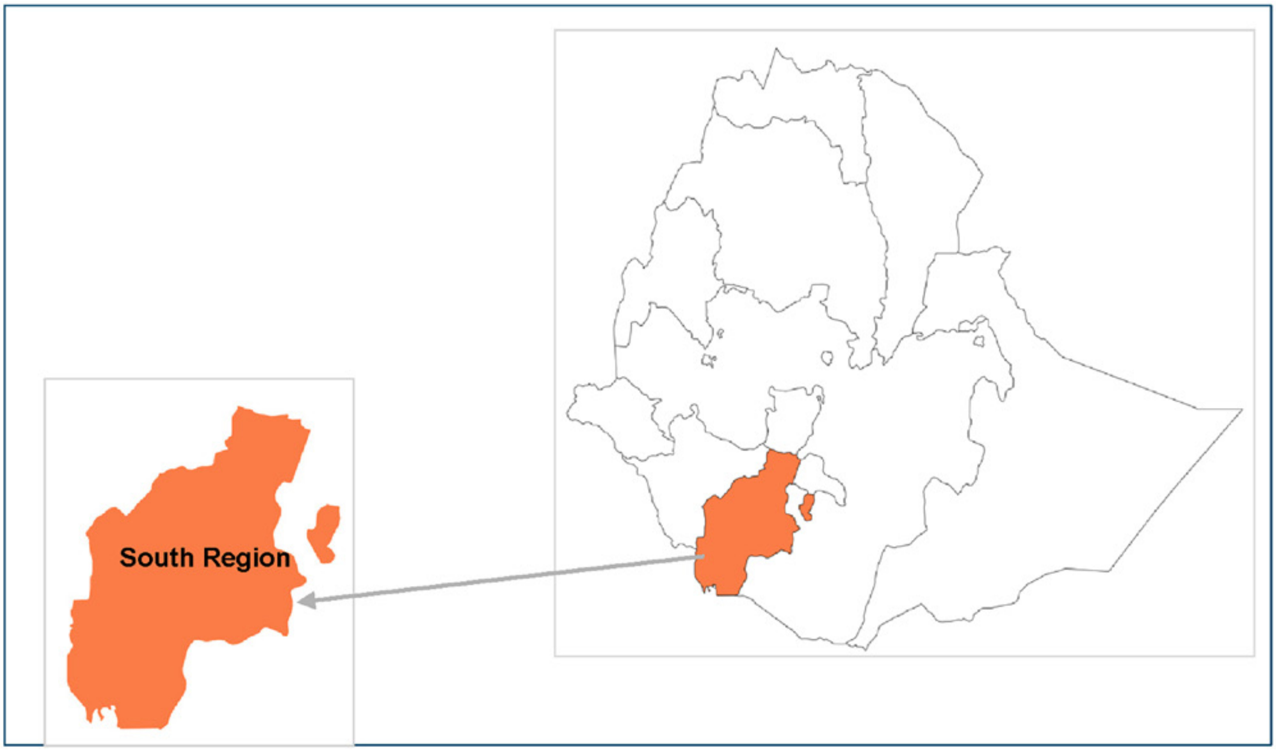

Fig. 1. Map of Ethiopia showing the South region.

Table 1. Value chain actors and sample size.

Actors	Sample size	Percentage
Input suppliers	6	1.18
Growers	266	52.47
Distributors	67	13.21
Processors	37	7.30
Consumers	131	25.84
Total	**507**	**100**

2 days of training. A pilot data collection was conducted prior to the actual data collection. The pilot data collection helped assess the reliability and feasibility of the data collection process, identify and address issues with the questionnaires, and train the enumerators. All questionnaires were developed on the KoboToolbox™ survey collection tool (Das, 2024).

Key informant interviews (KIIs) were conducted with various stakeholders, including government development agents, focal value chain representatives, NGOs, and farmers' representatives, to collect information and gain an understanding of the Moringa value chain.

Focus group discussions (FGDs) were conducted with various value chain actors, including growers, distributors, processors, and consumer groups, each comprising 8–12 members. The focus group discussions helped to gather comprehensive viewpoints from both female and male respondents, providing a gender-balanced understanding of the Moringa value chain, encompassing its production, processing, marketing and consumption stages.

The key informants and focus group discussions were used to contextualise and interpret the econometric results, as well as to inform the selection of key variables included in the model. In addition, insights from FGDs and KIIs helped to explain underlying patterns, relationships, and unexpected findings observed in the quantitative analysis.

METHODS OF DATA ANALYSIS

Mixed-methods approaches were used to analyse the collected data. Qualitative data from focus group discussions and key informant interviews were analysed using value chain mapping to understand the entire value chain. To analyse the quantitative data, including socio-economic, demographic, and community characteristics, both descriptive and econometric analyses were employed. Descriptive analyses, including means, standard deviations, mean differences, t-tests, and chi-square tests, were also employed. An econometrics model, specifically a multinomial endogenous switching regression (MESR) model, was used to examine the impact of pests and diseases on the Moringa value chain.

VALUE CHAIN MAPPING

Value chain mapping for Moringa involves tracing the flow of activities and actors from cultivation to final consumption to understand how value is created, added, and distributed along the value chain. Mapping the value chain not only reveals the economic and nutritional potential of Moringa but also highlights challenges such as limited access to quality seeds, inadequate processing technologies, weak market linkages, insufficient regulatory standards and the impact of pests and diseases. By identifying these gaps, value chain mapping provides a framework for strengthening Moringa's commercialisation, improving farmer incomes, and expanding its role in nutrition and health interventions.

EMPIRICAL MODELS

The MESR model was employed to analyse the impact of participation in different segments of the Moringa value chain, such as growers, distributors, processors, and consumers, on actors' income. Several econometric models are commonly used to analyse the impact of a programme, project, or policy, including difference-in-differences (DID), propensity score matching (PSM), instrumental variables, reflexive comparisons, and the MESR method. The dependent variable in the selection equation is categorical, and selection bias is expected. It is better to use MESR to control for selection bias rather than other impact analysis tools such as propensity score matching (PSM), Augmented Inverse Probability Weighting (AIPW), or the Inverse Probability Weighted Regression Adjustment (IPWRA).

The MESR was grounded in random utility theory, which assumes that actors choose a value chain segment that maximises their expected income and benefits. However, participation in a specific segment was not random; it was influenced by both observable and unobservable factors, which could introduce selection bias (Kassie *et al*., 2018). In addition, the MESR framework was used to assess the impact of pest and disease severity on the income of Moringa growers. Pest severity was categorised into low, medium, and high levels. Since growers may not experience pest severity at random, the MESR approach effectively corrects for selection bias and estimates the income effects for each severity regime.

The MESR model corrects for this bias by jointly estimating the participation decision and the corresponding outcome equations, thereby generating consistent and unbiased estimates of the income effects associated with value chain participation. The model consists of two stages: the selection equation and the outcome equation. In the first stage, multinomial logistic (MNL) regression was used to analyse factors influencing the value chain actors in the Moringa value chain and pest severity (Ogundari, 2017; Shah, 2020). Multinomial logistic regression models, measured on a nominal scale, were introduced by McFadden (1974).

The study employed MNL regression due to the categorical nature of the dependent variables, which are categorised into four value chain actors (growers, distributors, processors, and consumers) and three pest severity levels (low, medium, and high). The study used socio-economic and demographic variables as independent variables (Fig. 2). The dependent variables have more than two categories, each coded categorically, with one category serving as the reference or base category. In this study, growers from the value chain and those with low pest severity were used as a reference category.

The MNL is a generalised linear model used to estimate the probabilities for the *j* categories of a categorical dependent variable *Y*, using a set of explanatory variables *X*. According to Greene (2008), we define the multinomial logit (MNL) model for the study as:

$$P_{ij} = \frac{exp(\beta_j x_i)}{1+\sum_{j=1}^{3} exp(\beta)} \text{for } j = 1, 2, 3, 4 \ldots J \quad (1)$$

$$P(Y = j / X) = \frac{exp(\beta_{j0} + \beta_{j1}X_1 + \beta_{j2}X_2 + \ldots + \beta_{jn}X_n)}{1+\sum_{i=1}^{j-1} exp(\beta_{i0} + \beta_{i1}X_1 + \beta_{i2}X_2 + \ldots + \beta_{in}X_n))} \quad (2)$$

Let *Y* be the categorical dependent variable representing value chain actors and pest severity. X_i represents a vector of socio-economic characteristics of the *i*th household, *j* is a vector of regression parameter estimates associated with alternative *j*, and 1 to 4 or 3 was the number of value chain actors' and pest severity, respectively. The β_js are the coefficients for the predictor variables associated with category. The denominator sums over all categories except the reference category, which is usually the last *J*.

For instance, a positive coefficient indicates that the relative probability of joining other value chain actors increases relative to the likelihood of remaining as growers, or the relative probability of becoming medium or high pest severity level rises relative to the probability of remaining as low severity.

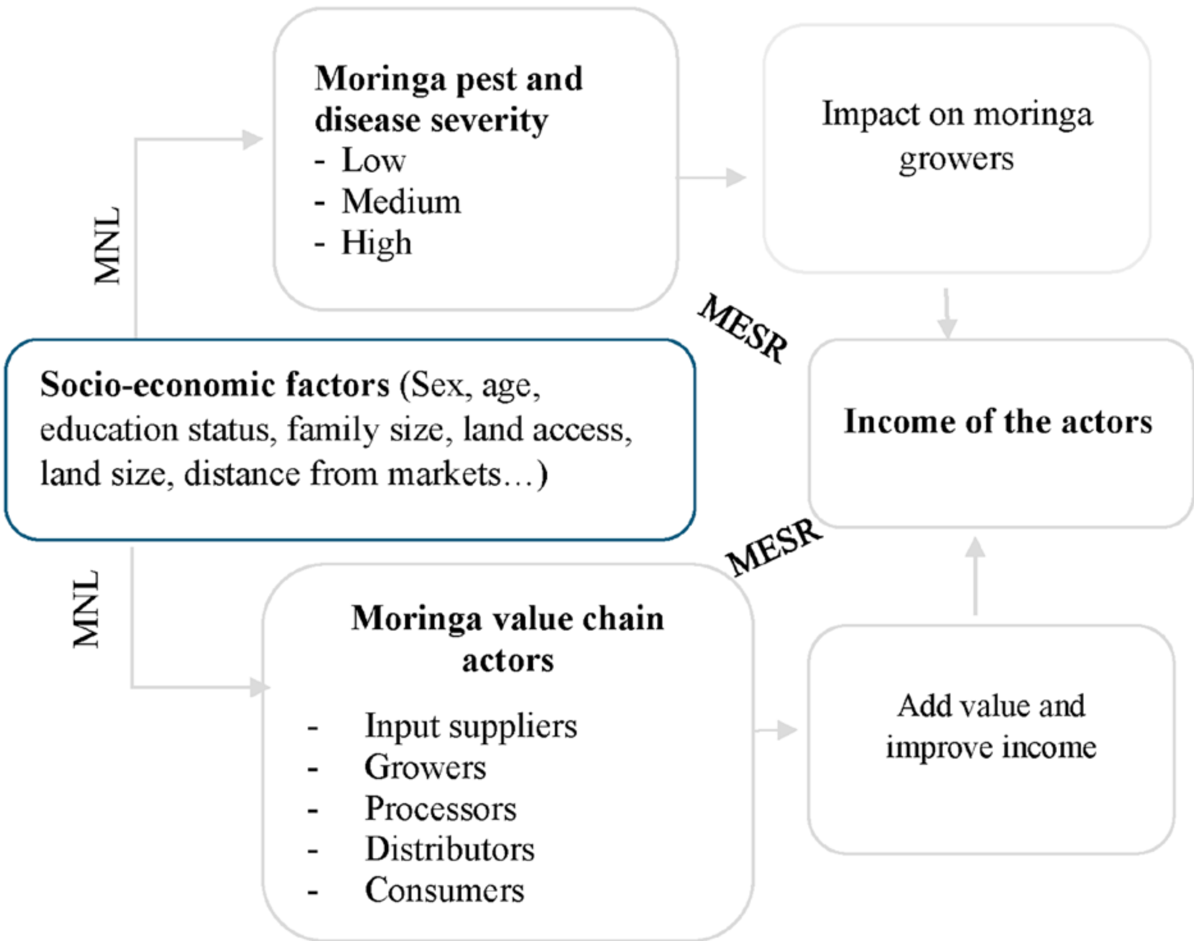

Fig. 2. Conceptual framework for pest severity, value chain participation and Moringa income.

The probability for the reference category is:

$$P(Y=J/X)=\frac{1}{1+\sum_{i=1}^{j-1}xp(\beta_{i0}+\beta_{i1}X_1+\beta_{i2}X_2+\ldots+\beta_{in}X_n)} \quad (3)$$

In the second step, the MESR model was used to analyse the impact of pests and diseases, as well as value chain actors, on respondent income. These estimates are essential for unravelling the socio-economic implications of pests and diseases on household income. Let Y_{ji} denote the outcome variables. In this study, we considered annual income as the outcome variable. We followed a flexible moment-based approach and a multinomial selection-bias correction framework (Bourguignon *et al*., 2007) to examine the relationship between Y_{ji} and the covariates Z and X.

In this study, we have two dependent variables. Namely, value chain actors:

$(j=1=growers(base\ category), 2=distributors,$
$3=processors, 4=consumers)$
and pest severity $(j=1=low(base\ category), 2=medium,$
$3=high)$.

The outcome equation for each value chain actor and pest severity is given as:

$$\{Regime\ 1: Y_{1i}=\sigma_1 Z_{1i}+\theta_1 X_{1i}+\varepsilon_{1i} \text{ if } L=1\ldots \\ Regime\ J: Y_{Ji}=\sigma_J Z_{Ji}+\theta_J X_{Ji}+\varepsilon_{Ji} \text{ if } L=J\ j=2,3,4 \quad (4)$$

Y_{ji}, covariates Z and X are defined as above. ε is the error term. We included demographic and socio-economic characteristics (e.g., sex of the respondents, age of the household, education status, and marital status). If μ and ε are dependent, then σ and θ will be inconsistent. To obtain consistent estimates for σ and θ, Bourguignon *et al.* (2007) proposed the inclusion of selectivity correction terms to Eqn 4 and estimated the model with MESR:

$$\{Regime\ 1: Y_{1i}=\sigma_1 Z_{1i}+\varphi_1\rho_{1i}+\theta_1 X_{1i}+\varepsilon_{1i} \text{ if } L=1\ldots \\ Regime\ J: Y_{Ji}=\sigma_J Z_{Ji}+\varphi_J\rho_{Ji}+\theta_J X_{Ji}+\varepsilon_{Ji} \text{ if } L=J \quad (5)$$

Where ε is the error term, φ denotes the covariance between μ and ε, ρ denotes the inverse Mills ratio calculated from the estimated equation (3). From the MESR model, we estimate the counterfactual and average effects of choosing a particular value chain and pest severity (Di Falco and Veronesi, 2014). The counterfactual is described as the income of value chain actors in the treated categories, assuming their characteristics estimates were the same as those of the value chain actors in the base category, and vice versa (Teklewold *et al*., 2013). The conditional expectations for the outcome variables were computed as:

Actual for value chain actor $(j=2,3,4)$:

$$E\left[\frac{Y_{Ji}}{L=j,Z_{ji},}X_{ji},\rho_{ji}\right]=\sigma_j Z_{ji}+\theta_j X_{ji}+\varphi_{j\mu}\rho_{ji} \quad (6)$$

Actual for base value chain actor $(j=1)$:

$$E\left[\frac{Y_{1i}}{L=1,Z_{1i},}X_{1i},\rho_{1i}\right]=\sigma_1 Z_{1i}+\theta_1 X_{1i}+\varphi_{1\mu}\rho_{1i} \quad (7)$$

Counterfactual for value chain actors $(j=2,3,4)$, if they had chosen the base value chain actor:

$$E\left[\frac{Y_{1i}}{L=j,Z_{ji},}X_{ji},\rho_{ji}\right]=\sigma_1 Z_{1i}+\theta_1 X_{1i}+\varphi_{1\mu}\rho_{ji} \quad (8)$$

Counterfactual for base value chain actor $(j=1)$ if they had chosen $j=2, 3, 4$

$$E\left[\frac{Y_{ji}}{L=1,Z_{1i},}X_{1i},\rho_{1i}\right]=\sigma_j Z_{1i}+\theta_j X_{ji}+\varphi_{j\mu}\rho_{1i} \quad (9)$$

Equations 6 and 7 are the expected annual income actually observed in the sample for the value chain actor and pest severity. Equations 8 and 9 are their corresponding counterparts.

Instrumental variables were used in the first stage of the model to address potential endogeneity and self-selection bias in household participation across different pest and disease severity levels and among various value chain actors.

In this study, distance to the extension office, cooperative membership, and district location were selected as instruments because they are expected to influence participation decisions but are unlikely to affect household income directly. For instance, proximity to extension services increases actors' access to information, training, and market linkages, which in turn shape their choice of value chain segments. Likewise, membership in Moringa cooperatives improves knowledge of Moringa products and enhances access to networks and credit, thereby significantly influencing participation. District location, specifically residence in Arba Minch or Derashe, captures differences in infrastructure, market access, and development programs that affect farmers' engagement with different value chain actors and their exposure to pest and disease conditions.

Similarly, the severity of pest and disease infestation (low, medium, or high) is associated with access to extension support and cooperative networks. Farmers located closer to extension offices and cooperative members are more likely to receive timely information and training on pest and disease management. As a result, they are more likely to experience lower levels of pest and disease severity than those farther away or not affiliated with cooperatives.

The instrumental variables should satisfy two conditions: they should significantly affect participation and satisfy the exclusion restriction. These conditions should be justified and validated to show that the instruments do not directly influence actors' income except through the participation decision (Bourguignon *et al*., 2007; Lokshin and Sajaia, 2004). Different tests were conducted to assess the validity and strength of the instrumental variables, including the Wald test and other robustness checks. The Wald test was applied to examine the joint significance of the instrumental variables in the first-stage equations. This test evaluates whether the selected instruments significantly explain variation in participation decisions across different value chain actors and pest and disease severity levels. A statistically significant Wald statistic indicates that the instruments are relevant and strongly correlated with the endogenous participation variables, a key requirement for valid instrumental-variable estimation (Stock and Watson, 2015). In addition, diagnostic tests were used to examine whether the instruments satisfied the exclusion restriction. This involved verifying that the instruments influenced household income only through their effect on participation and not directly (Lokshin and Sajaia, 2004).

Finally, the Average Treatment Effect on the Treated (ATT) is calculated as the difference between Eqns 6 and 8:

$$ATT=E\left[\frac{Y_{Ji}}{L=j,Z_{ji},}X_{ji},\rho_{ji}\right]-E\left[\frac{Y_{1i}}{L=j,Z_{ji},}X_{ji},\rho_{ji}\right] \quad (10)$$

Results and discussions

The results section is presented in seven subsections. The first subsection presents the results of value chain mapping. The second and third subsections describe the demographic and socio-economic characteristics of the sampled respondents and provide an overview of the Moringa pests and diseases in the study areas. The fourth and fifth subsections present the determinant factors. The last two subsections describe the impact of pests and diseases on income.

VALUE CHAIN MAPPING

The value chain mapping was used to map the Moringa value chain. The mapping exercise helps to identify the various actors, key activities, and enablers in the Moringa value chain. The information obtained from key informant interviews and focus group discussions was analysed using content analysis. First, all interview and discussion notes were carefully transcribed and reviewed to ensure accuracy and completeness. Second, themes and patterns related to value chain stages, actors, activities, and enabling factors were identified and grouped. Various actors are involved in the Moringa value chain in Ethiopia, including input suppliers, growers, distributors, processors, and consumers (Kelemu and Alemu, 2013). A wide range of activities is carried out by different actors, with multiple sectors supporting the value chain as enablers (Table 2).

The primary actors in the Moringa value chain are the input suppliers. The primary activities of input suppliers include collecting quality seeds, preparing seedlings, and distribution (Kelemu and Alemu, 2013). Input suppliers in the study areas included farmers, government extension offices, and private companies (Table 2). Most farmers used seeds from their own farms. The role of the government extension officers as input suppliers was through a safety net programme created by the district agriculture office to support smallholder farmers. One of the activities in this program is to prepare seedlings of various vegetables, fruits, and forest species, and distribute them to the surrounding farmers. The number of private input suppliers was minima.

Growers or producers are the major actors in the Moringa value chain. More than 50% of the respondents were categorised under growers (Table 2). The majority of Moringa growers in Ethiopia are private individuals or smallholder farmers who produce Moringa for their home consumption. Each household in the study areas, located in rural and semi-urban areas, had at least two or more Moringa trees in their backyard or on their farm. Most individual farmers plant Moringa trees in agroforestry systems, often alongside other trees or crops. Only a few commercial Moringa farms exist in Ethiopia, and most are in the early stages of production (UNIDO, 2022).

Distributors in the Moringa value chain in Ethiopia include wholesalers, retailers, and exporters (Table 2). Most wholesalers also act as retailers, selling Moringa products in bulk to other retailers while also selling directly to individual customers. Only a limited number of exporters are involved in exporting Moringa products to various countries; among them, Enat Moringa is a well-known company that both produces and exports organic Moringa products, including Moringa powder, seeds, oil, and capsules to international markets. The Czech Republic (CzechAid Development Agency) is one of the partner countries working with Enat Moringa to produce and market Moringa products to EU standards (CzechAid, 2019). Distributors sell various Moringa products, including fresh and dry leaves, as well as other Moringa-processed products such as powder, oil, capsules (supplements made from Moringa powder), and soap. Only about 13% of the respondents in the study area were distributors.

The processors are another actor in the Moringa value chain. Only a few processors are involved in the Moringa value chain in Ethiopia, including private companies, individual farmers, and cooperatives. Most individual farmers produce dry leaves; cooperatives produce dry leaves and powder, while private companies produce various Moringa products (powder, oil, capsules, and soap). Although findings from the group discussions revealed that most respondents were willing to participate in the value addition of Moringa products, only about 7% of respondents in the study area were actively engaged as processors. This low participation is largely due to limited access to land, inadequate training, insufficient financial support, and a lack of appropriate processing technologies.

The final actors in the Moringa value chain are consumers. Most consumers live in urban and pre-urban areas. In rural areas, most individuals grow Moringa for their own household consumption. In this study, 26% of the respondents were consumers.

DEMOGRAPHIC AND SOCIO-ECONOMIC CHARACTERISTICS OF SAMPLED RESPONDENTS

Table 3 presents the summary statistics for the demographic and socio-economic variables included in the empirical analysis. Of the 507 respondents interviewed in this study, 78% were male-headed households and 22% were female-headed households. Male-headed households were dominant among all the value chain actors. The majority of respondents, 87%, were married, compared

Table 2. Moringa value chain actors in Ethiopia.

Value chain stages	Actors	Key activities	Enablers
Input suppliers (2%)	- Smallholder farmers - Development offices - Seed suppliers	- Supplying seeds and agricultural inputs - Providing technical and advisory support - Facilitating access to improved inputs	- Government policies - Development offices - Agricultural extension services - NGO (FAO and UNIDO)
Growers (52%)	- Smallholder farmers - Commercial farmers - Cooperative members	- Land preparation - Plantation and management of the Moringa tree - Pruning - Harvesting - Marketing fresh Moringa leaves	- Access to Moringa seed/seedling - Training and capacity building, and value addition - Training on pest and disease management - Market linkage - Agricultural extension services - Moringa cooperatives
Distributors (13%)	- Wholesalers - Retailers - Exporters	- Selling fresh and dry Moringa leaves - Transport and logistics - Market linkage and coordination	- Transport infrastructure - Market linkage and information systems - Storage facilitation
Processors (7%)	- Smallholder farmers - Private companies - Cooperatives	- Processing and value addition - Packaging and quality control- - Storage and preservation - Market linkage and coordination	- Processing technology and equipment - Access to credit - Technical skills on value addition - Quality standards and certification
Consumers (26%)	- Urban consumers - Rural consumers	- Consumption from own production - Purchasing and consumption	- Market accessibility - Pricing and affordability - Consumer awareness of nutrition and food safety

Table 3. Categorical variable descriptive results.

		Value chain actors					
Variable	**Description**	**Input suppliers**	**Growers**	**Distributors**	**Processors**	**Consumer**	**Total**
Sex of the HH	Male	100.00	86.47	74.63	67.57	64.89	78.11
	Female	0.00	13.53	25.37	32.43	35.11	21.89
Marital_status	Married	100.00	94.36	73.13	89.19	77.86	86.98
	Single	0.00	1.88	19.40	0.00	17.56	8.09
	Divorce/widowed	0.00	3.76	7.46	10.81	4.58	4.93
Education Hh	No formal school	16.67	27.07	16.42	21.62	6.87	20.44
	Primary	33.33	54.89	37.31	64.86	29.01	45.76
	Secondary	16.67	11.65	23.88	10.81	12.98	13.61
	Dip/Cert.	16.67	4.89	14.93	0.00	20.61	10.06
	Undergrad	1.13	4.48	0.00	0.00	16.79	5.72
	Postgrad	0.00	0.38	2.99	2.70	13.74	4.34
Education spouse	No formal school	33.33	53.76	38.81	29.73	30.53	43.79
	Primary	33.33	36.47	38.81	45.95	22.14	33.73
	Secondary	0.00	7.14	10.45	18.92	18.32	11.24
	Dip/Cert.	16.67	1.88	2.99	2.70	13.74	5.33
	Undergrad	16.67	0.75	7.46	2.70	14.50	5.52
	Postgrad	0.00	0.00	1.49	0.00	0.76	0.39
Religion	Orthodox	33.33	25.19	32.84	18.92	60.31	34.91
	Protestant	66.67	74.06	65.67	75.68	38.17	63.51
	Muslim	0.00	0.00	1.49	0.00	0.76	0.39
	Catholic	0.00	0.38	0.00	0.00	0.76	0.39
	Traditional	0.00	0.38	0.00	5.41	0.00	0.39
Occupation	Farmer	83.33	96.24	28.36	91.89	16.03	66.07
	Business	16.67	1.13	68.66	5.41	30.53	18.15
	Employed	0.00	2.63	2.99	2.70	47.33	14.20
	Retried	0.00	0.00	0.00	0.00	6.11	1.58
Land access	Yes	83.33	96.24	50.75	86.49	19.08	69.63
	No	16.67	3.76	49.25	13.51	80.92	30.37
Land tenure	Titled	100.00	94.90	76.47	100.00	84.00	92.90
	Informal	0.00	5.10	23.53	0.00	8.00	6.53
	Communal	0.00	0.00	0.00	0.00	8.00	0.57
Training	Yes	16.67	55.64	53.73	91.89	23.66	50.10
	No	83.33	44.36	46.27	8.11	76.34	49.90
Training Moringa	Yes	16.67	17.18	19.44	79.41	0.00	16.17
	No	83.33	82.82	80.56	20.59	100.00	83.83
Pest severity	Low	0.00	5.64	32.84	32.43	3.82	10.65
	Medium	100.00	47.37	59.70	43.24	48.85	49.70
	High	0.00	46.99	7.46	24.32	47.33	39.64

Source: Authors' constructs.

to 8% who were single and 5% who were divorced or widowed. However, the percentage of single respondents was higher among distributors and consumers.

Gender plays a significant role in the Moringa value chain (UNDP, 2018). In many regions, women play a central role in agricultural production, processing, and marketing. Given the nature of Moringa value chain activities, women's participation makes the chain more efficient and profitable. Women's intense involvement in tasks such as harvesting, drying, sorting, and small-scale processing ensures careful handling and consistent product quality, which enhances market value. Their dominance in local marketing and retailing also strengthens the link between producers and consumers, facilitating faster product turnover and wider adoption of Moringa products. At the household level, women's role in promoting Moringa for nutrition increases its demand, while their collective engagement in cooperatives boosts processing and market access (Duguma *et al*., 2023; Derbo and Debelew, 2024). Altogether, women's active participation not only sustains the value chain but also enhances its overall efficiency, profitability, and long-term growth.

In terms of education, the results show that most household heads (46%) had attained primary school education, 13% had attained secondary school education, 10% held a diploma or certificate, and 20% of the household heads had not attended formal school. In contrast, the majority of spouses, 44%, had not attended formal school; 33% had attended primary school; and 11% had attended secondary school. This indicates that men were more educated than women in the study area. This is because most spouses were female (only 22% of household heads were female). Interestingly, tertiary education (diploma/certificate, undergraduate, or postgraduate) was highest among the consumers for the household heads but was high among the consumers and input suppliers for the spouses. This might be because most consumers and input suppliers reside in urban areas and have greater educational attainment. Hussen and Workie (2023) also found that women from rural areas were less likely than urban residents to attain higher levels of education in Ethiopia.

The majority of respondents in the Moringa value chain, except consumers, were Protestant religion followers. In terms of occupation, the majority of household heads (83.3% of input suppliers, 96.2% of growers, and 91% of processors) were farmers, while 68.7% of the distributors were engaged in business and 47.3% of consumers were employed. This suggests that most consumers reside in urban areas and lack access to land for farming. Access to land differed among value chain actors. The majority of input suppliers, growers, and processors had access to land, whereas only about half of the distributors had access to land, and the majority of consumers did not have access to land. Land access was titled for the majority of respondents across all the value chain actors.

The majority of input suppliers (83.33%), growers (82.82%), distributors (80.56%), and all consumers (100%) did not have access to training related to Moringa, whereas almost 80% of the processors had access to training related to Moringa. This may be because most Moringa processors are members of cooperatives established by the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Industrial Development Organization (UNIDO) (UNIDO, 2022). Some of the training provided by UNIDO focused on planting and managing Moringa seedlings, pruning and harvesting the leaves, packaging products for marketing, and adding value to Moringa products (UNIDO, 2022).

However, the majority of growers (55.64%), distributors (53.73%), and processors (91.89%) had access to different types of training, rather than Moringa-related training. The Ethiopian government established Farmers Training Centers (FTCs) in 2002 in each rural kebele (the lowest unit of administration in the country; Wonde *et al*., 2022). The FTCs provide training on improved varieties and farming techniques, market-oriented information and advisory services, and pest and disease management practices. Pest severity had a significantly greater impact on growers than on other actors in the Moringa value chain, which is not unexpected given their role. The findings highlight the importance of enhancing the capacity of FTCs, particularly in Moringa pest management practices such as Integrated Pest Management (IPM), across the study areas.

Table 4 describes the findings of the continuous variables. The mean age of the household head was 41 years, with an average family size of about six. The average land size was 0.62 ha, which

Table 4. Summary statistics of continuous variables.

Variables	Variable description	Mean (Standard dev.)
Age	Age of household head (HH) in years	41.24 (13.27)
Family_size	Number of household members	5.76 (2.76)
Land_size	Land size in hectares	0.62 (0.64)
Farm_experience	Farming experience in years	20.30 (15.89)
Total_livestock	Number of livestock (total livestock unit [TLU])	1.43 (2.10)
No_moringa tree	Number of Moringa trees	24.92 (34.96)
Distance_ext office	Distance from the extension office in km	2.75 (2.50)
Distance_district office	Distance from the district office	14.26 (11.25)
Distance_market	Distance from market	3.17 (4.45)
Outcome variables		
Input suppliers	Income of input suppliers	54675.00 (96641.68)
Growers	Income of growers	15736.77 (244472.60)
Distributors	Income of distributors	24741.07 (24360.65)
Processors	Income of processors	35306.76 (69246.96)
Consumers	Income of the consumer	14370.63 (22125.02)
Average income	Average income in birr	18462.69 (31623.24)

Source: Authors' constructs.

is in line with other studies (Holden and Tilahun, 2020). Most farmers have an average of 20 years of farming experience. The average number of Moringa trees in the study areas was about 25, ranging from 2 to 50. This finding aligns with Abay *et al.* (2015), who reported a range of 1 to 40, and is slightly lower than Demisse *et al.* (2024), who noted that the number of Moringa plants per household ranged from 1 to 100. In most of the study areas, local markets and extension offices were located nearby, at an average distance of 3.17 km and 2.75 km, respectively. The average annual income of the respondents was 18,462 birr (approximately US$ 120). On average, input suppliers got the highest income, followed by processors and distributors.

OVERVIEW OF MORINGA PEST AND DISEASE IN THE STUDY AREAS

Pests and diseases pose a significant threat to Moringa cultivation in Ethiopia, affecting both yield and quality (Kumssa *et al*., 2017). In Ethiopia, insect pests are the more critical factors in Moringa production compared to diseases (Kumssa *et al*., 2017). In this study, the majority of the respondents (75%) indicated that the Moringa moth was a common pest, 14% of the respondents indicated beetles as being common pests, 5% indicated aphids as common pests, and 6% indicated other pests (not specified in the questionnaire) as being common. The Moringa moth is the primary pest affecting farmers' livelihoods. These pests are seasonal, mostly appearing after the rainy season (Anjulo, 2009). Most farmers reported that the Moringa moth commonly appears from May to June and again from November to December. Respondents mentioned that the larval stage of the Moringa moth causes the most damage by feeding on the leaves, often resulting in severe defoliation, with 100% damage occurring in some instances. Anjulo (2009) also noted that during the severe infestation period of the Moringa moth, entire branches of Moringa trees were defoliated.

Farmers employed various pest and disease management practices, including the use of insecticides, as well as manual and cultural methods. Some of the manual methods used by farmers in the study areas to control insect pests included hand-picking larvae and pruning. Cultural practices such as harvesting Moringa leaves early before the insects appear and applying ash to control insect pests were also mentioned. The majority of farmers in Derashe district, nearly 70%, applied pest and disease management practices compared to only 20% in the Arba Minch district. Of concern, 54% of farmers in Derashe reported using broad-spectrum insecticides, such as synthetic pyrethroids and organophosphates, as their primary method of control (Fig. 3).

According to focus group discussions and key informant interviews, this is because most farmers in the Arba Minch district have received numerous trainings, including in IPM, compared to those in the Derashe district. This practice of chemical use as the primary method of control poses significant risks to human, animal, and environmental health (Cech *et al*., 2023), including an increased risk of pesticide resistance in the pest. Of additional concern is that, during the interviews, many farmers indicated that they use whatever insecticides are readily available in local markets, without specific guidance or regulation. Multiple studies confirm that the use of excessive and unsafe pesticides is increasing in Ethiopia (Negatu *et al*., 2021; Aschale *et al*., 2024; Asefa *et al*., 2024). This highlights the importance of raising awareness of the safe use of pesticides and of providing IPM training and capacity-building to promote sustainable pest management.

DETERMINATE FACTORS INFLUENCING PESTS AND DISEASE SEVERITY

In this analysis, we only considered Moringa growers' data, as they are directly affected by pests and diseases compared to other actors in the value chain. The MNL model was used to analyse the determinants of pest and disease severity by estimating the probability that growers fall into different severity categories (low, medium, or high), based on their socio-economic, farm and institutional characteristics.

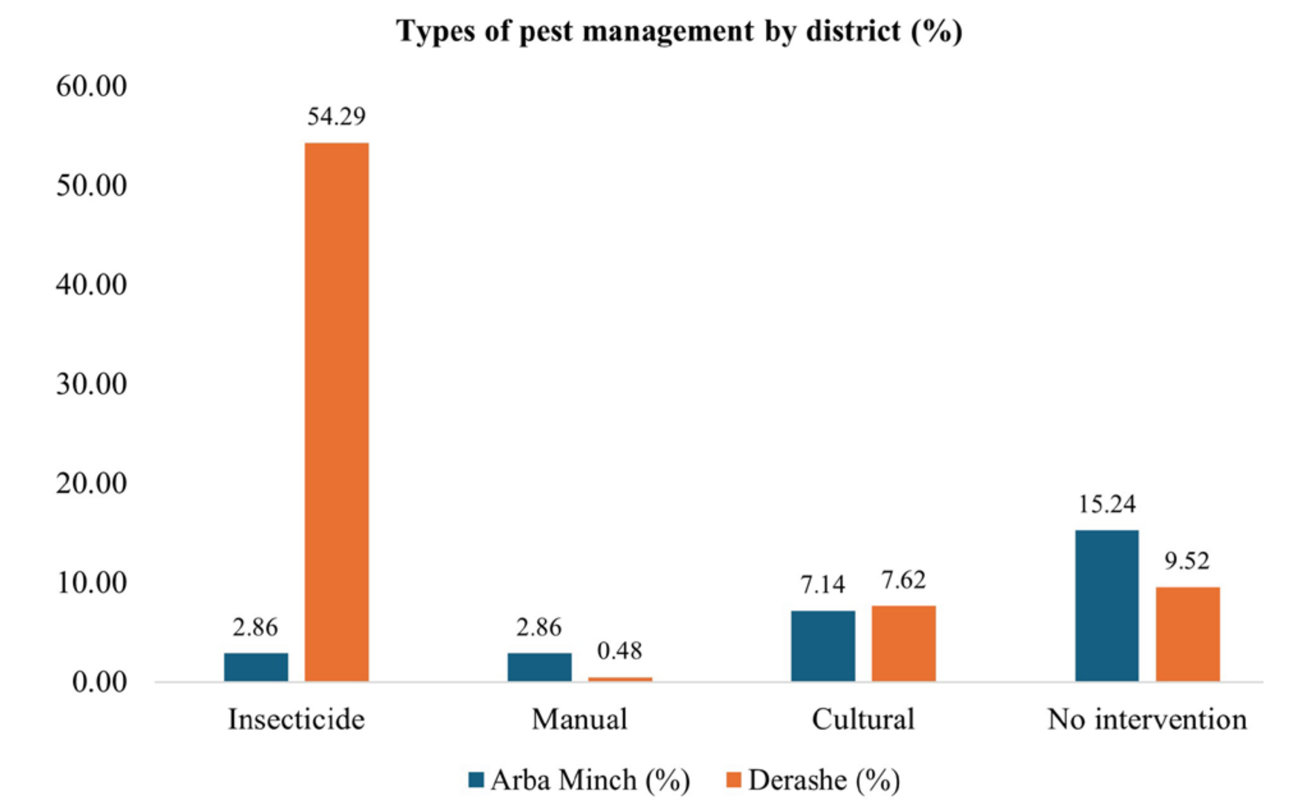

Fig. 3. Types of pest management practices by district.

Table 5 presents the MNL regression results. The age of the households was positively and statistically significantly associated with both the medium and high categories at the 10% significance level. The positive coefficients indicate that as age increases, the likelihood of experiencing medium or high pest severity increases relative to low severity. This might be due to older farmers having less labour capacity or using traditional practices that are less effective against pests. The sex of the household head was statistically significant at the 10% level for both the medium and high pest severity categories. The negative coefficients indicate that male-headed households have a lower probability of experiencing medium or high levels of pest severity compared to female-headed households. This might be due to male-headed households in Ethiopia often having greater capacity to manage pests and diseases than female-headed households, owing to better access to resources and information (Gebre *et al*., 2021). Access to training was statistically significant at the 5% level for medium pest severity. The negative coefficient indicates that farmers with access to training had a lower probability of experiencing a medium level of pest severity compared to those without access to training. These findings are consistent with many other studies showing that farmers who received training have better pest and disease management (Kassaw *et al*., 2025).

Most of the variables, including education, marital status, family size, access to land, land size, and distance from market, were not statistically significant predictors of pest severity. This indicates that there is no significant difference among growers categorised as low, medium, and high pest severity in these factors.

The instrumental variables, cooperative membership, and district were statistically significant at the 5% level for both medium and high categories. This result indicates that these instruments have a strong, significant effect on pest severity. The statistical significance of these variables confirms their relevance, as they are strongly correlated with pest severity. For instance, the negative coefficient on cooperative membership indicates that cooperative members are less likely to experience medium or high levels of pest severity than non-members. This may be attributed to their better access to information, training, and support related to pest and disease management practices through cooperatives. The positive and significant coefficient of the district dummy indicates that being in the Arba Minch district increases the likelihood of experiencing medium pest severity relative to low severity, compared to Derashe (Table 5). This may be because the majority of growers in the Derashe district practice periodic pollarding to encourage fresh leaves and resprouting. This tree management leads to Moringa

Table 5. Multinomial logit model estimates using the severity of pest and disease.

	Medium				High			
Variables	**Coef.**	**Std. Err.**	**P > z**	**dy/dx**	**Coef.**	**Std. Err.**	**P > z**	**dy/dx**
Age	0.029	0.015	0.056*	0.0022	0.026	0.015	0.075*	0.007
Sex_HH (1 = male; 0 = female)	−0.072	0.356	0.062*	0.031	−0.669	0.365	0.067*	0.026
Primary_edu	−0.232	0.501	0.643	0.024	−0.399	0.508	0.432	−0.047
Secondary_edu	−0.273	0.607	0.653	0.061	−0.646	0.624	0.301	−0.095
Diploma/cert_edu	−0.983	0.670	0.143	−0.079	−0.818	0.677	0.227	−0.006
Undergraduate	−0.403	0.837	0.630	−0.022	−0.378	0.852	0.657	−0.009
Postgraduate	0.304	1.215	0.802	−0.006	0.379	1.223	0.757	0.027
Single	0.027	0.544	0.900	0.041	−0.183	0.574	0.750	−0.047
Divorced/widowed	0.279	0.717	0.697	0.108	−0.219	0.765	0.775	−0.101
Family size	−0.006	0.075	0.940	−0.019	0.094	0.074	0.206	0.022
Access to land (1 = yes; 0 = no)	−0.543	0.449	0.227	−0.026	−0.543	0.459	0.236	−0.020
Land size	−0.206	0.344	0.550	−0.008	0.139	0.343	0.684	0.002
Training (1 = yes; 0 = no)	−0.863	0.359	0.016**	−0.002	−0.595	0.365	0.104	0.003
Livestock (TLU)	0.181	0.106	0.089	0.011	0.167	0.107	0.120	0.029
Distance_market	0.031	0.052	0.561	−0.001	0.039	0.053	0.453	0.003
Number of Moringa plants	0.003	0.008	0.520	0.002	0.003	0.008	0.745	−0.000
Cooperative member (1 = yes; 0 = no)	−0.899	0.456	0.048**	−0.021	−1.014	0.469	0.031**	−0.061
District dummy (1 = Arba Minch; 0 = Derashe)	0.362	0.423	0.018**	0.087	0.002	0.433	0.998	0.069
Constant	1.186	0.820	0.153		0.259	0.847	0.741	
Log likelihood				−455.954***				
Pseudo R^2				0.056				
Prob > chi^2				0.015**				
Observation				507				

Source: Authors' construct.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

moth egg-laying and subsequent larval feeding and damage, forcing farmers to use insecticides to control insect pests (Fig. 3). However, in addition to health and environmental risks, there is a high likelihood that pesticide resistance will evolve from repeated use.

DETERMINANT FACTORS INFLUENCING PARTICIPATION IN DIFFERENT STAGES OF THE VALUE CHAIN

To analyse the determinant factors that influence participation in various stages of the Moringa value chain, we merged input suppliers with growers due to the small sample size of input suppliers and because most of them also grow Moringa, and we refer to them collectively as growers, using them as the base category in the MNL regression. The results of the MNL regression, using growers as the base category, reveal several statistically significant factors influencing the likelihood of being categorised as distributors, processors, or consumers in the Moringa value chain (Table 6).

Age has a negative, statistically significant coefficient on the likelihood of being a distributor or processor relative to being a grower at the 1% significance level, indicating that younger individuals are more likely to participate in distribution and processing activities. This is because most young people in Ethiopia lack access to land for growing Moringa trees, so they engage in distribution and processing activities instead. Similarly, the sex of the respondent had a negative coefficient. The results were statistically significant at the 1% and 5% levels, indicating that male respondents are significantly less likely to be distributors, processors, or consumers compared to growers. This aligns with the findings in the UNIDO (2022) progress report, which indicates that most Moringa growers are men, while women primarily participate in processing, marketing, and distribution. Regarding educational status, individuals with secondary education were statistically significant at the 5% level (more likely to be distributors but less likely to be processors), possibly reflecting that most processors in the study areas are women farmers with lower access to education.

Marital status also plays a significant role, particularly for single individuals, who are more likely to be distributors and consumers than growers compared to married households. This might be because, in most cases, women are involved in small businesses (UNDP, 2018; UNIDO, 2022). Family size is negatively associated with being a distributor and consumer, suggesting that individuals from larger households may be more likely to remain growers.

Access to land was negatively associated with being a distributor and consumer, statistically significant at 1%, and with being a processor, statistically significant at 5%, indicating that individuals with access to land are more likely to be growers rather than distributors, processors, or consumers (Table 6). This is because most growers reside in rural areas and have access to land for growing Moringa, as mentioned above in the demographic and socio-economic results. Participation in training does not significantly affect the likelihood of being a distributor or processor. However, it is negatively associated with being a consumer, possibly indicating that consumers are less likely to attend trainings that are related to farming.

Distance from the market was also statistically significant at the 1% level for both distributors and consumers. The negative coefficient indicates that as the distance to the market increases, the probability of remaining at the growers' level is high rather than participating as a distributors or consumers. The number of Moringa plants owned was negatively associated with being a consumer, indicating that individuals with more Moringa plants are more likely to be growers instead of consumers. This might be because most consumers live in urban and sub-urban areas and do not have access to land to plant Moringa trees.

The instrumental variables, namely cooperative membership and district, were statistically significant at the 1% and 5% levels for both distributors and processors. This result indicates that these instruments have a strong, significant effect on participation across different stages of the Moringa value chain. The statistical significance of these variables in both model confirms their relevance condition, suggesting that they are valid instruments as they are strongly correlated with pest and disease severity and value chain participation. At the same time, since these variables are assumed not to directly influence the outcome variable except through participation decisions, the findings support the validity of the instrumental variable approach used in this study. The Wald test further confirms that the instrumental variables are jointly significant in determining participation in various value chain stages ($\chi^2 = 14.88$, $p < 0.05$). This finding provides evidence that the instruments are strongly correlated with the endogenous treatment variable, thereby supporting their relevance and appropriateness in the model. This finding supports the use of the MESR model to control for potential selection bias arising from unobservable factors that may simultaneously influence participation decisions and outcome variables.

Cooperative membership significantly increases the likelihood of becoming a distributor, and even more so, a processor. Most cooperative members in the study engaged in the distribution and processing stages of the value chain compared to growers (UNIDO, 2022). The district variable was also significant at the 1% level, indicating that respondents in the Arba Minch district are less likely to be distributors but more likely to be processors, reflecting spatial differences in value chain participation. This is due to access to infrastructure, training, and technologies; the Arba Minch district has better access to these than the Derashe district. Most of the processors were located in the Arba Minch district. This highlights the need for government intervention to enhance the Moringa value chain in the Derashe district by upgrading infrastructure and providing training.

THE IMPACT OF MORINGA VALUE CHAIN PARTICIPATION ON HOUSEHOLD INCOME

Table 7 presents the results of the MESR, which assesses the income implications of farmers' participation across different stages of the Moringa value chain, using growers as the reference category, and estimates the average treatment effect. The results indicate that individuals participating as distributors have an observed annual income of 12,937 birr (approximately US$ 85), whereas their expected income would have been 22,456 birr (approximately US$ 145). The corresponding ATT is −9519 birr (61 USD), 42% lower than remaining as growers, and statistically significant at the 1% level ($p < 0.01$), suggesting that distributors earn significantly less than they would have as growers. This might be because most distributors are small business owners, and selling Moringa might be their primary income source, unlike growers, who may have additional income sources (Kelemu and Alemu, 2013).

For processors, the observed income is 13,562 birr (approximately US$ 88), while the expected income as growers was 15,254 birr (US$ 100), resulting in an ATT of −1692 birr (US$ 11), which is 11% lower. However, this difference was not statistically significant, indicating no significant income difference between processors and growers. This is because most processors in the Moringa value chain are at the initial stages, and Moringa is the primary source of income for growers, who also have additional income sources (Kelemu and Alemu, 2013). With only a few processors operating at medium-scale capacity, they were excluded from the survey.

In contrast, individuals categorised as consumers report an observed income of 22,365 birr, whereas an expected income of 16,256 birr (105 USD) would have been had they remained growers. The ATT of 6109 birr (approximately US$ 40), 37% higher than that of growers, was statistically significant at the 1%

Table 6. Multinomial logit model estimates using different value chain actors.

	Distributors				Processors				Consumers			
Variables	**Coef.**	**Std. Err.**	**P > z**	**dy/dx**	**Coef.**	**Std. Err.**	**P > z**	**dy/dx**	**Coef.**	**Std. Err.**	**P > z**	**dy/dx**
Age	−0.060	0.019	0.001***	−0.005	−0.072	0.024	0.002***	−0.002	0.014	0.016	0.352	0.004
Sex_respondent (1 = M; 0 = F)	−1.046	0.382	0.007***	−0.046	−1.689	0.515	0.001***	−0.054	−0.877	0.425	0.036**	−0.022
Primary_edu	0.547	0.488	0.262	0.035	−1.141	0.672	0.089*	−0.081	0.553	0.603	0.348	0.045
Secondary_edu	1.094	0.598	0.067*	0.119	−1.946	0.898	0.030**	−0.113	0.122	0.744	0.869	−0.011
Diploma/cert_edu	1.173	0.739	0.113	0.112	−1.537	0.707	0.981	−0.159	0.711	0.789	0.362	0.039
Undergraduate	0.404	1.091	0.708	0.019	−1.421	0.229	0.994	−0.159	1.124	0.989	0.255	0.106
Postgraduate	1.701	1.628	0.296	0.071	−0.547	1.782	0.756	−0.082	2.353	1.479	0.113	0.161
Single	1.747	0.714	0.014**	0.132	−1.537	0.461	0.983	−0.076	1.831	0.770	0.017**	0.092
Divorced/widowed	0.576	0.791	0.467	0.054	0.514	0.849	0.544	0.018	−0.081	0.786	0.917	−0.033
Family size	−0.146	0.085	0.083*	−0.006	0.032	0.078	0.686	0.003	−0.179	0.088	0.039**	−0.009
Access to land (1 = Y; 0 = N)	−3.326	0.525	0.000***	−0.132	−1.809	0.782	0.021**	−0.029	−3.835	0.628	0.000***	−0.168
Land size	0.070	0.397	0.854	0.132	−0.302	0.425	0.477	0.033	−0.175	0.567	0.171	−0.005
Training (1 = Y; 0 = N)	0.080	0.377	0.898	0.036	0.792	0.577	0.181	−0.002	−0.892	0.404	0.025**	−0.077
Livestock (TLU)	−0.070	0.103	0.500	−0.001	−0.072	0.117	0.538	0.001	−0.142	0.142	0.298	−0.078
Distance from market	−0.228	0.079	0.004***	−0.012	−0.117	0.073	0.111	−0.002	−0.178	0.054	0.001***	−0.004
No. of Moringa plants	−0.011	0.010	0.280	0.006	0.001	0.009	0.908	0.001	−0.194	0.066	0.004***	−0.008
Cooperative (1 = Y; 0 = N)	1.128	0.573	0.049**	0.943	2.431	0.543	0.000***	0.189	−0.223	0.181	0.999	−0.014
District (1 = Arba Minch; 0 = Derashe)	−1.413	0.489	0.004***	−0.121	2.413	0.723	0.001***	0.107	−0.564	0.549	0.292	−1.831
Constant	5.671	1.008	0.000		1.969	1.323	0.138		4.321	1.081	0.000	−0.001
Log likelihood	−285.118***											
Pseudo R^2	0.508											
Prob > chi2	0.000***											
Observation	507											

Source: Authors' construct.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

level. Although this suggests a substantial income advantage for consumers relative to growers, it reflects the fact that most consumers live in urban and suburban areas and are employed in permanent or temporary jobs.

Overall, the findings demonstrate that remaining in the grower segment yields significantly higher income than participating as a distributor, while no significant difference was observed for processors. The consumer segment appears to offer the greatest income benefit; however, this income is not directly attributable to Moringa. This indicates that, despite the Moringa value chain contributing to job creation and income generation for distributors and processors, it remains underdeveloped in Ethiopia and requires further development.

THE IMPACT OF PESTS AND DISEASES ON GROWER INCOME

Table 8 presents the findings of the impact of pest severity levels on farm income. The results show no statistically significant differences. This indicates that there is no significant income difference among the three groups: low, medium, and high pest severity. The non-significant effect of pest impact on household income may be due to two reasons: most growers in the study area cultivate Moringa for household consumption, which is not the primary source of income, and the pest infestation lasted only a short period in the previous year.

In summary, the findings of the study show that demographic, institutional, and resource-related factors play key roles in determining the likelihood of participation in non-growing activities (distribution, processing, and consumption). Younger individuals, women, singles, and cooperative members were more likely to engage in distribution and processing. At the same time, larger household sizes and greater numbers of Moringa plants were associated with continued participation in growing. However, the age of the household head and the district affected the pest severity level. Growers in the Arba Minch district were more likely to experience medium pest severity compared to those in Derashe.

The income analysis using the MESR model indicated that distributors earned significantly less than they would have as growers; processors showed no significant difference in income, and consumers, primarily urban residents with other sources of income, appeared to have the highest earnings. However, Moringa still provides job opportunities for distributors and processors. Furthermore, the analysis of pest impact on grower income showed no statistically significant differences among low-, medium-, and high-severity groups, likely due to the short duration of infestations and the predominance of Moringa cultivation for household consumption rather than commercial purposes.

CONCLUSIONS

This study used primary data from different Moringa value chain actors in Arba Minch and Derashe District, South Ethiopia, to examine the socio-economic impact of pests and diseases on the Moringa value chain. The study employed a multinomial endogenous switching regression model to control for selection bias in the choice of Moringa value chain and pest severity level, accounting for both observable and unobservable factors.

The findings of the study suggest that Moringa is crucial for food security, provides employment opportunities for distributors and processors and offers medicinal and cultural benefits. Although the demand for Moringa products is increasing, the Moringa value chain in Ethiopia remains underdeveloped and is affected by pests and diseases. Policy interventions by the government and non-governmental organisations are very important for developing the Moringa value chain. Some of the intervention strategies could include improving access to transportation infrastructure, as Moringa is a very perishable leaf; access to cold storage; and access to training on production, processing, handling, and pest management. The findings also show that pesticide use in the Derashe district was extremely high. As Moringa is the main staple vegetable in the study area, raising awareness about the impact of pesticide use on humans, animals, and the environment is crucial. Promoting sustainable pest management practices, such as IPM, is vital. Otherwise, the production and consumption of Moringa may be hazardous in the near future in the study areas.

RECOMMENDATIONS FOR FURTHER STUDY

This study was conducted in only two districts in South Ethiopia, which may limit the generalizability of the findings to other Moringa-growing regions. Future research should include additional Moringa-growing areas to provide a more comprehensive understanding of the value chain across the country. In addition, the study used cross-sectional data, which may not fully capture the seasonal and long-term impacts of pests and diseases on the Moringa value chain and on the income and livelihoods of actors. Longitudinal studies using panel or time-series data are recommended to account for seasonal fluctuations, pest and disease dynamics, and key socio-economic factors.

Table 7. MESR-based average treatment effects of the choice of value chain actors.

	Value chain actors		
Outcome variable (income)	**Value chain actors (*j* = 2, 3, 4)**	**Reference actor (grower) (*j* = 1)**	**Average treatment effects (ATT)**
Distributors	12,937	22,456	−9519***
Processors	13,562	15,254	−1692
Consumers	22,365	16,256	6109***

Note: 1 is grower; 2 is distributors; 3 is processor; 4 is consumer; exchange rate: $1 = 154 birr.
Source: Authors' construct. ***$p < 0.01$.

Table 8. MESR-based average treatment effects of the impact of pest and disease.

	Pest impact		
Outcome variable (income)	**Pest impact (*j* = 2, 3)**	**Reference impact (low) (*j* = 1)**	**Average treatment effects (ATT)**
Medium	22,560	20,225	2335
High	19,562	22,256	−2694

Note: 1 is low; 2 is medium; 3 is high; exchange rate: $1 = 154 birr.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

ETHICS STATEMENT

The study followed the University of Pretoria's ethical guidelines and was approved accordingly (NAS040/2025).

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AUTHOR CONTRIBUTIONS

WF contributed in conceptualization, data curation, formal analysis, methodology, writing – original draft; AA contributed in conceptualization, project administration, writing – review & editing; MH contributed in funding acquisition, writing – review & editing; SAL contributed in funding acquisition, writing – review & editing; and BPH contributed in conceptualization, funding acquisition, methodology, project administration, supervision, writing – review & editing.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author.

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