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Does income inequality affect food security? Evidence from ECOWAS member countries

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Abstract
The global urgency to eradicate widespread hunger has become increasingly critical and challenging in the quest to meet sustainable development goals (SDG-2), thereby compelling scholars and policymakers to identify potential factors influencing food security. The preponderance of extant scholarship has predominantly focused on other determinants of food security, with less evidence on the critical role of income inequality in food security. This research seeks to bridge this gap by investigating the linkage between income inequality and food security in ECOWAS countries, which remains scarce in the literature. The empirical investigation was executed using a battery of econometric strategies, such as the panel autoregressive distributed lag model (PARDL), augmented mean group (AMG), fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and Dumitrescu and Hurlin causality test techniques. The empirical outcome reveals that deterioration in income distribution exacerbates food insecurity among households in the ECOWAS member countries. This finding indicates that rising income inequality poses greater challenges to sustainable food security in the countries analyzed. Furthermore, the causality test technique detects bidirectional causality between income inequality and food security. This study offers significant implications for curtailing food insecurity in this subregion.

Keywords Food security · Income inequality · ECOWAS member countries

JEL Classification I30 · I31 · Q01 · Q19

1 Introduction

The global urgency to eradicate widespread hunger remains a significant issue for policymakers and stakeholders in the pursuit of the United Nations Sustainable Development Goals (SDGs). Specifically, Sustainable Development Goal 2 (SDG-2) emphasizes the need

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to eradicate hunger and guarantee sufficient access to food for individuals on a global scale. Despite significant advancements and initiatives, rising famine hunger remains apparent worldwide, though at diverse magnitudes. For instance, the International Food and Policy Research Institution (2018) reported that one-third of the global population suffers from malnutrition, undernutrition, or micronutrient deficiencies. Furthermore, the World Health Organization (2019) stated that approximately 780 million individuals were deprived of adequate food necessary for a strong and fruitful existence in 2015, and this number has increased to 820 million. This indicates that if the present trend of food insecurity persists, it might pose a challenge to pursuing the Sustainable Development Goals (SDGs) by 2030. The World Food Summit defined food security as "food security, at the individual, household, national, regional, and global levels, is when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996).

The escalating food insecurity observed around the world has necessitated scholars to explore the numerous contributors of food security worldwide. The existing scholarly literature has notably identified factors such as poverty, economic growth, the COVID-19 pandemic, population growth, food prices, climate change, urbanization, trade openness, education, electricity access, human capital, and climate change, among others, as major determinants of food security (Candelise et al., 2021; Crush & Frayne, 2011; Dither & Abdulai, 2017; Fusco et al., 2020; Hjelm et al., 2016; Nidhi et al., 2022; Lefe et al., 2024; Pendleton et al., 2012; Segbefia et al., 2023; Timmer, 2004; Tiwari & Zaman, 2010).

Recent development has demonstrated that rising income inequality could pose a vital threat to food security. Specifically, Soriano and Garriano (2019) posited that income inequality exacerbates food security challenges in less-developed nations and that the income elasticity of food consumption is the highest among the most economically disadvantaged segments. Furthermore, the transition of labour from the agricultural to the non-agricultural segment concentrates wealth in the latter, potentially leading to income inequality and affecting the accessibility of food for low-income individuals (Szabo, 2016; Haini et al., 2023). The USDA (2012), however, observed that declining income disparity contributes to a lower food insecurity in Latin American economies. This underscores that more equitable income growth facilitates improvements in food security for impoverished members of society (OECD, 2013). Despite growing recognition of the influence of income disparity on food security, empirical contributions to the literature remain limited. Consequently, an investigation into the income inequality-food security nexus is of paramount importance for policy formulation and forecasting future food security. Therefore, this investigation delves into the linkage between income inequality and food security in the Economic Community of West African States (ECOWAS).

This investigation contributes to the burgeoning food security scholarship in the following fronts: First, this research pioneers the empirical scrutiny of the income inequality-food security nexus in the African region, specifically within the ECOWAS subregional context, where scholarly evidence remains limited. Extant scholarship has predominantly focused on the effects of other determinants, such as economic growth, trade openness, carbon emissions, food prices, the COVID-19 pandemic, agricultural export unemployment, human capital, climate change, and electricity access (e.g., Aragie et al., 2023; Candelise et al., 2021; Fusco et al., 2020; Haini et al., 2023; Karim and Tasnim, 2020; Khurshid & Abid, 2024; Lefe et al., 2024; Segbefia et al., 2023; Soriano & Garrido, 2016; Timmer, 2004; Tiwari & Zaman, 2010) with scant or no empirical evidence on the income inequality—food security nexus in the region. This presents a notable gap in the existing literature that necessitates additional empirical investigation. The positioning of the present study in

the ECOWAS subregion is based on the following reasons. The ECOWAS member countries represent a compelling empirical scenario for investigating this subject, as the subregion remains an area of concern because of deteriorating and unsatisfactory food security within the region. For example, the Food and Agriculture Organization (2020) reported that approximately 256 million individuals in Africa are witnessing severe hunger. This sub-region was also selected, as the ECOWAS countries were among the first to implement the Comprehensive African Agriculture Development Programme (CAADP) plans and have made substantial efforts to achieve CAADP in contrast to economies in other regions (De Pinto & Ulimwengu, 2017). Furthermore, income inequality is approximately 0.58 on the continent, as sub-Saharan Africa, including ECOWAS, contains ten of the 19 most unequal economies globally (UNDP, 2017). Second, this study expands the existing literature on food security by employing advanced comprehensive econometric techniques, including panel autoregressive distributed lag (PARDL), augmented mean group (AMG), fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and Dumitrescu and Hurlin causality test techniques, which address endogeneity bias, cross-sectional dependency, and slope heterogeneity. The present research diverges from existing scholarship that has extensively utilised single or traditional econometric strategies, including ordinary least squares (OLS), generalised method of moments (GMM), two-stage least squares (2SLS), logistic regression, and panel quantile techniques, which often neglect cross-sectional and heterogeneity issues and may bias outcomes and lead to incorrect implications (Brenya et al., 2024; Chandio et al., 2022; Debebe & Zekarias, 2020; Dither & Abdulai, 2017; Fusco et al., 2020; Haini et al., 2023; Karim & Tasnim, 2020; Mary, 2019). Finally, the outcomes of the investigation will offer valuable guidance to food stakeholders and policymakers in designing and formulating concerted, inclusive, and sustainable food security policies to mitigate food insecurity in the continent as well as around the world. The results of the investigation also offer an important understanding for stakeholders in designing inclusive, proactive, and sustainable development policies that contribute to the pursuit of SDG-10 in the region.

The subsequent segments of the research are organized in the following manner: Section two presents a comprehensive review of literature. Section three outlines the data sources and methodological approaches employed. Section four provides the findings of the techniques employed and section five discusses the outcomes with extant literature. Finally, the last section concludes the study by offering some policy recommendations.

2 Literature review

There is ongoing debate among scholars concerning the definition of food security over time. Specifically, scholars such as Timmer (2000) and Abdi et al. (2024) conceptualize food security as a condition wherein all households universally maintain physical, economic, and social opportunities to provide sufficient, nutritionally sufficient food that aligns with their dietary preferences and requirements, thereby facilitating the sustenance of active and healthy lifestyles. A comprehensive definition of food security includes the dimensions of food availability, accessibility, and utilization. Food availability emphasizes the capacity of a population to acquire food through imports or domestic production in adequate volumes. Food accessibility highlights the ability of households to secure sufficient resources to procure nutritious food, whereas food utilization pertains to the capacity

of individuals to optimize the effective use of food, water, and healthcare services to satisfy their physiological needs.

Over the past decades, a multitude of macroeconomic determinants, including economic growth, trade liberalization, carbon emissions, food prices, the COVID-19 pandemic, unemployment, agricultural exports, human capital, climate change, and access to electricity, have been recognized as pivotal factors influencing food security. Recently, the significant contribution of income distribution is increasingly acknowledged in the food security literature. The distribution of income may also play an instrumental part in enhancing access to food and alleviating pervasive hunger across households. Notably, scholars such as, Caracciolo and Santeramo (2013), and posited that increasing income disparity undermines poverty reduction roles of the government through its indirect, substantial adverse effect on food security and economic expansion. Furthermore, Debebe and Zekarias (2020) demonstrated that the execution of existing welfare-orientated strategies, which include intra-household resource allocation, active engagement in diversified business ventures, enhancements to the educational framework, and the formulation of a well-organized and inclusive financial institution, is essential for fostering a more equitable distribution of income.

The increasing concerns regarding chronic hunger and undernourishment in recent years have brought a discussion of food security issues across the globe to the forefront. Despite the expanding corpus of scholarly evidence on the contributors of food security, the contribution of income inequality to food security remains underexplored. For example, Timmer (2000) analyzed the macroeconomic drivers of food security and discovered that improvement in economic growth, substantial investment in agriculture, stable food pricing, and the mitigation of inequality are paramount for ensuring food security. In a subsequent study, Timmer (2004) also scrutinized the connectedness between food security and economic growth in Asian economies and detected that the relationship between the variables typically shifts from positive to negative throughout the analyzed period. Tiwari and Zaman (2010) assessed the roles of food price surges on undernutrition and ascertained that global food prices were responsible for the undernutrition of 63 million individuals. In a similar vein, Headey and Martin (2016) analyzed the effects of food price on poverty and food security. The findings revealed that variations in measurement approaches yield varying evidence on poor household reliance on food purchases and concluded that a rise in food prices increases poor segments' wealth and purchasing ability.

Soriano and Garrido (2016) assessed the connectedness between economic expansion and the prevalence of undernourishment across 27 developing economies. They found that a surge in economic expansion is correlated with an escalation in undernourishment rates, while spending in education, health, and sufficient provision of potable water are identified as mitigating undernourishment. Utilizing an extensive panel dataset, Dithmer and Abdulai (2017) analyzed the food security-trade openness linkages across large countries spanning 1980–2017. They found that increases in trade openness are associated with increased dietary energy intake and improved dietary diversity within the nations under consideration. Grzelak (2017) explored the linkages among income inequality and food security in OECD member states, covering the years 2010–2015. The findings reveal significant discrepancies in food security and income disparity among the countries studied, with the interrelation between the two being contingent upon the economic accessibility of food prices in these nations. In a parallel investigation, Mary (2019) scrutinized the influence of food trade openness on severe hunger in less-developed nations employing a two-phase analytical procedure. The author, however, found that the surge in food trade openness aggravates the food insecurity. Likewise, Fusco et al. (2020) analyzed the nexus among trade openness

and food availability within thirty-three selected European nations from 2000 to 2012. By utilizing the GMM approach, they uncovered that increasing commercial openness improves food security among individuals in the examined countries. Debebe and Zekarias (2020) scrutinized the influence of income disparity and poverty on food availability in Ethiopia employing the quantile regression methodology. They found that age, educational attainment, wages, remittance, status of family and health, access to electricity, and home ownership significantly contribute to variations in food security conditions within the countries.

Furthermore, Poudel and Gopmath (2021) assessed the difference within and among global food security measures, utilizing an array of data sources that encompasses the period from 1991 to 2018. The findings indicate that the changes in these measures can be attributed to factors including economic expansion, literacy rates, urbanization, and internet accessibility. Bene et al. (2021) conducted a worldwide investigation of the ramifications of the coronavirus disease on food supply across 62 nations, based on an evaluative analysis of 337 scholarly documents. This review elucidates that the severity and scope of the crisis have disseminated on a global scale, resulting in disruptions to both financial and physical access to food resources. In a related inquiry, Candelise et al. (2021) scrutinized the influence of energy accessibility on food availability within 54 developing countries spanning 2000–2014. They found that improvement in energy promotes food security, accounting for one-fifth of the effects related to income and distribution. Chegini et al. (2021) inspected the role of household welfare on food security via the administration of a questionnaire to 201 individuals residing in rural regions of Iran. The results from logistic regression analysis demonstrate that improvement in individual welfare enhances accessibility to food within the studied area. More recently, Karim and Tasnim (2020) assessed the contributing role of coronavirus disease on food supply among 220 households in Bangladesh. Employing the multivariate logistic regression approach, the authors identified that variables correlated with moderate to severe food insecurity were notably prevalent within low-income households. Similarly, Nidhi et al. (2022) investigated the role of coronavirus disease on food expenditure among households in India. They discovered that income levels, food pricing, household characteristics, mobility restrictions, and the escalating incidence of infections were instrumental in explaining the variations in food expenditure shares before and during the coronavirus disease. Haini et al. (2023) scrutinized the influence of unemployment and income disparity on food availability in 143 economies spanning 2000–2019 utilizing the GMM strategy. They uncovered that unemployment and income inequality exert detrimental effects on food security in developing nations, whereas such effects remain insignificant in advanced nations. Furthermore, Lee et al. (2023) explored the effects of ageing populations and artificial intelligence with respect to food security through the analysis of a panel dataset encompassing Chinese provinces. They discovered that the proliferation of artificial intelligence positively contributes to food security, while the increasing ageing population does not adversely affect food security. Saboori et al. (2023) investigated the influence of agricultural product diversification on food availability within the economies of the GCC spanning 2002–2018. The causality test outcomes show that agricultural product diversification is a significant contributor of food security.

Segbefia et al. (2023) explored the interrelationship among human capital, carbon emissions, and food security by employing a panel dataset encompassing five Anglophone economies over the time frame of 1990–2021, utilizing the CS-ARDL approach. They discovered that improvement in human capital positively influences food security, whereas carbon emissions adversely affect food security. Aragie et al. (2023) assessed the role of agricultural export on food availability in the contexts of Kenya, Ethiopia, and Uganda.

The results revealed that the rise in food prices within the examined nations negatively impacts their agricultural export promotion, thereby leading to increased food insecurity. Khurshid and Abid (2024) explored the nonlinear relationship between political globalization and CO_2 on food availability in Pakistan spanning 1981–2021. The outcomes from the NARDL indicate that the positive asymmetric impact of climate change on food supply surpasses the negative ramifications of political globalization on food supply. Utilizing a panel dataset of 40 SSA countries between 2001 and 2021, Lefe et al. (2024) investigated the influence of CO_2 variability on food security and discovered that CO_2 and precipitation are positively correlated with food supply, whereas temperature exhibited a negative outcome. In a similar vein, Naji et al. (2024) assessed the impact of watershed development and management practices on food availability in the provincial regions of Ethiopia, employing the ordered logit methodology, and identified that household wages, age of the individual head, and agriculture are the principal contributors to food availability. By applying fixed- and random-effects techniques over the period of 2001–2020, Brenya et al. (2024) uncovered that the circular economy, nutrition, and food innovation exert a favourable influence on food security. Manogna and Kulkarni (2024) analyzed the influence of agricultural goods on food availability, utilizing a panel dataset of five developed economies from 2000 to 2021. They found that the escalating agricultural goods prices intensifies food insecurity.

The preceding literature review highlights that the existing scholarship on food security discourse has predominantly concentrated on various determinants, including economic growth, food prices, trade liberalization, urbanization, the COVID-19 pandemic, inflation, and other variables, with income inequality still largely ignored. This reflects a notable gap in the existing scholarship on this subject. To the best of our knowledge, this investigation is the foremost empirical scrutiny into the nexus between income inequality and food security within the context of ECOWAS member nations. Furthermore, most prior scholarly contributions have primarily employed single or traditional econometric strategies, which often neglect comprehensive analysis of this subject in the literature. This also highlights the necessity for the use of robust and consistent econometric techniques to yield robust and consistent findings regarding this subject matter. To address these gaps, the primary research question guiding this investigation is: Does income inequality affect food security in ECOWAS countries?

3 Data source and methodology

3.1 Data and model

The current investigation delves into the effect of income inequality on food security by utilizing a dataset of 14 ECOWAS member countries[1] spanning 2001–2015. The rationale for the selection of both the temporal framework and the countries pertains to the accessibility of data, particularly on income inequality and the rates of undernourishment. Different operationalizations of food security have been employed among scholars, including food expenditure shares (in percentage), food consumption scores,

[1] The ECOWAS countries considered are Guinea, Mali, Ghana, Benin, Burkina Faso, Ivory Coast, The Gambia, Niger, Nigeria, Senegal, Liberia, Guinea-Bissau, Sierra Leone, and Togo.

high shares of calories from staple foods, dietary energy supply, and per capita calorie consumption (see, among others, Fusco et al., 2020; Hjelm et al., 2016; Sun & Zhang, 2019). Drawing inspiration from the works of Barrett (2010), Clandelise et al. (2021), Tiwari and Zaman (2010), and Soriano and Garrido (2016), we utilized two operationalization of food security, namely the food production index and the undernourishment prevalence as the outcome variables. Notably, Clandelise et al. (2021) pointed out that the undernourishment prevalence is regarded as an incomplete representation of food security, primarily reflecting access to adequate energy intake while neglecting remaining significant segment nonetheless, it has been recognized by the United Nations as the principal metric of food security for the entire population to evaluate progress associated to SDG-2. The principal explanatory variable of focus is income inequality proxied by two indicators: the Gini index and the top one percent (see, e.g., Osberg, 2017; Sitthiyot & Holasut, 2020; Saboori et al., 2023; Onatunji et al., 2024). The additional explanatory variables comprise total population as a measure of population growth, economic growth proxied by GDP per capita (constant 2010 US$), human capital represented by the mean number of years of secondary education as a proxy for educational attainment, urbanization, inflation proxied by the consumer price index and trade openness defined as the aggregate of imports and exports expressed as % of GDP. The rationale behind the selection of these covariates is predominantly guided by existing scholarly works on this topic. Candelise et al., 2021; Lefe et al., 2024; Manogna & Kulkarni, 2024; Poudel & Gopinath, 2021; Segbefia et al., 2023; Szabo, 2016).

The dataset employed in this analysis is extracted from numerous sources, comprising the Solt (2020) database of Standard World Income Inequality Database (SWIID) for measures of income inequality, the Penn World Table (2019) version 10.0 for the human capital index, and the World Development Indicators (WDI) for the remaining series. Table 1 illustrates the descriptive statistics of the series to provide insights into the basic characteristics of the series.

Table 1 Summary statistics

Variables	Mean	Median	Maximum	Minimum	Std. dev
FSP	109.134	103.935	165.450	48.780	22.742
UND	17.292	15.550	50.700	5.100	9.907
GDP	2841.506	120.520	273.320	272.991	741.194
POP	22371.772	1,250,852	1.63E+08	1,360,074	3,642,447
URB	895.005	411.075	722.300	663.337	149.399
EDU	1.530	1.477	2.404	1.078	0.316
INF	83.467	87.176	234.158	0.930	39.886
OPN	63.490	58.956	136.968	30.368	23.689
GINI	0.580	0.503	0.648	0.488	0.018
TOP1	0.688	0.691	0.774	0.509	0.037

Food production index (FSP), Prevalence of undernourishment (UND), economic growth (GDP), Population growth (POP), Urbanization (URB), Educational attainment (EDU), Inflation (INF), Trade openness (OPN), Gini index (GINI) and Top one percent (TOP1)

3.2 Empirical models

Following prior contributions such as Haini et al. (2023), Dithmer and Abdulai (2017), Lefe et al. (2024), and Mary (2019), we specify a dynamic reduced-form equation to represent the influence of income inequality on food security as follows:

$$InFSP_{it} = \alpha_0 + \beta_1 INQ_{it} + \theta_i InZ_{it} + \varepsilon_{it} \tag{1}$$

where $i = 1$—N; t = 2001—2015. $InFSP_{it}$ signifies food security measures including food production index and undernourishment prevalence of economy i at year t, INQ_{it} signifies income inequality indicators such as Gini index and the top one percent of economy i at year t, Z denotes the remaining covariates vector such as population, urbanization, education, economic growth, inflation, and trade openness. Furthermore, α_0, β_1, and θ_i are the unknown coefficients to be estimated and ε_{it} represents the unobserved disturbance term.

3.3 Methodology

We employ the panel autoregressive distributed lag (PARDL) procedure proposed by Pesaran et al. (1999) to uncover the long-and short-run dynamics of the nexus between income disparity and food security. This technique is suitable regardless of the integration order of the series, with the exception of I(2) series. The PARDL approach simultaneously estimates the long- and short-run linkages in a single phase, not losing any information. Furthermore, the technique integrates the pooled mean group (PMG) strategy, which features both averaging and pooling, accommodating the constant, error variances and short-run coefficient to change in all groups. The PMG technique is an enhanced type of the mean group (MG) procedure proposed by Pesaran and Smith (1995), which utilizes the mean value of the coefficients for each economy and consider the slope coefficients and error variance are uniform across countries. This methodology also mitigates endogeneity concerns by integrating the lag length of the outcome and explanatory series into the equation, thereby producing reliable and efficient estimates. Consequently, the PARDL model can be stated below:

$$FSP_{it} = \sum_{j=1}^{p} \lambda_{ij} FSP_{i,t-j} + \sum_{j=0}^{q} \phi'_{ij} X_{i,t-j} + \mu_i + \varepsilon_{it} \tag{2}$$

where $i = 1,2,\ldots,N$ signifies the number of considered nations (cross sections); $t = 1,2,\ldots,T$ denotes time span, FSP_{it} denotes the dependent variables including food production index and prevalence of undernourishment, $FSP_{i,t-j}$ is the lagged dependent series; X_{it} represents $kx1$ vector of independent series; φ'_{ij} denotes $kx1$ coefficient vectors, λ_{ij} signifies scalars, μ_i stands for nation-specific impacts and ε_{it} represents stochastic term. Assuming that all series in the equation exhibit long-run and the error term is *I(0)* for all cross sections. Hence, Eq. (2) is reformulated into error correction model as stated below:

$$\Delta FSP_{it} = \rho_i (Y_{i,t-1} - \varphi'_i X_{it}) + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta Y_{i,t-1} + \sum_{j=1}^{q-1} \phi'_{ij} \Delta X_{i,t-j} + \mu_i + \varepsilon_{it} \tag{3}$$

where $\rho_i = -(1 - \sum_{j=1}^{p} \lambda_{ij})$ stands for the adjustment speed; $\phi_i = \sum_{j=1}^{p} \lambda_{ij} / (1 - \sum_j \lambda_{ij})$ signifies the long run parameter vector; both $\lambda^*_{ij} = -\sum_{m=j+1}^{p} \lambda_{im}$ and $\varphi^*_{ij} = -\sum_{m=j+1}^{q} \varphi_{im}$ signifies the short-run coefficients correspondingly. The parameter is considered to



Fig. 1 Flow chart of the econometric strategies

Table 2 Cross-sectional dependence outcomes

Test	Statistics	Prob
Breusch-Pagan LM	221.864***	0.000
Pesaran Scaled LM	14.157***	0.000
Pesaran CD	8.627***	0.000

***P value < 0.01, **P value < 0.05, and *P value < 0.10

be negative and significant based on the previous assumption that the series show a convergence to a long-run equilibrium.

Additionally, the augmented mean group (AMG) proposed by Eberhardt and Teal (2010) is employed primarily due to its robustness against to cross-sectional dependency, slope variability, unobserved common factors, and issues related to potential endogeneity of series. This technique is also distinguished by its superior performance concerning bias, size, statistical power, and root mean square error (RMSE), thus rendering it more appropriate for analyses involving smaller sample dimensions (Eberhardt & Teal, 2010).

We also utilize the dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS) proposed by Kao and Chiang (2001) and Pedroni (2001), respectively, as a robustness verification for the long-run PARDL approach. These techniques are suitable for this study, as they have been adjudged among scholars to generate consistent and reliable results for panel studies that have cointegration relationships. Furthermore, these techniques also address the endogeneity concern within the independent series, as well as the attributes of the series in relation to the data generation procedure, integration level, and long-run links (Riti et al., 2022). Finally, the causal linkages between the variables are examined using the Dumitrescu and Hurlin (2012) causality test. Figure 1 Depicts the framework of the methodological strategies employed in this present research.

4 Empirical results

We begin the empirical investigation of the links between income inequality and food security by first determining whether there are cross-sectional dependencies among countries, as there may be common shocks among the countries under discussion. Accordingly, we utilize Breusch-Pagan LM, Pesaran Scaled LM, and Pesaran CD tests by Breusch and Pagan (1980) for cross-sectional tests. The findings of the cross-sectional dependency tests are illustrated in Table 2. The outcomes show that the null hypothesis of no cross-sectional dependency is not accepted, thus validating the presence of cross-sectional reliance between the nations.

The next phase of our empirical analysis involves ascertaining the integration status of the series using the CADF unit root test as advanced by Pesaran (2007) which is notable for

Table 3 Panel unit root test outcomes

	Constan		Trend	
	Level	Difference	Level	Difference
FSP	−1.479	−6.616***	−1.506	−7.589***
UND	−1.661	−4.752***	−1.999	−4.750***
GDP	−2.432	−6.420***	−2.180	−6.240***
POP	−1.951	−5.649***	−1.570	−6.951***
URB	−1.544	−6.868***	−1.366	−6.057***
EDU	−1.329	−8.913***	−1.316	−7.983***
INF	−0.778	−5.639***	−0.841	−5.674***
OPN	−4.922***	−9.417***	−4.928***	−9.421***
GINI	−2.140	−7.193***	−2.094	−7.490***
TOP1	−1.414	−5.570***	−1.395	−5.442***

***P value < 0.01, **P value < 0.05, and *P value < 0.10

its applicability when there is cross-sectional reliance among the series. Table 3 illustrates the outcomes of the CADF test. The outcome shows that all series appear stationary after taking the first difference, except for trade openness, which becomes stationary at the level.

Upon establishing the stationarity characteristics of the variables, we employ Westerlund's (2007) panel cointegration methodology to ascertain the presence of long-run cointegration among the series, given the inherent cross-sectional dependence within the dataset. Table 4 displays the outcomes of the Westerlund panel cointegration examination for the four models, each incorporating the two metrics of food security and income inequality separately. The results indicate that the null hypothesis, which posits the absence of cointegration among the series, is rejected, thereby implying the existence of a long-term association among the series.

Next, we explore the interrelations between income inequality and food security within the ECOWAS nations employing the PARDL technique. Table 5 illustrates the results of both long-term and short-term models, wherein models 1–2 and 3–4 present the findings of the food production index and the incidence of undernourishment as the outcome variables, correspondingly. The application of this PARDL technique necessitates the implementation of Hausman's (1978) test to ascertain the most reliable and suitable technique between the MG and PMG procedures. The findings presented in Table 5 indicate that the PMG approach is appropriate for this analysis as the null hypothesis is not rejected. The long-term outcomes reveal that the coefficients associated with

Table 4 The panel cointegration outcomes

Statistics	1	2	3	4
G_t	−4.201***	−3.730***	−5.184***	−4.861***
G_a	−11.549***	−12.934***	−7.861***	−6.842***
P_t	−7.210***	−8.821***	−6.350***	−3.214***
P_a	−9.130***	−10.618***	−4.927**	−8.594***

G_t and G_a represents the group mean tests. P_t and P_a denotes panel mean tests

***P value < 0.01, **P value < 0.05, and *P value < 0.10

Table 5 PARDL results

Variable	1	2	3	4
C	0.583 (0.682)	−0.148 (0.261)	0.683 (0.314)	0.409 (0.128)
GDP	0.119 (0.011)***	0.123 (0.000)***	−0.492 (0.015)***	−0.879 (0.000)***
POP	−0.195 (0.024)**	−0.176 (0.030)**	0.228 (0.010)**	0.364 (0.017)***
URB	−0.109 (0.205)	−0.076 (0.147)	0.415 (0.047)	0.541 (0.141)
EDU	0.143 (0.004)***	0.157 (0.057)**	−0.443 (0.018)***	−0.478 (0.000)***
INF	−0.196 (0.000)***	−0.201 (0.000)***	0.159 (0.000)**	0.609 (0.000)***
OPN	0.260 (0.016)***	0.266 (0.002)***	−0.705 (0.000)***	−0.772 (0.000)***
GINI	−0.748 (0.034)**		0.522 (0.000)***	
TOP1		−0.188 (0.009)***		0.209 (0.000)***
Short run				
Δ*GDP*	0.547 (0.000)***	0.540 (0.000)***	−0.338 (0.000)***	−0.321 (0.000)***
Δ*POP*	−0.203 (0.036)**	−0.206 (0.033)**	0.207 (0.000)***	0.189 (0.000)***
Δ*URB*	−0.221 (0.550)	−0.149 (0.681)	−0.319 (0.184)	−0.209 (0.117)
Δ*EDU*	0.749 (0.000)***	0.781 (0.000)***	−0.109 (0.000)***	−0.326 (0.000)***
Δ*INF*	−0.189 (0.000)***	−0.173 (0.000)***	0.194 (0.000)***	0.147 (0.034)***
Δ*OPN*	0.504 (0.000)***	0.151 (0.016)***	−0.464 (0.000)***	−0.106 (0.014)***
Δ*GINI*	−0.144 (0.033)**		0.595 (0.000)***	
Δ*TOP*1		−0.169 (0.000)***		0.734 (0.000)***
Δ*ECT*	−0.693 (0.000)***	−0.549 (0.000)***	−0.428 (0.000)***	−0.637 (0.000)***
Hausman test	0.510 (0.186)	0.463 (0.251)	0.430 (0.244)	0.383 (0.120)
Log likelihood	139.169	138.689	72.880	75.402

***P value < 0.01, **P value < 0.05, and *P value < 0.10. The values in parenthesis are P values correspondingly

economic growth are positively significant for the food production index (columns 1–2) while exhibiting negative significance for the prevalence of undernourishment (columns 3–4) across all model specifications. Similarly, the coefficients related to human capital as a proxy for educational attainment exert a positive influence on the food production index but a negative association with the undernourishment prevalence. Furthermore, the long-term estimates of the coefficients for trade openness yield a positive impact on the food production index but a negative impact on the prevalence of undernourishment across the models. On the flip side, the estimated coefficients for population growth demonstrate a positive association with the food production index while negatively related to the prevalence of undernourishment within the ECOWAS subregion. Similarly, the long-term coefficients of inflation exhibit a negative and positive association with food security indicators across all the estimated models. The long-term evidence shows that the coefficients for urbanization exert both negative and positive influences on food security indicators, albeit lacking statistical significance in all models. These results imply that urban migration to metropolitan areas among educated households does not detrimentally affect food security within the analyzed countries.

The bottom section of Table 5 illustrates the empirical results derived from the PARDL technique in the short run. The short-run outcomes show a positive nexus between trade openness, human capital, and economic growth with the food production index across model specifications. Conversely, the coefficients associated with population growth,

income inequality, urbanization, and inflation exhibit a negative association with the undernourishment incidence across the model specifications. Additionally, the results reveal that the ECT coefficients are negative and significant in all the models. This finding indicates that the rate of adjustment towards the long-run equilibrium is corrected for different time paths.

Next, this study turns to validating the findings of the long-run PARDL technique by employing the AMG strategy along with panel FMOLS and DOLS approaches. Table 6 displays the findings of the AMG, FMOLS, and DOLS methods. According to the

Table 6 AMG, DOLS and FMOLS outcomes

Variables	1	2	3	4
AMG				
GDP	0.281 (0.000)***	0.945 (0.000)***	−0.110 (0.037)**	−0.810 (0.014)**
POP	−0.215 (0.000)***	−0.579 (0.082)*	0.793 (0.000)***	0.114 (0.000)***
URB	−0.673 (0.129)	−0. 881 (0.111)	0.225 (0.189)	0.608 (0.205)
EDU		0.170 (0.000)***	0.241 (0.000)***	−0.375 (0.000)*** −0.155 (0.000)***
INF	−0.641 (0.000)***	−0.344 (0.029)**	0.786 (0.001)***	0.696 (0.082)*
OPN	0.287 (0.000)***	0.273 (0.051)**	−0.124 (0.000)***	−0.141 (0.000)***
GINI	−0.151 (0.000)***		0.196 (0.000)***	
TOP1		−0.144 (0.030)**		0.125 (0.000)***
FMOLS				
GDP	0.336 (0.000)***	0.282 (0.038)**	−0.175 (0.006)***	−0.592 (0.000)***
POP	−0.276 (0.046)**	−0.608 (0.051)**	0.132 (0.000)***	0.241 (0.000)***
URB	−0.143 (0.193)	−0.773 (0.168)	0.190 (0.673)	0.249 (0.0147)
EDU	0.728 (0.000)***	0.121 (0.000)***	−0.184 (0.000)***	−0.187 (0.036)**
INF	−0.120 (0.007)***	−0.296 (0.0103)***	0.636 (0.000)***	0.363 (0.000)***
OPN	0.128 (0.000)***	0.162 (0.005)***	−0.538 (0.010)***	−0.39 (0.003)***
GINI	−0.703 (0.020)**		0.150 (0.000)**	
TOP1		−0.592 (0.000)***		0.511 (0.000)***
R^2	0.910	0.912	0.890	0.819
$Adj.R^2$	0.902	0.903	0.964	0.804
DOLS				
GDP	0.264 (0.000)***	0.685 (0.014)***	−0.221 (0.000)***	−0.914 (0.000)***
POP	0.275 (0.025)**	0.777 (0.000)***	0.143 (0.036)**	0.304 (0.068)*
URB	−0.260 (0.310)	−0.470 (0.253)	0.131 (0.147)	0.727 (0.295)
EDU	0.103 (0.000)***	0.413 (0.017)***	−0.272 (0.000)***	0.790 (0.000)***
INF	0.208 (0.021)**	0.148 (0.000)***	0.142 (0.009)***	0.174 (0.000)***
OPN	0.447 (0.016)***	0.908 (0.006)***	−0.806 (0.059)**	0.182 (0.000)***
GINI	−0.722 (0.038)**		0.765 (0.000)***	
TOP1		−0.109 (0.015)***		0.509 (0.000)***
R^2	0.941	0.932	0.975	0.982
$Adj.R^2$	0.930	0.919	0.968	0.954

***P value < 0.01, **P value < 0.05, and *P value < 0.10. The values in parenthesis are P values correspondingly

findings of these approaches, population, inflation, income inequality, and urbanization are negatively related to the food production index indicator; however, positive results have been reported for the prevalence of undernourishment indicators. Conversely, economic growth, education, and trade openness have a positive impact on the food production index indicator and a negative impact on the undernourishment index indicator. Overall, the outcomes of these strategies support the validity of the long-run coefficients of the PARDL approach.

This investigation further examines the causal nexus among income inequality and food security within the ECOWAS utilizing the Dumitrescu and Hurlin causality tests. Table 7 reports the D-H causality test outcomes of the bivariate causal nexus between both income inequality and food security indicators only due to space conservation. The findings validate the existence of a bidirectional causal linkage between the Gini coefficient and the food production index, which serve as proxies for income inequality and food security, respectively, thereby implying a feedback effect between these variables. This result also illustrates that escalating food insecurity is exacerbated by increasing income inequality. Alternatively, the rising food security in ECOWAS nations catalyzes a rise in income disparity among households. Additionally, the outcomes reveal a bidirectional causality between the top one percent, representing income inequality, and the food price index, indicating that an upsurge in income inequality stimulates food security and vice versa. The finding, however, indicates that there exists only unidirectional causality between both income inequality metrics and undernourishment prevalent as a measure of food security. This outcome highlights that escalating income inequality can serve as a predictor for the food availability status of the analyzed countries. The findings further show that no causality running from both income inequality metrics to each other or food security indicators to each other is detected. Similarly, the outcomes do not show evidence of either unidirectional or bidirectional causality from the undernourishment prevalence to the Gini coefficient or from the prevalence of undernourishment to the top one percent. These findings imply that a neutral effect is identified in the causality tests that assess the relationship from the prevalence of undernourishment, as a food security measure, to both indicators of income inequality.

Table 7 Dumitrescu-hurlin causality test Path

of causality	Z-bar	Prob	Causality inference
GINI ≠ *FSP*	9.160***	0.000	Causality
FSP ≠ *GINI*	4.530**	0.01	Causality
GINI ≠ *TOP*	1.685	0.112	Non-causality
TOP ≠ *GINI*	0.890	0.327	Non-causality
GINI ≠ *UND*	4.114**	0.020	Causality
UND ≠ *GINI*	1.027	0.311	Non-causality
TOP ≠ *FSP*	8.192***	0.000	Causality
FSP ≠ *TOP*	4.656***	0.008	Causality
UND ≠ *FSP*	0.511	0.475	Non-causality
FSP ≠ *UND*	0.023	0.879	Non-causality
TOP ≠ *UND*	3.928**	0.051	Causality
UND ≠ *TOP*	1.034	0.722	Non-causality

***P value < 0.01, **P value < 0.05, and *P value < 0.10

5 Discussion

This investigation provides insights into the link between income inequality and food security in ECOWAS nations. The findings indicate that economic growth plays a crucial role in fostering food security in ECOWAS nations. This outcome underscores that increasing economic expansion resulting from investments and financial opportunities available to individuals leads to food accessibility and availability, thereby enhancing food security in the examined nations. Furthermore, this finding implies that the notable increase in economic growth observed in sub-regional nations augments household purchasing power and affords the government a greater capacity to maintain affordable food prices, thus furthering food security. This result highlights the necessity of pursuing higher growth, particularly inclusive growth, which is sustainable for long-term food security. This outcome aligns with the evidence of Singh (2018), Breisinger and Ecker (2014), Alle et al. (2021), Swietlik (2018), Teng (2020), and Yudhatama et al. (2021), as well as Becker and Elliot (2022), Segbeifa et al. (2023), Suryanto et al. (2023), and Manogna and Kulkarni (2024), who reported similar results in their respective studies. Similarly, the positive outcomes of human capital on food security underscores that advancements in human capital through increased educational attainment yield new insights into innovative agricultural productivity methods, thereby increasing food production and enhancing food security in the examined nations. This evidence further illustrates that an increase in literacy rates among the populations of the examined countries provides essential knowledge regarding the effective implementation of agricultural production techniques to boost food production and improve food security. The evidence also suggests that prolonged years of education correlate with enhanced employment opportunities, improved efficiency, superior decision-making, and enhanced disposable income, ultimately leading to enhanced food security. This evidence underscores the critical importance of robust investment in educational infrastructure as a means of elevating public socioeconomic awareness of food accessibility, thereby improving food security. This result corroborates findings from Bashir and Schilizz (2013), Mutisya et al. (2016), and Hassan et al. (2019), Mehmood (2022), and Segbefia et al. (2023), who established that economies characterized by higher educational levels are more likely to attain food security. Additionally, the findings indicate a significant contribution of trade liberalization towards strengthening food security within ECOWAS nations. This highlights that the economies of ECOWAS would benefit from greater openness facilitated by technology transfer, foreign investment, economies of scale, and specialization, which collectively enhance agricultural productivity and subsequently promote food security. Additionally, this result suggests that the ECOWAS subregion's openness to trade creates avenues for augmenting export revenues, thereby enhancing food security in the region by capitalizing on its comparative advantage in agricultural production. This evidence corroborates the assertions of Runge et al. (2003), who indicated that international trade is pivotal in ensuring improved food security by enabling world production to be concentrated in the most appropriate regions and facilitating the movement of food from areas with surplus supply to those experiencing deficits. This finding aligns with those reported by Dithmer and Abdulai (2017) and Fusco et al. (2020), Adesete et al. (2022), and Sun and Zhang (2021), who documented that openness of economies contributes to improvements in food security.

Furthermore, the adverse effects of population growth point out that increasing population sizes exceed agricultural output within the region, culminating in food insecurity among households, particularly among low-income households. This assertion holds

particularly true within the region, as a five-fold rise in population since the attainment of independence has intensified food insecurity, rendering Sub-Saharan Africa four times more affected than any alternative region (Bjornlund et al., 2022; FAO, 2017; Van Bavel, 2013). This result aligns with the conclusions drawn from earlier investigations conducted by Molotoks et al. (2021), Becker and Elliot (2022), Suryanto et al. (2023), Asare-Nuamah et al. (2023), and Lefe et al. (2024), which yielded similar findings. Similarly, the detrimental effect of inflation on food security reveals that escalating inflation rates in the analyzed nations raise the expense of agricultural inputs, thereby compromising the purchasing capacity of low-income households and exacerbating food insecurity within the region. The findings underscore that heightened inflation contributes to increased food prices, thereby restricting access to sufficient food, especially among economically vulnerable households, while simultaneously aggravating chronic hunger and undernutrition within the studied nations. The evidence validates with the results of Tiwari and Zaman (2010), Gazdar and Mallah (2013), Dithmer and Abdulai (2021), Candelise et al. (2021), Mumuni and Joseph Aleer (2023), and Lefe et al. (2024), who indicated that surges in food prices have precipitated a rise in global undernutrition.

The outcome of the principal variable shows that the detrimental impact of income inequality on food security within ECOWAS nations indicates that increasing income disparities impede access to affordable food systems for economically disadvantaged groups owing to their limited financial resources, thereby intensifying food insecurity among the households in the analyzed countries. This finding further emphasises that escalating income inequality forces low-income households to make calculated decisions between essential expenditure and food security, resulting in unpredictability and undermining the affordability of sufficient food security in the nations under consideration. This finding corroborates the assertion made by Fogel (1991), who argues that, in the context of food insecurity, only those households with privilege can evade chronic hunger and the persistent danger of famine. This result is consistent with empirical evidence presented by Kanbur (2016), Carmigan (2013), and Mary et al. (2018), Holleman and Conti (2020), and Haini et al. (2023), who contend that heightened income inequality diminishes the effectiveness of per capita GDP in alleviating individual food insecurity in the examined countries. Figure 2 depicts the summary of outcomes from the regression estimation approaches.

6 Conclusion

The urgency to achieve sustainable food security goals has motivated scholars and policymakers worldwide to search for the potential determinants of food security. However, scholars have largely ignored the notable role of income distribution on food security. This current research empirically investigates the linkage between income inequality and food security in ECOWAS countries for the period 2001–2015. The empirical analysis was accomplished using a battery of econometric strategies such as the PARDL, AMG, FMOLS, DOLS, and the Dumitrescu-Hurlin causality test approaches. The outcomes reveal that deterioration in income distribution exacerbates food insecurity among households in ECOWAS member countries. This finding indicates that rising income inequality poses greater challenges to sustainable food security in the analyzed countries. Furthermore, the outcomes from the Dumitrescu-Hurlin causality test technique show that

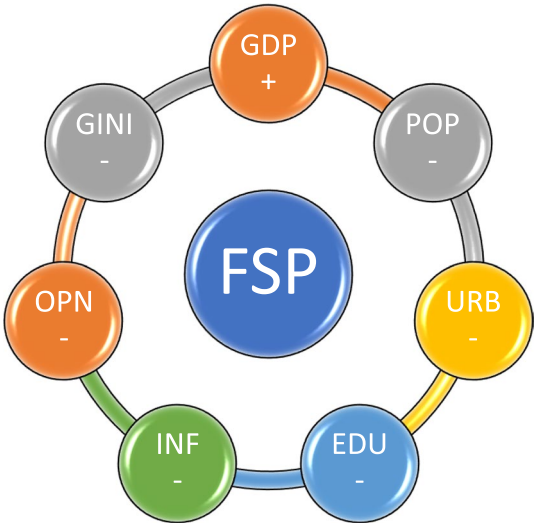


Fig. 2 Summary of findings derived from estimation regression methodologies

bidirectional causality between income inequality and food security is detected. This study offers important implications for curtailing food insecurity in this sub-region.

These findings have significant implications for food stakeholders and policymakers within the ECOWAS sub-region concerning the formulation of appropriate economic policies aimed at mitigating food insecurity. The findings indicate that an upsurge in economic performance within ECOWAS sub-regional nations can spur increased accessibility and affordability of food, thereby facilitating food security. This underscores the necessity for policymakers to emphasize the advancement of inclusive growth strategies that bolster income and employment opportunities, empower marginalized populations, and promote entrepreneurial skills that would augment food affordability, thus furthering food security in the analyzed nations. Furthermore, the adverse influence of inflation on food security highlights the implications of sustained inflationary pressures as a formidable challenge to the sustainability of food security in the sub-region. Consequently, monetary policymakers within the ECOWAS ought to reinforce their dedication to maintaining single-digit inflation within the region, as the attainment of sustainable food security objectives and the long-term integration of a unified monetary policy in the sub-region are predicated upon long-term commitments to anti-inflationary initiatives. This study further underscores that the realization of sustainable food security is viable when the subregion capitalizes on its abundant natural resource endowments, undertakes modern agricultural reforms, and engages in research and development that enhances food accessibility and affordability, thereby fostering sustainable food security for the subregion. Furthermore, the adverse outcomes of population growth underscore the imperative for the proactive implementation of birth control measures, family planning, education, and reproductive health initiatives to prevent a potentially explosive population increase in the sub-ECOWAS region, which may adversely impact agricultural productivity and subsequently lead to food insecurity. The outcomes further indicate that the enhancement of human capital through educational attainment is vital and consequential for achieving sustainable food security in the analyzed countries. Therefore, policymakers should intensify their commitment to ensuring sufficient funds in the educational sectors of the sub-region to promote equitable and universal access to basic education, vocational training, and reproductive health

services in accordance with the stipulations of the 2030 Sustainable Development Goals (SDGs). The finding that increasing income inequality inhibits the sustainability of food security necessitates a reorientation of policy to guarantee equitable access to affordable food security, particularly for deprived individuals that are frequently marginalized in terms of access to affordable food supplies within the subregion. The study further recommends the incorporation of fair and equitable redistributive policies, such as food stamps, nutritional assistance programs, provision of free school meals, social protection measures, and food price subsidies, into the formulation of food security strategies in the examined nations to achieve the Sustainable Development Goal (SDG) targets for the year 2030.

The present investigation offers significant insights regarding the nexus between income inequality and food security within the ECOWAS sub-region. Nonetheless, this research is not devoid of limitations, which presents opportunities for future investigation. A noteworthy constraint of this analysis is the limitations imposed by data availability, as it covers only fourteen ECOWAS member states, excluding Cape Verde. Furthermore, this data constraint preludes the exploration of an extended time period. Consequently, future investigation could broaden the time scope of this subject, contingent upon the accessibility of data. In addition, subsequent investigation could broaden the scope of this subject to consider a comparative country-specific analysis of the two sub-regional blocs, namely Francophone and Anglophone member nations, thereby providing more profound insights. Finally, future investigations could incorporate a variety of indicators pertaining to income inequality and food security to offer a more holistic comprehension of their interrelations.

Data availability The data that support the outcomes of this investigation are accessible on request from the corresponding author.

Declarations

Conflict of interest The author declares that there are no conflicts of interest pertaining to this article.

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