Scientific African 23 (2024) e01972

Contents lists available at ScienceDirect

Scientific African

journal homepage: www.elsevier.com/locate/sciaf

Comovement between agricultural commodities and stock returns of commodity-dependant sub-saharan Africa countries amidst the COVID-19 pandemic

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ARTICLE INFO

Editor: DR B Gyampoh

Keywords:
Commodities
Sub-saharan African stock market
COVID-19
Portfolio diversification
Time-frequency domain
Adaptive market hypothesis

ABSTRACT

The study analyses the comovement between agricultural commodities (cocoa, coffee, corn, cotton, and soybeans) and sub-Saharan African equities (BRVM, Ghana, Kenya, Mauritius, and Uganda) heavily exposed to shocks from the COVID-19 pandemic spanning from January 2017 to December 2022. Through bivariate and multivariate wavelet analysis, the study identifies the adaptive and asymmetrical nature of the sampled markets both in the pre-pandemic and pandemic periods. The results highlight commodities as the main driving force behind equities, with few exceptions, and reveal these markets' safe-haven and hedge potential during the pandemic and the normal periods, except for the multivariate case. The bivariate findings suggest that global investors can consider investing in agricultural commodities and the sampled equities for enhanced portfolio diversification. By examining the interconnectedness of the sampled market across different timeframes and investment horizons, the study has uncovered significant implications for policy-making, portfolio diversification strategies, and risk management approaches.

Introduction

Consecutive global financial downturns, including those emanating from the recent coronavirus (COVID-19, henceforth) pandemic, have instigated substantial changes worldwide, giving rise to widespread panic in the equity markets of commodity-dependant economies in Sub-Saharan Africa [1]. Accordingly, the equity performance index of most SSA economies underwent a significant decline, while key indicators such as turnover ratio, return on assets, and liquidity fell below acceptable levels. The World Bank [2] further indicated that the pandemic caused a substantial contraction in output within the SSA region, estimated to be around 2.4% in 2022, which exposed the region to escalating food prices, which in turn exacerbated insecurity and inflicted a more enduring menace than initially anticipated. Prior literature [1,3–5] further explained that these scenarios adversely impact the pecuniary system by inducing cutbacks and inflationary pressures, diminishing individuals' living standards, and prompting a shift towards precautionary savings, thereby driving investors to seek alternative risk mitigation methods amidst the commodity financialization process.

In line with the adaptive market hypothesis (AMH), when significant shifts or economic shocks like the pandemic occur, the market's evolutionary environment undergoes changes, which implies that assertions on market efficacy may falter in the face of upheavals, which intensifies investor risk aversion, leading to a shift in focus away from risky assets, thereby inducing synchronous

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https://doi.org/10.1016/j.sciaf.2023.e01972
Received 26 July 2023; Received in revised form 9 October 2023; Accepted 3 November 2023
Available online 13 November 2023
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movements [6,7]. Nonetheless, Markowitz's portfolio optimisation theory encourages portfolio diversification by combining high-risk assets such as equities with less risky assets like commodities [8]. As per existing literature [9–11], commodities offer hedging and safe-haven opportunities compared to equities due to their distinct price drivers linked to market supply and demand structures. Coincidentally, recent periods have witnessed price hikes in commodities, while most SSA economies and financial markets have undergone profound transformations [9,7]. Accordingly, the United Nations Conference on Trade and Development [12] revealed a rise in capital inflows from $39 billion in 2020 to $82 billion in 2022 into the region, signifying the growing prominence of SSA stock markets. Alagidede et al. [9] and Bossman and Agyei [7] further demonstrated that investors shift between different asset classes to incorporate those with secure returns during systemic risk, with the possibility of less vulnerable SSA stocks attracting considerable attention.

Despite the aforementioned and established impacts of the pandemic on these commodities and the interdependency of numerous SSA economies, most commodity-equity-related literature within the SSA context emphasises metals. For instance, data sourced from the "world-top-export" platform, as delineated by Workman [13], elucidate that the sample agricultural commodities cumulatively wield significant contributions in the sample capital markets and the broader SSA region. Noteworthy is the preeminence of cocoa as the foremost export of Ivory Coast, commanding a share of 30.2%, whereas in Ghana, its standing ranks as the third highest export at 13.7%. Conversely, the cumulative coffee exports of Kenya and Uganda surpass 50% of the continent's aggregate exports, while the collective output of cotton and corn across countries within the BRVM framework significantly bolsters the continent's export tally for these commodities. Additionally, echoing the sentiments posited by Tiffen [14], a considerable proportion of equity enterprises within SSA engage deeply in the full spectrum of production, refinement, and outbound shipment of commodities. This multifaceted engagement renders the equity marketplace susceptible to perturbations arising from the vagaries of these markets. Considering the above discussions, the relevance of this subject has intensified in light of the fluctuations observed in commodity prices following the health crisis, the continent's reliance on commodities, and the potential for investor diversification. Also, the immediate stakeholders, being investors, could rely on the findings of the study to make portfolio-based decisions. Evidence of these assets' inability to serve as havens during periods of instability and jeopardy informs investors to curtail their involvement in these specific asset categories. Conversely, feeble integration amongst these markets further informs investors to enhance their acquisition of these assets. Given this, it is imperative to investigate this nexus and ascertain the validity or refutation of previous study findings that overlooked the impact of the pandemic. Our study distinguishes itself from prior research in the following ways: Firstly, our study centres on agricultural commodities, which constitute a substantial proportion of the export earnings of sampled SSA economies, while also focusing on economies heavily impacted by the pandemic. Through this examination, the study's results pertaining to the lack of diversification in the multivariate case prove valuable for portfolio optimisation and ensure that investors remain well-informed about the augmented cross-market integrations, especially in light of the pandemic, which enhance the regulation of regional or international trade and simplify the complexities of asset management. Finally, to better examine the impact of the health crisis on the sampled market, we dissect our analysis into two distinct periods: the pre- and COVID-19 eras. This meticulous approach enables us to generate robust empirical outcomes that cater to participants engaged in trading across different timeframes and aid in portfolio diversification, especially during the pandemic period. Prior investigations have overlooked this crucial aspect, potentially impacting the empirical findings and conclusions.

Our analysis unveiled a comovement between agricultural commodities and the SSA stock market that is contingent upon both time and frequency. In accordance with the bivariate wavelet findings, the commodity-equity convergence was found to be varying and conditioned on diverse circumstances, including overdependence on the specific commodity, timeframe, and prevailing economic circumstances. Generally, there was a mixture of low and moderate (high) convergence between SSA equities and agricultural commodities across short and medium-term (long-term) horizons, with few exceptions. This comovement was further substantiated through multivariate analysis and a causality test. The study illuminated the commodity-equity driving prospects with few exceptions. Moreover, it sheds light on the adaptive behaviour of investors as well as the potential for portfolio diversification within the selected markets. Notably, the bivariate wavelet results demonstrated that both agricultural commodities and SSA stocks offer a hedge against each other under normal market conditions and serve as a safe haven during the COVID-19 pandemic.

The remaining paper is distributed as follows: the second section is a literature review that discusses and analyses the relevant literature. The third section is about the methodology that describes the research data and sample, variables measurement, pre-estimation data analysis, and econometric model. The fourth section namely results and discussion provides results and discussions of the econometric models. The last section christened Conclusions provides concluding remarks on the study.

Literature review

Bhardwaj and Dunsby [6] put forth an alternative investor-centric explanation for the time-varying co-movement of stocks and commodities, suggesting that investor risk aversion intensifies during challenging periods, prompting them to move into or out of risky assets. Consequently, the dynamics of different financial assets may reflect varying reactions to prevailing economic fundamentals. For instance, during the global recession, the stock market experienced heightened volatility, prompting investors to shift their investments towards safer alternatives such as commodities. As a result, portfolio managers must assess risk transmission across asset classes to identify opportunities for diversification across markets and over time, as emphasised by Bossman and Agyei [7]. The aforementioned assertion tends to explain the commodity-equity dynamics in light of precariousness and further underscore their significance in portfolio management across different markets.

Previous studies examining the correlation between commodities and equities have focused extensively on the continuous oscillations observed within these markets, yielding inconclusive results. However, a prevailing consensus amongst scholars has shown a

preference for developed and emerging markets in this regard. For instance, Creti et al. [15] examined the nexus between commodity and stock returns and discovered that oil, coffee, and cocoa have speculated benefits. de Boyrie and Pavlova [11] further examined the commodity-equity nexus using the DCC-GARCH model, focusing on the modifications in co-movements between commodities and Asian emerging and developed markets. It was revealed that Asian markets have significantly lower levels of commodity co-movement than developed markets, while Latin American equities have a higher level of integration. Billah et al. [4] further undertook an investigation into the intricate interdependencies between commodity prices and returns in the Saudi Arabian equity market, specifically within the beverage sector. By employing a connectedness index, the study uncovered that the degree of shock plays a pivotal role in determining the interconnectedness of returns. Conversely, Babar et al. [3] delved into the realm of return and volatility spillover amongst agricultural commodities and emerging stock markets during various crises. amongst the array of findings, the study revealed a tenuous association between commodities and equities. Moreover, corn emerged as the primary transmitter of shocks, while sugar displayed the least influence, with soybeans and coffee being the largest and smallest recipients of systemic shocks, respectively.

In contrast to the plethora of studies focused on developed and emerging economies, the scrutiny directed towards African stock and commodity markets has been relatively limited. The existing literature primarily centres around precious metals, with fewer studies, if any, exploring agricultural commodities. Accordingly, Alagidede et al. [9] used the DCC-GARCH technique to demonstrate that including African stocks in a portfolio of metals can reduce risks and enhance expected returns, both in normal and turbulent times. Tweneboah et al. [16] examined the asymmetric linkages between spot gold prices and African stocks using wavelet-based quantile regression techniques. Their study revealed significant asymmetric and frequency-dependant relationships between gold and stock returns in the selected markets, indicating a bidirectional connection between gold spot prices and stocks. Furthermore, Bossman and Agyei [7] investigated the interdependence structure of commodities and African equities and highlighted that commodity and African stock markets can offer stable returns when needed, and there exists a significant degree of short-term interdependence, with the degree varying based on the specific commodity.

Despite the growing body of research examining the interconnectedness of commodities and stock markets in SSA, none of the existing literature in the SSA milieu has specifically explored the relationship with agricultural commodities, despite their relevance and influential role in most SSA economies. Accordingly, these commodities have experienced significant price hikes during the uncertain periods brought about by the pandemic, making their diversification prospects for equities, especially in the SSA context, doubtful. Additionally, previous studies have not taken into account the impact of the pandemic, which has amplified global financial market uncertainty and the need for structured, diversified investment portfolios in SSA. As highlighted by Asafo-Adjei et al. [17], African stock markets are generally perceived as less advanced, less effective, and less integrated into global financial markets compared to their counterparts in other regions. This suggests that the stock market-agricultural commodity relationship observed in emerging economies may hold less significance in Africa. These observations highlight notable gaps in the existing literature which require attention.

Methodology

The study investigates the co-movement between commodities and the SSA equity market using the WCA algorithm. Thus, our study emphasises the wavelet algorithms (multivariate and pairwise) to evaluate the frequency and time-varying nexus of the study variables, assess the corresponding lead and latency ties, and further assess the haven and hedging prospects of these assets, particularly in the context of the COVID-19 pandemic. This technique involves two primary classifications: continuous wavelet transforms (CWTs) and discrete wavelet transforms (DWTs). This study focuses on the utilisation of both algorithms. Per scholarly investigations [7,17,18], the employment of CWT confers merits in apprehending temporal traits within time series. Conversely, Tweneboah et al. [16] elucidate the necessity to corroborate CWT outcomes with DWT, particularly when scrutinizing intrinsic risk and unveiling temporal-frequency nexus amongst variables. To capture the diverse dynamics at play, we not only examine the complete sample period but also undertake a meticulous dissection of the data into distinct periods encompassing both stable markets (pre-pandemic) and turbulent markets (pandemic), considering that the multivariate analysis is limited in capturing frequencies.

Bivariate wavelet

We employ bivariate analysis to scrutinise the interconnectedness structure amongst the sampled commodities, focusing on pairwise relationships across diverse timeframes. This analytical approach provides insight into the time-frequency dynamics between commodities and stocks. By adopting a spectral perspective, the model dissects the dataset, furnishing stakeholders, including investors, with the information needed to make informed economic decisions [17]. Bivariate analysis serves as a valuable tool for scholars to comprehend the fundamental type of variability and how it evolves through decomposition. This method remains one of the most prominent techniques for discerning variations in power between two time-series data sets [18]. In this context, we initiate the process by implementing the continuous wavelet transform due to its superior extraction capabilities. It also offers insights into the varying degrees of interdependence between dual markets across different time horizons [18]. Unlike numerous other bivariate econometric models that examine the connections between economic variables at static points, disregarding the dynamic nature of market participants and their evolving investment or transaction patterns over time, the wavelet bivariate approach addresses these gaps. It reveals how two markets or assets move in tandem or deviate over both time and frequency. Visualisations in blue and red, respectively, denote the points where these markets exhibit weak or strong correlations, aiding investors in their decision-making process.

As explicated by Torrence and Compo [19], the squared absolute value of a wavelet cross-spectrum normalization to a single

spectrum of wavelet power. The reckoning for the squared wavelet coefficients is represented in Eq. (1) as

$$\Re^2(x,y) = \frac{\left|\rho(\varsigma^{-1}\omega_{xy}(\varphi,\varsigma))\right|^2}{\rho(\varsigma^{-1}|\omega_x(\varphi,\varsigma)|^2)\rho(\varsigma^{-1}\left|\omega_y(\varphi,\varsigma)\right|^2)} \tag{1}$$

Where φ represent the location or time depicting the specific place of the wavelet and scale dilation component identified whiles ς further tells the stretched nature of the wavelet. ρ on the other hand indicates a smoothing factor, which balances resolution and significance, and $0 \le \Re^2_{xy}(\varphi,\varsigma) \le 1$. A value near to 0 specifies a weak nexus, while a value near to 1 designates a strong co-movement. The visual representation of the interdependence strength between two variables, commodities and equities, as illustrated in the wavelet plots, is emphasised through the utilisation of diverse colours. A darker hue signifies a more robust dependency, whereas a warm blue hue denotes a feeble and nearly uncorrelated series [18]. To scrutinise the statistical implications of this nexus, the Monte Carlo procedure is employed, given the unknown theoretical distribution of the Continuous Wavelet Transform (CWT) coefficient [19].

The coherence of the wavelet transforms and observed time series' phase difference indicates the interruptions in the vacillation concerning the observed time series. In the case of the observed series, the WTC phase difference shows breaks in the oscillation [18]. Following Bloomfield et al. [20], the phase difference between $x(\hbar)$ and $y(\hbar)$ is characterised as below

$$\mathfrak{WX}(\lambda\Im) = \frac{Corr(\omega_{\tau\Im t},\ \widehat{\omega}_{\tau\Im t})Cov(\omega_{\tau\Im t},\ \widehat{\omega}_{\tau\Im t})}{(Var(\omega_{\tau\Im t})Var(\widehat{\omega}_{\tau\Im t}))^{\frac{1}{2}}} \tag{2}$$

where $\Im$ and $\Re$ are the imaginary operators and real operator respectively. The dimensional phase patterns of the wavelet coherence map accentuate the influence of the disparity in wavelet coherence. Dimensional arrows serve to delineate distinct phase patterns, visually conveyed by arrows pointing in right, left, upward, or downward directions. Specifically, left and right arrows pointing upwards and downwards signify that the second variable takes the lead (acting as the market driver and responding last to external shocks in the bivariate portfolio). Conversely, right and left arrows pointing upward and downward identify the first variable as the leader. A colour scheme, along with surface colouring, vividly illustrates the co-movements between agricultural commodities and SSA equities. Areas depicted in a blue (cold) colour signify minimal co-movements, while those in red (warm) indicate substantial co-movements. Previous studies [7,17,18,21] offer an extensive representation of the bi-wavelet algorithm.

Wavelet multivariate

We employ the wavelet multiple algorithm, encompassing both wavelet multiple correlation and multiple cross-correlation, to scrutinize the extent of interdependence amongst the sampled agricultural commodities and SSA equities. The aim is to discern whether diversification prospects within these markets are confined solely to pairwise interactions or extend into more complex multivariate compositions. In the context of wavelet multiple correlation (WMC), weak coefficients within the sampled market affirm the principles of MPT by indicating the presence of diversification prospects. Conversely, a robust nexus signifies the absence of such diversification opportunities over time. Therefore, a feeble coefficient during normal (or turbulent) times implies the asset's potential to function as a hedge (or safe haven). The existence of such a potential suggests that amalgamating these asset classes in a singular portfolio can contribute to portfolio-based risk mitigation. On the other hand, the results from wavelet multiple cross-correlations unveil the assets' capacity to withstand portfolio-based shocks, given their ability to lead or lag at specific localizations. The significance of these models lies in their efficacy to capture such effects across intrinsic timeframes, spanning the short, medium, and long term.

Let $\mathfrak{X}_t = \mathfrak{x}_{1t},\ \mathfrak{x}_{2t},\ \ldots,\mathfrak{x}_{\eta t}$ specify a random technique with diverse parameters and let $\mathfrak{X}_t = \mathfrak{x}_{1t},\mathfrak{x}_{2t},\ldots,\mathfrak{x}_{\eta t}$ represent the resultant scale $\lambda_\Im$ by employing the MODWT. Fernández-Macho [22] outlines the WMC by $\mathfrak{WX}(\lambda_\Im)$ as a set of multiscale coherence computed from *Xt*. The square roots of the $\check{R}^2$ formed by the linear combination of $\omega_{\Im t} = \omega_{1\Im t},\omega_{2\Im t},\ldots,\omega_{\eta\Im t}$ variables for which such $\check{R}^2$ is maximum is calculated at each wavelet scale $\lambda_\Im$. From earlier studies, the R^2 conforming to the regression of a variable $\mathfrak{z}_\tau$ on a set of predictors $\{\mathfrak{z}_\kappa, \kappa \ne \tau\}$ is $\mathfrak{z}_t$, therefore the WMC is highlighted in Eq. (3).

$$\mathfrak{WX}(\lambda\Im) = \frac{Corr(\omega_{\tau\Im t},\ \widehat{\omega}_{\tau\Im t})Cov(\omega_{\tau\Im t},\ \widehat{\omega}_{\tau\Im t})}{(Var(\omega_{\tau\Im t})Var(\widehat{\omega}_{\tau\Im t}))^{\frac{1}{2}}} \tag{3}$$

where $\omega_{\tau\Im}$ is selected to maximise $\mathfrak{WX}(\lambda_\Im)$ predictions made by a regression model of $\widehat{\omega}_{\tau\Im t}$ parameterized on the remainder of the coefficients of wavelets λ_j.

We can frame WMCC by facilitating a lag π disparities regarding measurements and estimates at dimension $\lambda_\Im$ below

$$\mathfrak{WX},\tau(\lambda\Im) = Corr(\omega_{\tau\Im t},\widehat{\omega}_{\tau\Im t+\tau}) = \frac{Cov(\omega_{\tau\Im t},\widehat{\omega}_{\tau\Im t+\tau})}{Var(\omega_{\tau\Im t})Var(\widehat{\omega}_{\tau\Im t+\tau})} \tag{4}$$

Where WMC and WMCC coalesce at $\eta = 2$, correspond to the canonical waveform reflection and cross-correlation.

Projecting WMC and WMCC is feasible through the implementation of an intricate, erratic algorithm $\mathfrak{X}_t$ for $t = 1,\ 2,\ \ldots,\ T$ be $\mathfrak{X} = \{\mathfrak{X}_1,\ \mathfrak{X}_2,\ \ldots,\ \mathfrak{X}_T\}$ Integrating a sequential MODWT ב across univariable series $\{\mathfrak{X}_{1i},\ldots,\mathfrak{X}_{1T}\}$, for $\tau = 1,\ 2,\ \ldots,\ \eta$, the ב *length* $-T$ vectors of coefficients of MODWT $\widetilde{\omega}_\Im = \{\widetilde{\omega}_{\Im 1},\widetilde{\omega}_{\Im 1},\ldots,\omega\widetilde{\omega}_{\Im,\ T-1}\}, for\ \Im = 0,1,\ldots,$ ב is obtained.

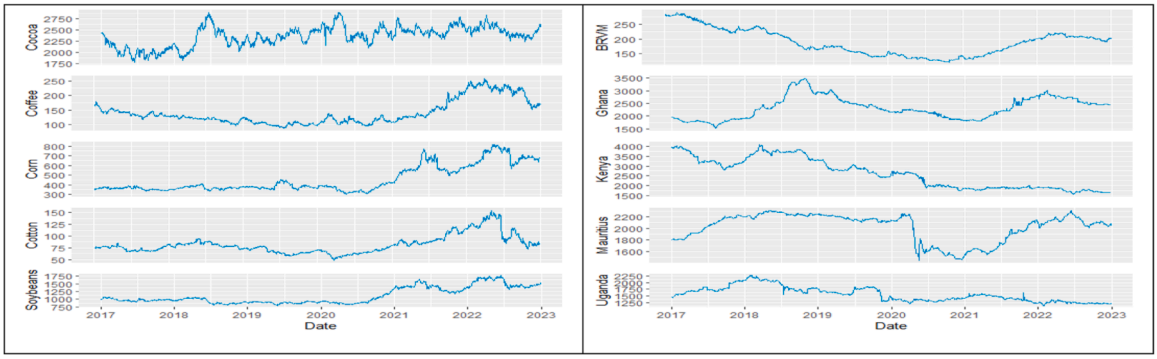

Fig. 1. Plots of agricultural commodities and SSA equities price series.

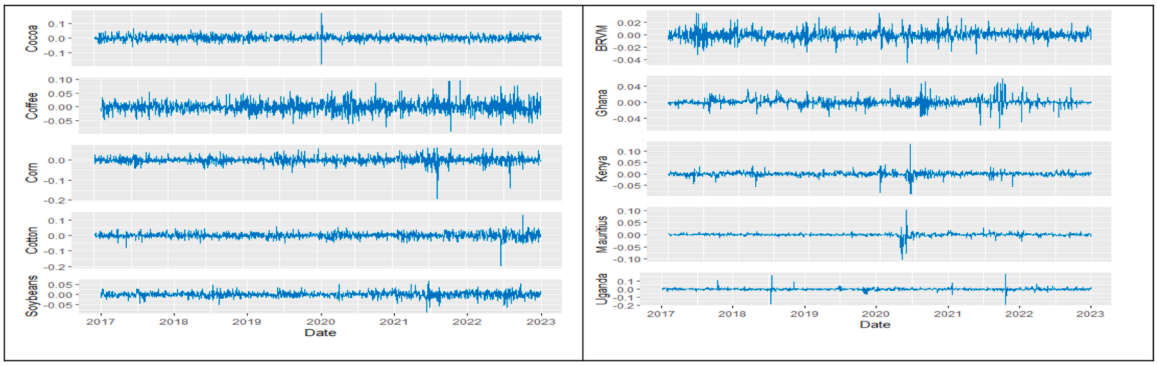

Fig. 2. Plots of return series for agricultural commodities and SSA equities.

From Eqn. (4), a function of all $\eta(\eta - 1)/2$ wavelet from the MODWT can be signified by

$$\mathfrak{W}\mathfrak{X}(\lambda\mathfrak{I}) = \left(1 - \frac{1}{maxdiag\,\tilde{\mathfrak{l}}_j^{-1}}\right)^{\frac{1}{2}} = \frac{Corr(\tilde{\omega}_{\tau\mathfrak{I}t}, \widehat{\tilde{\omega}}_{\tau\mathfrak{I}t}) Cov(\tilde{\omega}_{\tau\mathfrak{I}t}, \widehat{\tilde{\omega}}_{\tau\mathfrak{I}t})}{\left(Var(\tilde{\omega}_{\tau\mathfrak{I}t}) Var(\widehat{\tilde{\omega}}_{\tau\mathfrak{I}t})\right)^{\frac{1}{2}}} \tag{5}$$

where $\tilde{\omega}_{\tau\mathfrak{I}}$:: identical predictors in regression $\{\tilde{\omega}_{\kappa j}, \neq \tau\}$ maximises the $\check{R}^2$, $\widehat{\tilde{R}}_{\tau\mathfrak{F}}$ denotes meeting the conforming fitted values.

In the same vein, a consistent estimator of the WMCC can be computed as in Eqn. (6).

$$\widetilde{\mathfrak{W}}\mathfrak{X}, \pi(\lambda_{\mathfrak{I}}) = \frac{Corr(\tilde{\omega}_{\tau\mathfrak{I}t}, \widehat{\tilde{\omega}}_{\tau\mathfrak{I}t+\pi}) Cov(\tilde{\omega}_{\tau\mathfrak{I}t}, \widehat{\tilde{\omega}}_{\tau\mathfrak{I}t+\pi})}{\left(Var(\tilde{\omega}_{\tau\mathfrak{I}t}) Var(\widehat{\tilde{\omega}}_{\tau\mathfrak{I}t+\pi})\right)^{\frac{1}{2}}} \tag{6}$$

In calculating the confidence interval (CI) of WMC, Fernández-Macho [22] applies the transformation defined as arctan $\mathfrak{h}(r)$, where arctan $\mathfrak{h}(.)$ is the inverse hyperbolic tangent function for ease sake. The confidence interval is based on the same assumption of the realisation of $\mathfrak{X}$ in the estimation of WMC and WMCC and hence for $\widetilde{\mathfrak{W}}\ \mathfrak{X}(\lambda_{\mathfrak{F}})$ in Eq. (6). The significance of the WMC and WMCC pertains to the capacity of the model to unveil portfolio-based link and the resilience to absorb shocks within the assessed categories of assets, respectively. For an extensive representation of WMC and WMCC algorithm, kindly refer to Fernández-Macho [22].

Preliminary analysis

Fig. 1 and 2 portrays the dynamic nature of prices and returns of agricultural commodities and equities from SSA. It is evident that the fluctuations in agricultural commodities surpass those of SSA equities throughout the examined timeframe, underscoring the volatile and speculative characteristics associated with these commodities. The period spanning from 2017 to 2019 represents a relatively stable phase preceding the COVID-19 pandemic, with most frontier markets in SSA maintaining stability. During this period, the prices of agricultural commodities and stocks remained relatively steady. A closer examination of the price series reveals that in early 2020, the agricultural commodity markets experienced an upward trend following a previous downward trend, with the exception of cocoa, which exhibited a series of both upward and downward trends within the same timeframe. Conversely, the price series for stocks displayed a downward trend following a period of price stability. Towards the later part of 2021 and the early part of

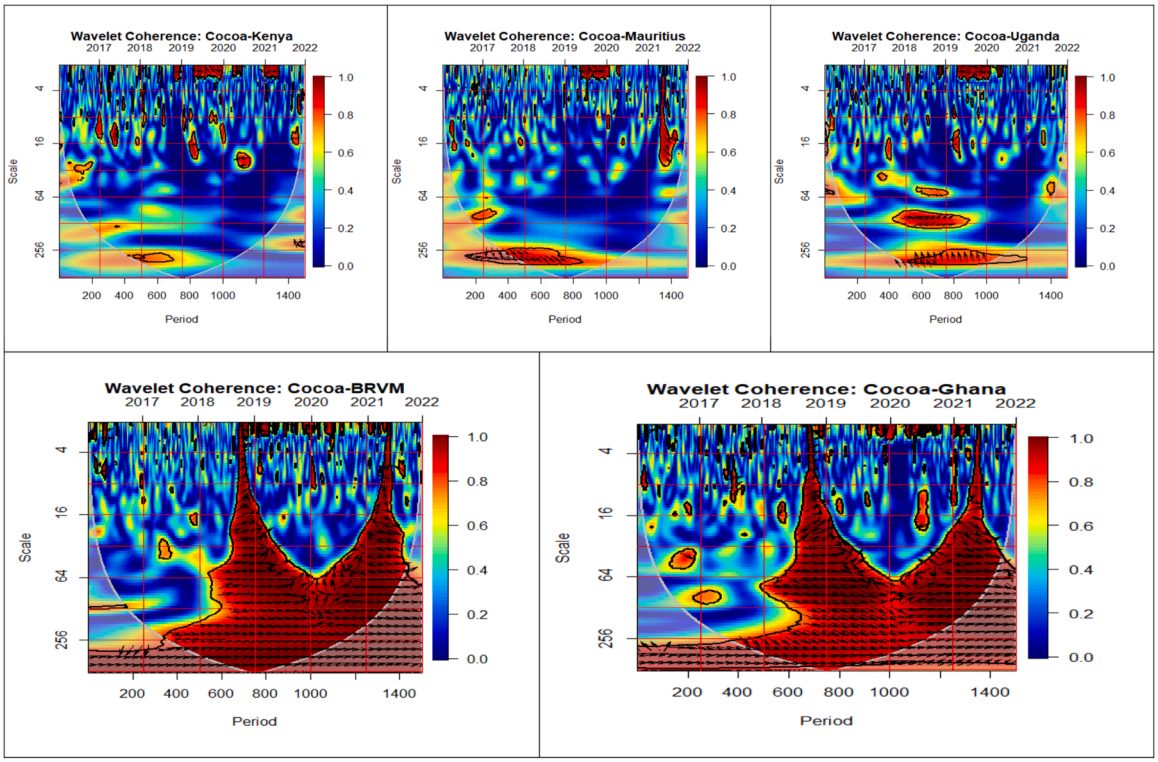

Fig. 3. Co-movements between Cocoa and SSA equities.

2022, both agricultural commodity and stock prices experienced a notable upward spike after a preceding downward trend. This observed scenario underscores the volatile nature of the sampled markets, particularly during the period characterised by global uncertainty.

Table 1 presents the descriptive statistics for the sampled commodity and equity markets, encompassing the entire dataset as well as distinct periods: pre-COVID-19 and during the pandemic. The majority of agricultural commodities exhibit positive average daily returns across all periods, except for cocoa, with negative returns during the pandemic. The pre-COVID-19 period witnessed a mix of negative and positive returns for agricultural commodities. Conversely, the selected equities demonstrated negative average daily returns throughout the sampled periods, except for Ghana and Mauritius in the full sample and pre-pandemic period and BRVM and Kenya during the pandemic. The standard deviation of all indices exceeds their mean, indicating a higher level of risk in these markets. Both the sampled commodity and equity markets demonstrate a combination of right and left skewness, indicating an asymmetric distribution while kurtosis values indicate leptokurtic behaviour in the markets. This suggests that the data used in the study deviates from normal distribution assumptions. The stationarity of the data series was assessed using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The observations from both tests, confirm that all data series meet the requirements for stationarity.

Additionally, given the observed presence of breaks within the series, an examination aimed at identifying structural changes is undertaken, employing the methodologies advanced by Bai and Perron [23] as well as the Superior Modified Zivot-Andrew (Sup MZ) test formulated by Ahmad, Haider, and Zaman [24]. The selection of these tests is informed by their capacity to detect multiple breakpoints within an extensive series, ensuring consistency in estimations of both the quantity and locations of structural disruptions. The findings suggest a significant structural breaks within the dataset during the period of the pandemic with few exception, underscoring the necessity of segregating the data into sub-periods. This is essential to preventing inaccuracies in model formulation and skewed parameter approximations [24,25]. The breakpoints, year, and the corresponding critical values are summarised in Appendix Table 2.

Data sources and description

The research utilised daily price data comprising agricultural commodities and SSA equities. The dataset covers the period from January 3, 2017, to December 30, 2022, resulting in a total of 1504 observations after removing any missing data points. The agricultural commodity (SSA equity) data was obtained from Yahoo Finance (EquityRT). The study emphasised equities from countries heavily affected by the pandemic and also dependant on commodities, including Ghana, Kenya, Mauritius, Uganda, and the Bourse Régionale des Valeurs Mobilières (BRVM), which serves as an integrated stock market for all eight member states of the West African Economic and Monetary Union (WAEMU). In terms of commodities, the study focused on cocoa, coffee, corn, cotton, and soybeans.

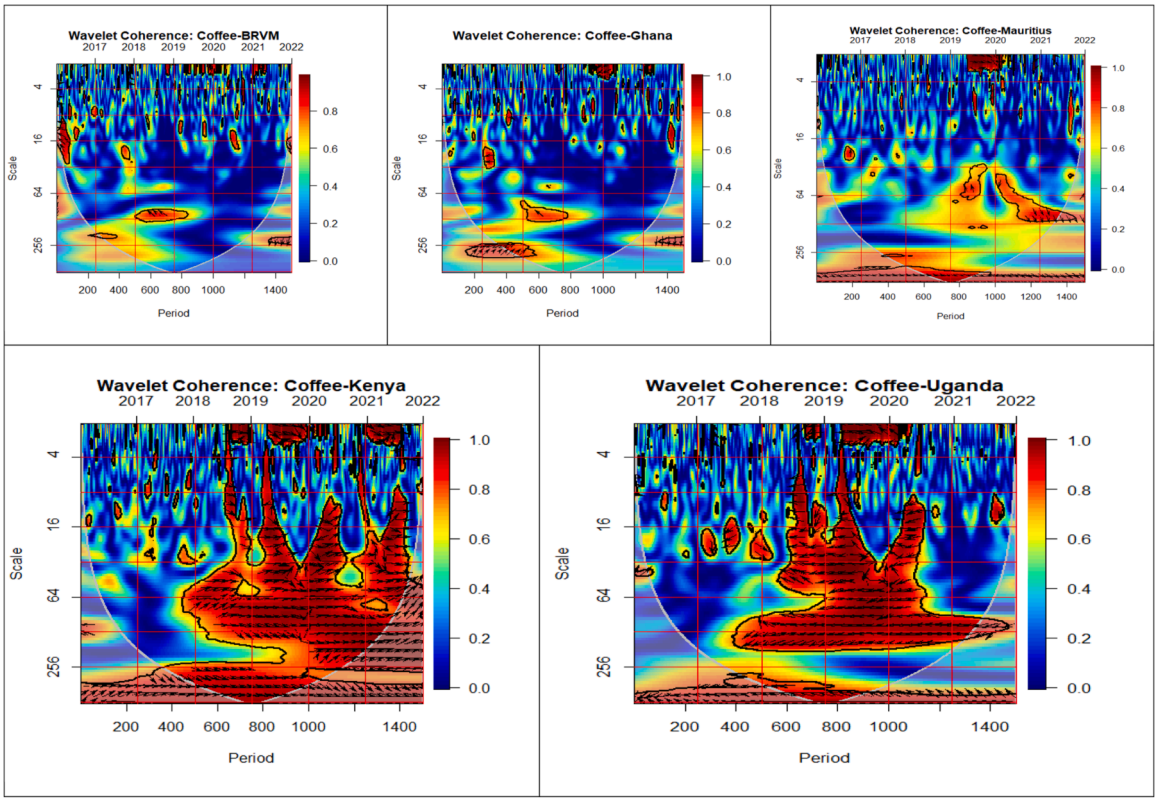

Fig. 4. Co-movements between Coffee and SSA equities.

The sample period was determined to account for various market conditions: from January 3, 2017, to March 10, 2020, representing normal market conditions and from March 11, 2020, to December 31, 2022, representing the period of global crisis characterised by muddled health crisis. The COVID-19 pandemic is considered the sole crisis period considered in this study, as it was deemed a chaotic event that severely impacted most SSA economies. The study utilised the daily equity and commodity returns as $r_t = \ln p_t - \ln p_{t-1}$ where r_t is the continually heightened return, p_t and p_{t-1} epitomises contemporary and prior indexes and prices respectively.

Empirical results and discussion

Trends and stylized facts from bi-wavelet estimations

We present the bi-wavelet technique to decipher the extent of comovement between the variables in both time and frequency domain. The horizontal axis presents the time domain (calendar time) and the vertical axis present the frequency (intrinsic time or time horizons) domain. The statistical interpretations and scripts for analysis were obtained from Gouhier et al. [26]. To ensure smooth interpretation of the data, right-pointing arrows and left-pointing arrows show when agricultural commodities and stock market returns are respectively in-phase (movement in the same direction) and anti-phase (movement in the opposite direction). Right (left) pointing arrows upwards (downwards) indicate that the first variable is leading, whereas left (right) pointing arrows upwards (downwards) indicate that the second variable is leading.

The degree of interdependence between the paired series is represented by the surface colour and the colour palette. The red (warm) colour signifies parts that have major interactions, while the blue (cold) colour shows a lower series of correlations [17,27]. The cone of influence (COI) within the biwavelet plots indicates the region where interpretation of the wavelet is significant, while the results outside the COI are insignificant since they are beyond the 95% confidence level. The interpretation of the scales in the case of data frequency of the wavelet factors are linked to times of, respectively, "2–4 days (intra week scales), 4–8 days (weekly scale), 8–16 days (fortnightly scale), 16–32 days (monthly scale), 32–64 days (monthly to quarterly scale), 64–128 days (quarterly to biannual scale), and 128–256 days (biannual to annual scale)" respectively, as indicated by Asafo-Adjei et al. [17] and Nkrumah-Boadu et al. [27]. We present the bivariate wavelet analysis in Fig. 3-7 with the multivariate analysis further considered in Figures 8–10.

Fig. 3 illustrates the frequency-dependant interaction between the equity returns of selected SSA countries and cocoa in terms of spatial and spectral frequencies. The presence of red (warm) colours in specific sections of all the plots (plots ensuing Fig. 3) signifies significant and robust interactions between cocoa (agricultural commodities) and equities. The level of co-movement between cocoa and the sampled equity markets was found to vary, with the strongest (weakest) integration observed between BRVM and Ghana

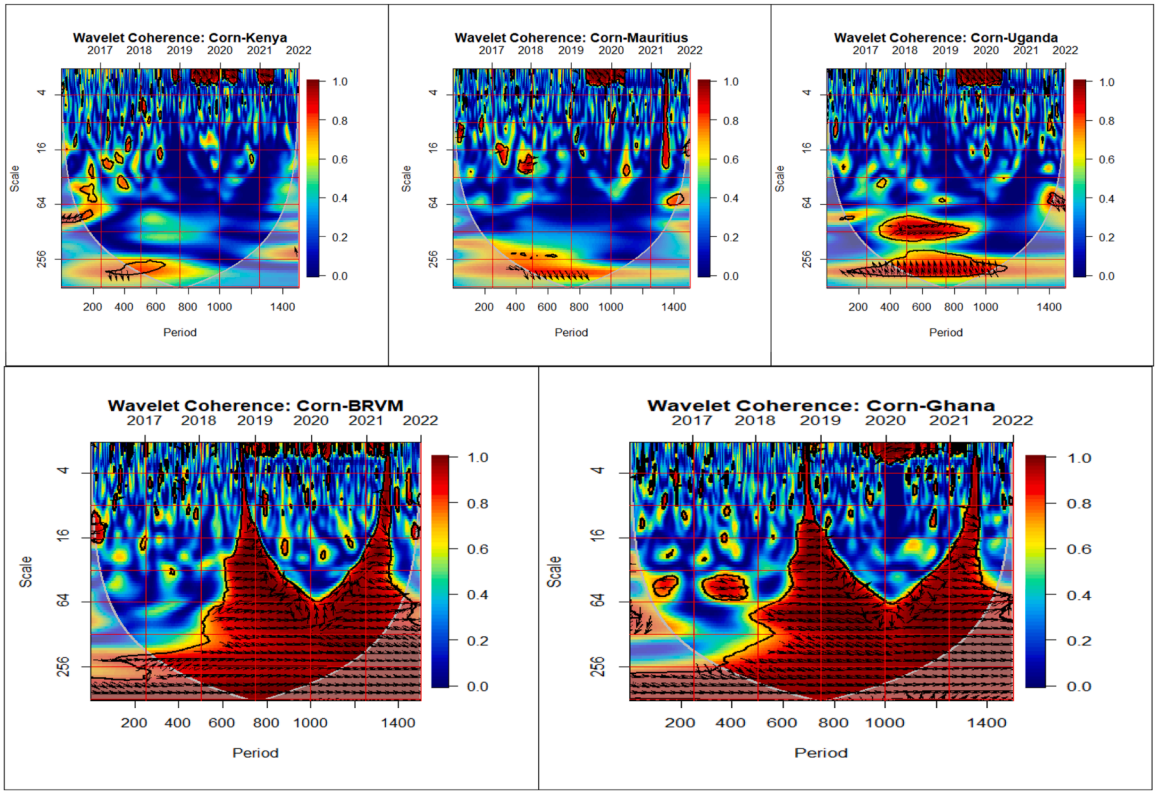

Fig. 5. Co-movements between Corn and SSA equities.

(Kenya, Mauritius, and Uganda). Surprisingly, apart from Ghana and BRVM, the remaining equity markets only exhibit convergence with cocoa in the intermediate and long term. However, an uncorrelated nexus between cocoa and the chosen SSA equities tainted the short term. For instance, during the pre-pandemic period (2017–2018), the co-movement between cocoa and equities showed a weak correlation across all scales, except for the very long term, spanning approximately 64–256 days in the case of all equity markets except Kenya. Between 2019 and 2022, there was limited medium- to long-term interactions observed between cocoa and equities (Kenya, Mauritius, and Uganda). According to Baur and Lucey [28], different asset combinations can result in diversification, safe haven, or hedging benefits. However, the cocoa-equity combination in the case of BRVM and Ghana exhibits near-perfect co-movement, particularly during the pandemic period in the intermediate and long term, indicating the absence of a safe haven effect within these asset combinations. Given the immediate affirmation, we can deduce that a nation's substantial reliance on a specific commodity denies its investors the potential for diversification with its equity markets due to their vulnerability to perturbations amidst uncertainty, as analogized by the global health crisis period. Nevertheless, the predominance of bluish areas in Fig. 3 suggests that cocoa and equities do not converge in a specific moment-frequency dimension and further reveals that not all the SSA sampled equity-commodity combinations derail investors from a possible diversification while also revealing the varying nature of these markets. The presence of uncorrelated regions, in particular, signifies the potential advantages of a safe haven or hedge under certain market conditions.

During the global health crisis period (2020–2022), the Mauritian and Ugandan equity markets exhibited a fragile intermediate and long-term interaction with cocoa, whereas the remaining markets displayed the same pattern in the very short term. This implies that rational investors seeking portfolio benefits could combine Mauritian and Ugandan equities with cocoa to mitigate potential losses, offering both a hedge from 2017 to 2019 and a safe haven, particularly during the pandemic (2020–2022). This further affirms our earlier assertion on diversification prospects' presence (deprivation) subject to heavy (weak) reliance on a given commodity. Thus, we surmise that the weak comovement between the above-stated equities and cocoa could be due to the non-reliance of these countries on cocoa. The upward-pointing arrows in the majority of the plots in Fig. 3 indicate that cocoa influences equity, except for Ghana, Mauritius, and Uganda, where the long-term dynamics reveal that equity drives cocoa. This corroborates the findings of Creti et al. [15], who established the market-driving potential and speculative nature of cocoa and coffee. It also confirms that changes in cocoa returns correspond with movements in SSA stocks, further affirming the stock market-driving ability of agricultural commodities, as suggested by previous literature [3,4,6,29]. However, during periods of high integration and turmoil, as analogized in this study, especially in the case of BRVM and Ghana, investors may consider these combinations as alternative portfolio options considering the strong correlation between the aforementioned equity markets and cocoa in line with the MPT [7,8].

Fig. 4, conversely, presents the interaction between selected SSA equities and coffee returns in terms of spatial and spectral frequencies. The observed pattern indicates that all equities exhibit movement in alignment with coffee strictly in the intermediate and

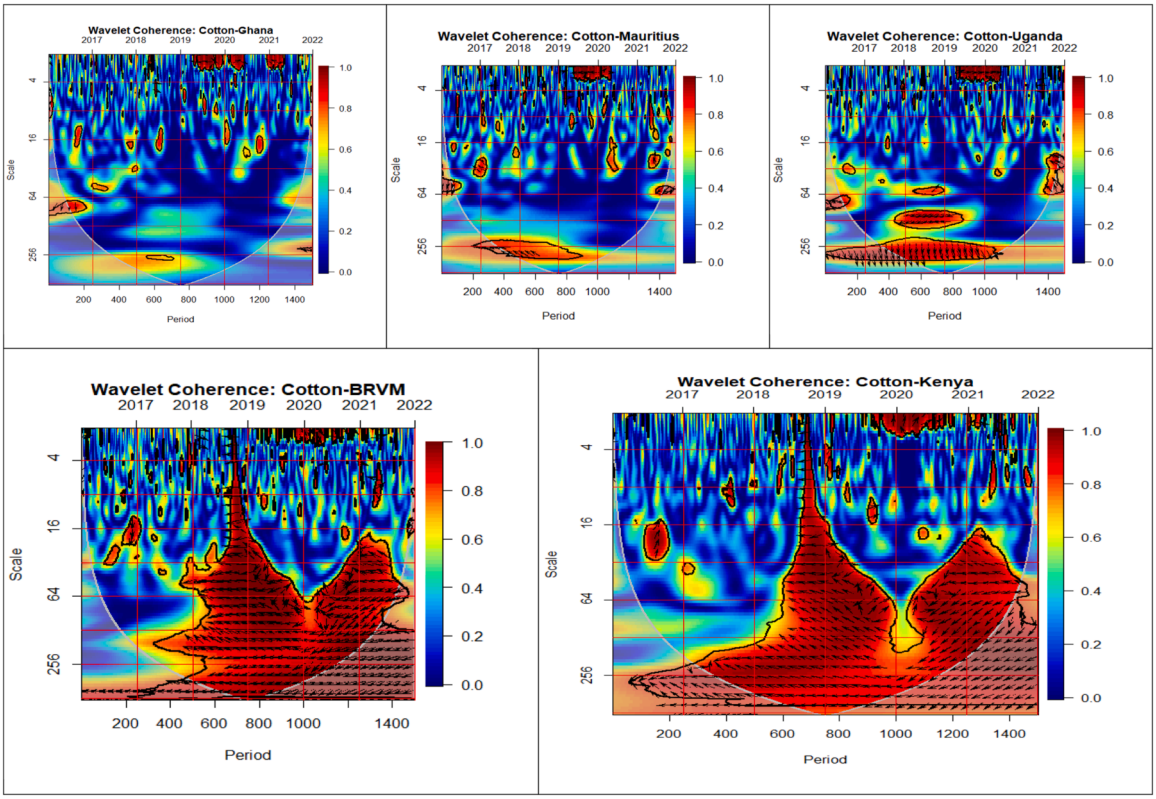

Fig. 6. Co-movements between Cotton and SSA equities.

long term likewise the short-term of the pandemic era. Notably, in the case of Kenya and Uganda, we observe near-perfect correlation with few exceptions, particularly during normal market conditions from 2017 to 2018. Furthermore, during the pre-pandemic era (2017–2019), coffee demonstrates either weak or no correlation with all equities in the immediate and medium-term (approximately 1–64 days), except for BRVM within a range of 4–8 days and Uganda, where the co-movement displays variation, especially in the medium term.

Moreover, with the exception of Kenyan and Ugandan equities, which exhibited robust correlations, particularly in the medium term, and Mauritius, which demonstrated a moderate co-movement in the long term, coffee displayed weakly characterised co-movements with all equity markets in the intermediate to long term, especially during the pandemic era from 2020 to 2022. As suggested by Baur and Lucey [28], these periods offer prospects for diversification, particularly as a safe haven given the weak level of integration and characterised by the presence of a bluish patch in Fig. 4. Thus, during the turbulent era from 2020 to 2022, the equity markets of BRVM, Ghana, and Mauritius exhibited a glimpse of weakly characterised convergence in the short and intermediate term, while Uganda's equity market displayed a similar pattern but only from 2021 to 2022, indicating the varying impact of the pandemic. This demonstrates that the co-movements between coffee and stock returns in these markets offer broad-based safe-haven benefits. Additionally, within a scale of 64–256, the interaction of coffee with equities (BRVM and Ghana) provides long-term benefits as both a safe haven (2020–2022) and a hedge (2017–2020). The right-pointing arches depicted in Fig. 4 signify that coffee drives the equity market, except for Uganda in the long term, where an indeterminate directional co-movement was observed. On the contrary, the left-pointing arrows accelerating from BRVM and Mauritius indicate that equities drive coffee, along with the inherent benefits of diversification.

Fig. 5 portrays the frequency-dependant interaction between selected SSA equities and corn returns. Accordingly, with the exception of BRVM and Ghana, which displayed relatively robust co-movements throughout the series, corn demonstrated convergence with equities solely in the intermediate term, particularly during the pre-pandemic period, approximately ranging from 4 to 128 days for Kenya and Mauritius and from 16 to 64 days for Uganda. During the pandemic era, corn and the aforementioned equity markets displayed very limited co-movements across all scales, except for Kenya and Mauritius, which exhibited a moderate correlation in the very short term, approximately spanning from 1 to 4 days. Similar to the findings in the cocoa-equity pairing, BRVM and Ghana exhibited a significant co-movement with corn across all wavelet scales during the pandemic, except for the very short term, where the co-movement was characterised as weak and moderate for BRVM and Ghana, respectively. The weak nexus characterised by the bluish area depicted in Fig. 5 indicates a feeble integration between corn and stocks (Kenya, Mauritius, and Uganda). More precisely, these regions exemplify the advantages of hedging during normal times from 2017 to 2019 or a safe haven during the turbulence of the COVID-19 pandemic from 2020 to 2022. Accordingly, the weak and uncorrelated connections observed between corn

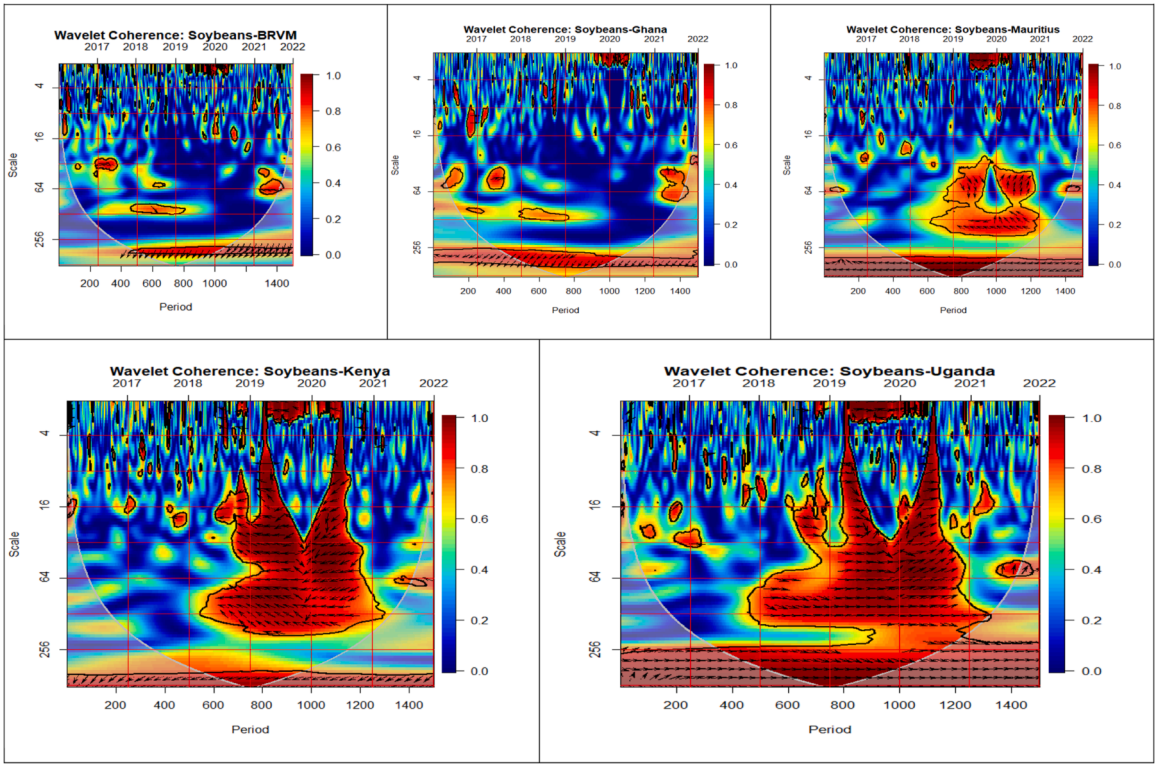

Fig. 7. Co-movements between Coffee and SSA equities.

and the equity markets of Kenya, Mauritius, and Uganda during the pandemic period imply that these markets offer safe-haven benefits. This corroborates the findings of Nagayev et al. [29] and de Boyrie and Pavlova [11] regarding the safe haven and diversification prospects of agricultural commodities. The right (left)-pointing upward (downward) arches depicted in Fig. 5 indicate that corn drives or influences changes in equity returns. In other words, fluctuations in the value of corn returns correspond to movements in SSA stocks. The predictive capacity of commodities on equities was consistent in the current pairings, with the exception of Mauritius and Uganda, where equities emerged as the driving force.

Fig. 6 showcases the co-movements between sampled SSA equities and cotton returns across different time frames and frequencies. The interaction between cotton and the sampled equity markets displays a combination of strong and weak co-movements, with convergence observed only in the short and long term. Conversely, the medium term is hindered by uncorrelated relationships between cotton and the selected SSA stocks. In terms of time, specifically during the normal period from 2017 to 2019, cotton and equity returns exhibit moderate convergence in the short term, spanning approximately 1 to 8 days, except for Kenya, where weaker co-movements are observed within the same timeframe. Moreover, there are instances of near-perfect co-movements in all equity markets during the very long term, except for Ghana, where the co-movement is comparatively weak. Furthermore, except for BRVM and Kenyan equities, which exhibited a series of strong correlations, particularly in the medium to long term, and Mauritius, which displayed a moderate co-movement in the intermediate term, cotton demonstrated weak co-movements with all equity markets across various scales, particularly during the pandemic era from 2020 to 2022. The presence of a bluish patch in Fig. 6 exemplifies the benefit of diversity, a haven, or a protective shield. Thus, during the turbulent era from 2020 to 2022, the equity markets of Ghana and Mauritius displayed weakly characterised convergence in the short and intermediate term, while the equity market of Uganda exhibited a similar pattern but only in the very short and intermediate term. This demonstrates that the co-movements between cotton and stocks in these markets offer broad-based safe-haven benefits. Additionally, on a scale of 32–256, the interaction between cotton and equities (Ghana and Mauritius) provides intermediate to long-term benefits as a safe haven from 2020 to 2022 and as a hedge from 2017 to 2019. The Ghanaian equity market offers a hedge across the same period, but only in the short and long term. Also, the driving capacity of cotton was marred by a series of inconsistencies in the cases of BRVM and Kenya, particularly in the long term, where the direction of influence frequently switched. This further indicates the heterogeneous nature of the predictive ability of commodities and the prevailing impact of the pandemic on these driving patterns and substantiates the significant integration in these markets despite the influence of the health crisis [4,16].

Fig. 7, conversely, presents a visual representation of the frequency-dependant interaction between selected SSA equities and soybean returns. It is noteworthy that all equities exhibit movement in alignment with soybeans across all time and frequency ranges, except for a specific long-term scale during the normal period from 2017 to 2019, where Kenya, Mauritius, and Uganda display some deviations. The short term experiences a moderately correlated relationship between soybeans and the selected SSA stocks, with the

Table 1
Results of Preliminary Analysis.

Full Period (03/01/2017–30/12/2022)	Mean	STD.	Skew.	Kurt.	Norm.	ADF	PP
Agricultural Commodities							
Cocoa	0.0000	0.0179	−0.0741	11.573	0.9443	−28.273***	−41.340***
Coffee	0.0000	0.0202	0.3508	1.8239	0.9817	−27.125***	−39.384***
Corn	0.0004	0.0167	−1.3989	15.791	0.9025	−27.378***	−37.922***
Cotton	0.0001	0.0178	−0.7097	11.961	0.9286	−25.931***	−37.822***
Soybean	0.0003	0.0128	−0.3708	3.7320	0.9615	−27.392***	−38.575***
SSA Equity Markets							
BRVM	−0.0002	0.0073	0.1395	3.5678	0.9553	−25.614***	−38.720***
Ghana	0.0001	0.0089	0.1865	10.774	0.8136	−24.932***	−37.776***
Kenya	−0.0006	0.0096	−0.0875	36.061	0.7849	−23.999***	−38.604***
Mauritius	0.0001	0.0069	−1.9583	89.942	0.5453	−25.212***	−29.217***
Uganda	−0.0001	0.0139	−0.2008	77.430	0.6174	−30.217***	−46.550***
Pre-COVID (03/01/2017–10/03/2020)							
Agricultural Commodities							
Cocoa	0.0002	0.0197	−0.0894	14.359	0.9165	−21.586***	−31.693***
Coffee	−0.0003	0.0170	0.1029	0.6200	0.9941	−20.112***	−30.383***
Corn	0.0001	0.0133	0.0758	2.6293	0.9617	−19.931***	−27.878***
Cotton	−0.0004	0.0139	−0.0633	2.5176	0.9711	−20.171***	−29.205***
Soybean	−0.0002	0.0104	0.0440	1.8683	0.9804	−19.061***	−28.154***
SSA Equity Markets							
BRVM	−0.0008	0.0077	0.4321	2.9674	0.9550	−19.652***	−28.999***
Ghana	0.0002	0.0072	0.1543	4.3206	0.9160	−15.708***	−26.035***
Kenya	−0.0005	0.0085	−1.1850	15.321	0.8712	−17.512***	−23.565***
Mauritius	0.0003	0.0028	0.2817	3.3108	0.9444	−19.136***	−23.149***
Uganda	−0.0001	0.0139	−0.1975	69.449	0.6314	−21.380***	−31.409***
During COVID (11/03/2020–30/12/2022)							
Agricultural Commodities							
Cocoa	−0.0002	0.0156	−0.0992	0.2070	0.9960	−14.013***	−20.548***
Coffee	0.0011	0.0229	0.5147	2.3369	0.9763	−14.243***	−19.490***
Corn	0.0010	0.0197	−2.0669	19.911	0.8722	−15.263***	−20.252***
Cotton	0.0016	0.0159	−0.1940	0.7898	0.9852	−16.161***	−22.386***
Soybean	0.0010	0.0142	−0.5604	5.1858	0.9377	−14.465***	−22.156***
SSA Equity Markets							
BRVM	0.0007	0.0072	−0.4391	5.4293	0.9344	−13.147***	−21.153***
Ghana	0.0005	0.0119	0.2747	8.0619	0.8061	−14.770***	−22.347***
Kenya	−0.0007	0.0127	0.4970	32.888	0.7174	−14.109***	−25.202***
Mauritius	−0.0001	0.0116	−1.3085	35.807	0.5939	−14.397***	−16.079***
Uganda	−0.0002	0.0154	−0.4226	89.041	0.5087	−19.631***	−32.464***

Note: STD, Skew., Kurt., Norm., ADF, and PP respectively represents standard deviation, skewness, kurtosis, normality test, Augmented Dickey-Fuller, and Philip and Perron test.
*** indicates significance at 1%.

exception of the earlier part of the pandemic era in 2020, where equities converge with soybeans in the case of Kenya and Uganda. Similarly, during the pre-pandemic era from 2017 to 2019, soybeans demonstrated moderate correlation with all equities in the immediate and medium-term, spanning approximately 1 to 64 days, except for Kenya and Uganda, where the correlation extended from 32 to 64 days.

Furthermore, with the exception of BRVM and Ghanaian equities, which exhibited a series of weak to moderate integration, particularly in the short and medium term, and Mauritius, which displayed a feeble co-movement in the medium term, soybean demonstrated strong co-movements with all equity markets in the intermediate to long term, particularly during the pandemic era from 2020 to 2022. The Kenyan and Ugandan markets showed the same pattern across all wavelet scales, indicating the absence of potential safe haven prospects in these markets. However, the remaining markets, excluding those immediate characterised, could potentially act as hedge from 2017 to 2019 and as a safe haven from 2020 to 2022. The presence of a bluish patch in Fig. 7 indicates the lack of convergence between soybeans and equities within a given moment-frequency realm. Thus, during the turbulent era, the equity markets of Ghana (from 2020 to 2021, approximately spanning 32 to 256 days) and Kenya (from 2021 to 2022) exhibited a weakly characterised convergence, highlighting the extent of divergence in the impact of the pandemic. Additionally, within a scale of 64 to 256, the interaction between soybeans and equities (specifically in Kenya) offers long-term benefits as a hedge from 2017 to 2019. The right-pointing arches depicted in Fig. 7 signify that soybeans drive the equity market, except for Uganda in the long term, where the direction of co-movement is indeterminable. This further indicates that variations in the value of soybean corresponds to movements in SSA stocks. On the other hand, the right-pointing downward arches with BRVM and soybeans signify that equities drive soybeans.

The aforementioned findings validate the market-driving potential of agricultural commodities, as previously established by extant literature [3,4,15]. This study further supports the notion that agricultural commodities have the ability to influence stock markets, as indicated in existing literature [3,4,6,29]. Moreover, the majority of the analysed commodities and equity markets demonstrate heterogeneous and adaptive behaviour in their co-movements [6,30], offering a limited means to mitigate portfolio risks for investors

Table 3
Summary of Stylized Facts from Bi-wavelet Estimations.

Comovement	Frequency	Alternatives (2017–2019)	Hedge (2017–2019)	Safe Haven (2020–2022)
Cocoa and Stocks	Short-term	BRVM and Ghana	Kenya, Mauritius, and Uganda	Mauritius and Uganda
	Medium-term	BRVM, Ghana, and Kenya	Mauritius	Mauritius and Uganda
	Long-term	BRVM, Ghana, and Uganda	Mauritius and Uganda	Mauritius and Uganda
Coffee and Stocks	Short-term	Kenya and Uganda	BRVM, Ghana, and Mauritius	Mauritius
	Medium-term	BRVM, Kenya, and Uganda	Mauritius	BRVM and Ghana
	Long-term	BRVM, Ghana, Kenya, and Mauritius	Mauritius	Ghana and BRVM
Corn and Stocks	Short-term	BRVM and Ghana	Kenya, Mauritius, and Uganda	Kenya and Uganda
	Medium-term	BRVM, Ghana, Kenya, and Mauritius	Uganda	Kenya and Uganda
	Long-term	BRVM, Ghana, and Uganda	Kenya and Mauritius	Kenya and Mauritius
Cotton and Stocks	Short-term	BRVM and Kenya	Ghana, Mauritius, and Uganda	Uganda
	Medium-term	BRVM and Kenya	Uganda	Uganda
	Long-term	BRVM, Kenya, and Uganda	Ghana	Ghana and Mauritius
Soybean and Stocks	Short-term	BRVM, Kenya, and Uganda	Ghana and Mauritius	—
	Medium-term	All Equities	—	Ghana
	Long-term	BRVM, Ghana, Mauritius, and Uganda	Kenya	Ghana

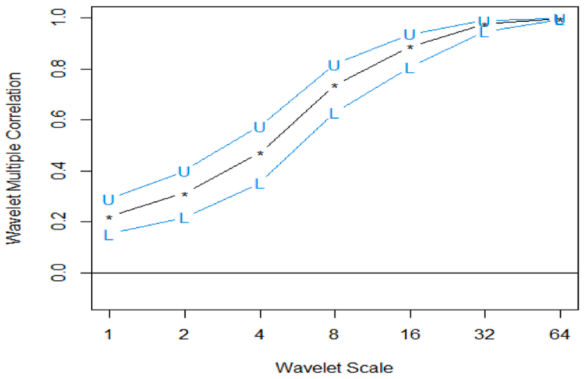

Fig. 8A. WMC Visualisation for the full sample period.

[9,11,29]. Also, the study's discoveries, notably in the midst of the global health crisis, reveal that an asset's potential for diversification aligns with its degree of dependence on the prevailing commodity. Consequently, the amalgamation of commodities and equities by a nation significantly reliant on that particular commodity is fraught with risk, owing to the evident positive and robust concurrent movements inherent between these markets. This correlation increases the likelihood of synchronous fluctuations in their respective valuations in terms of uncertainty [7]. This underscores the importance of investors contemplating the incorporation of equities from these markets to assess the economy's degree of reliance on the targeted commodity. Such consideration is crucial for averting potential losses in the event of unexpected peril.

However, during periods of high (feeble) integration, particularly in turbulent times, investors may consider these asset combinations as alternatives (complementary) elements for portfolio optimisation [7,11,8]. Moreover, given the asymmetric volatility dynamics observed in these markets, constructing a portfolio comprising agricultural commodities and equities could effectively mitigate risk. The theoretical implications of our findings on the bivariate co-movement between agricultural commodities and SSA equities align with the assumptions of the AMH (adaptive nature of investor reactions to shocks) and the MPT (diversification prospect amongst asset combinations both in normal and turbulence). These findings also complement the Heterogeneous Market Hypothesis by highlighting the diverse and distinct nature of co-movement observed amongst these asset classes. The results of the diversification prospect for the bivariate analysis summarised inTable 3.

Multivariate comovement between agricultural commodities and SSA equities

We further employ the WMC and WMCC techniques to elucidate the intricate interdependence patterns and the level of portfolio-related risks amongst the examined markets. This analysis is crucial as international investor portfolios encompass a diverse array of assets from multiple markets, extending beyond just dual assets. The WMC and WMCC methods, pioneered by Fernández-Macho [22] and Polance-Martinez and Fernández [31], are utilised to generate graphical representations that accurately illustrate the magnitude of the WMCC. These visualisations also highlight the time lag at which the most influential or precise wavelet correlation coefficient is concentrated, depicted through vertical black stripes on the schematic plot. A comprehensive summary of the coefficient of integration derived from the graphical depictions for both WMC and WMCC for the full and the sub-samples is presented in Table 3.

Table 4
Summary of results of the multivariate comovement between commodities and SSA equities.

Scales	WMC	WMCC	Leader	Lag
Panel A: Full sample (03/01/2017–31/12/2022)				
ϑ_1	0.2221	0.2858	Cocoa	0
ϑ_2	0.3129	0.3311	Soybeans	0
ϑ_3	0.4729	0.2235	Ghana	0
ϑ_4	0.7387	0.4215	Ghana	0
ϑ_5	0.8892	0.9726	Corn	1
ϑ_6	0.9780	0.9613	Corn	2
ϑ_7	0.9988	0.9993	Cotton	0
Panel B: Pre COVID-19 pandemic (03/01/2017–10/03/2020)				
ϑ_1	0.2008	0.1334	Corn	8
ϑ_2	0.2265	0.1150	Soybeans	−10
ϑ_3	0.4854	0.3246	Soybeans	−5
ϑ_4	0.7179	0.2512	Ghana	1
ϑ_5	0.8381	0.4408	Corn	0
ϑ_6	0.9430	0.9245	Soybeans	−5
Panel C: During COVID-19 Pandemic (11/03/2020–30/12/2022)				
ϑ_1	0.5118	0.1849	BRVM	0
ϑ_2	0.5951	0.1675	BRVM	0
ϑ_3	0.7203	0.2686	Ghana	0
ϑ_4	0.9403	0.5183	BRVM	−1
ϑ_5	0.9937	0.8907	Ghana	−2
ϑ_6	0.9989	0.9801	Kenya	−1

Notes: WMC is wavelet multiple correlations and WMCC is wavelet multiple cross-correlations. The lag represents the localisation and indicates the time lead or lag at which the strongest wavelet correlation values are localised.

Wavelet multiple correlations

(Figs. 8A-10A) present a comprehensive analysis of the integration between the selected commodities and SSA stocks across various periods, spanning from pre-COVID to the COVID-19 era, and across different scales, from short- to long-term. Our findings reveal significant variations in the WMC at different frequencies. In general, the degree of integration between the sampled commodities and equities shows some degree of relationship across all sampled periods and scales. For instance, in the full sample period depicted in Fig. 8A, the highest (lowest) level of correlation is observed at 22.2% (99.9%), corresponding to the intraweek (monthly-quarterly) scale. The level of integration tends to increase with decreasing frequency, implying that the lower frequencies exhibit higher degrees of integration. Notably, the quarterly scale shows near-perfect convergence, suggesting that time impacts diversification prospects. While the short and medium terms exhibit some degree of diversification potential for the sampled markets, the long term is characterised by reduced diversification possibilities, indicating that investors cannot effectively combine these assets in their portfolios both in normal and turbulent market conditions. The highest level of integration further indicates that the remaining variables can explain up to 99% of the variance in a single variable's quarterly returns, highlighting the interdependence and interconnectedness of the commodities and equity markets during this specific period.

Similarly, in the pre-pandemic period, we observed a significant level of integration, with the highest (lowest) reaching 94% (20%), while during the pandemic period, it remained at 99% (51.1%). Interestingly, the integration levels during the pandemic period, particularly in the long term, aligned with those of the full sample, while the short and medium terms deviated from this trend but rather matched the findings of the pre-pandemic period. Despite these observations, it becomes evident that the potential for diversification in the sampled markets was evident only in the full sample and pre-pandemic period, especially in the short and medium term, as the long term was plagued by a higher degree of integration. Similar to the long-term trends observed in the full sample and the pre-pandemic period, the pandemic period displayed a moderate (51%) to higher (99%) degree of integration across the intraweek to the monthly scale. Consequently, it was established that despite the rise in the returns of assets during the pandemic period, a portfolio comprising the sampled assets would lead to losses. Notably, the findings of the WMC align with those of the bivariate analysis, indicating weak correlations in the short term and the highest levels of integration in the long term, particularly during the pandemic period, with a few exceptions. Additionally, the lowest degree of integration observed in the short and medium term of the full sample and pre-pandemic period corroborates the conclusions of previous studies conducted by Nagayev et al. [29], de Boyrie and Pavlova [11], and Alagidede et al. [9]. Nevertheless, the higher interdependencies found amongst the sampled markets in the long term further validate the findings of Bhardwaj and Dunsby [6], Creti et al. [15], and Billah et al. [4], who respectively identified a strong nexus between agricultural commodities and stock returns in Asian emerging markets, especially during periods of turbulence.

WMCC results

Figures (8B–10B) present the WMCC analysis for the sampled asset markets, incorporating various amplitudes and approximately 30-day leads and lags. In this analysis, we ascertain the potential leading and lagging variables, and examine the positive and negative shocks. The lagging variable at each wavelet scale is indicated by positive lag localizations, while the leading variable is represented by negative lag localizations. The zero-lag localization lines (dashed) signify the absence of any significant lagging or leading. A variable on a scale signifies the asset that exhibits the potential to lead or lag all other variables. It corresponds to the maximum value in the

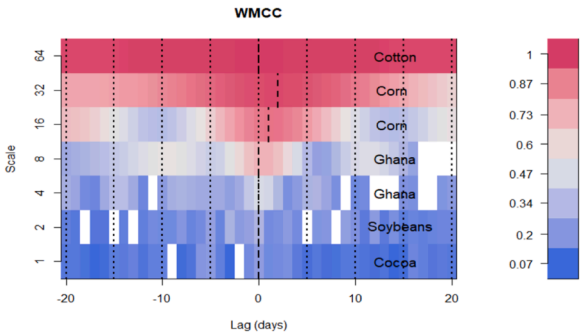

Fig. 8B. WMCC Visualisation for the full sample period.

Table 5
Summary of non-parametric causality test.

Series	BRVM		Ghana		Kenya		Mauritius		Uganda	
Original series	$\mathbb{X}\|\mathbb{Y}$	$\mathbb{Y}\|\mathbb{X}$	$\mathbb{X}\|\mathbb{Y}$	$\mathbb{Y}\|\mathbb{X}$	$\mathbb{X}\|\mathbb{Y}$	$\mathbb{Y}\|\mathbb{X}$	$\mathbb{X}\|\mathbb{Y}$	$\mathbb{Y}\|\mathbb{X}$	$\mathbb{X}\|\mathbb{Y}$	$\mathbb{Y}\|\mathbb{X}$
Cocoa	2.595***	2.497***	3.990***	2.352***	2.449***	1.944	2.557***	−0.232	2.820***	−0.067
Coffee	1.052	2.162**	1.989**	1.729	2.892***	2.557***	2.849***	1.822	2.958***	2.151**
Corn	2.270**	2.228**	3.562***	2.234**	−1.262	−0.729	3.117***	0.652	2.057**	1.097
Cotton	2.121**	1.912	3.549***	1.922	2.322**	1.303	2.808***	1.522	3.212***	1.627
Soybeans	2.208**	2.287**	1.805	1.013	2.730***	1.053	3.593***	1.883	2.821***	1.852
D_1										
Cocoa	7.181***	6.633***	7.079***	5.796***	2.118**	0.556	3.267***	−0.049	3.249***	0.325
Coffee	−1.394	1.072	2.386***	1.072	2.448***	1.716	3.020***	1.855	3.597***	1.392
Corn	1.116	1.003	2.489***	1.406	0.599	0.557	1.746	0.187	1.691	0.229
Cotton	2.066**	1.817	3.913***	1.413	2.130**	−0.979	3.167***	0.968	2.813***	1.553
Soybeans	0.996	−1.479	2.410***	−1.520	0.098	1.045	3.278***	1.301	3.725***	1.006
D_2										
Cocoa	6.439***	5.745***	6.093***	5.446***	2.329***	0.526	2.927***	−0.161	2.264**	1.373
Coffee	0.176	0.668	1.928	0.521	2.498***	1.472	2.948***	1.653	2.710***	1.084
Corn	1.721	1.045	3.041***	1.438	2.326**	0.575	3.022***	−0.157	2.264**	1.396
Cotton	2.165***	2.642***	3.042***	1.753	2.750***	1.600	2.681**	1.290	2.274**	1.680
Soybeans	1.655	1.118	2.754***	1.044	1.682	1.403	2.992***	1.530	2.813***	1.642
D_3										
Cocoa	1.482	2.021**	2.825***	2.026**	2.518***	0.632	1.300	0.152	2.115**	1.400
Coffee	0.141	0.685	1.865	1.843	4.293***	2.665***	1.579	−0.056	3.125***	1.217
Corn	1.798	2.261**	2.665***	2.664***	0.271	−0.654	0.507	−1.460	1.346	1.482
Cotton	2.350***	2.554***	2.306**	2.115**	2.312**	1.726	0.730	−1.563	2.318**	0.218
Soybeans	1.291	0.083	1.638	1.113	0.217	0.962	2.250**	1.761	3.037***	2.254**
D_4										
Cocoa	3.113***	2.419***	3.519***	2271**	2.594***	1.513	2.073**	−0.008	1.621	1.765
Coffee	1.452	1.387	0.367	−0.075	2.586***	3.767***	1.555	0.166	3.069***	1.781
Corn	1.598	1.761	2.175**	1.177	2.004**	1.721	1.077	1.545	2.379***	1.605
Cotton	3.011***	1.790	1.711	1.858	2.117**	−1.469	1.219	−0.937	1.973	1.487
Soybeans	0.922	1.725	0.987	−0.057	2.192**	1949	2.097**	1.831	3.299***	1.860
D_5										
Cocoa	3.198***	2.504***	2.640***	2.072**	2.445***	0.788	−0.565	0.699	3.332***	1.822
Coffee	−0.367	−1.036	−0.729	0.542	2.059¯¯	3.006***	1.081	0.476	2.220**	1.920
Corn	0.904	1.404	1.364	1.699	1.539	0.424	−1.784	−2.073	2.111**	−0.738
Cotton	3.089***	1.951	2.188**	1.940	1.613	0.995	0.917	−1.657	2.485***	1.234
Soybeans	−0.172	1.635	1.320	1.353	2.660***	1.601	0.459	0.252	2.716***	1.880
D_6										
Cocoa	2.257**	2.389***	2.630***	2.048**	0.186	−0.589	0.256	0.128	1.989**	−0.067
Coffee	1.870	0.040	−1.717	0.885	3.187***	1.245	2.058**	1.392	1.196	0.627
Corn	1.966**	1.771	1.211	0.452	0.840	−0.333	1.271	1.338	1.177	*0.418
Cotton	2.208**	1.862	1.656	1.883	2.070**	−1.787	−0.607	−1.877	0.357	0.244
Soybeans	2.095**	0.166	0.552	0.782	2.285**	1.461	1.812	0.455	2.267**	1.502

Note: The test is bidirectional; $\mathbb{X}|\mathbb{Y}$ represent variable X Granger-causes variable Y, and $\mathbb{Y}|\mathbb{X}$ demonstrates that variable Y Granger-causes variable X. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

linear combination of all variables at that specific scale. Accordingly, WMCC are economically significant because they determine the most influential variable at a given wavelet scale to act as either a leading (first variable to respond to shocks) or lagging (last variable to respond to shocks after the remaining variables) variable. The results of the WMCC for both the full sample and sub-sample is summarised in Table 4.

The outcomes of the full sample, as displayed in Fig. 8B, indicate that corn exhibits the capacity to lag by 2 and 1 at D5 and D6 (monthly and quarterly scales). This suggests that at these scales, corn may resist shocks from external factors or respond last to portfolio-related shocks. However, the absence of lead or lag at the D1, D4, D5, D6, and D7 scales for assets such as cotton, Ghana, soybeans, and cocoa, reveals their lack of skewness and ability to withstand shocks effectively. Similarly, the results of the pre-pandemic period, as presented in Table 3 Panel B, further demonstrate that corn and Ghana display potential lagging tendencies at the intraweekly and monthly scales (D1 and D5), while soybeans show potential leading behaviour at the weekly, fortnightly, and quarterly scales (D2, D3, and D6). Additionally, similar to the findings in the full sample, corn shows zero lags at the monthly scale (D5), indicating a lack of lead or lag prospects. Furthermore, during the pandemic period, a pattern similar to the full sample is observed, with multiple zero lags amongst the sampled markets across the intraweekly to the fortnightly scales (D1-D3). However, the BRVM, Ghana, and Kenya show potential leading behaviour at the fortnightly to monthly, monthly to quarterly, and quarterly scales (D4, D5, and D6). This suggests that during times of turbulence, as represented by the COVID-19 pandemic era, none of the sampled markets can effectively withstand external shocks when combined in multiple portfolios, as analysed in this study. Consequently, investors should avoid blending these assets into a single portfolio, particularly during crises. Notably, corn's ability to lag highlights its resilience to lower levels of shocks, but only under normal conditions. Additionally, the findings of the WMCC coefficients largely support those of the WMC. Nevertheless, these assertions do not negate the diversification potential of the sampled markets, as indicated in the bivariate analysis. Instead, they substantiate the assertions of Adebayo [18] that bivariate approaches are insufficient for fully understanding the portfolio-based interdependency structure of financial asset returns.

Wavelet-based nonlinear causality test

The current study employed the wavelet-centred causality test to evaluate the reliability of the WCA findings. This non-parametric causality test, utilising MODWT, enables the assessment of causal connections between the observed variables across different frequency ranges. Unlike traditional causality tests, this method overcomes issues such as excessively rejecting the null hypothesis due to changes in the data's structure [32] and addresses the sensitivity of variations in vector distributions. The null hypothesis of this analysis assumes the absence of nonlinear causal relationships, with the alternative hypothesis proposing the opposite. The majority of the results from the original series indicate a one-way causal connection from commodities to SSA equities with few exceptions, especially in the case of heavily dependant commodities, in line with the findings of the WCA, which are further confirmed by the disintegrated series. This suggests that the examined commodities possess predictive capabilities for each other across different frequencies. The results validate those of the WCA and provide noteworthy insights for policymakers and market participants in these equity markets. The results are presented in Table 5 for both the original and frequency-based data series.

Concluding remarks

Our contribution to the existing body of knowledge lies in the investigation of the time-varying co-movement between agricultural commodities and the stock market, utilising both bivariate and multivariate wavelet analyses while emphasising the global health crisis. The bivariate analysis revealed a moderate nexus between commodities and stocks, prevailing in the short, medium, and long term during normal market conditions. Conversely, the pandemic era exhibited a complex blend of significant (insignificant) and strong (weak) comovement amongst the sampled markets, with long-term comovement being particularly noteworthy. Notably, a robust relationship between SSA equities and commodities emerged, particularly for commodities heavily reliant on these economies. Within the bivariate pairings, evidence of hedging (in normal times) and safe haven properties (during the pandemic period) was observed, though there were some exceptions to this pattern. Agricultural commodities were found to lead SSA stocks in pairwise correlations across most wavelet scales, with a few exceptions, and this was validated through the wavelet-based causality test and partially confirmed by the multivariate analysis. Despite the perceived safe haven potential in the bivariate pairings, the WMCC results illuminated the perils of amalgamating all the assets into a single portfolio, as none of the assets were resilient enough to withstand the shocks induced by the pandemic. This indicates the inherent risk associated with such investments, particularly during periods of turbulence. Additionally, the pandemic significantly impacted the level of integration amongst these asset markets, as evidenced by weak integration in the short term, especially during the pre-pandemic era, and moderate to high integration in the short term during the pandemic era.

The study's findings imply that global investors can allocate their investments to the sampled commodities and stocks, especially in the short and medium term of the normal period, due to their weak to moderate comovement and only in a pairwise manner. Nevertheless, the strong level of integration in the multivariate analysis, especially during the pandemic era, indicates that a portfolio comprising all the commodity and equity markets will only prove costly for investors since these assets were moving in tandem and showed a directional susceptibility to the pandemic-related shocks. In addition, it is imperative for policymakers, particularly in the sampled SSA economies, to be cognizant of the ever-evolving patterns in these markets since such awareness can empower investors with the knowledge necessary to diversify their portfolios and optimise their returns effectively. Moreover, stringent regulation of information flows across these markets is crucial to dissuading investors from making hasty and ill-informed decisions that could prove detrimental to their investments. Investors, on their part, must exercise the utmost vigilance in monitoring the fluctuations and trends in these markets, given the interdependence of their risks. Nevertheless, the findings of this investigation were limited to selected commodities and the SSA equity markets. Consequently, the generalisability of these results may be hindered due to the exclusion of numerous comparable commodities and equities with similar uncertain characteristics. In future research endeavours, scholars could expand the scope by incorporating a larger number of markets, including countries that were not significantly affected by the pandemic, for comparative analysis, which would facilitate a more nuanced understanding of their dynamics and implications for

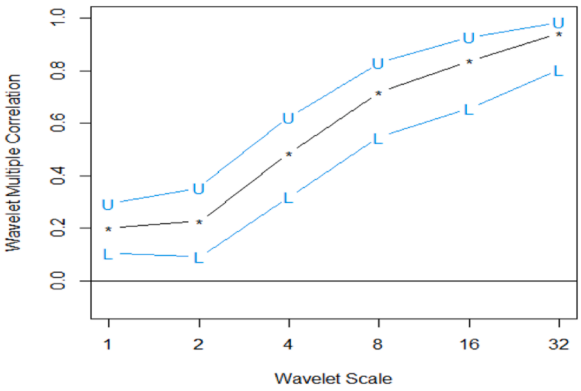

Fig. 9A. WMC Visualisation for the pre-pandemic period.

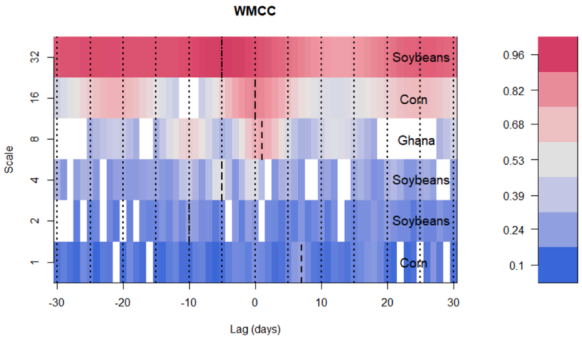

Fig. 9B. WMCC Visualisation for the pre-pandemic period.

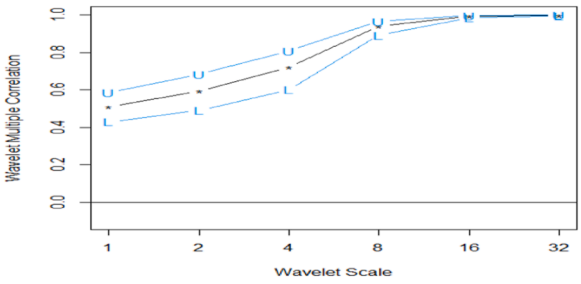

Fig. 10A. WMC Visualisation for the pandemic period.

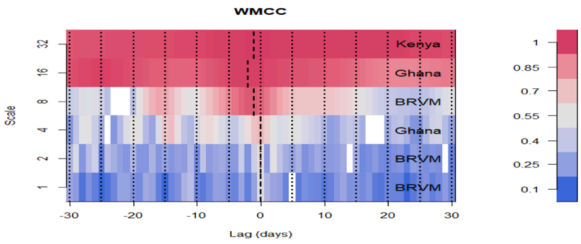

Fig. 10B. WMCC Visualisation for the pandemic period.

investment strategies (Fig. 10b,Fig. 9a,Fig. 9b).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sciaf.2023.e01972.

APPENDIX

Table 2
Summary of Bai and Perron and Sup MZ test for structural breaks.

Series	Bai and Perron				Supremum MZ		Break location	
	F-stats	Breakpoints	Break date	Significant BPT	SV	CV	Points	Year
Cocoa	3.357	810	2020	2017–2022	37.416	2.218	765	2020
Coffee	3.848	920	2020	2017–2022	99.072	3.754	473	2018
Corn	2.811	918	2020	2017–2022	173.064	3.414	1028	2021
Cotton	8.546	806	2020	2017–2022	268.120	2.455	1331	2021
Soybeans	3.031	839	2020	2017–2022	126.987	1.485	996	2020
BRVM	21.778***	956	2020	2017–2017; 2020–2022	65.188	1.224	1102	2021
Ghana	10.292**	1014	2021	2017–2022	118.054	1.922	1452	2022
Kenya	4.672	987	2020	2017–2022	115.947	1.167	985	2020
Mauritius	4.832	905	2020	2017–2022	987.730	−1.210	813	2020
Uganda	5.457	813	2020	2017–2022	111.216	2.236	366	2018

Note: B-P; Bai and Perron, SV; supremum value, CV; critical value, The sup MZ (Supremum Modified Zivot-Andrew) test remains the only test for detecting unknown break points in mean and variance [24]. Bai and Perron [23] test is the most significant test capable of automatically identifying the number of breaks and their corresponding positions without requiring prior knowledge or manual specification of breakpoints and provides consistent estimates of the number and locations of breaks, making it reliable for large datasets (Perron [25]). The critical value for the sup MZ test is computed under the null hypothesis of no break in mean and variance. If the test statistics are greater than the critical value, we reject the null hypothesis (no structural break) in favour of the alternative (existence of structural breaks).

** represent a 5% significance level.

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