Medicinal plant cultivation and smallholder welfare in Amatole, South Africa: A propensity score analysis

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The sustainable use of medicinal plants by smallholder farmers in the Amatole District Municipality in the Eastern Cape Province, South Africa, plays a vital role in rural livelihoods. Despite challenges such as limited inputs, capital, institutional support and market access, the cultivation of medicinal plants significantly contributes to smallholder welfare. However, research valuing this production remains limited. We therefore assessed the welfare effects of smallholder participation in medicinal plant cultivation in Amatole. Primary data were collected from 150 smallholder farmers using structured questionnaires and a multi-stage stratified sampling technique. Descriptive statistics, binary logistic regression and propensity score matching were used for analysis. Findings indicate that female farmers dominate medicinal plant production, with an average age of 44 and 10 years of schooling. The average household size was six, with family labour supporting production. The average farm size was 1 hectare. Extension services played a key role in improving farmers' knowledge. Participation was profitable, with an average monthly household income of ZAR19 091.72 and a return on investment of 0.71. Binary logistic regression showed that gender, household size, experience, extension visits and environmental protection positively influenced participation, while age and education had negative effects. Propensity score matching results revealed a significant positive impact of cultivation on farmers' welfare, with an increase of ZAR5624.64 in farm returns at the 5% significance level. To enhance outcomes, we recommend targeted policies that improve funding, extension services and support for female and experienced farmers. Scaling up medicinal plant cultivation can improve rural livelihoods and advance sustainable development in the Amatole District Municipality.

Significance:

This study highlights the crucial role of female farmers in medicinal plant cultivation, with most participants being women, with an average age of 44 years and over 10 years of schooling. Their involvement aligns with traditional caregiving roles and household health responsibilities. A binary logistic regression shows that household size and farming experience positively influenced participation, while higher education had a negative effect on participation. Using propensity score matching, we found that cultivation significantly improved household welfare. These results support the promotion of inclusive, gender-sensitive policies to strengthen medicinal plant value chains and enhance the livelihoods of rural smallholder farmers.

Introduction

Medicinal plants are internationally acknowledged and valued components of health supplements and medications.[1,2] In developing countries, raw medicinal plants are more easily accessible in rural areas than in urban areas; they often reach urban areas through rural smallholder farmers in pursuit of markets.[3,4] Omotilewa et al.[5] acknowledged the involvement of smallholder farmers in poverty reduction and the eradication of hunger in Africa through the production of medicinal plants. Smallholder farms are precisely small farms that are alleged to have a household-intensified technical labour force to maximise production while minimising costs. In sub-Saharan Africa, smallholder farmers produce on land smaller than 2 ha, often characterised by their adoption of local methods, using native skills and experiences that are passed down for generations.[6] South African smallholder farmers often live in rural settlements, which are regions that are richly endowed with fauna and flora. Medicinal plants form part of this biodiversity that surrounds these settlements and have been harvested extensively by the smallholder community as a traditional medicine for domestic use or as a product to sell.[7-9]

For centuries, rural communities have relied on medicinal plants as a primary source of natural healing, deeply embedding these plants within local healthcare practices. According to Umeta Chali et al.[10], smallholder farmers in rural areas are the principal custodians of Indigenous knowledge related to medicinal plants, playing a key role in preserving these resources as part of their cultural heritage. The cultivation of medicinal plants not only aids in the conservation of biodiversity but also provides smallholder farmers with opportunities to generate additional income.[11] In low-resource settings, where access to modern health care may be limited or prohibitively expensive, medicinal plants remain particularly significant. They serve as essential remedies for a wide range of ailments and contribute to reducing dependency on costly pharmaceutical drugs. Most notably, smallholder subsistence farmers who cultivate these plants within their local ecosystems, are central to sustaining this practice. Their efforts bridge the gap between agriculture and traditional medicine, reinforcing both economic resilience and community health. Thus, medicinal plant cultivation stands at the confluence of ecological conservation, rural health care and livelihood enhancement.[12,13]

Understanding the impact of medicinal plant cultivation on household welfare is critically important for several reasons. From an economic standpoint, growing medicinal plants provides smallholder farmers with a valuable means of income diversification, helping to reduce income volatility and strengthen household financial stability.[14] Furthermore, the expansion of medicinal plant production generates local employment opportunities, thereby fostering broader socio-economic development within rural communities. According to Petelka et al.[15], the income derived from medicinal herbs enables households to afford essential needs such as health care, food and education, thus ultimately contributing to an improved standard of living. In addition to its economic and social benefits, the cultivation of medicinal plants plays a vital role in biodiversity conservation.[3] Smallholder farmers often possess deep, context-specific knowledge of native plant species and their ecological requirements. By cultivating these plants, they contribute to the preservation of local flora and the safeguarding of genetic diversity. Moreover, sustainable medicinal plant farming practices have environmental benefits, including enhanced soil quality and reduced ecological degradation.[16-18] These contributions align with broader goals of ecological sustainability and support the creation of healthier, more resilient rural ecosystems.

Nevertheless, planting medicinal plants is not an easy venture. Smallholder farmers encounter several difficulties, such as limited inputs, lack of technical expertise and poor market accessibility. They could also face the problem of excessive harvesting and destruction of local ecosystems.[12] In addition to these challenges, the unregulated nature of, as well as quality control within, the medicinal plant market expose smallholder farmers to market risks, which affect their income stability. Therefore, it is important to investigate these challenges so that appropriate interventions can be put in place for smallholder farmers who are striving to develop income streams from medicinal plants.

Hence, we sought to assess the effect of merchandising these curative plants as a trade commodity on the welfare of smallholder farmers. There is a lack of evidence in the literature on the impact of utilising medicinal plants for profit on livelihood enhancement. Because the industry is unregulated, data on the employment rate, income generated and measures of available resources in the wild, are inconclusive. Therefore, the aim of this study was to supplement the prevailing literature and investigate the effects of the production of medicinal plants on household welfare.

Methodology

Conceptual framework for medicinal plant production involvement

Figure 1 illustrates the interlinkage of the factors that affect the production and sustainable use of medicinal plants by smallholder farmers. These factors signify a pivotal contribution to the outcomes (farm returns) that arise from the association of smallholder farmers in the production or wild harvesting of medicinal plants. These plants often play a pivotal role as remedial agents in the societies where smallholder farmers live. The contribution of smallholder farmers to the production and sustainable use of medicinal plants is highly influenced by socio-economic and institutional factors, market dynamics and information availability.

Figure 1 begins by illustrating the key challenges faced by smallholder farmers in the cultivation and utilisation of medicinal plants. Many of the factors identified are general determinants that commonly influence smallholder farmers' participation in various agricultural activities, but their impact is uniquely pronounced or shaped by the context of medicinal plant production. These challenges significantly hinder progress in the development and livelihood improvement of these farmers. Critical issues such as limited access to land, inadequate agricultural knowledge (both indigenous and technical), market dynamics, information availability, and poor access to market information serve as major barriers to the effective production and sustainable extraction of medicinal plants from the wild. Such constraints make it particularly difficult for smallholder farmers to domesticate and commercialise high-value medicinal species such as (*Agathosma betulina* (buchu), *Aloe ferox* (Cape aloe), *Artemisia afra* (African wormwood), *Sutherlandia frutescens* (cancer bush), *Pelargonium sidoides* (African geranium), *Sceletium tortuosum* (kanna) and *Sclerocarya birrea* (marula). The lack of resources for essential operational activities, including harvesting and marketing, further exacerbates the problem. When these challenges are clearly defined and persist within the communities in which smallholder farmers operate, they generate adverse externalities that weaken the positive effects of medicinal plant production on household welfare. As a result, benefits such as improved health care, increased income, and better living standards are undermined due to the unavailability of the necessary support systems and infrastructure. High-value medicinal plants hold immense potential to transform the livelihoods of smallholder farmers, given their strong market demand and international significance. Their integration into rural farming systems can bring substantial economic and social benefits. Therefore, it is imperative to implement effective conservation strategies aimed at protecting species diversity. Such measures will ensure that smallholder farmers can continue to benefit from medicinal plants in a sustainable and equitable manner. The cultivation of medicinal plants and the conservation of natural resources are closely interconnected. As smallholder farmers engage in cultivating medicinal plants, they reduce the pressure on wild plant populations, which are often overharvested and at risk of extinction. Cultivation provides a sustainable alternative that supports biodiversity by promoting the regeneration and protection of native species. Additionally, farmers who participate in medicinal plant production tend to develop a stronger appreciation for environmental stewardship, as the long-term viability of their crops depends on healthy ecosystems. Thus, medicinal plant cultivation not only enhances livelihoods but also contributes directly to the conservation of plant species and natural habitats.

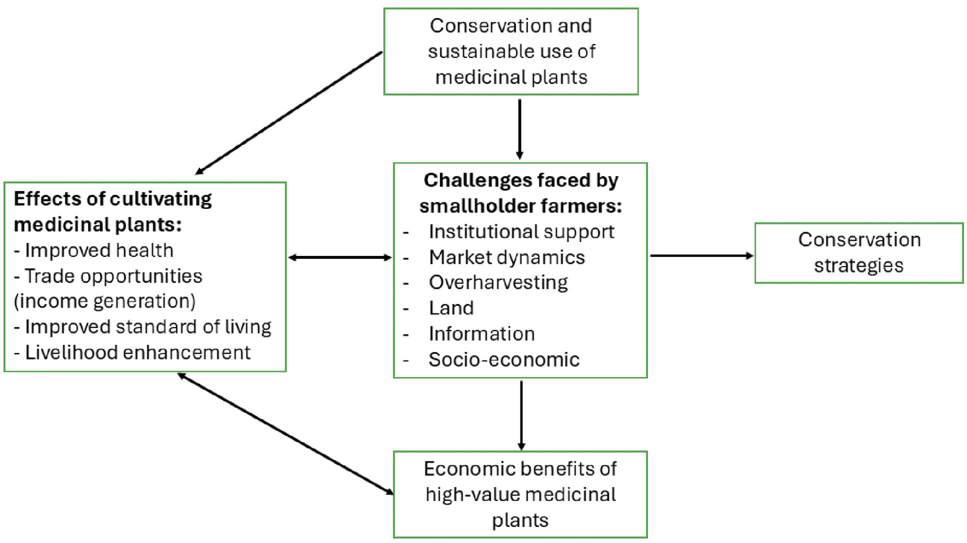

Figure 1: Conceptual framework of smallholder production of medicinal plants.

Description of the study

The study was conducted in the Amatole District Municipality (ADM) of the Eastern Cape Province of South Africa (latitude: –32.55895; longitude: 27.45919). The district municipality is situated in the former Transkei region, with predominantly rural settlements and some peri-urban settlements.[19] The majority of residents are involved in agriculture to maintain a basic livelihood. The study area is rich with natural resources across succulent grazing grasslands, forests, and marine life.[20] The climate of the ADM is similar throughout most of the region, but differs in some areas depending on their distance to the ocean.[21] The temperature fluctuates between the thresholds of 7 °C to 10 °C in the adequately dry and cool season, with a possibility of being snowy, and from 18 °C to 24 °C in the favourably humid season with hot weather. Adequate rainfall is expected in October and March, making them the rainiest months, and rainfall ranges from 750 mm to 1050 mm per annum.[21,22] Figure 2 shows the study area.

The ADM is classified as a Category C2 Municipality that is made up of six local municipalities: Amahlathi, Great Kei, Mbashe, Mnquma, Ngqushwa and Raymond Mhlaba. The ADM is home to a population of approximately 1.7 million people whose racial distribution is 91% African, 3% coloured and 6% white[23,24] and gender distribution is 52% female and 48% male[24]. The Amatole District Municipality Integrated Development Plan estimations suggest that 54% of the population survives below the poverty line and 66% make a living through social welfare grants because of high levels of unemployment.[25]

Data collection methods and sampling techniques

We used a quantitative research approach and an exploratory research design. We employed a cross-sectional design in which the data from smallholder medicinal plant farmers were obtained at a given point in time, and were careful not to repeat the targeted sample. This research design is suitable for a descriptive study and the determination of the connections among and between characteristics of each participant. The data were composed of numerous variables such as social demographics, the profitability of medicinal plants, challenges to adoption, production, and welfare. This approach is also cost-effective in terms of financial resources and very considerate of time.[26] According to Sharma[27], a sampling frame is defined as a list of units of the population from which the study sample will be drawn. The population of medicinal plants in the ADM was unknown, which is why we opted to use the Cochrane sample size formula to calculate the study sample size. The sampling frame for this study was unknown, as the medicinal plant farmers were not registered. Data about the performance level of the smallholder medicinal plant farmers was unknown. Hence, we used Cochrane's proportion to sample size calculator to estimate the sample size for the study. From the information collected, we identified the municipalities where medicinal plants are produced and the communities with an abundance of medicinal plant farmers. We depended on extension and advisory officers for assistance in finding medicinal plant farmers in the various communities of the ADM. The enumerators who were involved in the study were residents of the area.

A multi-stage sampling technique was employed to select participants for the study. A total of 150 smallholder farmers were carefully chosen to ensure the generation of credible and unbiased results. The multi-stage stratified sampling procedure employed in this research was designed to ensure that the sample accurately reflected the diversity of farming practices in the study area, with a particular focus on the cultivation of medicinal plants. This approach was structured in three stages to select a representative sample of smallholder farmers, ensuring that the study's findings would be reliable, valid and free from bias. Stage 1 involved the purposive selection of study sites, wards and villages in the ADM. This was a critical step, as it ensured the inclusion of areas where smallholder farmers were actively involved in medicinal plant production. The second stage involved dividing farmers into three distinct strata based on their primary farming activities: Stratum A – farmers engaged in medicinal plant production, Stratum B – crop farmers and Stratum C – livestock farmers.

Stratification was used to ensure that the diversity of farming practices in the study area was adequately represented, and allowed a focus on medicinal plant production, the primary area of interest. The final stage involved randomly selecting 125 farmers from Stratum A (medicinal plant farmers) and 25 farmers from Stratum B (non-medicinal plant farmers). This step was essential for ensuring that the sample size met the study's requirements while maintaining a representative distribution of participants. The random selection within each stratum minimised selection bias and allowed for a balanced comparison between medicinal and non-medicinal plant farmers. The random sampling method ensured that each farmer within the strata had an equal chance of being selected, providing a statistically sound basis for the findings and enhancing the generalisability of the results. The study's sample size was 150 smallholder plant farmers. Cochran's proportionate to size sampling methodology was used to determine the required sample size. The calculated sample size is shown in Equation 1:

$$n_1 = \frac{Z^2 p(1-p)}{e^2} = \frac{1.95 \times 0.5 \times 0.5}{(0.08)^2} = 150 \qquad \text{Equation 1}$$

where n is the required sample size; Z is the confidence level at 95% (standard value of 1.96); p is the estimate of smallholder medicinal plant farmers, which is at 0.89 (this was an assumption that 89% of smallholder

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Figure 2: Study area showing the study sites.

farmers participate in the production of indigenous medicinal plants in the study area); q is the weighting variable given by 1-*p*; e^2 is the margin of error at 5% (standard value of 0.05). The study used 125 medicinal plant farmers as participants, and 25 were non-participants. The selection of 125 medicinal plant farmers and 25 non-medicinal plant farmers allowed the study to focus primarily on the group of interest (medicinal plant farmers) while still incorporating a comparison group of non-participants in medicinal plant production. This design enabled the research to offer a nuanced understanding of the factors affecting medicinal plant farming and provided a comprehensive view of the agricultural landscape in the region.

This study relied on primary data collected directly from smallholder farmers engaged in agricultural activities, with a particular focus on those cultivating medicinal plants. Data collection was conducted through a combination of self-administered questionnaires and face-to-face interviews with those who volunteered to participate. Interviews were carried out in locations where smallholder farmers involved in medicinal plant production were accessible, continuing until the target sample size of 150 respondents was achieved. A well-structured questionnaire served as the primary data collection instrument. To ensure clarity and cultural relevance, three trained enumerators (fluent Xhosa, the local language) were responsible for administering the questionnaire. Their ability to communicate effectively in the respondents' native language enhanced understanding and accuracy in responses and contributed to more valid responses as farmers could express their views and experiences accurately in their own language. The enumerators were thoroughly trained in both the content of the questionnaire and effective data collection techniques. Training also emphasised ethical considerations, neutrality during interviews, and cultural sensitivity.

Prior to full deployment, the questionnaire was tested on 10% of the sample (15 farmers) to assess its reliability and ensure that the questions were clear, relevant and appropriate for the field conditions. The pilot test was to assess its clarity, consistency and relevance in the field. This pilot test helped identify ambiguous or confusing items, which were subsequently revised to improve the reliability and user-friendliness of the instrument. Feedback from the pilot test informed minor adjustments to improve the instrument's effectiveness. Validity was established through the careful design of the questionnaire, which was developed based on relevant literature, expert consultation and alignment with the study objectives. The questionnaire was structured to capture all essential variables related to smallholder participation in medicinal plant production and its impact on household welfare, ensuring comprehensive and relevant data collection. The data collection period spanned from July to August 2023. The collected data were farmers' demographic characteristics, type and use of medicinal plants they farmed, challenges they faced, factors affecting their participation in the production of medicinal plants, and the effect of participation in the production of medicinal plants on their household welfare. This timeline was strategically chosen to align with the agricultural calendar, ensuring the availability and responsiveness of participants. The combination of trained local enumerators, a well-tested questionnaire, and a structured approach to interviews contributed to the overall reliability and validity of the data collected. During data entry and cleaning, consistency checks were performed to identify and correct potential errors or outliers. This step ensured that the data set used for analysis was both accurate and reliable.

Empirical model specification

Budgetary technique

We employed the gross margin method to estimate the profitability of medicinal plants cultivated by smallholder farmers in the ADM. Gross margin, defined as the difference between gross income and total variable costs, is widely recognised in agricultural economics for its simplicity and effectiveness in assessing enterprise feasibility, especially when comparing ventures with similar capital and labour inputs.[28,29] This method has also been successfully applied by Thibane[30] to evaluate the economic viability of broiler production in the same district, revealing positive profitability among smallholder farmers. Despite its advantages, gross margin analysis does have limitations: it assumes linear relationships between inputs and outputs, overlooks interdependence among enterprises, and is typically short term in focus due to its reliance on periodic budgeting.[28] Nevertheless, given the widespread use of this method and the lack of proper record-keeping among many smallholder farmers, we selected gross margin as the most suitable and practical tool for estimating profitability. Consequently, the budgetary technique adopted assessed both the profitability and its key determinants in the production of medicinal plants in the region.[31] Equation 2 was used to calculate the gross margin:

$$GM(\pi) = \sum(TRi - TVCi) \qquad \text{Equation 2}$$

where GM is the mean gross margin per medicinal plant, TR is the total revenue from the production of medicinal plant *i* measured in terms of TVC, the total variable cost of production of medicinal plant *i*, measured in terms of direct and indirect costs. Costs included hired labour, transport, water for irrigation, seeds, chemicals and fertiliser.

The total revenue, which is equivalent to the gross income of each medicinal plant, was calculated using Equation 3:

$$TRi = Pi \times Qi \qquad \text{Equation 3}$$

where P*i* is the farmgate price of medicinal plants and Q*i* is the total quantity produced.

The total variable cost was calculated from Equation 4:

$$TVC = \sum_{i=1}^{2}(K_{it} + S_{it} + L_{it}) \qquad \text{Equation 4}$$

where K_{it} is the expenditure on seed, S_{it} is the total expenditure on fertiliser and L_{it} is the total labour expenditure in each enterprise.

Following the calculation of the gross margin, we proceeded to determine the return per rand invested by dividing the gross margin by the total variable costs. This metric was deemed important for evaluating not only the production costs but also the overall efficiency of the medicinal plant enterprises.[32] The return per rand invested serves as a key indicator of how effectively a business converts investment into profit, with higher values reflecting greater profitability per unit of investment. A higher return signifies that more profit is generated for every rand invested, indicating a more efficient and financially viable enterprise.

$$Return\ per\ Rand\ Invested = \frac{Gross\ Margin}{Total\ Variable\ Cost} \qquad \text{Equation 5}$$

We then calculated the net farm income, which is the difference between gross margin and fixed costs, with production costs deducted from the farm's gross margin. According to Tshiame[33] and Alabi et al.[32], it is significant to include net farm income in the profit estimation of medicinal plant farming by smallholder farmers as it considers the farmer's production cost.

$$\text{Gross Margin} = \text{Total Revenue (TR)} - \text{Total Variable Cost (TVC)} \qquad \text{Equation 6}$$

$$NFI = GM - TFC \qquad \text{Equation 7}$$

where NFI is the net farm income or profit, GM is the gross margin and TFC is the total fixed costs of the farm.

Logit model

We used the logit model to evaluate the factors influencing the participation of smallholder farmers in medicinal plant production. The logit model facilitates a statistical valuation of the effect of numerous variables on a dependent variable of a bilateral nature. The dependent variable can be expressed at two levels: 1 (medicinal plant participant) and 0 (non-participant).[34] The weakness of linear probability models makes the use of ordinary least squares null and void.[35] According to Jaza et al.[36], the logit or probit model could be more applicable to this research as the dependent variable (participation of smallholder farmers in producing medicinal plants) is qualitative, the explanatory variables are a combination of continuous and explanatory variables and the sample size is fairly manageable ($N = 150$).

Using the logit over the probit model is a matter of preference. The logit model offers the option to save the predicted values automatically, whereas probit cannot compute the predicted value of the probability. For this reason, the logit model was deemed suitable for this study. Jaza et al.[36] stated that the logit model uses the maximum likelihood estimation method to calculate the logit of the possibility of the occurrence of the event, for instance, the natural log of the likelihood ratio of accomplishing one or the other alternative (e.g. participation of smallholder farmers in producing medicinal plants). By indicating P as the probability of attaining an alternative from the prognosticators X_1 to X_{12}, the arithmetical composition of the binary logit model applied in this study is conveyed as:

$$Y = Logit(P) = ln\left(\frac{P}{1-P}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_{12} X_{12} \qquad \text{Equation 8}$$

where P is the probability that the farmer produces medicinal plants, 1-P is the probability that the farmer does not produce medicinal plants, Y is the farmers' group (with 1 = medicinal plant participant, 0 = non-participant), α is the intercept term (constant), $\beta_1, \beta_2, \beta_3, \beta_4, \ldots$ denotes the slope coefficient and $X_1, X_2, X_3, X_4, \ldots$ the explanatory or independent variables.

Propensity score matching

We implemented propensity score matching (PSM) to assess the effects of farmers' participation in the production of medicinal plants on household welfare. PSM is a good method to improve the capability of the regression to accumulate precise causal evaluations through its non-parametric method to stabilise covariates between the participant and non-participant groups.[37] To measure impact estimation, numerous econometric techniques were considered, such as reflexive comparison, instrumental variable methods, matching methods, and difference-in-difference methods. PSM is particularly suitable when the primary goal is to estimate the causal impact of a treatment (in this case, participation in medicinal plant production by smallholder farmers) on an outcome, such as household welfare. PSM creates a control group that is statistically similar to the treatment group based on observable characteristics, thereby allowing for a credible comparison. PSM assumes that selection for treatment is based on observable variables (a conditional independence assumption). PSM provides a straightforward and transparent method to match participants with non-participants who have similar characteristics, making the comparison more intuitive and easier to interpret. It avoids the need for identifying exclusion restrictions (variables that affect selection but not outcome), which are often required in the Heckman model and can be difficult to justify empirically. In this study, we had access to rich observable data, such as age, gender, education, household size, farming experience and access to extension services, which are likely to influence both participation and outcomes.

PSM avoids this duality by directly comparing outcomes between matched individuals, thereby reducing dependence on parametric assumptions. PSM is widely used in impact evaluation and policy analysis, especially in agricultural and development economics, where the goal is to assess how a particular intervention or activity (like medicinal plant farming) affects participants. The method aligns well with the study's objective of estimating the average treatment effect on the treated, providing clearer policy-relevant insights. We employed the use of matching methods to compare the effects of producing medicinal plants on the social welfare of participants and non-participants with relatable socio-economic background features. Matching solely controls for changes in the observable characteristics and biases are expected to occur, emerging from unobserved variables that have the potential to influence participation in the programme.[38] The average effect of treatment on the treated (*ATT*) is calculated using Equation 9[39]:

$$ATT = E(y_{li} - y_{0i} \mid D_i = 1) = E(y_{li} \mid Di = 1) - E(y_{01} \mid D_i = 1) \qquad \text{Equation 9}$$

where y_{li} symbolises the farm revenue for ith smallholder farmers generated through the production of medicinal plants, y_{0i} is the income of the smallholder farmers who are not participating in the production of medicinal plants, and D_i is a treatment gauge equal to 1 (sustainable production of medicinal plants) and 0 (otherwise). It was difficult to estimate what farm income would have been, given that there was no participation in the sustainable production of medicinal plants. Therefore, a key problem was that of estimating the suitable counterfactual: $y_{li} \mid D_i = 0)$. For reasons emanating from the self-selection of non-random farmers, comparison between non-participants and participants is prone to generating biased estimates. An appropriate control group of non-participants who had related, comparable demographics to participants was constructed through the use of PSM.[38] Empirically, the PSM technique adopts two stages. Firstly, a probability (Pr) model is created to evaluate each smallholder farmer's likelihood $p(x_i)$ to participate in the production of medicinal plants, assuming their prevailing characteristics, x_i[39]:

$$\Pr(D_i = 1 \mid x_i) \equiv p(xi) \qquad \text{Equation 10}$$

Secondly, the ATT of production of medicinal plants on household welfare of smallholder farmers (yi) is predicted, taking into account the matched observations of participants and non-participants as illustrated by Equation 11:

$$ATT^{psm} = E\,[y_{li} \mid D_i = 1,\ p(x_i)] - E\,[y_{0i} \mid D_i = 0,\ p(x_i)] \qquad \text{Equation 11}$$

where ATT^{psm} estimates the mean variance of medicinal plant participants matched with non-participants of similar socio-dynamics who reside in the same district.[34]

Data

Table 1 illustrates the data collected from smallholder farmers in the study area.

Findings and discussion

Socio-economic demographics of smallholder farmers in ADM

The effect of participating in the production of medicinal plants on the household welfare of smallholder farmers was measured through smallholder farmers who produce or extract medicinal plants to exchange them in the market for cash incentives. The 150 medicinal plant farmers who were interviewed revealed that 125 farmers had taken the initiative to sell the medicinal plants, and 25 of the farmers acknowledged only the production and use of curative plants and did not participate in selling their produce in market streams. Table 2 shows the socio-economic characteristics of the smallholder farmers in this study.

The majority (67%) of medicinal plant farmers in our study were women, who had an average age of 44 years. Similar findings were shared by Khoza et al.[40,41], who reported that women are responsible for farming in rural households. Our results also revealed that the medicinal plant farmers spent more than 10 years in school, placing them in a good position to understand the farm operation and easily accumulate knowledge about the health benefits. These results are similar to those of Bonokwane and Ololade[42], who realised that farmers with orthodox schooling are more than willing to put into practice modern technological innovations and upscale their production efficiency. Household size was used as the proxy for family labour in this study, as smallholder farmers rely on family labour for farm operations. The majority of households had an average of five members per household and owned land smaller than a hectare. This means that smallholder farmers must use self-labour in their farming activities to reduce labour costs. This is a worrisome factor in the progressive development of smallholder farming. Mazibuko[43] also highlighted that insufficient family labour is a limiting factor in smallholder production. Further, the results show that medicinal plant farmers had more than 10 years of experience

Table 1: Definition, measurement and summary statistics of variables used in the econometric model

Explanatory variables	Description	Category	Signs
Dependent variable			
Utilisation of medicinal plants	Participants = 1 Non-participants = 0	Continuous	+/–
Independent variables			
Gender	Female = 0 Male = 1	Dummy	+/–
Age	Actual years	Continuous	+/–
Education	Actual years spent in school	Continuous	+/–
Marital status	Married = 1 Single = 0	Dummy	+/–
Household size	Actual number in the household	Continuous	+/–
Member of association	Yes = 1 No = 2	Dummy	+/–
Location (originally from the study site)	Yes = 1 No = 0	Dummy	+/–
Employment	Categorical	Categorical	+/–
Level of income	Actual amount	Categorical	+/–
Extension	Number of visits by the extension officer	Continuous	+/–
Challenges faced by farmers	Categorical	Categorical	+/–
Economic value of high-value medicinal plants	Categorical	Categorical	+/–
Effects of producing medicinal plants	Categorical	Categorical	+/–

in production. This means that they possessed a superior understanding of the production, challenges and health benefits of these remedial plants.

Measuring the profitability of medicinal plant farming in ADM

We analysed the profitability of smallholder medicinal plant enterprises based on key financial indicators such as total revenue, total variable costs and gross margins to assess the economic viability of cultivating specific medicinal plant species under smallholder conditions. By examining returns on investment and cost-efficiency, we provide insights into which crops offer the greatest financial returns and sustainability potential. The results are shown in Table 3.

The data presented in Table 3 reveal important insights into the profitability of smallholder medicinal plant enterprises. Gross margins and the return per rand invested (RRI = gross margin/total variable cost) indicate that all four medicinal plant enterprises are profitable at varying levels, with *Artemisia afra* (*Umhlonyane*) emerging as the most lucrative. It boasts the highest gross margin (ZAR7320.62) and an impressive RRI of 2.77, indicating that for every rand spent on variable costs, a return of ZAR2.77 is achieved. This contrasts sharply with *Aloe candelabrum* (*Ikhala*), which has the lowest RRI at 1.10, suggesting a slimmer margin of profitability. While *Aloe candelabrum* generates the highest total revenue (ZAR21 750.52), its high variable costs (ZAR10 350.69) significantly reduce its relative profitability. The other two species, *Bulbine abyssinica* (*Intelezi*) and *Elephantorrhiza elephantina* (*Intolwane*), demonstrate moderate profitability, with RRIs of 1.18 and 1.67, respectively, suggesting they are viable but not the most efficient options. Taking a broader financial view, the total gross margin for all enterprises combined is ZAR26 872.46. After subtracting total fixed costs of ZAR7780.74, the net farm income stands at ZAR19 091.72. These results are in line with those of Mdoda and Obi[20] and Thibane[30], who also observed similar trends of profitability and viability in investing in medicinal plant production.

This net farm income gives a return on investment of 0.71, which means that for every rand invested in both variable and fixed costs, the enterprise returns 71 cents in net profit. While this return on investment reflects a positive return, it also signals room for improvement, particularly in managing input costs and scaling the more profitable species. The high RRI of *Artemisia afra* suggests that a strategic focus on expanding its production, while perhaps minimising less efficient crops like *Aloe candelabrum*, could significantly enhance overall farm profitability. Additionally, the relatively low fixed cost burden (just under 30% of gross margin) suggests that smallholders can maintain or improve profitability with careful resource allocation and crop selection.

Factors influencing participation in the production of medicinal plants

We used a logit regression to estimate the contributing factors that influence the participation of smallholder farmers in the space of medicinal plant production in the ADM. Table 4 shows the outcomes evaluated through the use of regression and the fitness of the model. The Pseudo-R^2 is the main indicator to note, in addition to the likelihood ratio chi-square, which is imperative for estimating the level of appropriateness that the model is ordered to suitably structure on assessed likelihoods. Per this study, the log-likelihood of -194.007 and a p-value of 0.0000 designates that the model is statistically significant. The R^2 (83%) and the adjusted R^2 (78%) suggest a good model fit.

Our findings highlight the significant role of a farmer's age in medicinal plant production. The age variable was found to have a negative impact on participation, with the coefficient being statistically significant at the 1% level. Specifically, as a farmer's age increases, the likelihood of participating in the production of medicinal plants decreases. This trend can likely be attributed to the physical decline that often accompanies ageing, leading to reduced strength and mobility, which are essential for the physically demanding tasks involved in farming. Such factors may have implications for the future sustainability of medicinal plant production. This finding aligns with the work of Rubhara and Mudhara[44], who noted that older farmers often experience a decline in physical stamina, which affects their participation in the production of medicinal plants as well as their productivity. Naturally, younger individuals tend to be more physically capable than their older counterparts.

Being female was found to have a positive influence on participation in the production of indigenous medicinal plants, with the effect being significant at the 1% level. This suggests that an increase in the number of female participants is likely to boost the output of medicinal plants, which in turn would enhance household welfare. These results are consistent with the findings of Assefa et al.[45], who observed that men were less likely to engage in farming activities, whereas women demonstrated a stronger drive to participate. Therefore, in the ADM, women emerge as more reliable and economically viable contributors to the production of medicinal plants compared to their male counterparts.

The education variable was found to have a negative coefficient, significant at the 5% level. This suggests that each additional year of schooling increased the likelihood of smallholder farmers participating in medicinal plant production. However, this relationship may be influenced by a perception among highly educated individuals, who often view raw medicinal plants as a commodity associated with poverty and may thus avoid engaging with them. This attitude could hinder the growth of medicinal plant production among smallholder farmers. These findings align with those of previous studies, which indicate that educated individuals are

Table 2: Socio-economic demographics of smallholder farmers who participate in producing and selling medicinal plants and those who only produce but do not sell

Demographics	% Participants ($n = 125$)		% Non-participants ($n = 25$)		Total % ($n = 150$)	
Gender (female)	59		74		67	
Extension visits	57		58		56	
Protection of natural resources	45		20		33	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age	0.56	0.053	0.32	0.045	0.44	0.051**
Educational level	7.4	0.08	12.8	0.27	10.6	0.18***
Household size	6.00	0.077	5.00	0.065	5.50	0.071
Farm size (ha)	0.92	0.075	0.98	0.084	0.95	0.080
Farming experience (year)	16.44	1.43	14.36	1.15	10.42	1.29

**$p < 0.05$; ***$p < 0.001$

Table 3: Profitability of medicinal plant enterprises of smallholder production

Plants produced (Xhosa name)	Total revenue (ZAR/ha)	Total variable cost (TVC) (ZAR/ha)	Gross margin (GM) (ZAR)	Return per rand invested (GM/TVC)
Aloe candelabrum (*Ikhala*)	21 750.52	10 350.69	11 399.83	1.10
Bulbine abyssinica (*Intelezi*)	9620.61	4406.81	5213.80	1.18
Elephantorrhiza elephantina (*Intolwane*)	4694.40	1756.19	2938.21	1.67
Artemisia afra (*Umhlonyane*)	9960.94	2640.32	7320.62	2.77
Overall gross margin	46 026.47	19 154.01	26 872.46	1.40

Gross margin (ZAR) = 26 872.46

Less fixed cost (land rental, depreciation of farm assets, farm tools)

Total fixed costs (ZAR) = 7780.74

Net farm income (ZAR) = 19 091.72

Return on investment ($\frac{NFI}{TC} = 0.71$)

NFI, net farm income; TC, total costs

more likely to embrace medicinal plants when they are processed into more commercially acceptable forms. As a result, this reluctance may lead to reduced participation in medicinal plant cultivation as farmers pursue higher levels of education.[2,46,47]

Household size was significant at 5% and had a positive coefficient, meaning that there was a positive relationship between an increase in household size and participation. An increase in the number of household members who assist with farming activities is likely to increase participation in the production of medicinal plants. These results are compatible with those of Mdoda et al.[48] who noted that a growth in household size means an intensification in labour. Therefore, the advantage of saving on casual labour consolidates a farmer's choice to participate in medicinal plant production to improve their welfare.

Farming experience was established to have a positive influence on participation in the production of medicinal plants, significant at 1%. This suggests that a higher level of experience creates a good chance of a positive stimulus on participation in the production of medicinal plants by smallholder farmers. This result is similar to those of Yeshiwas et al.[12] who found that experience is a cornerstone to a productive smallholder medicinal plant farm, because experienced farmers are more likely to make informed decisions based on experience.

Extension services had a positive coefficient, which is statistically significant at 5%. Therefore, there was a positive correlation between the intensification of extension services and an increase in participation in productivity in the ADM. An increase in agricultural knowledge is likely to positively influence the participation of farmers in the production of medicinal plants. These results resemble those of Nwafor et al.[49] who noted that extension and advisory services are a great booster for rural medicinal plant farmers through dedicated implementation of knowledge and skills by extension officers. Close mentorship by extension officers increases farmers' capacity to make informed decisions and solidifies their confidence to participate in medicinal plant production.

The variable representing the protection of natural resources had a positive coefficient and is statistically significant at the 1% level. This suggests

Table 4: Estimates of determinants of farmers' participation in the production of medicinal plants

Variable	Coefficient	Standard error	Significance
Age	−0.078	−0.05	−0.002***
Gender (female)	0.434	0.82	0. 004***
Education	−0.04	0.08	−0.037**
Household size	0.090	0.22	0.014**
Farming experience	0.14	0.08	0.008***
Extension visits	0.58	0.50	0.015**
Protection of natural resources	1.59	0.78	0.003***
Constant	0.047	0.082	1.976
Number of observations	150		
Log-likelihood	−194.007		
Prob > chi^2	0.000***		
R^2	0. 831		
Adjusted R^2	0.782		

$^{**}p < 0.05$; $^{***}p < 0.001$

a strong positive relationship between smallholder farmers' participation in the production of medicinal plants and efforts to conserve natural resources. In essence, as natural resources are more effectively protected from degradation or extinction, smallholder farmer participation tends to increase. These findings are consistent with the work of Astutik et al.[2], Yeshiwas et al.[12] and Nwafor et al.[49], who observed that enhanced conservation practices play a critical role in preserving species diversity. The preservation of biodiversity ensures a more reliable supply of medicinal plant materials, thereby encouraging greater involvement from smallholder farmers. Put simply, the more abundant and secure the natural resources, the more sustainable and appealing medicinal plant cultivation becomes for rural farmers.

Effects of participation on household welfare

We aimed to assess the effect of smallholder farmers participating in medicinal plant production on household welfare using PSM. By comparing participants and non-participants, the analysis evaluated changes in factors such as capital, labour, seed quality and cultivated land size. PSM techniques, including nearest neighbour and kernel matching, were applied to ensure a balanced comparison between treatment and control groups. The results indicate that medicinal plant cultivation had a measurable effect on the welfare of participating households (Table 5).

The analysis of the treatment's impact on household welfare using two different matching methods (kernel matching and nearest-neighbour matching) provides consistent evidence of a positive and statistically significant effect of medicinal plant production on smallholder farmers' welfare. Under the kernel matching method, the average treatment effect on the treated was estimated at 5624.64, with a standard error of 4912.56 and a p-value of 0.021. This indicates that, on average, treated households participating in the production of medicinal plants experience a welfare gain of approximately ZAR5625 as compared to similar untreated households that do not participate in the production of medicinal plants, with the effect being statistically significant at the 5% level. Despite the relatively high standard error, which implies some degree of variability in the estimate, the low p-value supports the robustness of the positive impact. This signifies that growth in the production of medicinal plant enterprises resulted in an improvement in farm returns and the welfare of farmers through the betterment of their standard of living through increased farm revenues. The nearest-neighbour matching method yielded a slightly higher average treatment effect on the treated of ZAR6472.69 with a standard error of

Table 5: Effects of farmers' participation in the production of medicinal plants on household welfare

Output variable	Kernel matching method		
	Average effect of treatment on the treated (ATT)	Standard error	p-value
Household welfare	5624.641	4912.56	0.021**
	Nearest-neighbour matching method		
	ATT	Standard error	p-value
Household welfare	6472.691	5472.691	0.003***

Number of observations = 150, matches requested = 7, treatment model = logit

$^{**}p < 0.05$; $^{***}p < 0.001$

5472.69, denoting statistical significance at the more stringent 1% level. This suggests an even stronger level of confidence in the positive welfare effect of the treatment. While both methods confirm a beneficial impact, the nearest-neighbour approach indicates a higher magnitude of effect and stronger statistical significance, albeit with slightly increased variability. Taken together, these findings reinforce the conclusion that the intervention has a meaningful and statistically credible effect on improving household welfare outcomes. Therefore, unwillingness to participate in the production of medicinal plants can be substantial. This result is similar to that of Nyang'au et al.[38] who revealed that the production of medicinal plants affects the welfare of smallholder farmers, and their rate of participation in medicinal plant production increases when they discover an increase in farm revenue.

Conclusion and recommendations

We investigated the effects of producing medicinal plants on the household welfare of smallholder farmers of the Amatole District Municipality in Eastern Cape, South Africa. Medicinal plants are critical assets that are indigenous to the rural areas where smallholder farmers live. This study underscores the significant positive impact of medicinal plant production on the household welfare of smallholder farmers in the Amatole District. The logistic regression results revealed that female gender, larger household size, greater farming experience, more frequent extension visits, and a strong commitment to natural resource protection all significantly increased the likelihood of participation, while age and higher levels of education reduced it. Furthermore, the PSM analysis confirmed a statistically significant and positive impact of medicinal plant cultivation on household welfare, with participating farmers experiencing welfare gains ranging from ZAR5624 to ZAR6472. This underscores the economic and social value of promoting medicinal plant farming as a viable strategy for improving livelihoods, enhancing food and health security, and supporting sustainable rural development in the region. Therefore, scaling up participation in medicinal plant production presents a promising pathway to bolster smallholder resilience and contribute to broader rural development goals.

Our findings indicate several important policy directions to enhance the adoption and benefits of medicinal plant cultivation among smallholder farmers. These findings highlight the importance of targeted policy interventions that support traditionally underrepresented yet highly motivated groups, such as women and experienced farmers, while enhancing extension services and integrating environmental sustainability into agricultural strategies. As younger and female farmers show higher participation rates, targeted interventions such as training, input subsidies and access to credit should prioritise these groups to maximise engagement and productivity. Given the positive influence of farming experience, policies should promote knowledge-sharing platforms and mentorship programmes, allowing experienced farmers to pass on traditional and technical know-how. Strengthening agricultural extension services is also critical; well-resourced and frequent extension visits focused on medicinal plants can significantly boost adoption. Furthermore, the strong link between natural resource protection and participation highlights the need to integrate environmental conservation into agricultural policy, encouraging sustainable land use alongside crop diversification. The inverse relationship between education and participation suggests a need to rethink formal education by embedding agroecological knowledge and the value of traditional crops into rural curricula. Large households, which may benefit from internal labour availability, should be supported through group-based incentives that enhance their productive capacity. Finally, the overall positive impact of medicinal plant cultivation on smallholder welfare indicates its potential as a strategic tool in rural development, poverty alleviation and biodiversity conservation initiatives.

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Data availability

Data can be made available from the corresponding author if there is substantial motivation.

Declarations

We have no competing interests to declare. No AI or LLM tools were used in this study. Ethical clearance was obtained from the University of KwaZulu-Natal's Humanities and Social Science Research Ethics Committee (HSSREC/00005086/2022). Approval to conduct research in the study area was granted by the Amatole District Municipal Institute of Learning. Respondents signed an informed consent form in their home language confirming their voluntary and confidential participation; they were free to withdraw at any time.

Authors' contributions

Z.M.: Conceptualisation, methodology, investigation, sample analysis, formal analysis, validation, data curation, writing – original draft, writing – review and editing. L.M.: Methodology, sample analysis, formal analysis, validation, writing – original draft, writing – review and editing, supervision, project leadership, project administration, funding acquisition. S.S.N.: Conceptualisation, methodology, investigation, formal analysis, validation, data curation, writing – original draft, writing – review and editing. N.M.: Methodology, sample analysis, validation, data curation, writing – original draft, writing – review and editing. Y.N.: Methodology, formal analysis, validation, data curation, writing – review and editing, supervision, project leadership, project administration, funding acquisition. All authors read and approved the final version.

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