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LINKING SMALLHOLDER AGRICULTURE, IRRIGATION ACCESS AND POVERTY REDUCTION IN SEMI-ARID ANGOLA

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ABSTRACT

This study analyzed the relationship between smallholder agriculture, irrigation access, and food security in the semi-arid context of Namibe Province, Angola, between 2019 and 2023. The research aimed to investigate the relationship between irrigation access, household income, poverty reduction, and food security among rural farming households operating under conditions of climatic instability and water scarcity. A mixed-methods approach was adopted, combining quantitative and qualitative analyses through a comparative multiple case study design. Data were collected from 57 rural households located in the municipalities of Namibe, Tômbwa, and Bibala using structured socioeconomic questionnaires, semi-structured interviews, field observations, and photographic records. The study evaluated household income dynamics, cultivated area, irrigation access, agricultural diversification, and food security indicators. In addition, a Food Security Index (FSI) was constructed using five dimensions: dietary diversity, meal frequency, food access, supply stability, and nutritional quality. The results demonstrated a substantial increase in average household income, rising from 34,200 Angolan Kwanza (AOA) in 2019 to 69,300 Angolan Kwanza (AOA) in 2023, corresponding to an approximate nominal growth of 102.6%. Households with irrigation access generally exhibited greater income stability, higher participation in horticultural production, and more favorable food security conditions than households dependent exclusively on rainfed agriculture. The average Food Security Index reached 2.90, indicating low to moderate food security conditions within the sample. A positive association was also observed between cultivated area and food security outcomes ($r = 0.78$; $p < 0.05$), suggesting that land and water access jointly influence household resilience and agricultural performance in semi-arid environments. The findings suggest that agricultural development strategies associated with irrigation access and production diversification may contribute to improved household welfare, poverty reduction, and food security among rural households. Nevertheless, persistent limitations in dietary diversity and unequal access to productive resources indicate the need for integrated policies combining irrigation expansion, climate-resilient agricultural practices, technical assistance, and nutrition-sensitive rural development strategies. This study contributes empirical evidence from an underrepresented semi-arid region of Angola and reinforces the importance of context-specific interventions for strengthening rural livelihoods under climate-constrained conditions.

Key words: Smallholder agriculture, Rural poverty, Food security, Irrigation, Angola, Semi-arid regions

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INTRODUCTION

Food security remains one of the most pressing global challenges, particularly in developing regions where agricultural production is predominantly rainfed and highly vulnerable to climate variability. In sub-Saharan Africa, smallholder farmers depend heavily on seasonal rainfall, resulting in unstable crop yields, limited food availability, and persistent poverty cycles. These conditions are further exacerbated by structural constraints such as low technological adoption, limited access to resources, and insufficient infrastructure, all of which restrict agricultural productivity and resilience [1].

In this context, irrigation has been widely recognized as a critical strategy to enhance agricultural productivity, improve income generation, and strengthen household food security. Small-scale irrigation systems, in particular, have demonstrated significant potential to increase crop yields, enable multiple cropping cycles, and reduce dependence on erratic rainfall patterns. Empirical evidence indicates that households with access to irrigation tend to achieve higher levels of food consumption, income stability, and asset accumulation compared to non-irrigating households, highlighting its importance as a tool for rural development and poverty alleviation [2].

Despite these benefits, the effectiveness of irrigation systems is closely linked to environmental conditions, especially in semi-arid regions where water scarcity and climate change pose additional challenges. Climate variability, including irregular rainfall patterns, droughts, and extreme weather events, continues to threaten agricultural systems and food security outcomes. In such environments, the adoption of sustainable and adaptive agricultural practices becomes essential to ensure long-term productivity and resilience, reinforcing the need for integrated approaches that combine irrigation, climate adaptation strategies, and efficient resource management [3]. Semi-arid regions present additional constraints to agricultural development due to water scarcity, soil limitations, and high climate variability, making food production systems particularly vulnerable. In these environments, family farming plays a central role in sustaining rural livelihoods, despite facing structural challenges such as limited access to technology, credit, and markets. Adaptive strategies, including agroecological practices and improved water management, have been increasingly adopted to enhance resilience and ensure food production under adverse conditions. These approaches are essential for maintaining agricultural sustainability and supporting the livelihoods of smallholder farmers in semi-arid regions [4].

Although a growing body of literature has highlighted the importance of irrigation for improving food security and reducing poverty, there remains a significant gap in

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empirical research focusing on semi-arid regions of Angola. In particular, limited attention has been given to understanding how irrigation interacts with other socio-environmental factors, such as climate variability, to influence agricultural outcomes. Therefore, this study aimed to analyze the relationship between irrigation access, agricultural production, food security, and poverty reduction in semi-arid regions, contributing to the advancement of knowledge on sustainable agricultural development under climate-constrained conditions [5].

Recent empirical studies reinforce the significant contribution of smallholder irrigation to household food security in sub-Saharan Africa. Evidence from Zimbabwe indicates that farmers with access to irrigation exhibit higher crop yields, increased farm income, and improved food consumption levels compared to non-irrigating households [2]. These findings highlight irrigation as a key determinant of food security, particularly in rural areas where livelihoods depend heavily on agricultural production [6]. However, despite its potential benefits, the expansion of irrigation systems remains constrained by several structural and institutional challenges. High investment costs, limited access to markets, and inadequate infrastructure often restrict the effectiveness of irrigation schemes, especially among poorer households.

Furthermore, unequal access to water resources and lack of institutional support can limit the distribution of benefits, preventing irrigation from fully contributing to poverty reduction and rural development [1]. In Angola, these challenges are particularly pronounced, as a significant portion of the population still experiences multidimensional poverty, especially in rural areas where agriculture is the main source of livelihood. Limited access to basic services, infrastructure, and productive resources continues to constrain agricultural development and food security outcomes [7].

In this context, improving agricultural systems through investments in irrigation and sustainable practices becomes essential to reduce poverty and enhance food security in vulnerable regions[8]. Additionally, large-scale and small-scale irrigation initiatives across Africa have demonstrated the potential to transform rural economies by increasing agricultural productivity and generating employment opportunities. Nevertheless, the long-term success of such interventions depends on effective governance, sustainable water management, and the integration of local socio-economic conditions into project design [8].

MATERIALS AND METHODS

Research Design

This study adopted a mixed-methods approach, integrating quantitative and qualitative data to examine the relationship between smallholder agriculture,

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irrigation access, food security, and poverty reduction in semi-arid areas of Namibe Province, Angola. The study followed a comparative multiple case study design based on the methodological framework proposed by Yin [8], allowing the investigation of livelihood dynamics across different household production systems under varying conditions of water access.

The quantitative component focused on household socioeconomic indicators, agricultural production, cultivated area, income variation, and food security outcomes. The qualitative component aimed to contextualize the quantitative findings through the interpretation of farmers' experiences, perceptions, and adaptive strategies related to irrigation, agricultural production, and household well-being.

Study Area

The research was conducted in the municipalities of Namibe, Tômbwa, and Bibala, located in Namibe Province, southern Angola. These municipalities were selected because they represent different agroecological conditions within the semi-arid region, including coastal arid environments and inland areas with relatively greater agricultural potential.

The region is characterized by low and irregular rainfall, with annual precipitation ranging from approximately 25 to 200 mm, high evapotranspiration rates, recurrent droughts, and strong climatic variability. Agricultural production is predominantly based on smallholder farming systems and is highly dependent on access to water resources, particularly small-scale irrigation systems.

Sampling Procedure

A purposive sampling strategy was employed to ensure the inclusion of households with different agricultural characteristics, including variation in cultivated area, crop type, production intensity, and irrigation access. The sampling approach was considered appropriate due to the exploratory nature of the study and the logistical limitations associated with data collection in dispersed rural communities. A total of 57 rural households were included in the quantitative stage of the study. Households were identified with support from local agricultural extension agents and community leaders from the Institute for Agrarian Development (IDA), prioritizing families actively engaged in agricultural production.

The inclusion criteria were: (i) permanent residence in the study area for at least five years, (ii) agriculture as the primary livelihood activity, and (iii) willingness to participate voluntarily through informed consent.

The sample included both irrigated and non-irrigated households, allowing comparative analysis between different production conditions. However, because the sampling strategy was non-probabilistic and purposive, the findings should not

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be interpreted as statistically representative of the entire population of Namibe Province. Instead, the results provide contextual empirical evidence regarding rural livelihood dynamics in semi-arid environments.

Irrigation Classification

For the purposes of this study, irrigation was defined as the regular use of artificial water supply systems to support crop production during periods of insufficient rainfall. The irrigation systems identified in the study area were predominantly small-scale and included manual watering, gravity-fed irrigation, water pumping from wells, and small motorized pumping systems connected to local water reservoirs. Households were classified as "irrigated" when they reported continuous or seasonal access to artificial water supply for agricultural production during the 2022–2023 agricultural cycle. Households relying exclusively on rainfall were classified as "non-irrigated." This distinction was established through field observation, farmer interviews, and direct verification of irrigation infrastructure during farm visits.

Data Collection Procedures

Data collection was conducted between March and October 2023 using multiple complementary techniques.

Quantitative Data

Quantitative data were collected through a structured socioeconomic questionnaire administered to all 57 households. The instrument collected information on household composition, cultivated area, crop production systems, irrigation access, income sources, agricultural commercialization, and food security conditions. Income data for 2019 and 2023 were obtained through retrospective recall interviews conducted in 2023. To reduce recall bias, respondents were encouraged to associate income estimates with relevant agricultural periods, drought events, harvest cycles, and major household events. Nevertheless, the use of recalled income information represents a limitation of the study and should be interpreted cautiously.

Qualitative Data

The qualitative component consisted of semi-structured interviews conducted with a subset of households selected to represent different agricultural conditions, including irrigated and non-irrigated systems, different farm sizes, and varying food security conditions. The interviews explored themes related to perceptions of poverty and well-being, experiences with irrigation, agricultural adaptation strategies, barriers to production, climate variability, and access to institutional support. All interviews were audio-recorded with participant authorization and subsequently transcribed for analysis. Field observations and photographic records of agricultural areas and

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irrigation systems were also conducted to support contextual interpretation of the findings.

Food Security Index Construction

A Food Security Index (FSI) was developed to provide a multidimensional assessment of household food security conditions. The index was adapted from food security dimensions commonly used in rural livelihood and household welfare studies and incorporated five components: (i) dietary diversity, (ii) meal frequency, (iii) food access, (iv) supply stability, and (v) nutritional quality.

Each component was evaluated using a five-point ordinal scale ranging from 1 (very low condition) to 5 (very high condition). The final FSI corresponded to the arithmetic mean of the five indicators, assuming equal weighting among dimensions due to the absence of sufficient empirical evidence supporting differentiated weights in the study context. The index was calculated for all 57 households included in the study. This approach enabled the assessment of food security variability across the sample and facilitated comparisons between irrigated and non-irrigated households.

To evaluate the internal consistency of the index, Cronbach's alpha coefficient was calculated for the five components. The reliability analysis demonstrated acceptable internal consistency for exploratory social research applications.

Data Analysis

Quantitative data were analyzed using descriptive statistics, including means, standard deviations, minimum and maximum values, and percentage variation in household income between 2019 and 2023.

Poverty classification was based on the national poverty threshold established for Angola (AOA 28,500 per capita per month, equivalent to approximately USD 35 PPP). Income values were additionally interpreted considering cumulative inflation estimates published by the National Bank of Angola during the study period. Pearson correlation analysis was used to evaluate the relationship between cultivated area and the Food Security Index (FSI). The analysis was conducted using data from the 57 households included in the study. Given the observational design and non-probabilistic sampling strategy, the results should be interpreted as indicative associations rather than evidence of causal relationships.

Comparisons between irrigated and non-irrigated households were additionally explored using descriptive and inferential statistical approaches to identify potential differences in income and food security outcomes.

Qualitative Analysis

Qualitative data were analyzed using thematic analysis following Braun and Clarke's methodological framework [9]. The analytical process involved six stages: (i)

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familiarization with the data, (ii) initial coding, (iii) identification of themes, (iv) thematic review, (v) theme definition, and (vi) interpretation of findings. The coding process was conducted manually through repeated reading of interview transcripts and organization of recurring themes related to irrigation access, agricultural productivity, livelihood vulnerability, food security, and adaptive practices.

Qualitative findings were integrated with quantitative results during interpretation to strengthen contextual understanding of the mechanisms linking irrigation, agricultural production, and household welfare.

Ethical Considerations

All participants were informed about the objectives of the research prior to data collection. Participation was voluntary, and informed consent was obtained from all respondents before interviews and field observations were conducted.

To preserve confidentiality, household names were anonymized during data processing and analysis. The study respected ethical principles related to voluntary participation, privacy protection, and responsible use of research information.

RESULTS AND DISCUSSION

Socioeconomic Profile of Households

Table 1 summarizes the socioeconomic characteristics of the sampled households, including demographic structure, cultivated area, irrigation access, crop diversification, and household income in 2019 and 2023. Of the 57 households surveyed, 35 (61.4%) had access to irrigation, while 22 (38.6%) relied exclusively on rainfed agriculture. In addition, 41 (71.9%) households practiced crop diversification by cultivating two or more crop species, whereas 16 (28.1%) were engaged primarily in single-crop production. Average monthly household income increased from 34,200 Angolan Kwanza (AOA) in 2019 to 69,300 AOA in 2023, representing a nominal increase of 102.6%.

The results indicate an average household size of 5.7 members, reflecting the predominance of relatively large family units commonly observed in rural communities of sub-Saharan Africa. Farm sizes remained relatively small, with a mean cultivated area of 1.02 hectares, confirming the predominance of smallholder farming systems in the study area.

Although the observational nature of the study does not permit causal inferences, the findings suggest that improvements in agricultural production, irrigation access, and production diversification may have contributed to improved economic conditions among the sampled households. Nevertheless, considerable variability in income levels was observed, indicating that the benefits of agricultural activities were not distributed uniformly across households. Access to irrigation was generally

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associated with more favorable economic outcomes, particularly among households engaged in horticultural production. Farmers with irrigation access reported greater production stability and higher income levels than households relying exclusively on rainfed agriculture. This pattern highlights the importance of water availability in semi-arid environments, where rainfall irregularity frequently constrains agricultural productivity and increases livelihood vulnerability.

In addition, crop diversification, particularly through horticultural production, was associated with higher household income levels. Households producing vegetables and other higher-value crops tended to exhibit more favorable economic conditions than those primarily dependent on staple crop production. Similar trends have been reported in other semi-arid regions of sub-Saharan Africa, where diversification into market-oriented crops contributes to income generation and improved food access among smallholder farmers. Nevertheless, unequal access to irrigation infrastructure, markets, and productive resources may limit the ability of poorer households to benefit equally from agricultural development opportunities.

Income Variation and Poverty Impact

Figure 1 illustrates the variation in monthly household income between 2019 and 2023, while Figure 2 presents the percentage growth rate observed across the sampled households. Overall, the results indicate a general upward trend in household income during the study period, although substantial differences in growth magnitude were observed among households.

The observed increase in income may be associated with improvements in agricultural production systems, particularly among households with irrigation access and engagement in higher-value crops. However, the variability observed among households suggests that income dynamics were influenced by multiple interacting factors, including cultivated area, water availability, household labor capacity, market participation, and production diversification. These findings reinforce the heterogeneous nature of rural livelihoods in semi-arid regions, where access to productive resources strongly shapes economic opportunities and resilience.

Among the 57 households surveyed, 35 (61.4%) had access to irrigation, whereas 22 (38.6%) relied exclusively on rainfed agriculture. Households with irrigation access generally reported more favorable production conditions and income outcomes than households relying exclusively on rainfed agriculture. This pattern is consistent with previous studies indicating that irrigation can reduce production risks associated with rainfall variability and support more continuous agricultural production throughout the year [2,7]. Nevertheless, the results should be interpreted

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cautiously given the purposive nature of the sample and the observational design of the study.

The increase in household income was also accompanied by improvements in poverty conditions within the sample. The proportion of households classified in more vulnerable poverty categories declined between 2019 and 2023, while the proportion of households in higher welfare categories increased. However, these improvements were not homogeneous, as some households remained economically vulnerable due to structural constraints such as limited land availability, reduced access to irrigation infrastructure, and larger household dependency ratios.

Qualitative evidence further supports these findings. Several participants reported that irrigation access reduced production losses during drought periods and enabled greater production continuity throughout the agricultural cycle. As one farmer stated:

“Before irrigation, production depended entirely on rainfall, and harvest losses were frequent during dry periods” (Household F3).

Similarly, households engaged in horticultural production emphasized the importance of crop diversification for income generation and food access:

“Vegetable production allowed us to sell more frequently and buy food even during difficult months” (Household F6).

These narratives reinforce the interpretation that irrigation access and production diversification may contribute to strengthening household resilience in semi-arid agricultural systems, although broader structural limitations continue to affect long-term livelihood sustainability.

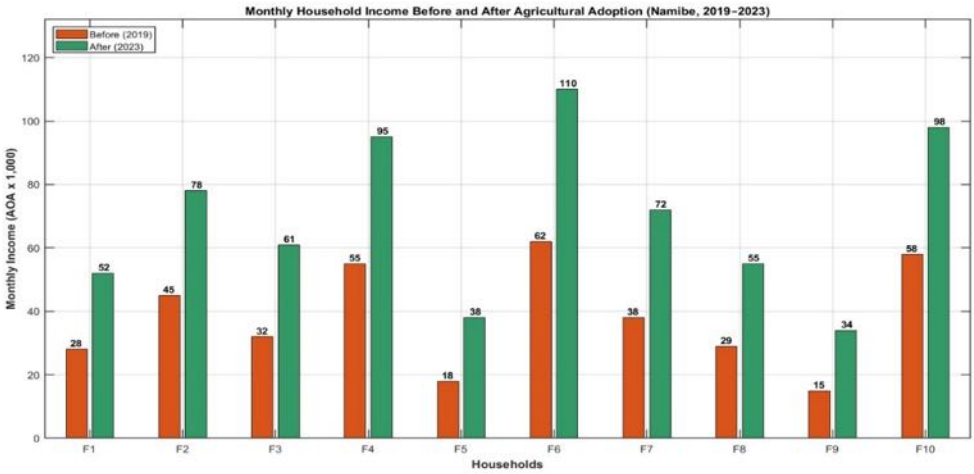

Figure 1: **Variation in monthly household income between 2019 and 2023 among sampled households in Namibe Province**
Source: Authors’ field data (2023)

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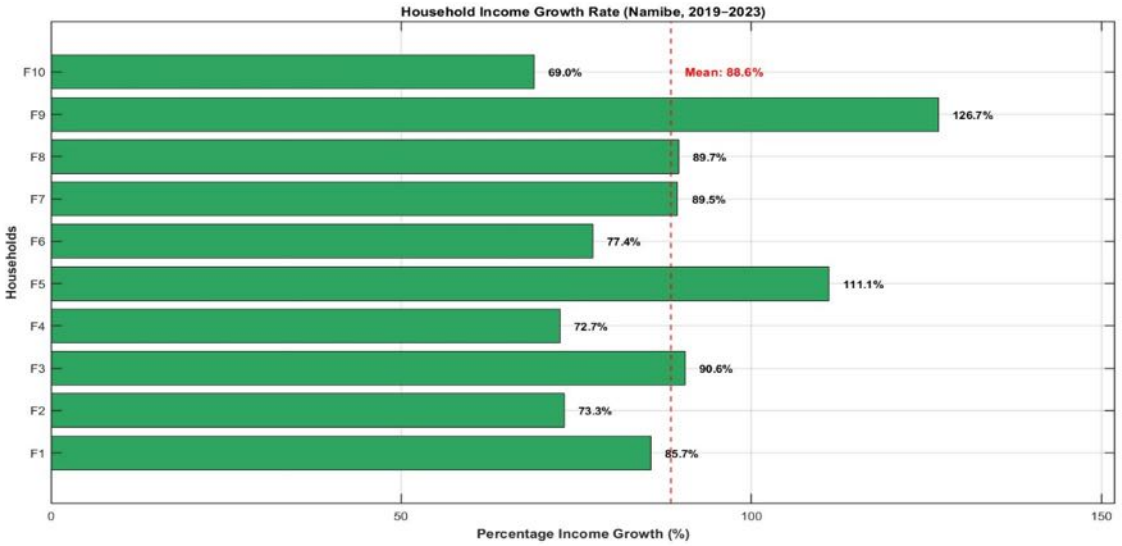

Figure 2: Percentage growth in monthly household income between 2019 and 2023 among sampled households in Namibe Province. The dashed line represents the sample mean growth rate
Source: Authors' field data (2023)

The average household income increased from AOA 34,200 in 2019 to AOA 69,300 in 2023, corresponding to a nominal growth of approximately 102.6%. After considering cumulative inflation during the study period (approximately 48%, based on data from the National Bank of Angola), the estimated real income growth remained positive, suggesting an improvement in household purchasing power among the sampled families. Nevertheless, because the income data were partially based on retrospective recall, these estimates should be interpreted with caution.

Household-level analysis revealed substantial heterogeneity in income trajectories across the sample. Some households experienced markedly higher income growth than others, reflecting differences in access to productive resources, cultivated area, irrigation availability, crop diversification, and market participation. Among the 57 households surveyed, 35 (61.4%) had access to irrigation and generally reported higher income levels and greater income stability throughout the study period. These findings suggest that water availability and production diversification may be important factors associated with economic resilience in semi-arid environments.

Conversely, the 22 households (38.6%) relying exclusively on rainfed agriculture tended to report lower income levels and slower income growth. Similar patterns have been documented in studies of rural livelihoods in semi-arid regions, where restricted access to productive assets and high climatic variability often constrain agricultural performance and household welfare [15,16].

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The observed variability among households reinforces the heterogeneous nature of rural production systems in Namibe Province. While some families appeared to benefit more substantially from favorable production conditions and resource availability, others remained constrained by structural limitations related to land access, water availability, and production infrastructure. These differences highlight the importance of considering local socioeconomic inequalities when interpreting the relationship between agriculture, food security, and poverty reduction in semi-arid regions.

Poverty Dynamics

Figure 3 presents the distribution of households across poverty categories in 2019 and 2023, revealing changes in the socioeconomic conditions of the sampled households over the study period. The results indicate substantial changes in household poverty status between 2019 and 2023. The proportion of households classified as extremely poor decreased from 50% in 2019 to 0% in 2023, while the proportion of non-poor households increased from 10% to 50% during the same period. Although the proportion of households classified as moderately poor increased from 40% to 50%, the complete elimination of extreme poverty and the expansion of the non-poor category suggest an overall improvement in household welfare conditions. These findings indicate that improvements in agricultural production and household income were associated with reduced economic vulnerability among part of the sample.

Households with irrigation access and greater production diversification generally exhibited more favorable socioeconomic conditions than households relying exclusively on rainfed agriculture. Among the 57 households surveyed, 35 (61.4%) had access to irrigation and 41 (71.9%) practiced crop diversification, whereas 22 (38.6%) relied exclusively on rainfed agriculture. However, given the purposive nature of the sample and the observational design of the study, these findings should not be interpreted as evidence of direct causality between irrigation access and poverty reduction.

Qualitative evidence further supports these observations. Several participants reported that irrigation reduced dependence on irregular rainfall and enabled more continuous food production throughout the year. As one respondent explained:

“With irrigation, we are able to continue producing even during periods with little rainfall” (Household F4).

Despite the overall trend toward improved income conditions, some households remained economically vulnerable due to structural constraints such as limited cultivated area, restricted access to irrigation infrastructure, and dependence on low productivity rainfed systems. These findings highlight the importance of integrated

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rural development strategies that combine agricultural support, irrigation expansion, technical assistance, and infrastructure improvements to strengthen long-term resilience in semi-arid regions.

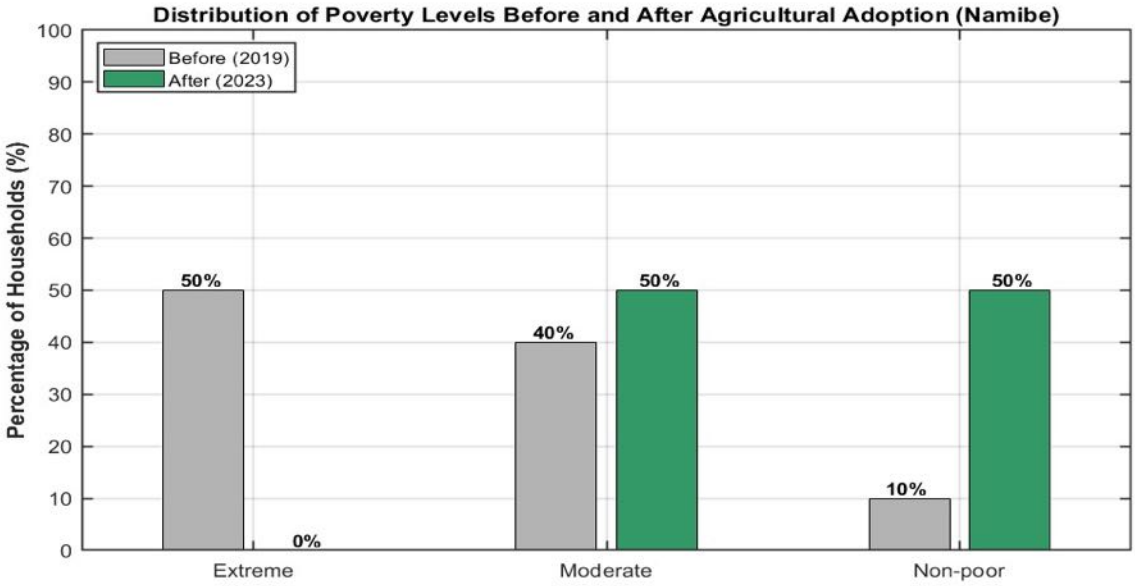

Figure 3: Distribution of household poverty levels in 2019 and 2023 among sampled households in Namibe Province
Source: Authors' field data (2023)

The results indicate an overall improvement in the living conditions of the sampled households between 2019 and 2023. Although extreme poverty indicators were no longer observed within the analyzed sample by the end of the study period, these findings should be interpreted cautiously given the relatively small purposive sample and the observational nature of the research design. Nevertheless, the results suggest that agricultural activities may contribute to reducing socioeconomic vulnerability in rural semi-arid contexts. Similar patterns have been reported in studies indicating that improvements in agricultural productivity are frequently associated with income growth and enhanced household welfare in developing regions, particularly where agriculture constitutes the primary livelihood activity [10].

The observed transition from more vulnerable poverty categories toward relatively improved economic conditions also highlights the potential role of smallholder agriculture in strengthening food security and local socioeconomic stability. Previous studies have demonstrated that family farming systems contribute not only to income generation but also to local food availability, reducing dependence on external food markets and increasing household access to agricultural products [10].

However, the benefits associated with agricultural intensification appeared unevenly distributed among households. Among the 57 households surveyed, 35 (61.4%) had

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access to irrigation and 41 (71.9%) practiced crop diversification, whereas 22 (38.6%) relied exclusively on rainfed production systems. Families with greater access to irrigation, larger cultivated areas, and higher-value crops generally experienced more favorable economic outcomes than those dependent exclusively on rainfed agriculture. This finding reinforces the importance of structural factors such as water availability, productive assets, and market access in shaping livelihood resilience in semi-arid environments.

Qualitative evidence further supports these interpretations. Several participants reported that irrigation access increased production stability and reduced vulnerability during drought periods. As one respondent explained:

“When rainfall was insufficient, irrigation allowed us to continue producing and avoid larger losses” (Household F7).

These findings suggest that investments in irrigation infrastructure, production diversification, and improved access to productive resources may contribute to strengthening household resilience and promoting sustainable rural development in semi-arid regions.

These findings suggest that agricultural development strategies in semi-arid regions may be more effective when combined with investments in irrigation infrastructure, technical support, and diversification opportunities capable of strengthening long-term household resilience [10]. Furthermore, the observed improvement in household well-being may be associated with multiple interconnected mechanisms, including greater food self-sufficiency, diversification of agricultural production, and the commercialization of surplus products. These strategies can contribute to increased income stability and improved household access to food, particularly in semi-arid environments characterized by climatic uncertainty and irregular agricultural production cycles.

Previous studies have identified production diversification and market participation as important factors associated with enhanced rural resilience, as they may reduce dependence on single-crop systems and mitigate household exposure to environmental and economic shocks [10]. In the present study, 41 of the 57 households (71.9%) practiced crop diversification, while 35 households (61.4%) had access to irrigation. These households generally demonstrated more favorable socioeconomic conditions compared to the 22 households (38.6%) relying exclusively on rainfed subsistence production.

Qualitative evidence also suggests that diversification strategies played an important role in supporting household livelihoods. Some participants reported that the sale of vegetables and other surplus products provided an additional source of income during periods of reduced staple crop production.

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As one farmer explained:

"Selling vegetables helped us buy other foods and support household expenses during difficult periods" (Household F2).

These findings reinforce the importance of integrated agricultural strategies that combine production diversification, irrigation access, and market participation to strengthen rural livelihoods and improve resilience in semi-arid regions [11]

Food Security: Composite Index

Table 2 presents the Food Security Index (FSI) and its component dimensions for the 57 households included in the study. The results provide a multidimensional assessment of food security conditions based on dietary diversity, meal frequency, food access, supply stability, and nutritional quality.

Overall, the average Food Security Index (FSI) reached 2.90, indicating low to moderate food security conditions among the sampled households. Among the five dimensions evaluated, food access presented the highest average score (3.12), suggesting relatively favorable availability of food resources for part of the sample. In contrast, dietary diversity and nutritional quality achieved comparatively lower scores, revealing persistent limitations in diet composition and nutritional adequacy. These findings suggest that improvements in agricultural production and food availability do not necessarily translate into more diversified or nutritionally balanced diets, a pattern also reported in previous studies of smallholder farming systems [12].

These findings suggest that improvements in agricultural production and resource availability may contribute to strengthening household food security in semi-arid environments.

To further interpret the distribution of food security conditions identified in Table 2, Table 3 categorizes households according to their FSI levels [13]. The results indicate that 21.1% of households were classified as having low food security, 42.1% as having moderate food security, and 36.8% as having high food security. This distribution suggests substantial variability in food security conditions across the sample, reflecting differences in access to productive resources, irrigation, and livelihood opportunities.

Qualitative evidence also supports the quantitative findings. Several participants reported that irrigation enabled more stable crop production throughout the year and reduced food shortages during drought periods. As one respondent explained:

"With irrigation, we can continue producing vegetables even when rainfall is insufficient" (Household F6).

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Despite the general improvement observed in food access, the relatively low nutritional quality scores indicate that increased food availability alone may not guarantee adequate dietary diversity. In semi-arid agricultural systems, production often remains concentrated on staple crops with limited nutritional variability, restricting broader dietary improvements despite gains in productivity [14]. This finding highlights the importance of integrating agricultural development policies with nutrition-sensitive interventions capable of promoting both food quantity and dietary quality.

Furthermore, the persistence of low and moderate food security conditions among a considerable proportion of households reinforces the influence of broader structural constraints, including unequal access to irrigation infrastructure, limited productive resources, and vulnerability to climatic variability. These findings suggest that improving food security in semi-arid regions requires integrated strategies combining irrigation access, production diversification, nutrition education, technical assistance, and climate-resilient agricultural practices [15]

Correlation between Cultivated Area, Irrigation Access and Food Security

To further explore the structural determinants of food security among rural households, an additional analysis was conducted examining the relationship between cultivated area and the Food Security Index (FSI), while considering irrigation access as an important contextual factor associated with food security outcomes. In semi-arid regions, land and water availability represent two of the main productive resources influencing agricultural performance, food availability, and household resilience. Consequently, understanding how these factors interact is essential for interpreting variations in food security outcomes among smallholder farming systems.

Previous studies have demonstrated that rural households operating under conditions of limited land access and water scarcity tend to face greater vulnerability to climatic instability, lower agricultural productivity, and reduced income generation capacity [16].

In contexts such as Namibe Province, where agricultural production is strongly constrained by irregular rainfall patterns, access to irrigation may partially mitigate these limitations by stabilizing production cycles and enabling more continuous cultivation throughout the year.

However, the relationship between cultivated area, irrigation, and food security is not necessarily uniform across households. Differences in productive assets, labor availability, market access, and agricultural diversification may also influence household capacity to convert agricultural production into improved food security conditions. Therefore, the present analysis seeks to identify potential associations

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among these variables while recognizing the broader socioeconomic heterogeneity that characterizes rural livelihoods in semi-arid environments.

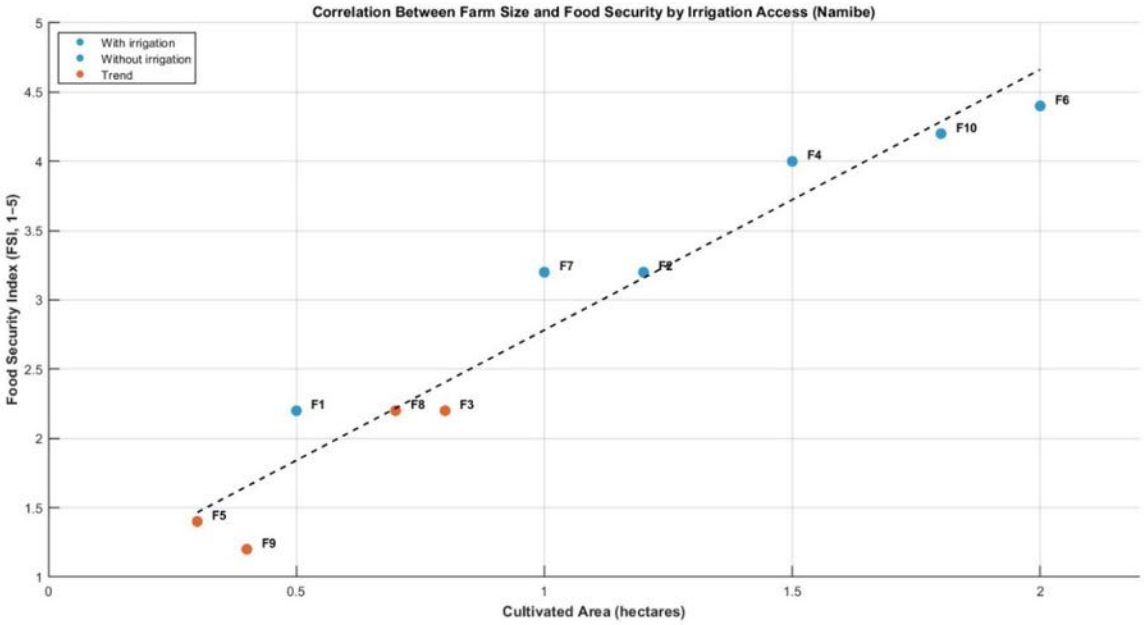

Figure 4: Correlation between cultivated area and food security index, by irrigation access (Namibe, 2023)

The results presented in Figure 4 indicate a positive association between cultivated area and the Food Security Index (FSI), suggesting that households with larger production areas tended to achieve more favorable food security conditions. This pattern is consistent with the role of smallholder agricultural systems in supporting food availability and income generation, particularly in resource-constrained rural environments. The observed correlation $r = 0.78,\ p < 0.05$ suggests a relatively strong relationship between land availability and food security outcomes within the analyzed sample [17]. However, given the limited sample size and exploratory nature of the analysis, these findings should be interpreted cautiously and not as evidence of direct causality.

More importantly, the differentiation between irrigated and non-irrigated households highlights the importance of water access in shaping food security outcomes in this relationship. Households with irrigation generally clustered at higher FSI levels and demonstrated greater consistency in food security outcomes, even among families with similar cultivated areas. This finding reinforces previous evidence indicating that irrigation may contribute to stabilizing agricultural production in semi-arid regions, where rainfall irregularity frequently limits productivity and increases vulnerability [18].

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Qualitative evidence obtained during interviews also supports this interpretation. Among the 57 households surveyed, 35 (61.4%) had access to irrigation, and several participants reported that irrigation reduced crop losses during drought periods and enabled more continuous production throughout the year. As one respondent explained:

“When rainfall is insufficient, irrigation allows us to continue cultivating and maintain food production” (Household F1).

In addition, the 35 households (61.4%) with irrigation access and the 41 households (71.9%) practicing crop diversification generally reported greater participation in horticultural production and commercialization of surplus products, factors that may contribute to improved income stability and food access. Nevertheless, the results also indicate that irrigation alone does not fully eliminate household vulnerability. Differences in land availability, labor capacity, market access, and production diversification continued to influence food security conditions across the sample. Consequently, the 22 households (38.6%) relying exclusively on rainfed agriculture remained more exposed to climatic variability and production constraints.

From a broader structural perspective, the observed trend reflects the persistent limitations typical of semi-arid agricultural systems, where water scarcity remains one of the principal constraints affecting productivity and livelihood resilience. Even when land is available, insufficient access to water can restrict input utilization, reduce production stability, and limit opportunities for agricultural expansion. Consequently, the 22 households (38.6%) relying exclusively on rainfed agriculture remained concentrated at comparatively lower Food Security Index (FSI) levels, whereas the 35 households (61.4%) with access to irrigation generally exhibited more favorable food security outcomes, as illustrated in Figure 4 [19].

To provide a broader overview of the variables analyzed in this study, Table 4 summarizes the descriptive statistics for household income, cultivated area, family size, food security, and income growth. The results reveal substantial variability across households, highlighting the structural heterogeneity that characterizes rural livelihoods in Namibe Province. Household income increased from an average of AOA 34,200 in 2019 to AOA 69,300 in 2023, reinforcing the general upward trend previously identified in Figures 1 and 2. However, the relatively high standard deviation associated with income growth (36.4 percentage points) indicates that improvements were unevenly distributed among households [20].

Similarly, the observed variation in cultivated area (0.3 to 2.0 hectares) and household size (3 to 9 members) demonstrates considerable differences in productive capacity and household dependency ratios across the sample. These structural differences directly influence agricultural production potential, labor

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availability, food consumption needs, and resilience to environmental shocks, thereby contributing to the variability observed in food security outcomes [21].

Previous studies on family farming systems have similarly demonstrated that household welfare and food security are strongly associated with unequal access to productive resources, institutional support, and agricultural diversification opportunities [13]. In this context, the findings suggest that development interventions in semi-arid regions may achieve greater effectiveness when adapted to local socioeconomic conditions rather than relying exclusively on generalized agricultural policies [22].

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

This study provides empirical evidence on the relationship between smallholder agriculture, irrigation access, and food security in the semi-arid context of Namibe Province, Angola. The findings suggest that agricultural intensification, particularly when associated with irrigation access and production diversification, may contribute to improved household income and reduced socioeconomic vulnerability among rural households. However, due to the observational nature of the study and the purposive sampling strategy, the results should be interpreted cautiously and not as evidence of direct causality.

The results also indicate that food security outcomes are influenced not only by agricultural production and income, but also by structural factors such as water access, land availability, and diversification capacity. Households with irrigation generally presented more favorable food security conditions and greater production stability compared to non-irrigated households, reinforcing the importance of water availability in semi-arid agricultural systems.

Nevertheless, the persistence of moderate food security levels and relatively low nutritional quality suggests that increased food production alone may not guarantee adequate dietary diversity. These findings highlight the importance of integrating agricultural development with nutrition-sensitive interventions, including crop diversification, food education, technical assistance, and climate-resilient practices.

From a policy perspective, the results suggest that interventions adapted to local socioeconomic and environmental conditions may be more effective than generalized agricultural strategies. Investments in irrigation infrastructure, extension services, and diversified production systems may contribute to strengthening rural livelihoods and resilience in semi-arid regions.

Despite the relevance of the findings, some limitations should be acknowledged. The relatively small purposive sample and the use of retrospective income data limit broader generalization of the results. Future studies using larger samples,

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probabilistic sampling strategies, and longitudinal approaches may contribute to a deeper understanding of the relationship between irrigation access, agricultural production, food security, and rural well-being in semi-arid regions of sub-Saharan Africa.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to this study.

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Table 1: Socioeconomic characteristics of sampled rural households (n = 57) and income changes between 2019 and 2023, Namibe Province

Variable	Mean	Std. Dev.	Min	Max
Household size (members)	5.7	1.9	3	9
Farm size (ha)	1.02	0.58	0.3	2.0
Income before (AOA)	34,200	15,600	15,000	62,000
Income after (AOA)	69,300	26,200	34,000	110,000

Note: AOA = Angolan Kwanza. Household income refers to monthly income values for 2019 and 2023. Farm size is expressed in hectares. Poverty level classification is based on the national poverty line
Source: Authors' calculations based on field data (2023)

Table 2: Food Security Index (FSI) and its components (n = 57, 2023)

Indicator	Mean	Std. Dev.	Min	Max
Dietary diversity	2.74	0.98	1	5
Meal frequency	2.89	1.02	1	5
Food access	3.12	0.87	1	5
Supply stability	2.95	1.01	1	5
Nutritional quality	2.81	1.04	1	5
Food Security Index (FSI)	2.90	0.86	1.2	4.8

Note: FSI = Food Security Index (scale 1–5). The index was calculated as the arithmetic mean of five dimensions: dietary diversity, meal frequency, food access, supply stability, and nutritional quality. Results are based on the full sample of 57 households
Source: Authors' calculations based on field data (2023)

Table 3: Distribution of households by food security level (n = 57, 2023)

Category	FSI Range	Households	Percentage
Low food security	< 2.0	12	21.1%
Moderate food security	2.0–3.0	24	42.1%
High food security	> 3.0	21	36.8%

Note: FSI = Food Security Index (scale 1–5). Food security categories were established according to the overall FSI score. Source: Authors' calculations based on field data (2023)

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Table 4: Descriptive statistics of key variables (n = 57 households, Namibe, 2023)

Variable	Mean	Std. Dev.	Min	Max
Household size (members)	5.7	1.89	3	9
Cultivated area (ha)	1.02	0.57	0.3	2.0
Income before (AOA/month)	34,200	15,648	15,000	62,000
Income after (AOA/month)	69,300	24,890	34,000	110,000
Food Security Index (FSI, 1–5)	2.90	0.86	1.2	4.8
Income growth (%)	97.9	36.4	53.3	177.8

Note: AOA = Angolan Kwanza. FSI = Food Security Index (scale 1–5). Income growth (%) refers to the percentage change in household income between 2019 and 2023. **Source:** Authors' calculations based on field data (2023)

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