

Economic and technological drivers of rural youth engagement in sugar palm agro-industry in South Sulawesi, Indonesia

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²Department of Forestry, Faculty of Forestry, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km. 10, Makassar 90245, South Sulawesi, Indonesia. Tel./fax.: +62-411-586025, *email: ernaawati265@gmail.com

Manuscript received: 24 December 2025. Revision accepted: 26 April 2026.

Abstract. *Ernawati, Syahidah, Mujetahid A. 2026. Economic and technological drivers of rural youth engagement in sugar palm agro-industry in South Sulawesi, Indonesia. Asian J Agric 10 (1): g100158. <https://doi.org/10.13057/asianjagric/g100158>. Palm sugar derived from sugar palm (*Arenga pinnata*) supports rural livelihoods in Indonesia, yet declining youth participation may weaken enterprise regeneration. Youth refer to individuals aged 15-30 years. This study examined how social, economic, and technical (technological capital) factors, as well as environmental factors, are associated with youth involvement in the sugar-palm agroindustry in South Sulawesi, Indonesia. A census-based survey was conducted in Rompegading and Limapoccoe Villages (Maros District) with 51 respondents aged ≥ 15 years who were already engaged in tapping, processing, or marketing; interpretation emphasizes the youth subgroup where relevant. Indicators were measured using a three-point Likert scale and aggregated into composite indices for each factor and youth involvement. Multiple linear regression was used to assess associations between the factor indices and youth involvement. Technical (technological capital) and economic factors were positively associated with youth involvement, while social and environmental factors were not statistically significant. Findings suggest that youth engagement may be strengthened through practical training, safer and more efficient tools and processing practices, and measures that enhance income predictability and market access. Because the study is cross-sectional and site-specific, the findings should be interpreted as associative; broader, multi-site, and longitudinal studies are recommended to verify and extend these insights.*

Keywords: Agroforestry, Indonesia, rural youth, sustainable livelihood framework, technological capital

Abbreviations: KHDTK: *Kawasan Hutan Dengan Tujuan Khusus*; Special Purpose Forest Area, NTFP: Non-Timber Forest Products, SLF: Sustainable Livelihood Framework

INTRODUCTION

The sugar palm (*Arenga pinnata*) is a versatile smallholder crop that supports rural livelihoods through multiple products, including sap for palm sugar, fiber, and other non-timber forest products. In Indonesia, palm sugar processing is commonly embedded in mixed farming and agroforestry systems and contributes to household income and local employment (Withaningsih et al. 2021; Makarennu et al. 2023; Zahra and Ariyanti 2025). Beyond its direct income role, sugar palm can strengthen livelihood resilience by providing a locally available raw material for household-based processing and small-scale marketing.

This potential is evident in Maros District, South Sulawesi, Indonesia, which is recognized as a production center where tapping and palm sugar processing remain economically important (Mujetahid et al. 2023; Harahap et al. 2025). However, producers frequently report constraints related to labor availability, skill transfer, and the continuity of household enterprises across generations. Declining participation of younger generations is particularly concerning because sugar-palm work relies on practical know-how, such as safe climbing, sap handling,

and processing, and these skills are often transmitted through experience within families and communities.

Youth participation is increasingly viewed not only as a demographic concern but also as a strategic component of agricultural sustainability and sectoral regeneration (Ningsih and Syaf 2015; Nguyen et al. 2021; Duffy et al. 2021). Continued engagement of younger generations helps ensure intergenerational knowledge transfer, labor continuity, and adaptive capacity within the sugar-palm value chain. In the absence of youth regeneration, local agroforestry-based enterprises risk stagnation, declining productivity, and eventual contraction. Conversely, active youth involvement can facilitate technological upgrading, entrepreneurial diversification, and improved market responsiveness within rural palm-sugar systems.

In this study, "youth" refers to individuals aged 15-30 years. The analysis draws on respondents aged ≥ 15 years who were already engaged in tapping, processing, and/or marketing, with interpretation emphasizing the youth subgroup where relevant (Hasbia and Firdamayanti 2023; Arifianto et al. 2024). Youth disengagement also intersects with broader rural transformation, including decisions to pursue non-farm work or migrate in search of alternative opportunities (Destiana et al. 2023; Yani and Alam 2024).

Push–pull perspectives suggest that limited local earning prospects and demanding work conditions can “push” young people away, while education, wages, and perceived status in urban or non-farm jobs can “pull” them toward other pathways (Lee 1966; Bhagat 2020; Nguyen et al. 2021).

For rural youth themselves, participation in sugar-palm agroindustry may represent both an economic pathway and a site of capability formation. When supported by adequate technological conditions, safety standards, and predictable returns, palm-sugar activities can provide locally embedded livelihood opportunities, reduce distress migration, and support youth entrepreneurship within agroforestry systems. However, when work conditions are physically demanding and economically uncertain, disengagement becomes more likely. Understanding the determinants of youth participation is therefore essential for evaluating whether sugar-palm agroindustry can remain a viable and attractive livelihood option for younger rural cohorts.

To examine these dynamics, we draw on the Sustainable Livelihood Framework (SLF), which explains livelihood strategies as shaped by asset endowments (capitals), institutions, and vulnerability contexts. SLF-based studies typically emphasize human, social, natural, physical, and financial capital; however, technology is often treated implicitly, for example, by being folded into physical assets or human skills. In agroindustry value chains, this can obscure how tools, processing equipment, safety practices, and knowledge of production techniques affect productivity, product quality, and the perceived attractiveness of the work, especially for youth.

Academically, this study contributes to the rural youth and livelihood literature by explicitly operationalizing technological capital as a measurable construct within an SLF-based quantitative framework applied to a specific agroforestry value chain. By isolating technical readiness from broader physical or human capital categories, the study offers clearer empirical insight into how production conditions shape youth engagement decisions. Empirical evidence from Indonesia also expands the geographic representation of quantitative studies on youth participation

in smallholder agroindustry, contributing to broader discussions on generational renewal in agriculture in low- and middle-income countries.

Despite the importance of sugar-palm agroindustry for rural livelihoods, few studies provide quantitative evidence on the determinants of youth engagement while explicitly measuring technological capital through a dedicated index. This study addresses that gap by operationalizing technological capital (captured here through the technical factor index) as a distinct asset within an SLF-oriented framework in a sugar-palm value chain context. Specifically, we (i) construct composite indices for social, economic, technical (technological capital), and environmental factors, and (ii) test their associations with a youth involvement index using multiple linear regression. We hypothesize that higher scores on each factor index are positively associated with youth involvement, with technical (technological capital) and economic factors expected to show the strongest positive relationships. In contrast, social and environmental factors are expected to be positive but potentially weaker.

MATERIALS AND METHODS

Study area

The study was conducted in Rompegading Village and Limapocoe Village, Cenrana Sub-district, Maros District, South Sulawesi Province, Indonesia, an area where sugar palm is commonly managed within smallholder agroforestry and mixed-farming systems. The sites are situated in and around the KHDTK (*Kawasan Hutan Dengan Tujuan Khusus*; Forest Area for Special Purpose) management landscape, where community-based production and processing of sugar-palm sap into palm sugar is an important livelihood activity. The study area is situated at $04^{\circ}59'55.3''$ S and $119^{\circ}46'33.1''$ E, at approximately ± 500 m a.s.l., with humid tropical conditions (Mujetahid et al. 2023). A map of the research location is presented in Figure 1.

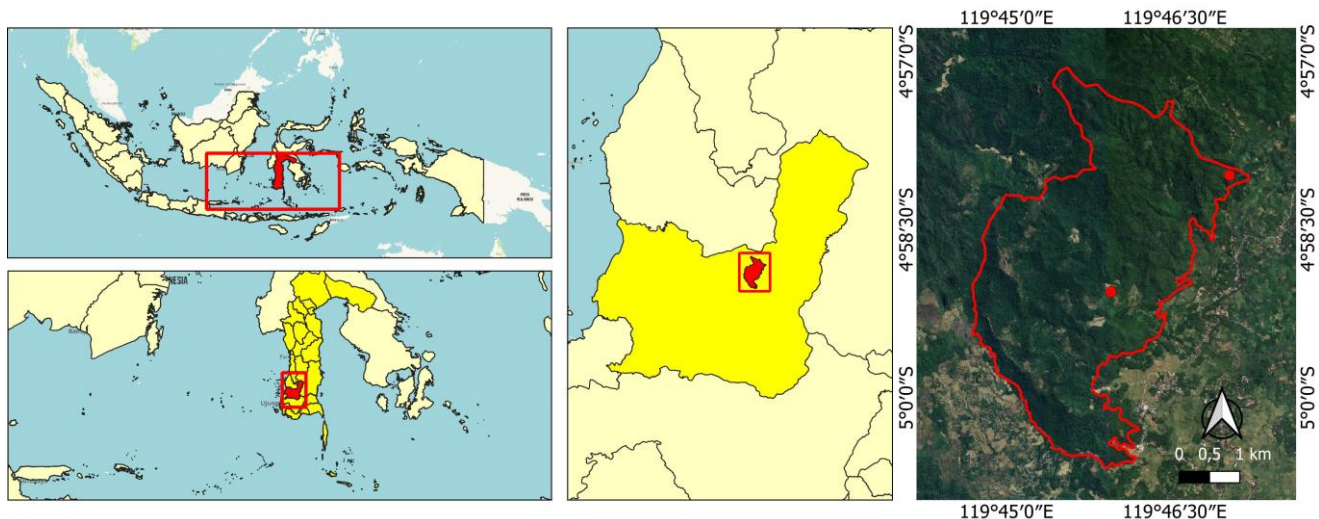


Figure 1. Map of the study area in Maros District, South Sulawesi, Indonesia

Study design

A quantitative cross-sectional survey design was applied to examine associations between livelihood-related factors (social, economic, technical, and environmental) and engagement in the sugar-palm agroindustry. The design enables identification of correlational patterns and priority leverage points for interventions in the study area. Because data were collected at a single time point, the estimated relationships are interpreted as associations rather than causal effects (Effendy et al. 2020; Ruhkmauddin et al. 2024).

Unit of analysis and population

This subsection describes the unit of analysis, the target population, the verification of engagement, the data collection period, and the sampling strategy used in the study. The unit of analysis was the individual household member aged ≥ 15 years, rather than the household, because participation in tapping, processing, and marketing activities is an individual-level decision that may vary among household members. All study variables, including perception-based measures of social support, economic conditions (e.g., perceived income stability and access to capital), technical readiness, environmental awareness, and youth involvement, were collected and measured at the individual respondent level. Although some economic indicators relate to household enterprise conditions, responses reflect the individual's perception and level of involvement.

The target population included all individuals aged ≥ 15 years residing in Rompegading and Limapocoe Villages who were directly or indirectly involved in sugar-palm enterprise activities at the time of the survey (tapping, processing, and/or marketing). "Active involvement" was operationally defined as current engagement in at least one value-chain activity (tapping, processing, or marketing) at the time of data collection.

"Youth" was defined as individuals aged 15-30 years, consistent with Indonesian Youth Law (Law No. 40/2009 on Youth), which defines youth within this age range. This definition is also aligned with commonly used operational ranges in rural development and agricultural youth studies. For interpretation, respondents were categorized as youth (15-30 years) and non-youth (>30 years). Verification of engagement was conducted through a combination of (i) self-report screening during recruitment, (ii) cross-checking names with village-level palm-sugar producer groups and local community leaders, and (iii) confirmation during field visits that respondents were recognized as active actors in tapping, processing, or marketing activities. Because no formal cooperative registry exists in the study area, verification relied on community-based listing and field confirmation. A preliminary listing of eligible actors was conducted in collaboration with village officials and local palm-sugar producer groups. Names were compiled from group records and validated through consultation meetings with community leaders to reduce the risk of omission. The list was subsequently cross-checked during field visits to ensure completeness.

A census (full enumeration) approach was used. Field listing supported by local groups identified 51 eligible individuals, all were included as respondents. All identified eligible individuals agreed to participate and completed the survey; therefore, no eligible actors were unavailable during the data collection period, and non-response within the defined population was minimal. The use of a census approach is methodologically appropriate when the study population is small and fully identifiable, allowing complete coverage and eliminating sampling variability within the defined population frame (Cochran 1977; Lohr 2019). By enumerating all eligible actors, sampling error within the defined study boundary is minimized because no probabilistic selection is applied. Data were collected between December 2024 and August 2025 through structured face-to-face interviews using a standardized questionnaire administered to all eligible respondents identified through the census listing process. Because the population definition focuses on actors already linked to the sugar-palm value chain, inferences are limited to youth within existing palm-sugar households/actors rather than youth who have never participated or have existed in the sector.

Variables and measurement

Study variables were derived from the SLF and operationalized as four independent composite indices: social (X_1), economic (X_2), technical (X_3), and environmental (X_4) and one dependent composite index, the youth involvement index (Y). The operational definitions, main indicators, and expected directions of association are summarized in Table 1.

Perception-based indicator responses were scored and aggregated into composite indices. Table 1 summarizes the indicators and expected directions of association for each construction. Details on the Likert scale, theoretical score ranges, and procedures for composite index construction are provided in the composite index construction subsection (Aybek and Toraman 2022).

Instrument, pilot test, validity, and reliability

The questionnaire was pilot tested with 10 respondents outside the study sample to evaluate item clarity and appropriateness. Item validity was assessed using Pearson product-moment correlation, and all items were significant ($p < 0.05$) (Fuady et al. 2023). Internal consistency reliability was evaluated using Cronbach's Alpha, with coefficients of 0.602 for social (X_1), 0.602 for economic (X_2), 0.688 for technical (X_3), 0.624 for environmental (X_4), and 0.644 for youth involvement (Y), indicating acceptable reliability for exploratory research ($\alpha > 0.60$).

Composite index construction

All constructions were measured using a forced-choice three-point Likert scale with the following response anchors: (1 = disagree, 2 = somewhat agree, and 3 = strongly agree). The middle category ("2") represents moderate or partial agreement rather than a neutral position (Aybek and Toraman 2022; Obon et al. 2025). A forced-choice design was used to reduce central-tendency bias and

encourage respondents to express directional perceptions, which is particularly important in small-sample rural surveys where neutral clustering may limit variability. Each construct was measured using multiple items derived from the Sustainable Livelihood Framework (SLF) domains and adapted to the sugar-palm agroindustry context. The number of items per construct was: social (X_1)=5 items; economic (X_2)=5 items; technical (X_3)=7 items; environmental (X_4)=5 items; and youth involvement (Y)=5 items. All items were positively worded and coded in the same direction; no reverse-coded items were included. Items were mapped conceptually to SLF asset categories: social capital (e.g., family support, peer influence), financial capital (e.g., perceived income stability, access to capital), physical/technological capital (e.g., access to tools, training, safety, and ease of tapping/processing), and natural capital (e.g., ecological awareness, perceived sustainability). The youth involvement construct captured behavioral engagement and future orientation (e.g., participation intensity and intention to continue). Items for this study were developed based on SLF theory and relevant agroforestry and rural youth literature, and refined through pilot testing to ensure contextual clarity and appropriateness.

Conceptual model

Figure 2 illustrates the study's conceptual model based on the Sustainable Livelihood Framework (SLF), depicting the hypothesized relationships between social (X_1), economic (X_2), technical/technological capital (X_3), and environmental (X_4) factors and the youth involvement index (Y). The directional arrows represent the expected positive associations tested in the regression analysis, with X_1 – X_4 modeled as predictors of Y .

Data analysis and regression diagnostics

Data analysis. Data were coded and analyzed using IBM SPSS Statistics v25. Descriptive statistics for respondent characteristics and all composite indices were calculated and presented as mean \pm SD. To examine factors associated with youth involvement in the sugar-palm agroindustry, multiple linear regression was estimated with the youth involvement index (Y) as the dependent variable and the social (X_1), economic (X_2), technical/technological capital (X_3), and environmental (X_4) indices as independent variables. The model was specified as:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon$$

Regression results are reported using unstandardized coefficients (B) with standard errors, standardized coefficients (β) to facilitate comparison of relative effect sizes across predictors, and 95% confidence intervals for B for key predictors (Zano and Santoso 2019; Iba and Wardhana 2024).

Table 1. Operational definitions of variables and measurement indicators used in the regression model

Variable	Symbol	Main indicators (see instrument subsection)	Type/scale	Expected relationship with Y
Social Factor	X_1	Family support, peer influence, and perceived social status of palm-sugar work	Composite index (summed Likert treated as continuous)	+ / weak
Economic Factors	X_2	Perceived income level and stability, access to capital, price security	Composite index (summed Likert treated as continuous)	+
Technical Factors	X_3	Tool availability/condition, technology training, ease, and safety of tapping/processing	Composite index (summed Likert treated as continuous)	+
Environmental Factors	X_4	Ecological awareness, perceived sustainability of palm-sugar agroforestry, and environmental concern	Composite index (summed Likert treated as continuous)	+ / weak
Youth Involvement	Y	Participation in tapping/processing/marketing, working time, and intention to continue	Composite index (summed Likert treated as continuous)	Dependent variable (not applicable)

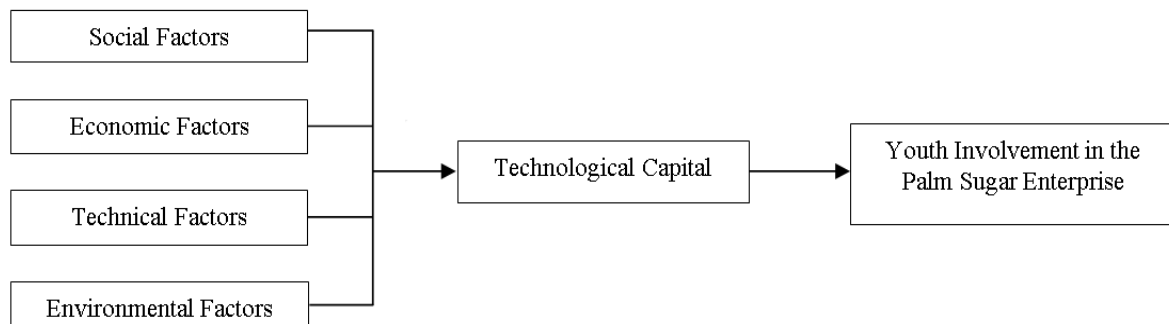


Figure 2. Conceptual framework of factors influencing rural youth involvement in palm sugar agroindustry

Regression diagnostics

Model assumptions were evaluated using standard diagnostics in SPSS. The normality of regression residuals was assessed using the Kolmogorov-Smirnov test (Asymp. Sig.=0.151), indicating no significant deviation from normality ($p>0.05$). Potential heteroscedasticity was examined using the Glejser test; all predictors showed non-significant results ($p>0.05$), indicating homoscedastic residual variance. Multicollinearity was evaluated using tolerance and Variance Inflation Factor (VIF) statistics; tolerance ranged from 0.862 to 0.957, and VIF ranged from 1.045 to 1.160, suggesting no problematic multicollinearity. Overall, these diagnostics support the conclusion that the multiple linear regression assumptions were satisfactorily met for model estimation (Zano and Santoso 2019; Iba and Wardhana 2024).

RESULTS AND DISCUSSION

Respondent characteristics

This section summarizes the socio-demographic profile of the respondents included in the study ($N=51$). The descriptive statistics are presented to provide background information on the participants involved in sugar-palm agroindustry activities. Table 2 reports the age distribution of respondents, while Table 3 presents their educational attainment.

As shown in Table 2, respondents were predominantly within the 31-59 age group, while youth (15-30 years) constituted roughly one-third of the sample. This indicates that although younger actors are present in the value chain, participation remains more concentrated among mature-age individuals. In terms of education (Table 3), most respondents had completed elementary-level schooling, suggesting that palm-sugar activities rely more on

experiential and intergenerational knowledge transfer than on formal educational attainment.

Model feasibility

Model feasibility was supported by acceptable measurement reliability and satisfactory regression diagnostics. Internal consistency across the composite indices was acceptable, with Cronbach's Alpha ranging from 0.602 to 0.688. Residual normality was supported by the Kolmogorov-Smirnov test (Asymp. Sig.=0.151, $p>0.05$). Multicollinearity was not problematic, with VIF values ranging from 1.045 to 1.160 and tolerance ranging from 0.862 to 0.957. Overall, these results indicate that the indices were sufficiently reliable and that key regression assumptions were met, supporting the feasibility of the estimated multiple linear regression model.

Factors associated with youth engagement

Multiple linear regression was used to examine the associations between the four factor indices (social X_1 , economic X_2 , technical X_3 , and environmental X_4) and the youth involvement index (Y). In this manuscript, technical factors (X_3) are consistently used to represent technological readiness/technological capital, as captured by indicators related to tools, training, and the ease and safety of tapping and processing activities. As shown in Table 4, technical factors (X_3) were positively associated with youth involvement and were statistically significant ($B=0.235$; $SE=0.084$; $p=0.007$). Economic factors (X_2) were also positive but borderline significant ($B=0.203$; $SE=0.101$; $p=0.050$), exactly at the conventional 0.05 threshold; therefore, this association should be interpreted with caution. Social (X_1) and environmental (X_4) factors were not statistically significant predictors at $\alpha=0.05$ (Table 4).

Based on the unstandardized coefficients, the estimated regression equation was:

$$Y = 3.854 - 0.359X_1 + 0.203X_2 + 0.235X_3 + 0.169X_4$$

Table 2. Age distribution of respondents involved in palm sugar agroindustry activities in Maros, South Sulawesi, Indonesia

Age group (years)	Number (Person)	Percentage (%)
15-30 (Youth)	17	33.3
31-59	33	64.7
>60	1	2
Total	51	100

Table 3. Educational attainment of respondents involved in palm sugar agroindustry activities in Maros, South Sulawesi, Indonesia

Education level	Number (people)	Percentage (%)
Elementary school (SD)	30	59
Junior high school (SMP)	12	24
Senior high school (SMA)	9	18
Total	51	100

Table 4. Regression coefficients estimating the association between factor composite scores (X_1 – X_4) and the youth involvement score (Y)

Model	Unstandardized coefficients		Sig.
	B	Std. Error	
(Constant)	3.854	1.634	0.023
Social factors (X_1)	-0.359	0.187	0.062
Economic factors (X_2)	0.203	0.101	0.050
Technical Factors (X_3)	0.235	0.084	0.007
Environmental Factors (X_4)	0.169	0.106	0.118

Descriptive pattern across indices

Figure 3 summarizes the descriptive pattern of the four factor indices (X_1 - X_4). To improve interpretability, the figure and accompanying text now report each index as mean \pm SD, with error bars (± 1 SD) shown in Figure 3. Theoretical score ranges are also provided to contextualize the magnitude of the observed means: social (X_1) and economic (X_2) range from 5-15, technical/technological capital (X_3) ranges from 7-21, and environmental (X_4) ranges from 5-15. Using these ranges as reference points, the technical/technological capital index (X_3) had the highest mean score. In contrast, the economic index (X_2) had the lowest mean score, suggesting that perceived technological readiness conditions were relatively stronger than perceived economic conditions among respondents in the study area.

Discussion

The findings indicate that technical readiness, interpreted here as technological capital, plays a central role in shaping youth involvement in the sugar-palm agroindustry. In this study, technological capital (X_3) reflects respondents' perceptions of access to appropriate tools and equipment, participation in training and skills development, and the ease and safety of tapping and processing activities. Practically, a one-unit increase in the technical index (X_3) reflects a modest but meaningful improvement in production readiness, including better access to tools, increased exposure to hands-on training, and safer working conditions. These improvements reduce the physical and operational barriers that often discourage younger generations from participating in labor-intensive agroforestry activities.

This finding is consistent with broader agricultural development literature emphasizing that access to technology, technical knowledge, and production-support infrastructure strongly influences youth participation and retention in rural livelihoods (Nguyen et al. 2021; Montesclaros and Teng 2023). Previous studies have shown that younger rural actors are generally more willing to engage in agricultural activities when production systems are perceived as modern, efficient, and economically promising rather than physically demanding and technologically stagnant. In Southeast Asia, digital and technological transformation in agriculture has increasingly been recognized as an important factor shaping youth perceptions of farming attractiveness and long-term livelihood feasibility (Montesclaros and Teng 2023).

The present findings also align with Sustainable Livelihood Framework (SLF) perspectives suggesting that technological and physical assets can strengthen livelihood capability, productivity, and adaptive capacity (Scoones 1998). In the context of sugar-palm agroindustry, technological capital appears particularly important because tapping and processing activities involve physically demanding tasks, occupational risks, and practical production skills that directly affect work efficiency and safety. Improved technical conditions may therefore reduce barriers to entry while simultaneously

increasing the perceived desirability of remaining in the sector.

Economic conditions were also positively associated with youth involvement, although the relationship should be interpreted cautiously because statistical significance was borderline ($p=0.050$). Substantively, a one-unit increase in the economic index (X_2) corresponds to improvements in perceived income stability, price certainty, and access to working capital. These economic considerations influence whether younger individuals perceive palm-sugar activities as capable of providing stable and competitive livelihood opportunities relative to off-farm employment alternatives.

This result is comparable to findings from rural youth studies in Indonesia and other developing countries showing that income predictability and perceived economic viability are among the strongest determinants of agricultural participation among younger generations (Yami et al. 2019; Effendy et al. 2020; Ruhkmauddin et al. 2024). Similar evidence has been reported in African and Southeast Asian contexts, where youth are more likely to remain in agricultural sectors when farming activities provide reliable returns, market access, and opportunities for economic mobility. The result also supports push-pull migration perspectives, where limited rural earnings and difficult working conditions "push" youth away from agriculture, while urban employment opportunities "pull" them toward alternative occupations (Lee 1966; Bhagat 2020).

Nevertheless, the borderline significance of the economic variable suggests that economic incentives alone may not fully explain participation decisions within the study context. This may partly reflect the relatively small census-based sample size, which reduces statistical power and limits the detection of weaker associations. It may also indicate that economic considerations interact with other enabling conditions, particularly technological readiness and work safety, rather than operating independently.

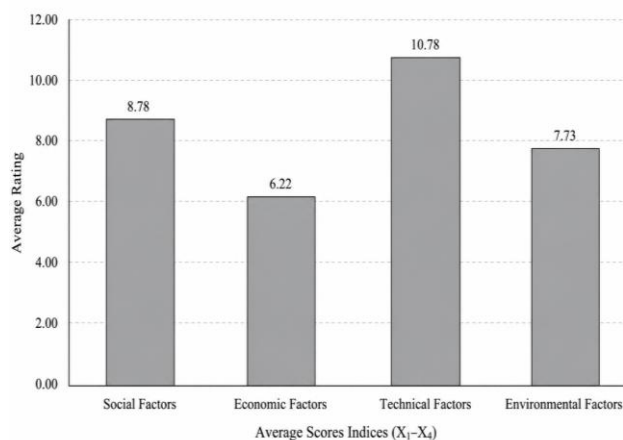


Figure 3. Mean total composite scores of factor constructs (X_1 - X_4) across respondents

By contrast, social (X_1) and environmental (X_4) factors were not statistically associated with youth involvement in this study. However, the absence of statistical significance does not necessarily imply that these factors are unimportant. Instead, social support and environmental awareness may function as indirect or background enabling conditions that are relatively homogeneous among respondents already involved in the sugar-palm value chain. Because respondents were recruited exclusively from active palm-sugar actors, variation in social norms, family support, and environmental perceptions may have been insufficient to produce strong statistical differentiation.

This interpretation is supported by previous livelihood studies showing that immediate technical and economic constraints often exert stronger influence on day-to-day participation decisions than broader normative or environmental considerations (Scoones 1998; Duffy et al. 2021; Nguyen et al. 2021). In many rural production systems, environmental awareness tends to influence long-term sustainability attitudes rather than short-term labor participation behavior. Similarly, family and community support may encourage initial entry into agricultural work but may be less influential in determining continued engagement when economic and technical barriers remain substantial.

Another possible explanation relates to the socio-cultural structure of the study area, where sugar-palm production is already embedded within longstanding household and community traditions. Under such conditions, social support may become relatively normalized across respondents, thereby reducing its explanatory power within regression analysis. Comparable patterns have been reported in studies of intergenerational agricultural participation where shared community norms produce limited statistical variation despite their broader social importance (Yami et al. 2019; Duffy et al. 2021).

Taken together, these findings suggest that strategies aimed at sustaining youth engagement in the sugar-palm value chain are likely to be more effective when they simultaneously address capability constraints and economic incentives. On the technical side, interventions that improve access to safer and more efficient equipment, strengthen practical training systems, and reduce occupational risks may substantially improve the attractiveness of sugar-palm work among younger people. On the economic side, strengthening market access, improving price information systems, and supporting more predictable returns may increase the perceived viability of remaining in the sector.

More broadly, the findings contribute to ongoing discussions on generational renewal in agriculture by demonstrating that youth participation is shaped not only by social encouragement or cultural continuity, but also by tangible production conditions and livelihood feasibility. The study therefore extends previous rural livelihood literature by empirically highlighting the importance of technological capital as a distinct and measurable determinant of youth engagement within a smallholder agroforestry value-chain context.

Implications

In the Maros KHDTK context, the findings are consistent with several practical, low-regret options to support youth engagement, while recognizing that causal impacts cannot be inferred from this cross-sectional analysis. First, technical upgrading could focus on improving occupational safety and work efficiency, for example, through demonstrations and adoption of safer tapping equipment, improved climbing and sap-handling practices, and basic processing improvements that reduce heat exposure and accident risk. Second, structured skills apprenticeships or short modular training sessions implemented through existing local groups and facilitated by relevant institutions operating in or near KHDTK (e.g., extension services or university outreach programs, such as Universitas Hasanuddin) could strengthen practical skills and reduce entry barriers for youth. Third, economic viability could be strengthened through simple market and financial support, such as basic financial literacy for household enterprises, improved price information, and small-group marketing or collective purchasing arrangements to stabilize returns and reduce transaction costs. These options are presented as illustrative interventions that align with the observed associations. However, they should be pilot-tested and evaluated in broader samples before being recommended as definitive policy measures.

Limitations and future research

This study has several limitations that should be considered when interpreting the findings. First, the cross-sectional design captures relationships at a single point in time; therefore, the regression results should be interpreted as associations rather than causal effects. Second, the analysis focuses on individuals aged ≥ 15 years who are already involved in tapping, processing, and/or marketing activities within the sugar-palm value chain; consequently, the findings may not represent youth who have never participated or who have exited the sector. Third, the study relies on summed Likert-type composite indices derived from a relatively small, census-based sample in two villages, which may limit generalizability and the ability to detect smaller effects, particularly for non-significant predictors. Future research could strengthen inference by using larger multi-site samples, including non-participating youth as a comparison group, and applying longitudinal or quasi-experimental designs to test causal pathways. Further work could also examine subgroup differences across value-chain roles (tapping, processing, and marketing) to refine intervention targeting.

Overall synthesis

Overall, the results suggest that strengthening youth engagement in sugar-palm agroindustry should prioritize two complementary levers identified in the regression model technical readiness (X_3 ; $B=0.235$; $p=0.007$) and economic viability (X_2 ; $B=0.203$; $p=0.050$) within a statistically significant but partial explanatory framework ($F=4.574$; $p=0.003$; Adjusted $R^2=0.222$). Social (X_1) and environmental (X_4) factors were not significant at $\alpha = 0.05$,

yet they remain relevant as enabling conditions that may support longer-term sustainability when integrated with practical technology packages, market incentives, and institutional support (Scoones 1998; Greenhalgh et al. 2004; Duffy et al. 2021; Withaningsih et al. 2021; Montesclaros and Teng 2023; Lillo et al. 2025). Given the cross-sectional design, these findings should be interpreted as associations that help prioritize intervention entry points rather than as causal effects.

In conclusion, this study examined factors associated with youth involvement in the sugar-palm agroindustry in Maros District, South Sulawesi, using an SLF-oriented framework that treats the technical factor as technological capital. The results indicate that technological capital (X_3) and economic conditions (X_2) are positively associated with youth involvement, whereas social (X_1) and environmental (X_4) factors are not statistically significant in this sample. These findings contribute to the livelihood literature by operationalizing technological capital as a distinct, measurable asset within the sugar-palm value chain. Although the relationships identified are associative and context-specific, they suggest that the sugar-palm agroindustry becomes more attractive to rural youth when participation is safer and more efficient, thanks to improved tools and skills, and when it offers more predictable and viable economic returns. Future research with larger multi-site samples and longitudinal or intervention-based designs is recommended to test causal mechanisms and refine targeting of youth-oriented value-chain support.

ACKNOWLEDGEMENTS

The acknowledgements section was revised to ensure consistent spelling of geographic and institutional names with the main text, including Rompegading Village, Limapocoe Village, Cenrana Sub-district, and Maros District, South Sulawesi, Indonesia, as well as the Faculty of Forestry, Universitas Hasanuddin, Indonesia. To align with journal preferences on anonymity and privacy, acknowledgements were also phrased in a more general form by referring to community leaders, local groups, and respondents without listing individual full names.

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