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Assessing the impacts of commercializing medicinal plants on livelihood outcomes: evidence from indigenous knowledge holders in South Africa

Peter Tshepiso Ndhlovu[1,2] · **Abiodun Olusola Omotayo**[3] · **Kehinde Oluseyi Olagunju**[4] · **Wilfred Otang-Mbeng**[2] · **Adeyemi Oladapo Aremu**[1]

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Abstract
Globally, botanicals and associated by-products often provide income that is recognized as an important contributor to livelihoods particularly in rural areas. However, limited data currently exists on the impact of commercializing medicinal plants on livelihoods. Using a dataset collected from 101 indigenous knowledge holders (IKHs) with interest in childhood diseases, we assessed the factors influencing their decisions to commercialize medicinal plants, and how the commercialization impacts livelihood outcomes measured by net returns and per capita total expenditure. We used the Propensity Score Matching as the analytical technique to correct for endogeneity bias resulting from the observed characteristics. The results revealed that commercializing medicinal plants significantly increased net returns and per capital total expenditure by 3.60% and 1.42%, respectively. Furthermore, factors such as age, education, access to water and membership of association significantly influenced the decision of IKHs to commercialize medicinal plants. Policy efforts that seek to provide support for formal and vocational training, access to irrigation technology and participation in farmer groups, particularly among the experienced IKHs may encourage the commercialization of medicinal plants.

Keywords Biodiversity · Childhood diseases · Conservation · Poverty · Traditional medicine · Welfare

1 Introduction

The vital role medicinal plants as alternative to orthodox medicine are receiving widespread recognition in many countries including South Africa (Dold & Cocks, 2001; Kepe, 2007; Makinde et al., 2015; Mudau et al., 2022; Ndhlala et al., 2011). The increasing disease burden coupled with new pandemics particularly COVID-19 and its ripple effects (unemployment, poverty and food insecurity) has significantly strained the healthcare system. As a result, medicinal plants continue to gain increasing importance as major natural resources for meeting healthcare needs and source of livelihoods in many impoverished communities. Despite the general agreement that medicinal plants and their by-products

Extended author information available on the last page of the article

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are important in alleviating poverty, serving as safety nets and gap fillers, their importance in reducing poverty and improving livelihoods is not well-understood (Hickey et al., 2016). Furthermore, the exacerbated and indiscriminate collection of botanicals with therapeutic effects poses serious threat to biodiversity globally (Astutik et al., 2019; Kepe, 2007; Seile et al., 2022; Sher et al., 2014; Van Wyk & Prinsloo, 2018).

Generally, medicinal plants are known to have considerable economic value at local and national markets. In most developing countries, the trade in biopharmaceuticals contributes an estimated US $83 billion, which is more lucrative than the trade in non-timber forest products (Street & Prinsloo, 2013). Likewise, Bareetseng (2022) predicted that plant-based products are expected to reach US$ 104.78 billion by 2026. However, the pharmaceutical companies receive almost all the benefits without considering the rights of the local communities to their land and natural resources (Ijinu et al., 2023). According to Cunningham (1991), the market and economic value of medicinal plants justifies the need to critically assess and review the relationship that is existing between humans and natural resources. The economic value of some orthodox medicine is linked to natural resources especially higher plants (Dovie, 2003; Ivanova et al., 2022). Harvesting of these natural sources has increased significantly due to limited healthcare service in rural communities and affordability of conventional medications (Godoy et al., 2005; Nilsson et al., 2011). Many indigenous communities particularly the indigenous knowledge holders (IKHs) rely on harvesting of medicinal plants from the wild as a source of income. However, many households in developing countries, even those harvesting medicinal plants, continue to live in poverty. Many plants have commercial potential, but most stakeholders including collectors have limited knowledge on how to commercialize them. Despite their relevance, there is inadequate socioeconomic data on botanicals used to manage health related issues in children. This includes their contribution to household food security and income, product development, and commercialization.

Globally, evident of the potential of medicinal plants contributing to livelihoods in rural communities have been demonstrated (Hickey et al., 2016; Omotayo & Aremu, 2020; Omotayo et al., 2020; Van Wyk & Prinsloo, 2018; Van Wyk et al., 1997). Furthermore, previous studies focused on livelihood approaches, forest and related natural resources as well as their conservation, and development issues. Following off-farm activities (38%), agriculture (crops and animals) (37%), and estimated income ranging from 6 to 44% of total household income, the forest earnings generated 22% of household income (Angelsen et al., 2014; Belcher & Schreckenberg, 2007; Shackleton et al., 2007; Sunderlin et al., 2003; Vedeld et al., 2007). Many literatures focusing on how natural resources contribute to income and livelihood among rural communities are known to have methodological discrepancies and biases, making generalizations challenging (Angelsen et al., 2014).

According to Vedeld et al. (2004), existing research has shown that there is a significant degree of methodological and theoretical heterogeneity, methodological difficulties, and flaws. Studies on medicinal plants linked to revenue generation have some disadvantages such as extended recollection intervals underestimating or seasonally biasing data (Jagger, 2012), inconsistent operationalization of key variables, method incompatibilities (Vedeld et al., 2004), and survey implementation challenges particularly the differences in intra-household participants (Das & Basu, 2022). There is a direct correlation between absolute income from natural resources which increases with the total income, while the relative income from natural resources decreases with higher income (Cavendish, 2000;

Damania et al., 2020; Escobal & Aldana, 2003; Prado Córdova et al., 2013; Vedeld et al., 2004). Likewise, literature on medicinal plants "safety net", "poverty trap" and livelihood discussion tend to assess how reliance on natural resources including the utilization of plants serves ‘safety net’ by helping poor households from falling into poverty and improving their livelihood (Angelsen et al., 2012, 2014; Barbier, 2010; McSweeney, 2004). The dependency of underprivileged communities on natural resources often leads to asset poverty and market access issues (Barbier, 2010). Factors such as market access are exogenous to the households, an indication that the "safety net" interpretation is more appropriate than the poverty trap interpretation. As articulated by Angelsen et al. (2014), relying on natural resources could be labeled as a “poverty trap’ solely in situation where alternative livelihood strategies exist but policies, donor projects, or other external interventions seek to retain individuals in their low-yield economic activities.

The aim of this study is to examine the factors influencing the commercialization of medicinal plants and how commercializing affects welfare, measured in terms of net returns and per capita expenditure. From a policy perspective, examining the commercialization-welfare nexus is vital for designing policy instruments to define the roles of market participation among the IKHs for improved livelihood and sustainable rural development.

2 Literature review

2.1 Overview of medicinal plants and indigenous knowledge holders

Despite enormous progress in the field of pharmaceuticals, the importance of plants as ingredients for drugs in modern medicine cannot be overemphasized (Yuan et al., 2016). In addition, medicinal plants remain vital for addressing the health challenges of a significant population residing in developing countries (World Health Organization, 2013). Over the generations, human beings have learned how to use botanicals to combat illness and maintain their health status (Mmamosheledi & Mncengeli, 2019). Medicinal plants often contain diverse secondary metabolites that can be used to treat different ailments (Yimer et al., 2019).

In Africa, a significant portion of the populations often utilize traditional medicine for meeting their healthcare needs (World Health Organization, 2013). South Africa has a large land mass resulting in a geographical advantage which is the basis for the rich biodiversity (Hoveka et al., 2020). Traditional medicine entailing the use of botanicals is well enriched among different ethnic groups in South Africa. An estimated 30,000 plants are known to occur in the country and more than 3000 plants are associated with therapeutic value. Particularly, approximately 771 are utilized by IKHs for healing purposes and often available for purchase in local herbal markets (Bareetseng, 2022).

2.2 Traditional healthcare systems

Traditional health practitioners and traditional medicine are important component of the primary healthcare in sub-Saharan Africa (Abdullahi, 2011). This is largely due to poverty, inadequacy and inaccessibility of the western health services, which is further exacerbated with the shortage of health workers. Even when the facilities exist, shortage of drugs and equipment is often reported (World Health Organization, 2013).

In the last decade, traditional health practitioners and IKHs have become more popular in Africa. This is partly due to the economic situation in the developing countries, the high cost of orthodox medicine and the increase in drug resistance to common diseases (Mahomoodally, 2013). According to Mander (1998), the demand for medicinal plants is anticipated to remain high in the future as the use of traditional medicine rises. Plant-based remedies as an alternative to conventional medicine are also becoming increasingly common globally (Abouzekry et al., 2021; Agisho et al., 2014; Fisher, 2017).

Traditional knowledge is often kept in secrecy as traditional health practitioners or IKHs are more inclined to pass on their knowledge to family members. As a result, indigenous knowledge on plants is subject to loss given the fragility of orally transmitted knowledge (Mahwasane et al., 2013). Moreover, plant resources and indigenous knowledge are being lost due to the rapid degradation of many habitats and severe environmental disturbance (Tahir et al., 2023).

3 Methodology

3.1 Study area

As detailed by Ndhlovu et al. (2023), the data were collected between April to August 2021 in Bojanala Platinum and Ngaka Modiri Molema districts of North-West Province, South Africa (Fig. 1). The spatial reference of the two districts lies between 22° South of the Equator and 28° East of the Greenwich meridian, covering the area of 116,320 km^2. This

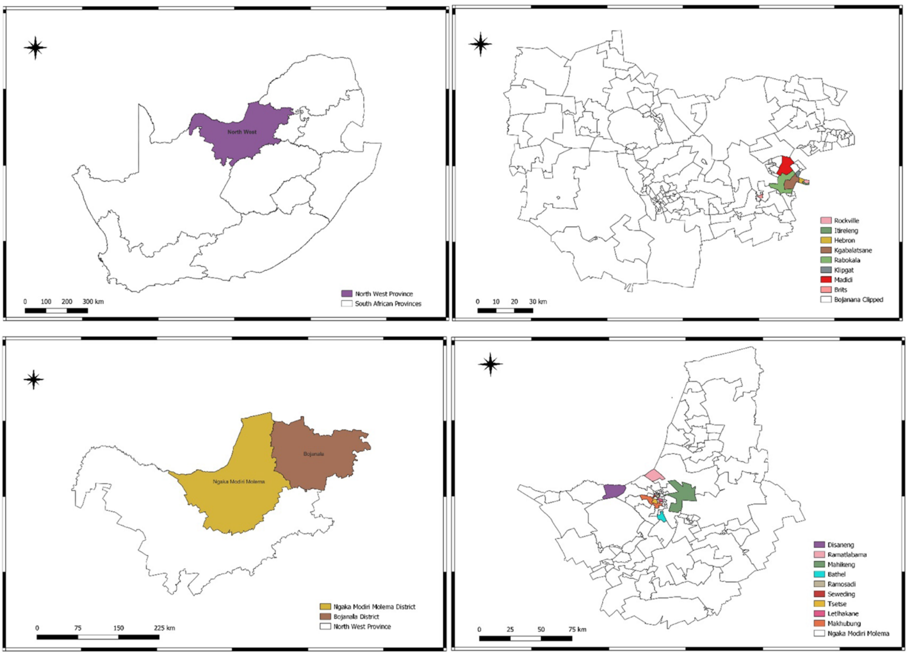

Fig. 1 Geographical location of the study areas within the two District Municipalities, North-West Province, South Africa

area covers about 9.5% of the total surface area in South Africa. Annual rainfall averages 360 mm which is generally experienced during the summer months from October to April (Kruger & Nxumalo, 2017). The two selected districts are known to have rich biodiversity and diverse economic activities. The selected areas represent 50% of the province, ensuring that quality, and avoiding biased results. The population has the highest percentage distribution of Black African (94%), and Setswana is the most dominant language spoken. The selected districts share similar features such as the number of local municipalities found within the two selected districts and the biomes (Fisher, 2017).

The livelihoods of the participants consist of the three traditional pillars namely: (i) limited public healthcare services; (ii) considerable utilization of alternative medicine; (iii) botanicals; and trading of botanicals. In the study area, *Aptosinum elongatum Eng*., *Bulbine frutescens* (L) Willd. *Commelina diffusa* Burm. f., and *Euphorbia prostrata* Aiton are the most common botanicals that are utilized to treat and manage diseases in children (Ndhlovu et al., 2023).

The North-West Province has about 3,748,435 people across the four districts. Dr. Kenneth Kaunda and Dr. Ruth Segomotsi Mompati are less populated when compared to the two selected districts (Stats SA,). In the selected areas, there is access to commercial medicinal plants that are harvested in communal areas regulated by traditional leadership and government regulations as previously highlighted (Ndhlovu et al., 2023).

The semi-structured interviews recorded the socioeconomic traits including age, size of the household, education status, and net returns of the participants. The participants were selected on the basis of their knowledge and experience through non-probability sampling (including purposive sampling) (Palinkas et al., 2015). This involved identifying and selecting participants that are proficient and well-informed in the subject matter (Kothari, 2004). It also involved the willingness to participate and the ability to communicate experiences and opinions articulately and expressively (Etikan et al., 2016). A total of 101 participants were interviewed in Bojanala Platinum and Ngaka Modiri Molema districts in the North-West Province, with a proportional distribution reflecting the number of the key participants in the two selected districts.

3.2 Data collection

Based on detailed procedure described by Ndhlovu et al. (2023), the data were collected between April to August 2021. In April 2022, we had additional follow-up visits with the key participants. Data collection was done using semi-structured interviews (face-to-face) which was translated to Setswana, the major language in the North-West Province. The duration of interviews was 40–60 min which was sufficient for the participants to answer the questions. The semi-structured interviews collected ethnobotanical data including childhood disease prevalence and the contribution of recorded medicinal plants to the livelihood of the participants. The semi-structured interviews were aligned to the Poverty Environment Network format and guidelines (Angelsen et al., 2012, 2014). This research tool allows for a structured quantification of total income for the participants, economic, and commercialization status of the recorded medicinal plants utilized for managing diseases in children.

3.3 Research instrument, validity, and reliability

The study adopted the ethnobotanical guidelines developed by De Vynck et al. (2016) and Martin (2010). We compiled a list of known recognized childhood diseases using the information from several reliable sources (Department of Health, 2019; Freed et al., 2009; Ndhlovu et al., 2021; World Health Organisation, 2019). Photographs were extracted from the above-mentioned literature and the internet. Following the conclusion of the semi-structured interviews, we collected all the medicinal plants reported by the participants (**Appendix 1**). These plants were collected, and voucher specimens were prepared and deposited at the herbarium of the South African National Biodiversity Institute (SANBI), Pretoria, South Africa. Confirmation of the scientific names for the recorded plants was established by the taxonomist at the herbarium following a detailed regional dichotomous key (Leistner, 2000).

3.4 Ethical consideration

The study was assessed and approved by the North-West University Health Research Ethics Committee (Certificate no: NWU-00485-20-A1). Plant collection permit (ID NW 27370/10/2020) was issued by the North-West Department of Economic Development, Environment, Conservation, and Tourism. The research adhered to the Declaration of Helsinki and approval from the local authorities. All the participants read and signed an informed consent prior to the commencement of the research.

3.5 Propensity score matching (PSM)

We applied the Propensity Score Matching (PSM) approach to analyze the impacts of commercialization of the recorded medicinal plants (Appendix Table S1). This technique, as developed by Rosenbaum and Rubin (1983), addresses endogeneity issue that may arise from non-random selection of observations into treatment group. Several studies have applied the PSM to examine the impacts of treatment variable, programs or interventions on different outcomes of interest (Ogunniyi et al., 2017; Olowo et al., 2022).

The analytical technique compares the outcomes of the treatment group (IKHs who commercializes medicinal plants) with that of the control group designated as IKHS who do not commercialize medicinal plants (Rosenbaum & Rubin, 1983). Given that both groups are comparable on the basis of observed socioeconomic characteristics, except for their participation in commercialization, the differences in outcomes are assumed to be attributed to their participation in commercialization. The estimated propensity score for subject $e(x_i)$, $(i=1,\ldots, N)$ is 'the conditional probability of being assigned to a particular treatment, given a vector of observed covariates x_i (Olowo et al., 2022; Rosenbaum & Rubin, 1983):

$$e(x_i) = \Pr\left(z_i = 1 | \mathrm{x_i}\right) \tag{1}$$

and

$$\Pr\left(Z_i, \ldots, X_1, \ldots X_n\right) = \sum_{i=1}^{N} e\left\{X_i\right\}^{Zi}\{1 - e\{X\}^{1-Zi} \tag{2}$$

where z_i is either 1 (treatment) or 0 (control), and x_i is the vector of observed covariates for the *i*th observation.

The propensity score is a probability and ranges from 0 to 1. In a randomized experiment having two groups, the scoring for individual participant is 0.50 given that any particular participants have 50% probability allocation between the treatment and control groups. In this study, we applied the PSM to evaluate the determinants of commercialization decision of the IKHs and enable the calculation of the mean effect of the commercialization on the livelihood of participant. If Y_1 denotes the possible results on the commercializing medicinal plants and Y_0 denotes the possible results on non-commercialization of medicinal plants, the impact of commercialization is given by:

$$\Delta = Y_1 - Y_0 \tag{3}$$

In this study, we used the matched sample to compute the Average Treatment Effect for the treatment (impact) as shown below:

$$\mathrm{ATT} = \mathrm{E}(\Delta|\mathrm{D} = 1, \mathrm{X}) = \mathrm{E}(\mathrm{Y}_1 - \mathrm{Y}_0|\mathrm{D} = 1, \mathrm{X} \tag{4}$$

$$= \mathrm{E}\left(Y_1|D = 1, \mathrm{X}\right) - \mathrm{E}\left(\mathrm{Y}_0|D = 1, \mathrm{X}\right) \tag{5}$$

where $D=1$ denotes medicinal plant commercializing IKHs (treatment), and **X** is a set of variables on which the subjects were matched. Equation (3) would have been easy to estimate except for the equation E (Y_0 | $D=1$, **X**). This is the mean of the counterfactual and indicates what the outcome would have been among participants had they not participated in the treatment, with PSM providing a way of estimating this equation:

$$\mathrm{ATT} = \mathrm{E}\left[Y_1|D = 1, P(\mathrm{X})\right] = \mathrm{E}\left[Y_0|D = 0, P(\mathrm{X})\right] \tag{6}$$

Equation (5) is pertinent to single programs where the treatment variable is between two mutually exclusive categories. However, the equation is easily generalized to multiple programs (Hirano & Imbens, 2004; Lechner, 1999, 2001). The *ATE*, i.e., the average effect of the treatment for an individual drawn randomly from the overall population and depicted below:

$$\mathrm{ATE} = \frac{N_1}{N} \times \mathrm{ATT} + \frac{N_0}{N} \times \mathrm{ATU} \tag{7}$$

where N_1 and N_0 = number in the treatment and control group, respectively. The relationship between ATT (average treatment on the treated), ATE (average treatment effect on an individual), and ATU (average treatment on the untreated) may be seen in the equation above. The description and the summary statistics of the variables used in the analysis are presented in Table 1.

4 Results and discussion

4.1 Socioeconomic characteristics of commercialized and non-commercialized Indigenous knowledge holders (IKHs)

The results show that 56.4% of the IKHs commercialized medicinal plants used for diseases in children (Table 2). On average, the per capita expenditure and net returns made

Table 1 Overview of the applied variables in the study

Variable	Description	Mean	Standard deviation
Commercialization	1 = participant commercializes medicinal plant, 0 otherwise	0.56	0.497
Gender	1 = male participant, 0 = female	0.782	0.415
Age	Age of household head in years	47.911	15.383
Education	1 = participant is formally educated, 0 otherwise	0.733	0.445
Household size	1 = size of household is greater than 5, 0 otherwise	0.436	0.498
Training	1 = participant has received training, 0 otherwise	0.190	0.394
Off-farm	1 = participant involved in off-farm activity, 0 otherwise	0.720	0.451
Experience	Years of experience for a participant	18.030	10.301
Land	1 = participant with access to land, 0 otherwise	0.396	0.492
Market	1 = participant with access to market, 0 otherwise	0.406	0.494
Water	1 = participant with access to water, 0 otherwise	0.436	0.498
Member	1 = participant has membership of a relevant association, 0 otherwise	0.822	0.385
Per capita food expenditure	Household monthly per capita food expenditure (Rands)	1621.267	1341.731
Net returns	Participant household net returns from sales (Rands)	2784.059	2367.200
Per capita expenditure (log)	Natural logarithm of household monthly per capita food expenditure	7.194	0.727
Net returns (log)	Natural logarithm of the participant household net returns	7.116	1.921

Table 2 Mean comparisons between commercialized and non-commercialized indigenous knowledge holders (IKHs)

Variable	Commercialized	Non-commercialized	Mean difference
Outcome variables			
Per capita expenditure (log)	7.201 (0.111)	7.184 (0.079)	0.017*
Net returns (log)	7.193 (0.261)	7.012 (0.280)	0.180**
Control variables			
Gender	0.793 (0.053)	0.767 (0.065)	0.026
Age	46.578 (20.203)	49.721 (2.012)	3.151 **
Education	0.79 (0.05)	0.65 (0.07)	0.14*
Household size	0.413 (0.065)	0.465 (0.077)	−0.051
Training	0.333 (0.073)	0.086 (0.037)	0.247***
Off-farm	0.672 (0.062)	0.786 (0.064)	−0.113
Experience	17.686 (1.43)	18.488 (1.447)	−0.798
Land	0.413 (0.065)	0.372 (0.074)	0.041
Market	0.431 (0.065)	0.372 (0.074)	0.058
Water	0.534 (0.066)	0.302 (0.070)	0.232***
Membership	0.860 (0.053)	0.793 (0.053)	0.673
No of observations	57	44	

Level of significance: 1% (***), 5% (**) and 10% (*). Standard errors are shown in parentheses

by IKHs were significantly higher than non-commercialized IKHs. The result of the *t* tests comparing the mean differences between commercialized and non-commercialized IKHs revealed significant differences in some of the variables. For example, there is significant differences between commercialized and non-commercialized IKHs in variables such as age, educational status, access to training and access to water (Table 2). The IKHs who engaged in commercialization are significantly older, educated and had access to training and water than non-commercialized IKHs. Similar pattern was observed in the study by Sebatta et al. (2014).

On average across the pooled sample, the age of IKHs was found to be 47 years, indicating that participation in commercialization may require some level of activeness to endure physical demand of the market. Studies found that majority of those who are endowed with indigenous knowledge are aged between 40 and 45 years (Awotide et al., 2014; Omotayo & Aremu, 2020; Sebatta et al., 2014). The results revealed most (73.3%) of the IKHs were formally educated, and about 43.6% had farm size greater than 5 ha.

4.2 Determinants of commercialization of medicinal plants

The results of these diagnotics measures revealed that the specified model is of good fit. The Wald chi^2 statistics is significant, suggesting joint significance of the parameters for the commercialization. The average marginal effects are estimated and reported to ensure that the results are better interpreted (Greene, 2003; Olowo et al., 2022). We also reported another measure of goodness of fit for the model - Pseudo R^2.

The empirical evidence on the relationship between age and commercialization decision has been inconclusive, i.e., neither postive and negative. Existing studies suggest a positive relationship between age and decision to commercialize by arguing that older IKHs have experience on production and marketing pratices including market participation (Abdullah et al., 2019; Tafesse et al., 2020). On the contrary, Randela et al. (2008) found a negative relationship where it was explained that younger IKHs are well exposed to innovative technologies that are capable of enhancing market participation. To contribute to the literature on the unclear age-commercialization decision relationship, we included age varibale in its linear and quadratic form to capture the complex relationship. The current findings reveal that age variable in its linear form has a negative relationship with commercialization decision while its quadratic term has a postive relationship. This suggests that the impact of age on commercialization increases as IKHs get older. In addition, older IKH are well-experienced on the market dynamics and hence well-placed to commercialize (Abdullah et al., 2019; Sebatta et al., 2014).

Another signficant factor influencing commercialization decision is education. The results indicated that IKHs who are educated are likely to commercialize medicinal plants. One possible explanation is that education provides knowledge and understanding required by IKHs in making informed decisions regarding the potential added value associated with commercialization. Several studies have reported similar findings that education increases the likelihood of commercialization in countries such as Ethiopia (Tafesse et al., 2020) and Uganda (Sebatta et al., 2014). The results also show that IKHs with access to water are likely to commercialize medicinal plants. Likewise, Tafesse et al. (2020) estabilihed that access to water increases production of marketable surplus, and hence increasing the potential for commericalization (Table 3).

Findings also revealed that membership of association had a positve and significant relationship at 10% confidence level. This suggests that IKHs who have memberhsip of association are likely to commercialize medicinal plants. This can be attributed to

Table 3 Estimates of the determinants of commercialization decision

Variable	Coefficient	Standard error	Marginal effect (d_y/d_x)	Standard error
Gender	0.308	0.377	0.120	0.148
Age	−0.173***	0.065	−0.066***	0.025
Age squared	0.002**	0.001	0.001**	0.000
Education	0.970**	0.412	0.372**	0.148
Household size	0.048	0.325	−0.018	0.125
Training	1.621	0.430	−0.571	0.110
Off-farm	0.208	0.393	0.081	0.153
Experience	0.014	0.022	0.005	0.008
Land	0.074	0.328	0.028	0.125
Market	−0.276	0.343	0.105	0.128
Water	1.039***	0.375	0.375***	0.121
Membership	0.715*	0.420	0.246*	0.124
Constant	3.592	1.673		
Wald chi^2				
Pseudo R^2				
Observations	101		101	

Level of significance: 1% (***), 5% (**) and 10% (*)

Table 4 Matching quality test: balancing property

	Before matching	After matching		
		Radius	NNM	Kernel-based
Pseudo R^2	0.028	0.058	0.044	0.001
Mean bias	11.000	8.000	4.132	2.142
LR χ^2	54.79***	37.267***	11.145	2.125
p value	0.000	0.000	0.117	0.886

Level of significance: 1% (***). Nearest neighbor matching (NNM)

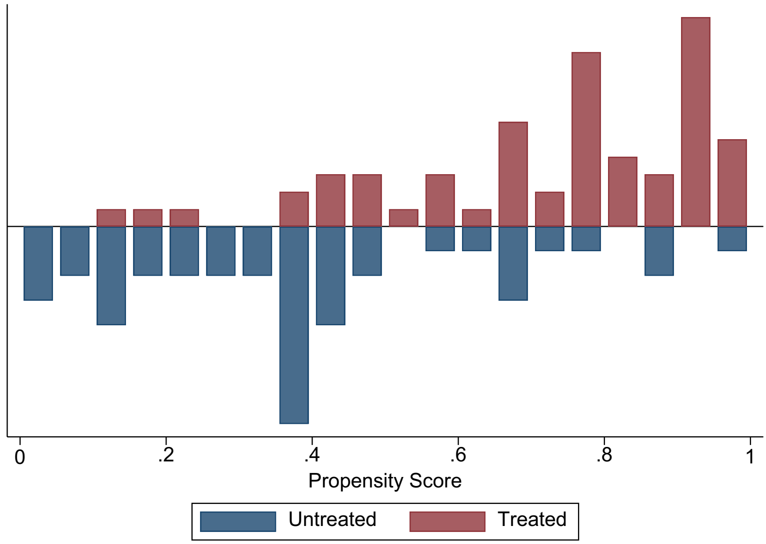

Fig. 2 Density of the propensity scores and common support

fact that membership facilates access to productive inputs and access to market. Hence, IKHs having memebership are likely to commercialize medicinal plants (Neupane et al., 2022; Olagunju et al., 2021).

4.3 Impacts of commercialization of medicinal plants on livelihood outcomes

Applying PSM requires the matching samples of IKHs who commercialize botanicals and those who do not based on similar characteristics. This is followed by estimating the average difference in the outcome variables between the two groups. The reliability of PSM depends on the quality of procedure of matching between IKHs who are involved in commercialization and those who are not. This was ascertained using the balance test and the common support graph. Based on the applied algorithms, it was evident that Kernel-based matching produced the best matching output (Table 4). The common support graph for commercialization decision is presented in Fig. 2. The assessment of the chart of the distribution estimated propensity scores for IKHs involved in commercialization and those who do not; it can be inferred that the condition for common support is fulfilled.

Table 5 Estimates of the treatment effects of commercialization of medicinal plants on livelihood outcomes: Propensity Score Matching

Livelihood Outcome measures	Mean outcomes		ATT	Change (%)
	Commercialized	Non-commercialized		
Net returns	7.462	7.193	0.269 (0.059) ***	3.60
Per capita expenditure	7.305	7.201	0.104 (0.018) ***	1.42

Average treatment effects (ATT) on the treated. Net returns and Per capita expenditure are in natural logarithm forms. Values in parentheses are the standard errors

Level of significances: 1% (***), 5% (**) and 10% (*)

Based on PSM approach, the findings show that the ATT effect of commercialization on net return is 0.269 and significant, corresponding to 3.60% increase in net-returns (Table 5). This finding is consistent with the Sebatta et al. (2014) that show that commercialization increases market participation which increases returns from market. In addition, the result shows that the treatment effect on per capita expenditure is positive and significant 0.104, corresponding to 1.42% increase in per capita expenditure for commercialized IKHs than the non-commercialized. Positive and significant impact of commercialization on per capita expenditure was evident in studies conducted in Nigeria (Awotide et al., 2014) and Uganda (Sebatta et al., 2014). The finding on the positive impact of commercialization underscores the need for policy attention to encourage IKHs to commercialize, capable of having significant positive impact on their livelihoods. Commercialization of medicinal plants provides diverse benefits to humanity which include food, medicines, and resource for shelter and clothing.

4.4 Robustness analysis using the inverse probability weighted regression methods

While the PSM estimates treatment effects of commercialized IKHs, we performed robustness checks on the analysis (Lu & White, 2014), by estimating the treatment effects of commercialization on the outcome variables using the Inverse Probability Weighted Regression Method (Williamson et al., 2014). Reported estimates of the IPWRA show that commercialization impacts net returns (log) and per capita expenditure (log) positively and significantly (Table 6), with ATT estimates of net returns (log) is 0.084 and that of per capita expenditure (log) is 0.309. These results are in consistent with that which were obtained in the PSM estimates, confirming the robustness of PSM using alternative technique.

Table 6 Robustness checks using IPWRA model

Outcomes	ATT	Standard error
Net returns (log)	0.084	0.018**
Per capita expenditure (log)	0.309	0.034**

5 Conclusion and policy implications

Using primary dataset obtained from 101 IKHs, we analyzed the factors influencing the commercialization of medicinal plants and how commercializing impact livelihood outcomes. The PSM approach was used to analyze the data to correct for bias attributed to observed factors. In addition, the IPWRA was applied to check the robustness of the PSM estimates. The results show that commercialization decision is influenced positively and significantly by factors including age, education access to water and membership of association. The empirical results also show that commercialization significantly increased net returns by 3.60% and per capita expenditure by 1.42%. The robustness of these findings is established by estimations using the IPWRA model.

The current findings provide important policy contributions toward improving livelihoods of households including IKHs. The livelihood improvement impact of commercialization as established in this study suggests that policy reforms that seek to foster active market participation of IKHs should be encouraged. This is specifically relevant to South Africa and some other developing countries where poverty and economic sustainability pose a serious threat. Furthermore, the results identified policy strategies that can help overcome constraints associated with the commercialization of medicinal plants. Younger IKHs may lack the experience to penetrate the market and therefore, faced with resistance to commercialization. Given that education has a positive relationship with commercialization, policy effort to facilitate formal and informal training that can enhance market participation remain pertinent. Access to water and membership of association were identified as an important driver of commercialization. This suggests that concerted efforts through policy formulation targeted at encouraging farmer group formation may enhance access to input and output markets which are key to commercialization of medicinal plants.

Appendix

See Table S1.

Table S1 Medicinal plants prescribed for childhood diseases in Ngaka Modiri Molema and Bojanala districts of North-West Province, South Africa

No [#]	Scientific name and Family [Voucher number]	Local name (Setswana)	Childhood diseases/conditions	Conservation status
1	*Acacia caffra* (Thunb.) Willd **Fabaceae [TPN 061]**	Poo tshetlha	Ulcer, sores and stop vomiting	Least concern
2	*Acrotome inflata* Benth **Lamiaceae [TPN 015]**	Mogato	Weakness, urinary tract infection, measles and sunken fontanelle	Least concern
3	*Aloe arborescens* Mill **Asphodelaceae [TPN 060]**	Lekgala	Skin itching and irritation	Least concern
4	*Aloe maculata* All **Asphodelaceae [TPN 010]**	Lekgala la thaba	Bladder inflammation, urinary tract infection, umbilical cord, diarrhea and burns	Least concern
5	*Aptosinum elongatum* Eng **Scrophulariaceae [TPN 016]**	Ditantanyane	Umbilical cord, muscle fits, measles, bladder inflammation, weight and appetite	Least concern
6	*Artemisia afra* Jacq. Ex Willd **Asteraceae [TPN 059]**	Lengana	Influenza	Least concern
7	*Asparagus exuvialis* Burch **Asparagaceae [TPN 018]**	Tlhokabotswaro	Teething	Least concern
8	*Barleria macrostegia* Nees **Acanthaceae [TPN 032]**	Thotsethunya	Sunken fontanelle	Least concern
9	*Argemone ochroleuca* Sweet **Papaveraceace [TPN 056]**	Sepodise	Teething	Invasive alien
10	*Baillonella toxisperma* Pierre **Sapotaceae [TPN 030]**	Mpumbulo	Sunken fontanelle	Invasive alien
11	*Boophone disticha* (L.f.) Herb **Amaryllidaceae [TPN 054]**	Lesoma	Ringworm	Least concern
12	*Boscia foetida* subsp. *longipedicellata* (Gilg) Toelken **Capparaceae [TPN 020]**	Motsetsigaralele	Sunken fontanelle and weaning	Least concern
13	*Bulbine frutescens* (L) Willd **Asphodelaceae [TPN 004]**	Makgabenyane	Sunken fontanelle, umbilical cord; body rash, sores, phlegm and urinary tract infection	Least concern
14	*Cadaba aphylla* (Thunb.) Wild **Capparaceae [TPN 052]**	Monna-montsho	Cleansing the child, sunken fontanelle	Least concern

Table S1 (continued)

No [#]	Scientific name and Family [Voucher number]	Local name (Setswana)	Childhood diseases/conditions	Conservation status
15	*Centaurea scabiosa* L **Asteraceae [TPN 055]**	Cornflower	Wounds and sunken fontanelle	Invasive alien
16	*Combretum apiculatum* Sond. subsp *apiculatum* **Combretaceae [TPN 058]**	Kgosi ya ditlhare	Infective eczema	Least concern
17	*Combretum hereroense* var. *parvifolium* (Engl.) Wickens Kew Bull **Combretaceae [TPN 005]**	Makakaba	Constipation	Least concern
18	*Commelina diffusa* Burm.f **Commelinaceae [TPN 039]**	Kgopokgolo	Umbilical cord, purgative the child, preventing evil spirits and weak child	Least concern
19	*Corchorus olitorius* f. *grandifolius* De Wild **Malvaceae [TPN 048]**	Juta mellow	Constipation and cramp	Least concern
20	*Cotyledon orbiculata* L **Crassulaceae [TPN 04]**	Tsebe ya kolobe	Pain, inflammation, sunken fontanelle and constipation	Least concern
21	*Cullen tomentosum* (Thunb) J.W.Grimes **Fabaceae [TPN 043]**	Mojakubu	Rash and sores	Least concern
22	*Clutia pulchella* var. *obtusata* (Sond.) Müll.Arg **Peraceae [TPN 007]**	Pudimolwetsi	Weaning	Least concern
23	*Dianthus mooiensis* F.N Williams subsp. *Kirkii* (Burtt Davys) SS Hooper **Caryophyllaceae [TPN 053]**	Letlhoka la tsela	Weaning, sunken fontanelle and body rash	Not evaluated
24	*Dicerocaryum senecioides* (Klotzsch) Abels **Pedaliaceae [TPN 011]**	Tshetlho ya mibitla e mebedi	Body rash	Least concern
25	*Dichrostachys cinerea* (L.) Wight & Arn **Fabaceae [TPN 051]**	Moselesele	Diarrhea	Least concern
26	*Dicoma anomala* Sond **Asteraceae [TPN 029]**	Tlhonya	Diarrhea, body rash and sunken fontanelle	Least concern
27	*Disparago anomala* Schltr. Ex Levyns **Asteraceae [TPN 041]**	Mojakabomo	Sunken fontanelle, weaning and constipation	Least concern

Table S1 (continued)

No [#]	Scientific name and Family [Voucher number]	Local name (Setswana)	Childhood diseases/conditions	Conservation status
28	*Elephantorrhiza elephantina* (Burch) Skeels **Fabaceae [TPN 051]**	Mositsane	Infective eczema, diarrhea, ulcer, burns and measles	Least concern
29	*Eucomis autumnalis* (Mill). Chitt **Asparagaceae [TPN 052]**	Mathubadifala	Urinary inflammation, oral blisters and infective eczema	Least concern
30	*Euphorbia prostrata* Aiton **Euphorbiaceae [TPN 019]**	Letswetlane	Constipation and phlegm	Not evaluated
31	*Euphorbia serpen* Kunths **Euphorbiaceae [TPN 030]**	Lwetsane	Weaning and sunken fontanelle	Least concern
32	*Eucalyptus camaldulensis* Dehnh **Myrtaceae [TPN 047]**	Eucalyptus	Ringworm, tuberculosis and influenza	Least concern
33	*Gomphocarpus fruticosus* (L.) W.T.Aiton **Apocynaceae [TPN 012]**	Segamelamatshi	Sunken fontanelle	Least concern
34	Harpagophytum procumbens subsp. procumbens DC. ex Meisn **Pedaliaceae [TPN 033]**	Sengaparile	Bladder inflammation, kidney failure, pneumonia, liver failure, pain and inflammation, urinary tract infection, gaining weight and bronchitis	Not evaluated
35	*Helichrysum nudifolium* (L). Less **Asteraceae [TPN 40]**	Motlhatlhabadimo/Mphepho	Enhance child growth	Least concern
36	*Helichrysum paronychioides* DC. Humbert **Asteraceae [TPN 037]**	Phate ya ngaka	Sunken fontanelle, ulcer, bladder inflammation, influenza and nappy rash	Least concern
37	*Hibiscus calyphyllus* Cav **Malvaceae [TPN 017]**	Motshididi	Impetigo	Least concern
38	*Hilliardiella elaeagnoides* (DC) Swelank and J.C.Manning **Asteraceae [TPN 025]**	Ntshikologa	Diarrhea	Least concern
39	*Hypoxis hemerocallidea* Fisch., C.A.Mey. and Ave-Lall **Hypoxidaceae [TPN 058]**	Tshuka ya poo	Sunken fontanelle, bladder inflammation, kidney failure, urinary tract infection, bronchitis pneumonia, child cleanse influenza and ulcer, gastro-intestinal and appetite	Least concern

Table S1 (continued)

No [#]	Scientific name and Family [Voucher number]	Local name (Setswana)	Childhood diseases/conditions	Conservation status
40	*Hydnora africana* Thunb **Hydnoraceae [TPN 031]**	Letlhoele	Coughing blood	Least concern
41	*Ipomoea oblongata* E.Mey.ex Chiosy A **Convolvulaceae [TPN 001]**	Mokatelo/morobe	Chickenpox, measles and umbilical cord and appetite	Least concern
42	*Lycium horridum* Thunb **Solanaceae [TPN 042]**	Motlhalawadikonyana	Umbilical cord, warts, skin irritation and sunken fontanelle	Least concern
43	*Nigella sativa* L **Ranunculaceae [TPN 035]**	Blackseed	Immune booster and burns	Invasive alien
44	*Opuntia ficus-indica* (L) Mill **Cactaceae [TPN 022]**	Toorofeye	Diabetes and cholesterol	Least concern
45	*Ozoroa paniculosa* (Sond.) R.Fern. and A.Fern **Anacardiaceae [TPN 034]**	Monokwana	Impetigo and body rash	Least concern
46	*Pentanisia prunelloides* (Klotzsch ex Eckl. and Zeyh.) Walp **Rubiaceae [TPN 027]**	Setimamollo	Cancer, impetigo, skin irritation, sunken fontanelle and chicken pox and oral blisters	Least concern
47	*Punica granatum* L **Lythraceae [TPN 021]**	Pomegranate	Diarrhea	Not evaluated
48	*Prunus persica* (L.) Batsch **Rosaceae [TPN 013]**	Perekisi	Constipation and cramp	Least concern
49	*Ricinus communis* L ***Euphorbiaceae*[TPN 010]**	Mokura	Chicken pox	Not evaluated
50	*Sansevieria hyacinthoides* (L) Druce **Asparagaceae [TPN 014]**	Mosekelatsebeng	Earache and sores	Least concern
51	*Searsia pyroides* (Burch.) Moffett **Anacardiaceae [TPN 038]**	Mohitla/Bohitlha	Influenza	Least concern
52	*Senna italica* subsp. arachoides Burch Lock **Fabaceae [TPN 028]**	Sebetebete	Constipation and ulcer	Least concern

Table S1 (continued)

No [#]	Scientific name and Family [Voucher number]	Local name (Setswana)	Childhood diseases/conditions	Conservation status
53	*Senna tora* (L.) Roxb **Fabaceae [TPN 009]**	Monepenepe	Diarrhea	Least concern
54	*Siphonochilus aethiopicus* (Schweinf.) B.L.Burtt **Zingiberaceae**	Serokolo	Weaning, sunken fontanelle, influenza, appetite, ulcer and diarrhea	Critically endangered
55	*Solanum campylacanthum* Hochst. ex A.Rich. subsp. *panduriforme* (Drege ex Dunal) J **Solanaceae [TPN 002]**	Tolwane nnye	Sunken fontanelle, umbilical cord, bladder inflammation and gastroenteritis	Least concern
56	*Solanum lichtensteinii* Willd **Solanaceae [TPN 036]**	Tolwane (Kgaba)	Sunken fontanelle, bladder inflammation, umbilical cord, stop vomiting and enhance growth in children	Least concern
57	*Sutherlandia frutescens* (L.) R.Br **Fabaceae [TPN 006]**	Lerumolamadi	Body rash, bladder inflammation, kidney failure and Urinary tract infection	Not evaluated
58	*Teucrium sessiliflorum* Benth **Lamiaceae [TPN 026]**	Setlhokotlhko	Diarrhea and sunken fontanelle	Not evaluated
59	*Warburgia salutaris* (G.Bertol.) Chiov ***Canellaceae*** **[TPN 049]**	Lekwati/Molaka	Pneumonia, influenza, sores	Endangered
60	*Withania somnifera* (L) Dunal **Solanaceae [TPN 003]**	Modikasope	Sunken fontanelle, restless and weaning, for sores or pulse and constipation	Least concern
61	*Ziziphus oxyphylla* Edgew **Syn:** *Ziziphus acuminata* Royle **Rhamnaceae [TPN 024]**	Sekgalofatshe	Diarrhea	Least concern

Names for the plants were verified using the World flora online (http://www.worldfloraonline.org/), and conservation status were based on the South African Red data list (http://redlist.sanbi.org/species). Details of the complete inventory of the recorded medicinal plants is available in Ndhlovu et al (2023)

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Author contributions Conceptualization was done by PTN, AOO, WOM, KOO, and AOA. PTN conducted the field study, analyzed the data and prepared the manuscript. Supervision by AOO, KOO, WOM, and AOA. All the authors reviewed and approved the final manuscript for submission.

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Declarations

Conflicts of interest We declare no conflict of interest regarding this research.

Consent for publication The participants provided consent for the research findings to be published as we obtained inform consent from each of them prior to the data collection.

References

Abdullah, Fazli, R., Ahamad, R., Sajjad, A., Abbas Ali, C., Waqar, A., Aasir, I., & Ud Izhar, D. (2019). Determinants of commercialization and its impact on the welfare of smallholder rice farmers by using Heckman's two-stage approach. *Journal of the Saudi Society of Agricultural Sciences, 18*, 224–233.

Abdullahi, A. A. (2011). Trends and challenges of traditional medicine in Africa. *African Journal of Traditional, Complementary and Alternative Medicines, 8*, 115–123.

Abouzekry, S. S., Badawy, M. T., Ezzelarab, N. M., & Abdellatif, A. (2021). Phytotherapy for diabetes mellitus; A review of Middle Eastern and North African folk medicinal plants. *Journal of Herbmed Pharmacology, 10*, 1–13.

Agisho, H., Osie, M., & Lambore, T. (2014). Traditional medicinal plants utilization, management and threats in Hadiya Zone, Ethiopia. *Journal of Medicinal Plants Studies, 2*, 94–108.

Angelsen, A., Jagger, P., Babigumira, R., Belcher, B., Hogarth, N.J., Bauch, S., Börner, J., Smith-Hall, C., & Wunder, S. (2014). Environmental income and rural livelihoods: A global-comparative analysis. *World Development, 64*, S12–S28

Angelsen, A., Larsen, H. O., & Olsen, C. S. (2012). *Measuring livelihoods and environmental dependence: Methods for research and fieldwork*. Routledge.

Astutik, S., Pretzsch, J., & NdzifonKimengsi, J. (2019). Asian medicinal plants' production and utilization potentials: A review. *Sustainability, 11*, 5483.

Awotide, B., Abdoulaye, T., Alene, A., & Manyong, V. M. (2014). Assessing the extent and determinants of adoption of improved cassava varieties in southwestern Nigeria. *Journal of Development and Agricultural Economics, 6*, 376–385.

Barbier, E. B. (2010). Poverty, development, and environment. *Environment and Development Economics, 15*, 635–660.

Bareetseng, S. (2022). The worldwide herbal market: Trends and opportunities. *Journal of Boimedical Research and Environmental Sciences, 3*, 575–584.

Belcher, B., & Schreckenberg, K. (2007). Commercialisation of non-timber forest products: A reality check. *Development Policy Review, 25*, 355–377.

Cavendish, W. (2000). Empirical regularities in the poverty-environment relationship of rural households: Evidence from Zimbabwe. *World Development, 28*, 1979–2003.

Cunningham, A. (1991). Development of a conservation policy on commercially exploited medicinal plants: A case study from southern Africa. *Conservation of Medicinal Plants, 337*, 338–362.

Damania, R., Joshi, A., & Russ, J. (2020). India's forests–Stepping stone or millstone for the poor? *World Development, 125*, 104451.

Das, S. K., & Basu, J. P. (2022). Tribal livelihood vulnerability due to climate change: A study across tribes of Paschim Medinipur district of West Bengal. *SN Business and Economics, 2*, 103.

De Vynck, J. C., Van Wyk, B.-E., & Cowling, R. M. (2016). Indigenous edible plant use by contemporary Khoe-San descendants of South Africa's Cape South Coast. *South African Journal of Botany, 102*, 60–69.

Department of Health. (2019). *Integrated management of childhood illness* (pp. 1–79). South African Department of Health.

Dold, A. P., & Cocks, M. L. (2001). Traditional veterinary medicine in the Alice district of the Eastern Cape Province, South Africa: Research in action. *South African Journal of Science, 97*, 375–379.

Dovie, D. B. (2003). Rural economy and livelihoods from the non-timber forest products trade. Compromising sustainability in southern Africa? *The International Journal of Sustainable Development and World Ecology, 10*, 247–262.

Escobal, J., & Aldana, U. (2003). Are nontimber forest products the antidote to rainforest degradation? Brazil nut extraction in Madre De Dios, Peru. *World Development, 31*, 1873–1887.

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics, 5*, 1–4.

Fisher, R. (2017). *Local action for biodiversity: Wetland management in a changing climate* (pp. 1–44). ICLEI—Local Governments for Sustainability—Africa Secretariat.

Freed, G. L., Dunham, K. M., Switalski, K. E., Jones, M. D., & McGuinness, G. A. (2009). Recently trained general pediatricians: Perspectives on residency training and scope of practice. *Journal of Pediatrics, 123*, 38-S43.

Godoy, R., Reyes-García, V., Byron, E., Leonard, W. R., & Vadez, V. (2005). The effect of market economies on the well-being of indigenous peoples and on their use of renewable natural resources. *Annual Review of Anthropology, 34*, 121–138.

Greene, W. H. (2003). *Econometric analysis*. Pearson Education India.

Hickey, G. M., Pouliot, M., Smith-Hall, C., Wunder, S., & Nielsen, M. R. (2016). Quantifying the economic contribution of wild food harvests to rural livelihoods: A global-comparative analysis. *Food Policy, 62*, 122–132.

Hirano, K., & Imbens, G. W. (2004). The propensity score with continuous treatments. *Applied Bayesian Modeling and Causal Inference from Incomplete-Data Perspectives, 226164*, 73–84.

Hoveka, L. N., van der Bank, M., Bezeng, B. S., & Davies, T. J. (2020). Identifying biodiversity knowledge gaps for conserving South Africa's endemic flora. *Biodiversity and Conservation, 29*, 2803–2819.

Ijinu, T., Rajasekharan, S., George, V., & Pushpangadan, P. (2023). *Access and Benefit sharing in indigenous knowledge stewardship and sustainable development, biodiversity conservation through access and benefit sharing (ABS) Himalayas and Indian Sub-Continent* (pp. 163–185). Springer.

Ivanova, T., Bosseva, Y., Chervenkov, M., & Dimitrova, D. (2022). Lamiaceae plants in Bulgarian rural livelihoods-diversity, utilization, and traditional knowledge. *Agronomy, 12*, 1631.

Jagger, P. (2012). Environmental income, rural livelihoods, and income inequality in western Uganda. *Forests, Trees and Livelihoods, 21*, 70–84.

Kepe, T. (2007). Medicinal plants and rural livelihoods in Pondoland, South Africa: Towards an understanding of resource value. *The International Journal of Biodiversity Science and Management, 3*, 170–183.

Kothari, C. R. (2004). *Research methodology (Method and technqiues)*. New Age International (P) Limited, Publishers.

Kruger, A. C., & Nxumalo, M. P. (2017). Historical rainfall trends in South Africa: 1921–2015. *Water SA, 43*, 285–297.
Lechner, M. (2001). *Identification and estimation of causal effects of multiple treatments under the conditional independence assumption, econometric evaluation of labour market policies* (pp. 43–58). Springer.
Lechner, M. (1999). Earnings and employment effects of continuous Gff-the-job training in east germany after unification. *Journal of Business and Economic Statistics, 17*, 74–90.
Leistner, O. A. (2000). *Seed plants of southern Africa: Families and genera*. National Botanical Institute Pretoria.
Lu, X., & White, H. (2014). Robustness checks and robustness tests in applied economics. *Journal of Econometrics, 178*, 194–206.
Mahomoodally, M. F. (2013). Traditional medicines in Africa: An appraisal of ten potent African Medicinal Plants. *Evidence-Based Complementary and Alternative Medicine, 2013*, 617459.
Mahwasane, S. T., Middleton, L., & Boaduo, N. (2013). An ethnobotanical survey of indigenous knowledge on medicinal plants used by the traditional healers of the Lwamondo area, Limpopo province, South Africa. *South African Journal of Botany, 88*, 69–75.
Makinde, S., Ojekale, Ab., Osinake, T., & Awusinu, T. (2015). An Ethnomedical and Ethnobotanical survey of Plants Herbal Therapy used for Obesity, Asthma, Diabetes and Fertility by the Badagry people of Lagos State, Nigeria. *Journal of Medicinal Plants Studies, 3*, 01–06.
Mander, M. (1998). *Marketing of indigenous medicinal plants in South Africa - A case study in Kwazulu-Natal*. Food and Agriculture Organization (FAO) of the United Nations, Rome, Italy.
Martin, G. J. (2010). *Ethnobotany: A methods manual*. Routledge.
McSweeney, K. (2004). Forest product sale as natural insurance: The effects of household characteristics and the nature of shock in eastern Honduras. *Society and Natural Resources, 17*, 39–56.
Mmamosheledi, E. M., & Mncengeli, S. (2019). African traditional medicine: South African perspective. In M. Cengiz (Ed.), *Traditional and complementary medicine*. IntechOpen.
Mudau, T. E., Olowoyo, J. O., & Amoo, S. O. (2022). Ethnobotanical assessment of medicinal plants used traditionally for treating diabetes in Vhembe district, Limpopo Province, South Africa. *South African Journal of Botany, 146*, 304–324.
Ndhlala, A. R., Stafford, G. I., Finnie, J. F., & Van Staden, J. (2011). Commercial herbal preparations in KwaZulu-Natal, South Africa: The urban face of traditional medicine. *South African Journal of Botany, 77*, 830–843.
Ndhlovu, P. T., Asong, J. A., Omotayo, A. O., Otang-Mbeng, W., & Aremu, A. O. (2023). Ethnobotanical survey of medicinal plants used by indigenous knowledge holders to manage healthcare needs in children. *PLoS ONE, 18*, e0282113.
Ndhlovu, P. T., Omotayo, A. O., Otang Mbeng, W., & Aremu, A. O. (2021). Ethnobotanical review of plants used for the management and treatment of childhood diseases and well-being in South Africa. *South African Journal of Botany, 137*, 197–215.
Neupane, H., Paudel, K. P., Adhikari, M., & He, Q. (2022). Impact of cooperative membership on production efficiency of smallholder goat farmers in Nepal. *Annals of Public and Cooperative Economics, 93*, 337–356.
Nilsson, K., Sangster, M., & Konijnendijk, C. C. (2011). *Forests, trees and human health and well-being: Introduction, Forests, trees and human health*. Springer.
Ogunniyi, A., Oluseyi, O. K., Adeyemi, O., Kabir, S. K., & Philips, F. (2017). Scaling up agricultural innovation for inclusive livelihood and productivity outcomes in Sub-Saharan Africa: The case of Nigeria. *African Development Review, 29*, 121–134.
Olagunju, K. O., Ogunniyi, A. I., Oyetunde-Usman, Z., Omotayo, A. O., & Awotide, B. A. (2021). Does agricultural cooperative membership impact technical efficiency of maize production in Nigeria: An analysis correcting for biases from observed and unobserved attributes. *PLoS ONE, 16*, e0245426.
Olowo, S. F., Omotayo, A. O., Lawal, I. O., & Aremu, A. O. (2022). Improving rural livelihood through the cultivation of indigenous fruits and vegetables: Evidence from Ondo State. *Nigeria. Agriculture, 12*, 372.
Omotayo, A. O., & Aremu, A. O. (2020). Underutilized African indigenous fruit trees and food-nutrition security: Opportunities, challenges, and prospects. *Food and Energy Security, 9*, e220.
Omotayo, A. O., Ndhlovu, P. T., Tshwene, S. C., & Aremu, A. O. (2020). Utilization pattern of indigenous and naturalized plants among some selected rural households of North West Province, South Africa. *Plants, 9*, 953.
Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research, 42*, 533–544.

Prado Córdova, J. P., Wunder, S., Smith-Hall, C., & Börner, J. (2013). Rural income and forest reliance in highland Guatemala. *Environmental Management, 51*, 1034–1043.
Randela, R., Alemu, Z. G., & Groenewald, J. A. (2008). Factors enhancing market participation by small-scale cotton farmers. *Agrekon, 47*, 451–469.
Rosenbaum, P. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika, 70*, 41–55.
Sebatta, C., Mugisha, J., Katungi, E., Kashaaru, A., & Kyomugisha, H. (2014). Smallholder farmers' decision and level of participation in the potato market in Uganda. *Modern Economy, 5*, 895–906.
Seile, B. P., Bareetseng, S., Koitsiwe, M. T., & Aremu, A. O. (2022). Indigenous knowledge on the uses, sustainability and conservation of African Ginger (*Siphonochilus aethiopicus*) among two communities in Mpumalanga Province, South Africa. *Diversity, 14*, 192.
Shackleton, C. M., Shackleton, S. E., Buiten, E., & Bird, N. (2007). The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. *Forest Policy and Economics, 9*, 558–577.
Sher, H., Aldosari, A., Ali, A., & de Boer, H. J. (2014). Economic benefits of high value medicinal plants to Pakistani communities: An analysis of current practice and potential. *Journal of Ethnobiology and Ethnomedicine, 10*, 71. https://doi.org/10.1186/1746-4269-10-71
Stats, S. A. (2015). Living conditions of households in South Africa. In P. Lehohla (Ed.), *An analysis of household expenditure and income data using the LCS 2014/2015* (pp. 1–232). Statistics South Africa.
Stats, S. A. (2018). Provincial profile: North West Community Survey 2016. In R. Maluleke (Ed.), *Provincial profile: North West/Statistics South Africa* (pp. 1–93). Statistics South Africa.
Street, R., & Prinsloo, G. (2013). Commercially important medicinal plants of South Africa: A review. *Journal of Chemistry, 2013*, 205048. https://doi.org/10.1155/2013/205048
Sunderlin, W. D., Angelsen, A., & Wunder, S. (2003). Forests and poverty alleviation. *State of the World's Forests, 2003*, 61–73.
Tafesse, A., Megerssa, G. R., & Gebeyehu, B. (2020). Determinants of agricultural commercialization in Offa District, Ethiopia. *Cogent Food & Agriculture, 6*, 1816253.
Tahir, M., Asnake, H., Beyene, T., Van Damme, P., & Mohammed, A. (2023). Ethnobotanical study of medicinal plants in Asagirt District, Northeastern Ethiopia. *Tropical Medicine and Health, 51*, 1. https://doi.org/10.1186/s41182-023-00493-0.
Van Wyk, A. S., & Prinsloo, G. (2018). Medicinal plant harvesting, sustainability and cultivation in South Africa. *Biological Conservation, 227*, 335–342.
Vedeld, P., Angelsen, A., Sjaastad, E., & Kobugabe Berg, G. (2004). *Counting on the environment: Forest incomes and the rural poor*. IBRD Washington.
Vedeld, P., Angelsen, A., Bojö, J., Sjaastad, E., & Berg, G. K. (2007). Forest environmental incomes and the rural poor. *Forest Policy and Economics, 9*, 869–879.
Williamson, E. J., Forbes, A., & White, I. R. (2014). Variance reduction in randomised trials by inverse probability weighting using the propensity score. *Statistics in Medicine, 33*, 721–737.
World Health Organisation. (2019). *Global strategy on diets, physical activity, and health, Obesity and overweight*. WHO.
World Health Organization. (2013). *World health Organization traditional medicine strategy 2014–2023* (pp. 1–78). WHO.
Van Wyk, B.-E., Van Oudtshoorn, B., & Gericke, N. (1997). Medicinal plants of South Africa. Briza.
Yimer, E. M., Tuem, K. B., Karim, A., Ur-Rehman, N., & Anwar, F. (2019). *Nigella sativa* L. (black cumin): A promising natural remedy for wide range of illnesses. *Evidence-Based Complementary and Alternative Medicine, 2019*, 1528635. https://doi.org/10.1155/2019/1528635
Yuan, H., Ma, Q., Ye, L., & Piao, G. (2016). The traditional medicine and modern medicine from natural products. *Molecules, 21*, 559.

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Authors and Affiliations

Peter Tshepiso Ndhlovu[1,2] · Abiodun Olusola Omotayo[3] · Kehinde Oluseyi Olagunju[4] · Wilfred Otang-Mbeng[2] · Adeyemi Oladapo Aremu[1]

✉ Adeyemi Oladapo Aremu
Oladapo.Aremu@nwu.ac.za

Peter Tshepiso Ndhlovu
Tshepiso.Ndhlovu@ump.ac.za

Abiodun Olusola Omotayo
Olusola.Omotayo@nwu.ac.za

Kehinde Oluseyi Olagunju
Kehinde.Olagunju@daera-ni.gov.uk

Wilfred Otang-Mbeng
Wilfred.Mbeng@ump.ac.za

1 Faculty of Natural and Agricultural Sciences, Indigenous Knowledge Systems Centre, North-West University, Private Bag X2046, Mmabatho 2745, South Africa

2 Faculty of Agriculture and Natural Sciences, School of Biology and Environmental Sciences, University of Mpumalanga, Private Bag X11283, Mbombela 1200, South Africa

3 Faculty of Natural and Agricultural Sciences, Food Security and Focused Area Research Group, North-West University, Private Bag X2046, Mmabatho 2745, South Africa

4 Economics and Evaluation Branch, Department of Agriculture, Environment and Rural Affairs, Belfast BT4 3SB, UK