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Gender differentials in primary processing and market participation by mopane worm harvesters in Zimbabwe: insights from the COVID-19 pandemic phase

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Abstract

Background Gender disparities in access to inputs, markets, financial inclusion, and participation in strategic value chains are major developmental challenges in emerging economies. Participation in the edible insect value chain has become an essential source of income, food, and nutrition in some African countries. This paper uses a bivariate probit model to examine the gender differentials for primary mopane worm harvesters' participation in primary processing and market participation during COVID-19 in Southeastern Zimbabwe. Using a structured questionnaire, the data were gathered from 393 primary harvesters in five purposively selected wards in the Gwanda District of Zimbabwe. This study examines the gender differentials for primary mopane worm harvesters' participation in primary processing and market participation during COVID-19 in Southeastern Zimbabwe.

Results Results show that women are likelier to participate in primary value addition to preparing for the lean season opportunities. There are gender differentials in the participation in markets during COVID-19. Results show a significant negative relationship between participants' ages and female engagement in mopane processing and a positive correlation with female involvement in lean COVID-19 season marketing. Male harvesters' participation in the lean market during the COVID-19 pandemic was significantly correlated positively with age and education level, while the choice to participate in the lean market was negatively correlated with the dependency ratio.

Conclusions Collaborative, community-centric, and gender-accommodative development of the mopane worm value chain is important. Focal issues are on supporting primary value addition for lean season market participation and during market shocks such as COVID-19. This can be a leap towards gender equality and improving livelihoods of women and men in mopane harvesting areas. The study recommends marketing and district-specific policies explicitly addressing mopane worm harvesting and marketing affects market participation and primary value-addition decisions.

Keywords Gender gaps, Mopane worm farming, Community resources management, Value addition, COVID-19 pandemic

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Introduction

Gender equality is one of the central pillars of socio-economic development. Gender differentials manifest in skewed access to inputs, markets, financial inclusion, and participation in strategic value chains. These mismatches have persistently threatened economic development in sub-Saharan Africa (SSA). Analysis of gender differentials in previous studies has been too localized and focused extensively on the primary production decisions by households. As Donkor et al. [7] reported, there are substantial gender differentials in the drylands of Uganda across multiple livelihood options. The authors said that males mainly own production resources while females are sidelined to use without ownership. Gondo et al. [8] noted the need to realign market access for male and female producers as a gateway to improved marketing efficiency in Zimbabwe. In South Africa, Baiyegunhi and Oppong [2] also reported the gender imbalances in the value chain's cotton production and marketing nodes and attributed these to structural differences in resource ownership.

Given that the Mopane worm is an essential source of income, food, and nutrition among most communities in rural Zimbabwe, they have been gradually integrated into mainstream food systems [21]. Households depend on the worms as a locally available and principal source of subsistence. Before integrating the mopane business into mainstream food systems, there were minimal external harvesters, and marketing prospects were negligible. The gender differential is in Namibia, Malawi, Zambia, and Zimbabwe, where female mopane worm harvesters dominate, representing approximately 65% of the primary harvesters [31]. However, these women face challenges such as a lack of financial support, support networks, and independent decision-making regarding marketing proceeds [32, 35]. Gender mainstreaming and women empowerment initiatives (e.g., forming women-led cooperatives, tailor-made financing packages, and capacity-building programs) have since taken center stage in supporting the marketing of these worms to integrate them into food systems effectively. This has been the case across most locally driven rural development programs in parts of Zimbabwe where mopane worm is abundant. These initiatives have also been streamlined to address the gender disparities that characterize mopane worms' marketing in Zimbabwe. This has been further compounded by the commercial infiltration of mopane worm marketing practices along different value chain nodes, including children's cereals and snacks [16].

The trading of mopane worms is gradually becoming a commercial business in Zimbabwe. It provides a valuable source of income, nutrition, and health benefits to rural people, where significantly high financial returns per hectare have been reported relative to any other land use in these communities [31]. This is primarily because the worms grow naturally, hence, no initial costs are involved in increasing the number of worms. Tapping into these positives can be a substantial motivating factor for investments in processing facilities and enhanced participation during lean season periods. The middleman has hijacked the mopane worm value chain, which now plays a central role between the primary harvester and the final consumers. The different dimensions of the intermediaries' functions have resulted in the worms penetrating the lucrative urban markets, including the informal roadside markets, formal local shops, and supermarkets [29]. The *modus operandi* is that the intermediaries buy dried worms from the local primary collectors in the rural areas and supply them to several urban markets [8]. Women entrepreneurs have taken up the roles of the middleman and established marketing groups that sell the worms in urban areas, thus reducing transport costs and increasing their bargaining power. Several factors, including the distance to the market, availability of the worms (seasonal or annual), processing costs, and transport costs, affect the worms' price. Recently, the demand for worms in Zimbabwe has increased. According to Looy et al. [14], urban consumers are paying four folds in the end market as much as the rural primary harvester. This shows the prospects of mopane worms to be a commercially lucrative seasonal enterprise that can reduce food and income insecurity [3]. Some harvesters process the mopane worms and store them to sell during the lean season market when the prices are relatively higher due to the shortages of the worms in the markets.

The main research question is whether the harvesters who store worms for selling during the lean season participate in the market during the lean season period, such as COVID-19. This paper examines the gender differentials for primary mopane worm harvesters' participation in primary processing and market participation during COVID-19 in Southeastern Zimbabwe.

There are indications that, in the future, the continued reduction in the availability of mopane worms and other edible insects may increase malnutrition and poverty among rural communities. This can be attributed to competition for the same niche with other species and land use changes, leading to deforestation, overgrazing, and subsequent harvest loss [24]. Given the importance of mopane worms in Zimbabwe, it may also be critical to migrate from the traditional reliance on the natural occurrence of the worms and invest in creating mopane worm farms to increase yields and reliability. These farms have been pilot-tested in South Africa [2], where the primary limitation was the disease outbreaks and parasitism of egg masses. Designing these mopane worm farms can

be a panacea to improving the current poor communal management of worms [28].

As in Africa, the harvesting, processing, and marketing of mopane worms in Southeastern Zimbabwe are significantly affected by environmental and socioeconomic changes that disrupt the value chain. Since, in most cases, the harvesters move from communities, establish camps in forests, and move from one forest to the other, this was significantly compromised due to the movement restrictions during COVID-19. In addition, given that the marketing of mopane worms has extended to export markets where targeted processing is done, these market chains were significantly disrupted [19]. This was also compounded by the domestic markets, which absorbed less of the mopane worms due to dwindling purchasing power, especially in the urban areas, as people lost their sources of income during COVID-19. In Zimbabwe, the effects of different factors on the market participation of primary harvesters during COVID-19 are not adequately documented. This can be a research gap that can be further explored to improve the marketing of mopane worms during shocks such as COVID-19. This paper contributes to the debate about the drivers of gender differentials in mopane worms marketing in Zimbabwe to focus the policy and practice interventions on commercializing the commodity.

The rest of the paper is organized as follows. The next section presents the methodology of the study. Followed by results and discussions, respectively. The last section provides the conclusions of the study.

Methodology

Conceptual framework

The conceptual framework of the study is presented in Fig. 1. The key components of the framework were based on a literature review [7, 20, 25]. As shown in Fig. 1, the marketing of mopane worms is influenced by social, economic, and institutional factors, which determine a harvester's market participation decision. COVID-19 restrictions were expected to reduce market participation [20]. However, those who had processed and stored mopane worms in preparation for the next lean season could still participate in local markets, assuming that the consumers could absorb the worms. At the same time, the harvesters would also get utility-maximizing revenue.

The concept of market integration, namely access to and participation in markets, has gained prominence in recent studies [39]. Farmers' market integration during the COVID-19 pandemic depended on the extent to which the pandemic drove the anticipated changes in farmers, institutional access, social factors, economic

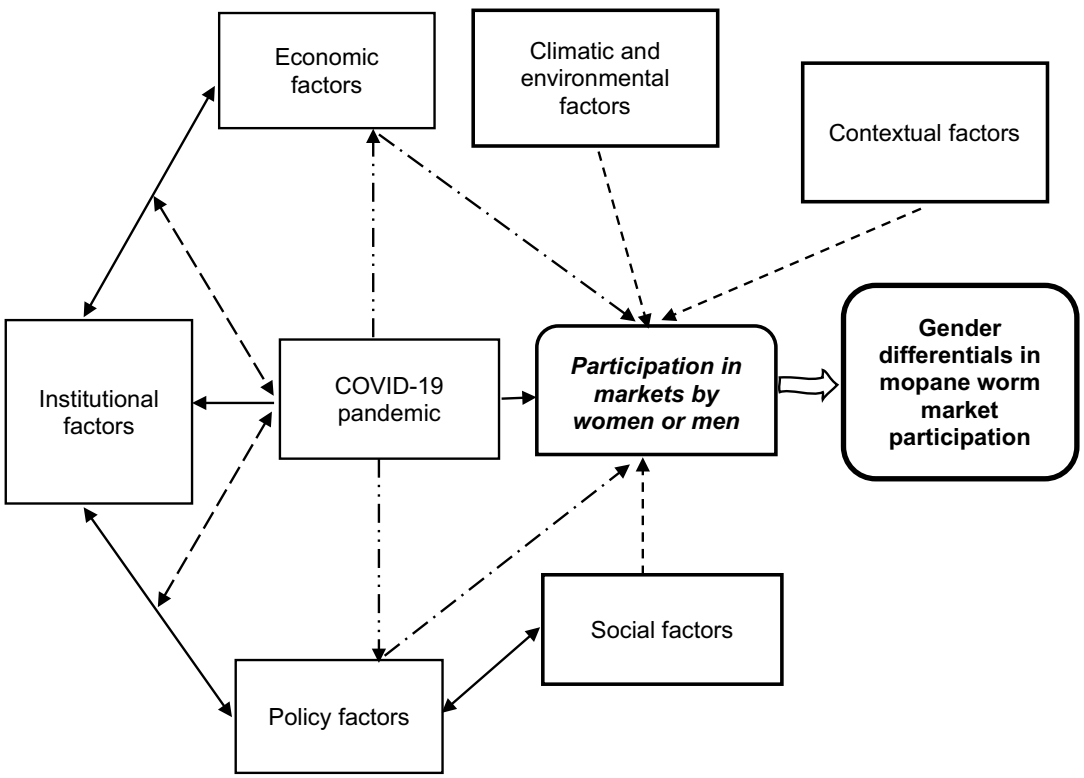


Fig. 1 Conceptual framework. Source. Authors' construction

factors, climatic and environmental, policy factors, pandemic, and contextual factors [5].

It focuses on the stressors and drivers of market participation and how the communities take advantage (or fail to) of existing institutional (association; extension contact; training; storage, distance, information), climatic and environmental (temperature, light, wind, water, humidity), social (age, education, dependency), economic factors (price, payment, buyer, income, transport), policy factors (harvesting, policy) and contextual factors (natural, sensorial, temporal, built, economic, political, cultural, social, physical, mental, social, cultural) to make marketing decisions. The framework also captures the indigenous knowledge systems and practices in decision-making processes for mopane worm market participation [25] or some form of deviance caused by COVID-19 in the gender lens. The study adopted the action theory to understand how the different factors define the interconnected processes that determine the impact of COVID-19 policy interventions on the market participation of mopane worm harvesters. This theory then splits the willful market participation by harvesters who had prepared for the lean season market.

Social, economic, institutional, and other contextual factors, such as the location of harvesting sites and markets, were identified as possible influencers of the mopane market participation decisions [26]. An analysis was made in the context of COVID-19 and the decision by the farmer to store worms for marketing during the lean season. Literature on market participation for mopane worms and other insects guided the section on these variables. Mufandaedza et al. [21] reported that social factors, including the harvester's education level, are essential in determining the likelihood of market participation during the lean season. The authors also identified the household structure variables, such as household size and the dependency ratio, as determining whether the harvester will participate in mopane marketing during the lean season.

Sekonya et al. [28] reported the significance of institutional factors such as access to market information and isolated the central role of associations as potential hubs of information for mopane worm harvesters. They noted that these factors enhance the functioning of the mopane worm value chains and can sustain market participation activities even during shocks such as COVID-19. Interestingly, Ndlovu et al. [24] also traced the potential effects of mopane worm farming in reducing market disruptions and thus provided insights into the impact of harvesting locations on market participation decisions. Sekonya et al. [28] also analyzed the linkages between social and economic factors in determining the effect of COVID-19 lockdowns on market participation. They reported a strong positive relationship between the level of other sources of income in the context of COVID-19 and the decision to participate in marketing.

This framework in Fig. 1 explains the relationships across the various factors in a way that helps to reshape the knowledge landscape about the gender differentials in the marketing of mopane worms, especially during two critical phases of COVID-19 and the preparation for the lean season market through primary processing. The framework, therefore, emphasized the impact of social, economic, and institutional factors on market participation during the COVID-19 period and how the same factors affect the decision by the harvester to process and store mopane worms for selling during the lean season. This framework is appropriate since it traces two related decisions of storing for lean season markets (preparing for an uncertain condition) and participating in markets during COVID-19 (also an uncertain situation) in Southeastern Zimbabwe.

Study area

The data were collected in the Gwanda district of Zimbabwe in July–August 2022. The district is the provincial administrative capital of Matabeleland South Province (Fig. 2). The coordinates of Gwanda district are 20°56′20.0″S, 29°01′07.0″E, and the district is located at an average elevation of 668 m above the mean sea level. The district has twenty communal wards (an administrative unit within the district), one commercial ward, and three resettlement areas [22]. Gwanda district falls within natural regions IV and V, characterized by low, erratic rainfall patterns and extreme agricultural and hydrological droughts. The mean annual rainfall in the district is 340 mm, with rainfall patterns decreasing along the Gwanda North to Gwanda South gradient. The average effective rainfall is 380 mm per annum in the North and 300 mm per annum in the South. The rainfall season characteristically spans from October to April but is characterized by intermittent mid-season dry spells. Additionally, Gwanda exhibits long, hot summers (September to March) and short, cool winters (April to August), averaging 30 ℃ for the former season and 18 ℃ for the latter.

Given that the communities in the district are mainly rural, dependency on agriculture still dominates, with 76% of households directly or indirectly dependent on agriculture. Livestock production is the primary livelihood activity in the area, with goats and cattle breeding projects scattered around the district. In areas where water sources are available, community gardens supported mainly by non-governmental organizations also offer income and food for the households, thus pushing some communities towards self-sufficiency. Crop

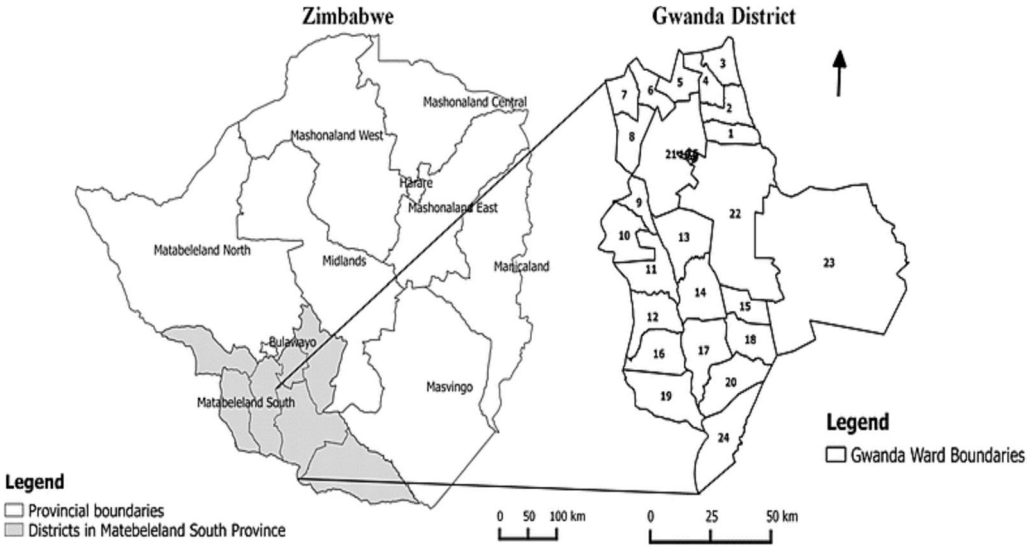


Fig. 2 Map showing Gwanda district and the wards. Source: Authors' construction

production is also actively practiced with small grains, especially sorghum and pearl millet, widely produced by farmers [38]. These crops account for over 79% of the annual cropped area in the district. Communities also depend on harvesting wild mopane worms for subsistence and supplying local and external markets. More recently, in recognition of the role of mopane as an economic base, Gwanda Rural District Council (RDC) is drafting bylaws aimed at commercializing the harvesting of mopane worms in the area. This is essential in protecting the local communities from being crowded out by external harvesters and encouraging community-based management of these natural resources.

The mopane worms are primarily found in Matabeleland South province in Matobo, Bulilima, Beitbridge, and Gwanda districts and other areas along the country's border with Botswana. Gwanda district dominated and was therefore purposively selected in addition to crafting the bylaws governing the harvesting of mopane worms, thus making it an appropriate case study for unlocking market participation opportunities as motivated in this study while reducing gender disparities in the markets. In Gwanda district, the mopane worms are harvested in large quantities during the early months of the rainy season (November to January) and another smaller second harvest from April to May. Mopane worms top the list of eight edible insects in Zimbabwe. They are followed by Cicada insects *Cicada spp.* (Nyenze/Nyezhe), termites alates *Macroterms spp*. (Ishwa), flying black ants *Carebara vidua* (Tsambarafuta), solder termites *Macrotermes spp.* (majuru), Stink bugs *Encosternum delegorguei* (Harurwa), Chafer beetles *Amphimallon majale* (Mandere), and tobacco cricket *Brachytrupes membranaceus* (Gurwe) in that order [33]. This makes the mopane worms an essential source of food, nutrition, and income among rural communities who harvest them and trade them in various markets that serve the urban communities that are the primary consumers.

Sampling

Gwanda Rural District was targeted for the study. The area has an estimated population of 124,548 [6], up from 97,890 a decade ago [37]. The study utilized a multistage stratified sampling approach to select the wards and harvesters to be studied. Five wards, namely Gwaranyemba (13), Silonga (15), Insindi (21), Coleen Bawn (22), and Dwala (23), were purposively sampled while accounting for the geographical spread and coverage of the district while accommodating the major mopane worms harvesting areas. The harvesting hotspots in the sampled wards were sampled for local harvesters to be studied using a systematic random sampling technique. The harvesters were then stratified into females and males and sampled using the proportionate sampling technique, which accounted for the proportional gender differences. This generated a representative sample of harvesters in the district and mirrored the compositions of male and female harvesters. A structured questionnaire was administered to 393 local mopane harvesters, using a proportion of 138 males and 255 females. The sample size was then estimated using the Yamane [36] formula with a known population, as shown in Eq. 1:

$$n = \frac{N}{1 + N(e)^2} 1, \tag{1}$$

where n = sample size; N = population size and e = confidence level (95%).

$$n = \frac{124548}{1 + 124548(0.05)^2} = 393 \text{ harvesters.} \tag{2}$$

The female-to-male proportion among the harvesters was determined to be 65%: 35%, similar to the 68%: 32% as reported by ZimVac [38]. This was used to compute the proportion composition based on gender. Table 1 summarises the sample calculation process.

Research approach and empirical model

A positivist research approach was used for the study and adopted the quantitative strategy, as informed by Majeed [15]. Using a quantitative methodology was appropriate to increase depth and coverage for the study area's multiple and diverse markets, including capturing the challenges and opportunities faced by the harvesters. The positivist philosophy guided the rapid rural appraisal-based survey research design. As Husam and Pius [10] indicated, the design enables the researcher to concentrate on a wide range of relatively unknown factors, thus illuminating how every variable affects participation in various markets. Informed by Kivunja [12], recommendations for policymakers and other relevant development stakeholders are more effectively based on explanatory design patterns.

Gender differentials in market participation are usually analyzed using the multivariate probit and Tobit methods [7, 18]. These approaches enable the analysis of how gender differences in resource and information access to resources and the associated returns caused by the mobilization of resources affect gender differences. This motivated the use of a bivariate probit regression model to compare the conditional predicted probabilities of participation during COVID-19 and the primary processing for lean season market preparation between women and men. The study used the bivariate probit model to jointly analyze the mopane worm harvesters' correlates of participation in markets during COVID-19 and the processing for lean season period preparations.

The bivariate probit model was appropriate because it accounts for the mutually inclusive decision to participate in markets during COVID-19 and prepare for the lean season. The model also factors in their interdependence. For example, the harvester's decision to participate in the market highly depends on the decision to process since the mopane worms are processed before being sold. However, some harvesters sell the worms as raw and are not concerned about preservations for the lean market season. It is also most likely that a harvester who processed worms in preparation for the lean season markets also participated during COVID-19 due to the existing resilient marketing strategies. The argument presented by this paper is that if a harvester can process and store adequate volumes of the mopane worms, then even in extreme conditions such as COVID-19, which blocked traveling to the harvesting fields, they can still sell the stored worms. This is an essential lesson for building resilient marketing systems for the mopane worm harvesters, where processing and storage take center stage. The models for female and male harvesters were estimated using the same covariates since the dataset is partitioned according to the gender of the harvester. The empirical analysis commenced with the specification of the bivariate probit model. The conceptual framework (Fig. 2) shows that the female and male harvester's decision to market mopane worms during COVID-19 and processing in preparation for the lean season period is affected by policy factors such as access to the harvesting sites, social, economic, and institutional factors. Following Gong and Johnson [9], a reduced form of the bivariate probit regression is given as:

$$M^*_{ijk} = \alpha_{jk} X_{ijk} + \varepsilon_{ijk}, j = 1, \ldots, J; \text{k } = 0(\text{male}), 1(\text{female}), \tag{3}$$

$$M_{ijk} = 1 if M^*_{ijk} > 0 \text{ and } 0 \text{ otherwise,} \tag{4}$$

where M^*_{ijk} denotes the jth latent dependent variable. M_{ijk} denotes a set of dependent variables under investigation related to ith primary harvester. The dependent variables are participation in primary processing in preparation

Table 1 Population and sample sizes by gender in the targeted wards

Ward	Population	Male total	Male in sample	Female total	Female in sample
Gwaranyemba	5123	1793	30	3330	56
Silonga	4896	1714	29	3182	54
Insindi	4163	1457	25	2706	46
Coleen Bawn	5018	1756	30	3262	55
Dwala	3998	1399	24	2599	44
Total	**23,198**	8119	**138**	15,079	**255**

Source: ZimVac [38] and authors' compilations

for the lean season market and during COVID-19. X_{ijk} is a vector of contextual factors related to *i*th primary harvester for *j*th choice. The descriptions of the contextual factors affecting the two decisions are presented in Table 2. α_{jk} is a set of parameters to be estimated andε_{ijk}, (j = 1, …,J) are the error terms distributed as bivariate normal, each with a mean of zero, and variance–covariance matrix V, where V has values of 1 on the leading diagonal and correlations $\rho_{jk} = \rho_{kj}$ as off-diagonal elements [4].

Equations (1–2) indicate that two distinct bivariate probit models are estimated for female and male harvesters. The parameters in the bivariate probit model are estimated using the simulated maximum-likelihood method [9]. Stata software version 15 was used. The gender differentials in the market participation decisions during COVID-19 and the processing in preparation for the lean season market were computed as the mean differences between female and male harvesters' predicted probabilities of participating in the two conditions as shown in Eqs. (3–4):

$$\Delta Differential1 = p1F - p1M, \tag{5}$$

$$\Delta Differential2 = p2F - p2M, \tag{6}$$

where ΔDifferential1 and ΔDifferential2 are the gender differentials related to participation in the lean market phase and during COVID-19. The p1F and p1M are the predicted probabilities of female and male harvesters' participation in the lean market; p2F and p2M represent the predicted probabilities of female and male harvesters' participation in markets during COVID-19. These predicted probabilities are computed based on Eq. (1). The independent *t* test was used to separate and validate if the gender differentials were statistically different from zero. Per standard practice, the bivariate probit model is validated using the likelihood ratio (LR) test. The test is used to check the null hypothesis that no correlations exist between the error terms, $\rho_{12} = 0$. If the null hypothesis is

Table 2 Description of variables included in the models and descriptive statistics

Variable	Description	Total sample mean	Female (*N* = 255) mean	Male (*N* = 138) mean	Mean difference-test
Location dummies					
Gwaranyemba	Dummy variable if harvester is from Gwaranyemba ward (0 = no, 1 = yes)	0.226	24.30	21.98	1.57**
Silonga	Dummy variable if the harvester is from Silonga ward (0 = no, 1 = yes)	0.218	31.78	17.95	2.36*
Insindi	Dummy variable if the harvester is from Insindi ward (0 = no, 1 = yes)	0.187	13.08	20.88	− 2.10*
Coleen bawn	Dummy variable if the harvester is from Coleen Bawn ward (0 = no, 1 = yes)	0.221	20.56	22.71	− 1.00**
Dwala	Dummy variable if the harvester is from Dwala ward (0 = no, 1 = yes)	0.147	10.28	16.48	− 2.34*
Social factors					
Age	Age of the harvester in years	44.72	43.41	45.23	− 1.10**
Dependency	Dependency ratio of the harvester's household	33.26	33.42	33.19	0.11
Education	Harvester's years in formal education	8.23	7.81	8.39	− 1.26**
Economic factors					
Price	The weighted average market price in US$/standardized tin	33.37	32.89	33.6	− 0.45
Payment	Time taken to be paid after a sale in hours	11.29	11.61	11.18	0.18
Buyers	The approximate average number of reliable buyers in the markets	3.34	3.13	3.42	− 0.88
Income	Natural logarithm of total household income from other sources in US$/month	5.74	5.73	5.74	− 0.20
Transport	Harvester perceives transport as affecting market participation (0 = no, 1 = yes)	0.74	0.79	0.72	1.46**
Institutional factors					
Associations	Number of associations to which the harvester subscribes	1.70	1.52	1.77	− 1.85**
Extension	Number of extension contacts	5.27	5.59	5.15	1.30**
Training	Whether the harvester received training in the past 12 months (0 = no, 1 = yes)	0.34	0.36	0.34	0.51
Storage	Whether the harvester has storage facilities (0 = inadequate, 1 = adequate)	0.71	0.78	0.69	1.69**
Distance	Average travel time to the market in minutes	73.65	70.98	74.69	− 0.38
Information	Whether the harvester has access to market information (0 = no, 1 = yes)	0.72	0.72	0.71	0.10
Policy factors					
Harvesting	Whether the harvester has reliable access to harvesting sites (0 = no, 1 = yes)	0.58	0.56	0.59	− 0.51
Policy	Harvester perceives absent harvesting policy affects marketing (0 = no, 1 = yes)	0.43	0.39	0.45	− 1.09**

Source: Authors' computation

*; ** and *** indicate *p* values significant at 1%, 5% and 10% levels, respectively; *t* test was used for difference tests

rejected, the bivariate probit model is appropriate in the study context.

Results and discussion

Gender-differentiated descriptive statistics of the harvesters are presented in Table 2. These results show that females comprise the majority of 65% ($n=255$) of the sampled mopane worm harvesters, while 35% ($n=138$) comprise male harvesters. This demonstrates the dominance of females in the mopane worms harvesting business in Zimbabwe due to gender-balancing policies, which have also influenced local-level decision-making processes in agriculture and the broader economy. This agrees with traditional views that regard the collection and processing of mopane worms as a female's occupation since it is relatively localized to their communities. Mopane worms provide women with a self-sufficient supplementary household income they may maintain control over. van Huis and Oonincx [34] reported similar results where gender mainstreaming in emerging agricultural marketing decisions was a priority in most rural communities that depended on natural resources for livelihood.

Male and female participation in processing and the COVID-19 market significantly differed at $p<0.05$ based on different locations. Females were higher than males in the Gwaranyemba and Silonga areas, while the opposite is true for the remaining three wards. This can be attributed to the different livelihood and cultural matrices in the study locations, which can most likely lead to switching livelihood activities based on gender. Results also show that youthful harvesters are more likely to be females than males, which is explained by middle-aged men traveling to cities to look for alternative employment. At the same time, women remain behind and take care of the family properties and children. However, males spend more years in formal education than females.

Traditionally, in African rural communities, including most parts of Zimbabwe, females are usually not considered candidates for continued education. For example, if girls fell pregnant, they would be automatically moved out of the schooling system. Female harvesters perceived the transport situation as a significant hindrance to their participation in the lean season market during COVID-19 than their male counterparts. This shows the flexibility of male harvesters in finding alternative transport even during the lockdown periods of COVID-19.

The number of mopane worm business-related associations a harvester belongs to also differed between males and females. The results show that male harvesters are likelier to belong to an association than their female counterparts. This can be slightly different from the general associations' scenario where van Musvoto et al. [23] reported the dominance of female insect harvesters. The significant take-home policy implication of this finding is the need to structure tailormade associations and strive to strike a gender balance on these strategic information-sharing platforms. In addition, females had more access to extension services and storage facilities than their male counterparts (Table 2). Women have the proclivity to pull resources together and establish collection and storage points, thus reducing the risk of losses and theft of the edible insects that are mainly harvested far from their residences [7]. Many male harvesters perceived that the absence of a policy on harvesting mopane worms greatly impacted their participation in processing for the lean season market and the COVID-19 market more than females. This can be a strong motivation for the bylaws that the Gwanda district administration is currently drafting to curb excessive harvesting and poaching by external harvesters.

The bivariate probit results on the factors influencing female and male participation in primary processing in preparation for the lean season market and during COVID-19 in Southeastern Zimbabwe are shown in Table 1. Several preliminary tests were performed before the ultimate bivariate regression analysis. According to the likelihood ratio test, the bivariate probit model's overall goodness of fit is statistically significant for males and females at the $p<0.05$ significance level. This demonstrates that explanatory factors explain the likelihood of simultaneously partaking in the two activities. The chi-square statistics of the likelihood ratio (LR) test of pooling are statistically significant at the 1% level, implying that disaggregating the data based on gender is more appropriate than pooling the data and incorporating gender as a dummy variable. Also, using the LR test, the study tested the assumption of no correlation$(\rho_{01})=0$ between the error terms associated with worms processing for the lean season market and COVID-19 market models for the gender groups in the bivariate probit model.

The chi-square statistics from the LR test are statistically significant at the 5% level (Table 1). Thus, it shows a correlation between harvesters' participation in processing in preparation for the lean season market and the COVID-19 market. This justifies the appropriateness of the application of the bivariate probit model. In addition, Wald's chi-square statistics from the bivariate probit model of gender group are statistically significant at the 1% level, implying that the covariates incorporated in the models jointly explain the primary harvesters' participation in processing for the lean season market and COVID-19 market (Table 3).

The study integrated the primary harvesters' sites (namely the five sampled Gwanda district wards) into the participation simulation. Except for Silonga and Insindi wards, which exhibit a significant positive connection with male

Table 3 Bivariate probit estimates of harvesters' participation in primary processing activities and COVID-19 period market

Variables	Female (255)				Male (138)			
	Primary processing		COVID-19 market		Primary processing		COVID-19 market	
	Coeff	SE	Coeff	SE	Coeff	SE	Coeff	SE
Location dummies (Gwaranyemba = base category)								
Silonga	− 0.23	0.38	− 0.29	0.30	1.46**	0.67	− 0.65	0.59
Insindi	− 0.29	0.37	0.03	0.29	1.45**	0.86	− 0.05	0.72
Coleen bawn	− 0.50	0.38	0.09	0.29	1.20	0.74	− 0.85	0.61
Dwala	− 0.37	0.41	− 0.95*	0.31	1.39	2.49	− 2.33*	0.74
Social factors								
Age	− 0.02**	0.01	0.02**	0.01	0.01	0.15	0.13*	0.02
Dependency	− 0.03	0.06	− 0.07	0.05	0.04**	0.02	-0.03*	0.01
Education	− 0.02	0.03	0.02	0.03	− 0.04	0.06	0.09***	0.05
Economic factors								
Price	− 0.03	0.09	− 0.01	0.01	− 0.06	0.03	− 0.01	0.02
Payment	0.03	0.06	− 0.02**	0.01	− 0.04	0.02	0.02	0.01
Buyers	0.02	0.05	-0.08	0.04	− 0.41*	0.15	0.00	0.10
Income	0.02	0.25	0.12	0.17	− 0.01	0.50	− 0.54	0.35
Transport	2.32*	0.24	0.27	0.19	3.43*	0.72	0.40	0.39
Institutional factors								
Associations	− 0.19***	0.10	− 0.09	0.07	0.29	0.22	− 0.25	0.15
Extension	− 0.09**	0.04	0.01	0.03	− 0.18***	0.10	− 0.03	0.06
Training	− 0.40***	0.23	0.32***	0.19	− 0.59	0.49	0.14	0.37
Storage	0.24	0.24	− 0.21	0.19	0.32	0.59	− 0.14	0.43
Distance	− 0.04	0.10	− 0.03	0.11	0.01***	0.01	− 0.03	0.03
Information	− 0.14	0.25	0.07	0.19	0.09	0.46	− 0.15	0.40
Policy factors								
Harvesting	0.46**	0.23	− 0.14	0.18	1.00***	0.55	0.16	0.37
Policy	0.14	0.24	− 0.29***	0.18	0.06	0.46	0.31	0.38
Diagnostic statistics								
$\rho_{01} = 0$	43.84**				82.28**			
LR test of pooling: chi-square	124.68*							
Wald's chi-square	138.21*				50.07**			
Log-likelihood	− 243.21				− 72.09			
Observation	255				138			

*,**, *** indicate statistical significance at 1%, 5% and 10% respectively

participation in mopane worm processing, the results demonstrate that the other location dummies were insignificant. The significant and positive coefficients for Silonga and Insindi wards imply that male harvesters are more likely to engage in the primary processing of mopane worms in preparation for the lean season market than in Gwaranyemba. This can be explained by their proximity to Gwanda town, where there are immediate consumers of the worms and hence the incentive to process. The coefficient for Dwala is negative and significant in the COVID-19 market for both females and males, suggesting that both female and male harvesters were less likely to participate in the COVID-19 market. This is unsurprising given the risk involved in public places such as the informal markets, where there is a greater likelihood of getting infected with the COVID-19 virus. The possible explanation for this is that these communities have diverse livelihood options, including cross-border trading, given their proximity to the border town of Beitbridge. As such, the motivation to participate in lean season marketing of mopane worms is relatively low. This shows the variability in community livelihood structures, which is critical in defining the reliability of mopane worms as a source of income and food. In contrast, other communities use emerging innovations such as conservation farming to sustain the family's food needs [27].

Among the social and economic factors, the results show that age is negative and significant for participation in primary processing among females. This implies

that older women are less likely to engage in the primary processing of mopane works. However, older women and men are likelier to participate in the lean COVID-19 season marketing. This finding indicates that young and youthful women are primarily involved in mopane worm harvesting and processing, while older women are involved in marketing. This was expected as collecting and processing mopane worms is a demanding task that older women shy from while willingly partaking in marketing activities. The findings confirm a study by Mafandaedza et al. [21], who demonstrated that most mopane worm harvesters are 30 to 40 years old. This is consistent with Donkor et al. [7], who also reported a similar finding in a study on grasshopper market complexities in Uganda.

Male harvesters were also positively correlated with their perceived dependency ratio. This implies that males tend to engage more in economic activities when they feel pressure from family demands. Those with a lower dependency ratio are more flexible. Male harvesters' participation in the lean market during the COVID-19 pandemic in the Gwanda area is significantly correlated with their age and education level, while their choice to participate in the lean market was negatively correlated with their dependency ratio. Makkar et al. [17] also observed a similar pattern when they reported that a family with higher dependency ratios participates in value addition in stock feed projects to supplement income sources and meet family expenses. Kwiri et al. [13] expanded the argument and noted that these initiatives could only be effective if the projects are done within a cooperative setup where both male and female harvesters participate.

Male engagement in mopane processing negatively correlates with the number of reliable customers in the market. In contrast, male participation in mopane worm processing is positively correlated with the availability of transportation. The findings also show a negative correlation between the time it takes to pay harvesters and their involvement in lean season markets.

For the institutional factors, a female harvester's membership with associations is negative and significantly associated with engagement in mopane worm processing. The number of associations the harvester belongs to is associated with engagement in mopane worm processing and her access to extension services. This could have been caused by the nature of the associations, which had little to do with mopane worm-related activities and thus were not influential in determining participation by the harvesters. The Associated Press [30] also observed similar patterns but reported female dominance in associations and market participation in most parts of Zimbabwe. Female harvesters who have received training in the last 12 months are most likely to participate during the COVID-19 masked lean season market but are less likely to be involved in the processing. This could be explained by the fact that during the COVID-19 outbreak, the Zimbabwe government imposed a lockdown and curfew, so it is tricky for harvesters to travel long distances to collect and harvest mopane worms. COVID-19-induced lockdowns and curfews were confirmed by several researchers to negatively impact the value chains of various food commodities [19]. The number of extension contacts is significant and negatively associated with men and women engagement in mopane worm processing. This implies that the associations and current extension services are not tailored to the mopane worm activities and do not positively influence marketing decisions.

On the other hand, while training is positively correlated with female harvesters' involvement in the lean season, it is negatively correlated with their decision to participate in mopane worm processing. This is an indication of the variability in the training packs that are available for the harvesters in the study area. These interactions can also be viewed from the perspective of expanding agro-processing opportunities for the mopane worm harvesters in Gwanda district but aligning payment time with distance to the market, thus balancing the transaction costs basket. Of note are the training activities conducted by Non-Governmental Organisations (NGOs), which specifically target risk management during the lean seasons. Male harvesters' decisions to process mopane worms during the COVID-19 epidemic in Southeastern Zimbabwe, Gwanda, was negatively related to their access to extension services and positively correlated with the distance to the market as determined by the number of hours required to travel from their residence to the market. Muvhuringi et al. [19] reported the disruption of agricultural supply chains due to the COVID-19 pandemic, which affected both males and females in terms of both access to market information and the availability of traditional local markets. The pandemic implies that the harvesters had to find means to supply in faraway markets, affecting males and females differently. Both males and females were observed to process more mopane worms as their access to harvest sites increased. However, female participation in the lean season market negatively correlates with the harvester's perception of the district's absence of a mopane worm harvesting policy.

Policy constraints are essential since they offer fair harvesting and marketing opportunities. Harvesters increased their participation in mopane worm processing with increased access to harvesting locations. This is an expected result since traditional leaders have minimal control of access to harvest sites. Traditional leaders try to limit the number of harvesters who are not residents in their communities so that this natural resource could benefit the local community more. However, as Gondo et al. [8] outlined, effective regulatory control is needed to

monitor the collection and harvesting of mopane worms beyond the local level, an initiative for which the Gwanda Rural District Council has already drafted the required bylaws. Thomas [31] also noted the importance of these guiding regulations. He suggested that the government should help communities establish indigenous natural resources management systems, thereby strengthening property rights and institutional arrangements that regulate the utilization of mopane worms. Female harvesters who believe that the absence of a mopane harvesting policy in the district hinders participation in the industry were less likely to engage in the lean season market.

If these are missing, those who dominate the sites have high chances of exploitation. Akpalu et al. [1] also alluded to the same idea and reported that these policies also help to conserve the mopane worms and the harvesting sites. The study found that male harvesters were less likely to participate in processing mopane worms when the estimated number of reliable buyers was low. This result could be interpreted, as males in the study sample are unwilling to take risks and prefer to engage in other economic activities for income. However, they were willing to participate in the lean season market despite the unavailability of reliable transport. Males are more resilient in manual labour, carrying their baggage to the market center. The findings also show a negative correlation between the amount of time it takes to pay harvesters and their involvement in lean season markets.

Khoza et al. [11] reported conflicting findings in a study on agro-processing determinants in South Africa. They argued that building trust among market players in the agro-processing industry is the pillar of value chain success, as opposed to the number of buyers and sellers *perse*. These differences show the context-specific nature of value chain dynamics. They can be a learning point for policy and practice in the study area where stakeholders must adopt diverse relationships between buyers and sellers in markets. These can include binding contracts as well as group marketing strategies. Summary of the findings are provided in Appendix A.

Conclusions and implications for policy

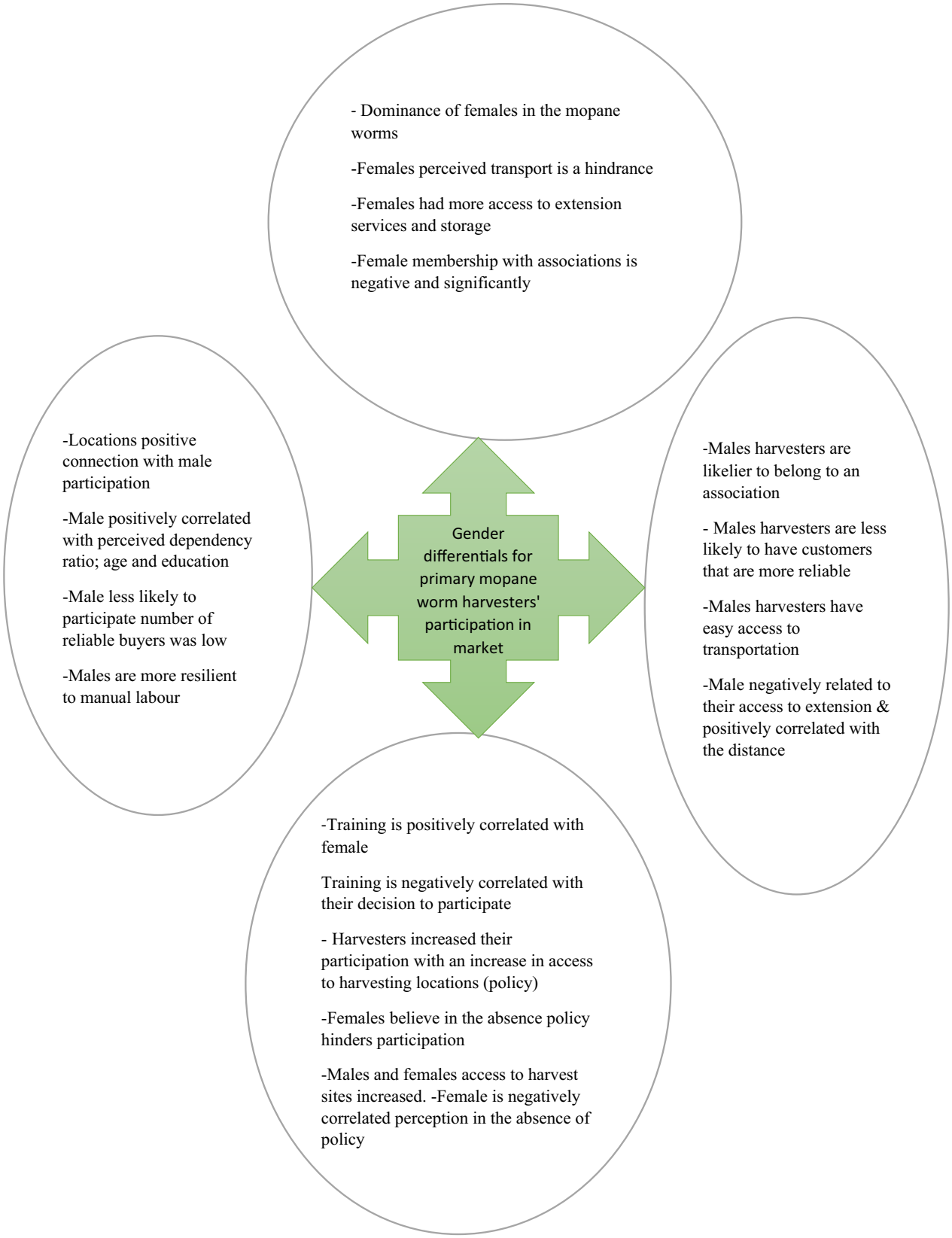
We examine the gender differentials for primary mopane worm harvesters' participation in primary processing and market participation during COVID-19 in Southeastern Zimbabwe. The paper adopts a bivariate probit regression model and data collected from 393 local mopane harvesters. The study concludes that there is a gender difference in the participation in primary value addition in preparation for the lean market and during the COVID-19 period. This result shows that developing the mopane value chain, especially in preparation for shocks such as COVID-19, can enhance food security and the livelihoods of women and men mopane worm harvesters. This underlines the urgent need to prioritize the development of the mopane worm value chain, especially the value addition and lean season market aspects, in Zimbabwe's Vision 2030 to 'transform Zimbabwe into an upper-middle-income economy by 2030' (GoZ, 2013). This should be supported by locally available resources and indigenous knowledge practices, which aim to protect local sources of livelihood.

The study finds that male and female involvement in mopane worm processing and the lean season market vary with location-specific variables, social, economic, institutional, and policy factors.

The study also concludes that the two analyzed processing decisions in preparation for the lean season market and participation in mopane worm markets during COVID-19 are related, but the factors that influence their outcomes are not necessarily the same between males and females. A gender-sensitive policy must be implemented to continually create agribusiness opportunities, especially for female harvesters in the dominant mopane worm areas. The study recommends that a policy that intensifies socioeconomic research and awareness of edible insect value chains should be supported to gain more insights into developing the chain to benefit young women and men inclusively. The study also concludes that both males and females observed that a policy explicitly addressing mopane worm harvesting and marketing affects market participation and primary value-addition decisions. The current district-level acts being developed need expedition and capture aspects of marketing places, storage facilities, and awareness campaigns to support the mopane worm value chain.

The study recommends further research exploring the mopane worm value chain, especially at the upper levels, wholesaling and retailing, and the associated food security impacts. One significant opportunity in the mopane worm value chain is the increasing demand based on the healthy food notion. Therefore, it becomes unavoidable for future research to directly examine consumers' preferences for the various value-added mopane worm products. This should provide adequate information informing upstream value chain actors such as retailers, other entrepreneurs, and potential investors regarding the value-added products consumers prefer in local and export markets. In terms of limitations, the paper reports results of only one season, and as such, future research should consider other seasons. Ultimately, this will catalyze the further development of mopane worm products while making them more available, especially during the lean seasons and shocks such as COVID-19. The study also considered only Gwanda Rural District; future research should consider other districts to ascertain locational differences or disparities in market participation.

Appendix A


- Dominance of females in the mopane worms
-Females perceived transport is a hindrance
-Females had more access to extension services and storage
-Female membership with associations is negative and significantly
-Locations positive connection with male participation
-Male positively correlated with perceived dependency ratio; age and education
-Male less likely to participate number of reliable buyers was low
-Males are more resilient to manual labour
Gender differentials for primary mopane worm harvesters' participation in market
-Males harvesters are likelier to belong to an association
- Males harvesters are less likely to have customers that are more reliable
-Males harvesters have easy access to transportation
-Male negatively related to their access to extension & positively correlated with the distance
-Training is positively correlated with female
Training is negatively correlated with their decision to participate
- Harvesters increased their participation with an increase in access to harvesting locations (policy)
-Females believe in the absence policy hinders participation
-Males and females access to harvest sites increased. -Female is negatively correlated perception in the absence of policy

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Author contributions
JPM, YTB, and RM were involved in conceptualizing and designing the research protocols. JPM, FM, and YTB did the investigation, provided the data, and were involved in data curation. RM, JPM, and FM designed the methodology. JPM and RM did the formal analysis, prepared the manuscript with contributions from all co-authors, and corrected the final manuscript. AHA and OSE contributed to the writing and revision of the manuscript. All authors read and approved the final manuscript.

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Declarations

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Competing interests
The authors declare that they have no competing interests.

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