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# Structural, climatic, and cost drivers of wheat production in South Africa: an ARDL analysis (1990–2022)

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This study investigates the main structural, climatic, and cost-related determinants of wheat production in South Africa, with the objective of identifying the dominant long-run and short-run constraints shaping domestic supply. Annual data for the period 1990–2022 are analyzed using an Autoregressive Distributed Lag (ARDL) model with an error-correction specification to capture both equilibrium relationships and adjustment dynamics between wheat output, cultivated area, fertilizer use, input price inflation, and rainfall variability. The results confirm a stable long-run cointegrating relationship among the variables. Cultivated area is the most influential long-run driver of wheat production, followed by rainfall, while input cost inflation exerts a statistically significant and economically negative effect on output. Fertilizer use is significant but displays a small elasticity, indicating limited marginal productivity under prevailing structural and climatic conditions. The error-correction term indicates moderate adjustment toward long-run equilibrium, reflecting rigidity in land allocation and input procurement. These findings imply that policies focused solely on input intensification are insufficient to stabilize wheat production. Instead, policy efforts should prioritize land-use incentives, reduced exposure to input price volatility, and improved climate-risk management to enhance long-term production resilience and food security.

### KEYWORDS

ARDL, climate variability, input markets, South Africa, wheat production

## 1 Introduction

South Africa's wheat economy operates at the crossroads of climate uncertainty, market dominance, and structural reliance on imports. These are key factors that collectively influence national food security and increasingly complicate its management amid global shocks (Mphateng, 2022; Mokone and Ndhlovu, 2025). Rising food inflation, especially in wheat-based staple foods, continues to erode household purchasing power, with SA (2025) noting that wheat-derived foods constitute a significant part of urban and peri-urban household expenditure. Unlike maize, which mostly follows domestic production cycles, wheat prices in South Africa are susceptible to international markets through parity

pricing, exchange rate fluctuations, and the dollar-linked variable tariff system overseen by ITAC (2025). As a result, the domestic market remains vulnerable to global disturbances, including those related to climate, geopolitics, and trade (Rauschendorfer and Krivonos, 2022).

Over the past three decades, wheat production in South Africa has declined and been volatile, driven largely by a sustained reduction in cultivated area despite gradual improvements in yields. This contraction has occurred alongside increasing climatic variability, particularly heightened rainfall uncertainty and more frequent drought conditions in key dryland wheat-producing regions. Given the strong dependence of domestic wheat systems on seasonal precipitation, these climatic pressures have amplified production instability and contributed to growing reliance on imports.

At the same time, the foundational structures of domestic wheat production have weakened. Since the early 1990s, the area dedicated to wheat cultivation has declined significantly, while output has remained inconsistent despite notable yield improvements driven by improved cultivars and more efficient farming techniques. This divergence underscores underlying economic pressures, including high fertilizer and fuel costs, concentrated input supply chains, and competition from alternative crops, all of which diminish farmers' incentives to maintain or expand wheat cultivation. Current estimates from the Crop Estimates Committee (CEC) and South African Supply and Demand Estimates (SASDE) indicate that South Africa now produces only 45–50% of its annual wheat needs compared to what it produced in the past decade and this is despite the strong demand in wheat and wheat products in the country, making South Africa increasingly reliant on imports from a few dominant global exporters, most of whom are G20 members (CEC, 2025).

These dynamics clearly position South Africa's 2025 G20 Presidency within a strategic framework. In the Group GAW, 2025. Key priorities include food security, market transparency, and resilience to climate and trade shocks. The establishment of South Africa's Food Security Task Force (FSTF) aims to improve domestic policy coordination and to push reforms on input market concentration, tariff predictability, and early-warning systems. This effort is supported by the global wheat trade, which remains heavily concentrated among a limited number of G20 exporters. The G20 platform offers a unique institutional opportunity for South Africa to enhance transparency regarding export restrictions, promote stable grain markets, and develop climate-resilient production strategies. These issues directly align with concerns raised by Grain SA, the National Grain Council, and OECD-FAO market assessments (Yanagi, 2024).

Despite extensive descriptive evidence of these structural challenges, the empirical links between climate shocks, market concentration, and wheat security in South Africa remain unclear (Ajillogba and Walker, 2023). Current research looks at these factors separately, but few combine them within an econometric framework that captures both short-term fluctuations and long-term equilibrium relationships (Senbeta and Worku, 2023; Chen et al., 2025). This paper addresses this gap by employing an Autoregressive Distributed Lag (ARDL) model to assess how climatic variability, concentrated input markets, and macroeconomic conditions jointly affect wheat production

outcomes in the context of South Africa's evolving G20 policy commitments. In doing so, the study offers both analytical and institutional contributions: analytically, by modeling the structural forces influencing wheat security; and institutionally, by situating these findings within the G20 food security agenda and South Africa's initiatives to enhance market resilience, reduce volatility, and boost domestic production capacity (Table 1).

## 2 Literature review

The structural development of South Africa's wheat sector must be understood within a global context that emphasizes the interaction between climatic constraints, upstream market power, and trade-related volatility in food-importing economies. Figure 1 illustrates the long-term decoupling between wheat area and yield performance: while cultivated area has steadily declined since the early 1990s, yields have risen considerably, particularly after 2008.

International studies identify similar intensification patterns in semi-arid wheat systems, where yield improvements come from cultivar innovation and precise input use rather than land expansion (Grote et al., 2021; Erenstein et al., 2022). However, as Hossain et al. (2021) indicate that such gains are vulnerable to climatic shocks, soil moisture stress, and variability in seasonal rainfall. Evidence from South Africa confirms these risks: dryland wheat zones remain highly sensitive to rainfall patterns and heat shocks, while irrigated systems face rising water and energy costs (Senbeta and Worku, 2023; Yanagi, 2024; Dube et al., 2025). The literature suggests that productivity-led intensification is limited by both biophysical and economic factors.

A second strand of literature concerns the role of input market concentration in shaping agricultural production incentives. Global evidence shows that oligopolistic fertilizer, agrochemical, and seed markets amplify price volatility and increase cost-push pressures on producers (Raihan, 2013; Rudloff et al., 2024; Morão, 2025). These effects are particularly pronounced in import-dependent economies where exchange-rate pass-through and logistics costs compound global shocks. South Africa exemplifies this structure, whereby high concentration ratios characterize fertilizer and chemical markets, limited domestic manufacturing capacity, and dollar-denominated pricing (Omar, 2016). Scholars such as Angus et al. (2015) Choudhary et al. (2018) would allude to research by Grain SA and the National Grain Council, which highlights that persistent fertilizer inflation and fuel-based cost escalation have depressed wheat margins and contributed to the abandonment of wheat in favor of more profitable alternative crops. There is minimal econometric quantification of how input cost inflation interacts with climate shocks or trade-linked price formation to influence production outcomes, constituting a clear empirical gap that an ARDL approach can address (Ajillogba and Walker, 2023).

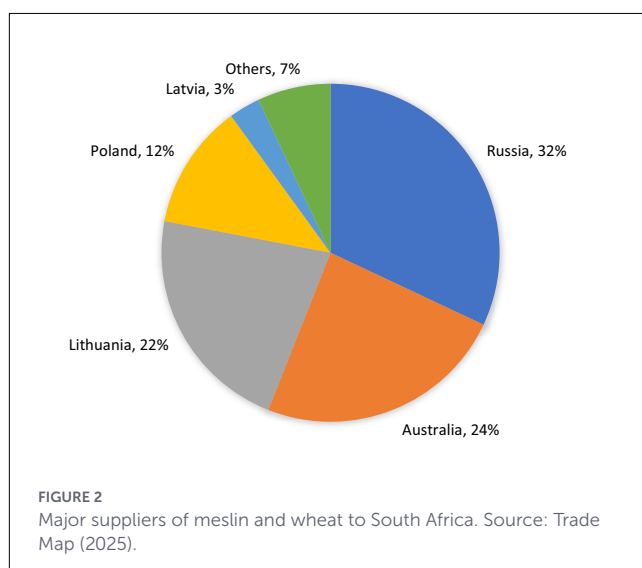
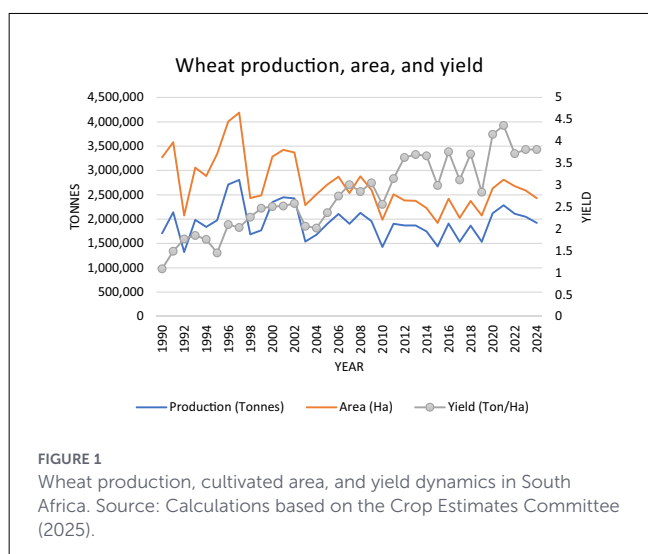
Figure 2 shows that South Africa's wheat imports primarily originate from Russia, Australia, Lithuania, and Poland, countries that are closely involved in the G20 cereals governance framework.

Rudloff et al. (2024), Halecki and Bedla (2022) emphasize that global wheat trade is increasingly affected by export restrictions, speculative storage, and freight disruptions, with G20 exporters at the center of these trends. Research on price transmission

TABLE 1 Summary of selected empirical studies on wheat production.

| Author(s) and Year       | Country/region  | Methodology                 | Key variables                    | Main findings  |
|--------------------------|-----------------|-----------------------------|----------------------------------|--|
| Shew et al. (2020)       | South Africa    | Panel and simulation models | Rainfall, temperature            | Wheat yields are highly sensitive to climatic stress                     |
| Hossain et al. (2021)    | Global          | Empirical synthesis         | Climate variability              | Rainfall variability and drought reduce wheat productivity               |
| Senbeta and Worku (2023) | Ethiopia        | Econometric analysis        | Area, climate, irrigation        | Land expansion and climate adaptation raise wheat output                 |
| Roberts et al. (2023)    | Southern Africa | Market structure analysis   | Fertilizer prices, concentration | Input market concentration raises costs and suppresses supply incentives |
| Ruark et al. (2018)      | Global          | Agronomic-economic analysis | Fertilizer use                   | Fertilizer exhibits diminishing marginal productivity                    |

Source: Compiled from reviewed literature.



confirms that in highly import-dependent markets such as South Africa, where domestic production accounts for only 45–50% of annual demand (van Berkum and de Steenhuijsen Piters, 2025), parity pricing mechanisms rapidly and strongly transmit global shocks. Exchange-rate volatility further amplifies these effects, creating more uncertainty for producers and diminishing investment incentives. Despite extensive research on consumer price pass-through, few studies examine how international price shocks impact domestic supply decisions. The existing literature thus lacks an integrated model that considers the interconnected effects of global wheat prices, climate variability, and structural input costs on domestic production (Berck et al., 2009; Forbes et al., 2020).

Emerging global research shows that food-system resilience depends on diversifying input markets, ensuring tariff predictability, and maintaining macroeconomic stability (Béné, 2020; Rimhanen et al., 2023; Olufemi-Phillips et al., 2024). Studies from Hernandez et al. (2024), Perego et al. (2024) indicate that concentrated fertilizer markets limit supply responsiveness, while uncertainty in multilateral trade increases producer risk. In South Africa, institutional fragmentation across tariff-setting, input

regulation, grain trade, and strategic reserves causes coordination failures that worsen volatility (Peterson, 2022). These issues have been central to discussions within the 2025 AWG, where South Africa’s FSTF has focused on transparency in export-restriction reporting, early-warning systems, and reforms to the wheat-dollar reference price system.

Across these strands, three insights emerge: (i) wheat production is limited by climatic sensitivity within a model dependent on intensification; (ii) market concentration for inputs raises production costs and reduces incentives; and (iii) shocks to global trade strongly influence import parity pricing. However, no published study has simultaneously modeled these dynamics within an econometric framework capable of distinguishing short-term adjustments from long-term equilibria. This study thus addresses a significant analytical gap by employing an ARDL model to integrate climatic variability, input cost fluctuations, macroeconomic pressures, and global price transmission into a cohesive explanation of South Africa’s wheat production behavior.

Existing empirical studies on wheat production in South Africa and comparable semi-arid economies emphasize climatic variability, land-use dynamics, and input costs as important

determinants of output; however, these factors are predominantly examined in isolation or within short-run analytical frameworks. The literature lacks an integrated econometric assessment that simultaneously quantifies the relative short-run and long-run effects of climatic variability, structural land allocation, fertilizer use, and input price inflation on wheat production. In particular, there is limited evidence distinguishing transitory climatic shocks from persistent structural constraints in import-dependent wheat systems. Moreover, while fertilizer use is commonly assumed to enhance production, few studies evaluate its marginal contribution relative to land availability and climate under conditions of rising input costs and rainfall uncertainty. This study addresses these gaps by applying an ARDL–ECM framework to test whether cultivated area and rainfall exert dominant positive effects on wheat production, whether input cost inflation constrains supply, and whether fertilizer use plays a secondary role. These relationships are formally evaluated through testable hypotheses derived from the empirical literature.

## 3 Methodology

### 3.1 Dataset and variables

The study utilizes annual time-series data for South Africa, covering 1990–2022 (33 observations), to investigate how structural input costs, fertilizer use, cultivated area, and climate variability affect wheat production. The dependent variable is total wheat production (PROD, tons). The explanatory variables are:

- AREAH – area harvested under wheat (hectares), capturing structural land-use dynamics.
- FUSE – total nitrogenous fertilizer use in agriculture (tons), serving as a proxy for fertilizer intensity and exposure to input market conditions at the sector level.
- PPI – Producer Price Index for agricultural inputs, serving as a structural proxy for input cost inflation and concentrated upstream market power.
- AARF – average annual rainfall (millimeters), reflecting climate variability.

Production, area, and fertilizer use data were obtained from FAOSTAT, while PPI was sourced from FAOSTAT's economic indicators database. AARF was derived from the World Bank Climate Portal, which provides country-level annual precipitation totals. All variables were transformed into natural logarithms to stabilize variance and enable the estimated coefficients to be interpreted as elasticities. Data cleaning, transformations, and estimation were carried out in Stata 19.

### 3.2 Econometric strategy

The study adopts an Autoregressive Distributed Lag (ARDL) modeling framework to examine both the short-run dynamics and long-run equilibrium relationships between wheat production and its structural, climatic, and cost determinants. The ARDL

approach is particularly suitable given the moderate sample size and the mixed order of integration among the variables, provided none is integrated of order two. Unlike conventional cointegration techniques, ARDL allows consistent estimation of long-run coefficients while simultaneously modeling short-run adjustment through an error-correction mechanism. This framework is well aligned with agricultural production systems, where output responds with lags to climatic shocks, land allocation decisions, and input price changes. The empirical strategy follows the ARDL framework of Pesaran and Shin (1995), to capture both short-run dynamics and long-run equilibrium relationships between wheat production and its determinants. ARDL is appropriate here because:

- The sample size is moderate ( $T = 33$ ),
- The variables are a mixture of  $I(0)$  and  $I(1)$ , and
- Agricultural production adjusts with lags due to biological growth cycles, climatic shocks, and input market constraints, which is consistent with a partial-adjustment process.

Lag lengths for the ARDL model were selected using the Akaike Information Criterion (AIC), resulting in an ARDL(1,1,0,0,1) specification for the preferred model.

### 3.3 Stationarity and cointegration testing

The time-series properties of all variables were examined using the Augmented Dickey–Fuller (ADF) unit root test (Silveira et al., 2022). Consistent with ARDL requirements, none of the series was integrated of order two,  $I(2)$ . Given the mixed integration orders [ $I(0)$  and  $I(1)$ ], the bounds testing approach to cointegration proposed by Pesaran and Shin, (1995) was applied to test for the existence of a long-run relationship between wheat production, area harvested, fertilizer use, PPI, and rainfall.

### 3.4 Model specification

The general ARDL ( $p, q, r, s, v$ ) error-correction representation estimated in this study can be written as:

$$\Delta \ln(PROD)_t = \alpha_0 + i = 1 \sum p\beta_i \Delta \ln(PROD)_t - i + j = 0 \sum q\gamma_j \Delta \ln(AREAH)_t - j + k = 0 \sum r\delta_k \Delta \ln(FUSE)_t - k + l = 0 \sum s\theta_l \Delta \ln(PPI)_t - l + m = 0 \sum v\theta_m \Delta \ln(AARF)_t - m + \lambda ECT_t - 1 + \varepsilon_t$$

Where:

- $\Delta$  denotes the first difference operator.
- $\ln(PROD)_t$  is the natural log of wheat production at time  $t$ .
- $\ln(FUSE)_t$ ,  $\ln(PPI)_t$ , and  $\ln(AARF)_t$  are the corresponding logs of area harvested, fertilizer use, Producer Price Index, and rainfall.
- $ECT_t - 1$  is the lagged error correction term derived from the long-run cointegrating relationship.
- $\lambda$  measures the speed of adjustment back to the long equilibrium.

- $\epsilon_t$  is a white noise error term.

### 3.5 Diagnostic and Stability Tests

Model adequacy was evaluated through a comprehensive set of diagnostics. The Durbin–Watson statistic and Breusch–Godfrey LM test were employed to identify serial correlation; White’s test was used to assess heteroskedasticity; and the Jarque–Bera test was applied to examine residual normality. Furthermore, CUSUM plots of recursive residuals were utilized to test for parameter stability throughout the sample period.

### 3.6 Limitations and future research

This study is subject to several limitations that should be acknowledged. First, the analysis relies on nationally aggregated annual data, which may mask spatial heterogeneity in climatic conditions, fertilizer application, and land-use decisions across wheat-producing regions. Second, fertilizer use is measured at the aggregate agricultural level due to data constraints, which may underestimate crop-specific input responses. Third, climatic variability is proxied by average annual rainfall, which does not capture intra-seasonal distribution or extreme weather events. Future research could address these limitations by employing regionally disaggregated panel data, incorporating temperature and drought indices, and exploring farm-level responses to input price volatility. Extending the analysis to include policy variables such as tariffs, exchange rate volatility, and irrigation investment would further deepen understanding of wheat supply resilience in import-dependent economies.

## 4 Results

### 4.1 Unit-root and bounds test

The Augmented Dickey–Fuller results (Table 2) show that wheat production (lnPROD) and average annual rainfall (lnAARF) are stationary at levels I(0), while area harvested (lnAREAH), fertilizer use (lnFUSE) and the Producer Price Index (lnPPI) become stationary after first differencing I(1). No variable is I(2), confirming the suitability of the ARDL framework. Although lnAARF is I(0), differenced rainfall terms appear in the ARDL as part of the general distributed-lag structure, which remains consistent with ARDL modeling principles.

The bounds test (Table 3) shows an F-statistic (127.301) well above the 95% upper bound (4.49). Similarly, the t-statistic (−19.173) is more negative than the critical value (−3.99), confirming a cointegrating relationship among the variables. This indicates a stable long-term equilibrium linking wheat production to area expansion, fertilizer use, input cost inflation, and rainfall variability.

TABLE 2 Stationary test for variables.

| Variables             | ADF test      |        |               |        |
|-----------------------|---------------|--------|---------------|--------|
|                       | Level [I (0)] |        | Level [I (1)] |        |
|                       | t-stats       | 5% CV  | t-stats       | 5% CV  |
| $\ln(\text{PROD})_t$  | −3.417***     | −2.980 |               |        |
| $\ln(\text{AREAH})_t$ | −1.033        | −2.989 | −4.397***     | −2.626 |
| $\ln(\text{FUSE})_t$  | −1.388        | −2.983 | −4.778***     | −2.986 |
| $\ln(\text{PRI})_t$   | −0.394        | −2.986 | −5.300***     | −2.992 |
| $\ln(\text{AARF})_t$  | −5.312***     | −2.978 | −10.308***    | −2.980 |

Source: Own calculations. \*, \*\*, and \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively.

### 4.2 ARDL short-run results

Short-run results (Table 4) reveal that wheat production responds strongly to current production conditions. Changes in the harvested area today were associated with higher output (0.681;  $p = 0.090$ ), aligning with quick adjustments in land use and flexible mechanized planting during the winter wheat season. Rainfall has an immediate positive impact (0.107;  $p = 0.059$ ), emphasizing its significance for soil moisture, germination, and early crop development. The more notable effect of lagged rainfall (0.359;  $p = 0.018$ ) suggests cumulative hydrological effects such as soil recharge, which influence yield formation beyond the current year.

Fertilizer use is statistically significant ( $p = 0.003$ ;  $p < 0.01$ ), but economically marginal. This reflects the fact that national fertilizer data capture aggregate agricultural use rather than wheat-specific application rates, and that South African wheat producers may already be operating close to agronomically optimal nitrogen levels, resulting in low short-term marginal yield responses.

Input cost inflation is negative and significant (−0.094;  $p < 0.01$ ), indicating that rising input prices, especially in concentrated fertilizer and fuel markets, undermine short-term production responsiveness. Lagged output is insignificant, confirming that wheat production has limited inertia and is mainly driven by current-season shocks rather than past production momentum.

### 4.3 ECM long-run results

The error-correction term ( $\text{ECT} = -0.101$ ;  $p < 0.01$ ) indicates that 10.1% of disequilibrium adjusts each year, reflecting moderate rigidity in land allocation, credit constraints, and structural delays in input procurement. Long-run elasticities (Table 5) reveal a clear hierarchy of determinants.

The harvested area is the primary factor, and a 10% increase in cultivated land is associated with a 7.68% increase in output (0.768;  $p < 0.01$ ). This confirms that land availability, land-use incentives, and competing crop returns remain crucial for production potential (Yanagi, 2024). Rainfall is an important climatic factor, with a long-term rainfall elasticity of 0.253 ( $p < 0.01$ ), indicating the combined influence of moisture availability, soil recharge, and seasonal hydrological conditions on yield formation. This reinforces the

TABLE 3 Bound test for cointegration.

| Cointegration test |         | Calculated test stats | 95% lower bound | 95% upper bound | Decision     |
|--------------------|---------|-----------------------|-----------------|-----------------|--------------|
|                    | F-stats | 127.301               | 2.86            | 4.49            | Cointegrated |
|                    | t-stats | -19.173               | -2.86           | -3.99           | Cointegrated |

Own calculations.

TABLE 4 ARDL analysis.

| Variables                | ln(PROD) <sub>t</sub> |       |
|--------------------------|-----------------------|-------|
|                          | Coefficient           | Prob. |
| Constant                 | 0.243***              | 0.006 |
| ln(PROD) <sub>t-1</sub>  | 0.0123                | 0.818 |
| ln(AREAH) <sub>t</sub>   | 0.845***              | 0.000 |
| ln(AREAH) <sub>t-1</sub> | 0.068*                | 0.090 |
| ln(FUSE) <sub>t</sub>    | 0.003***              | 0.002 |
| ln(PPI) <sub>t</sub>     | -0.094***             | 0.002 |
| ln(AARF) <sub>t</sub>    | 0.107*                | 0.059 |
| ln(AARF) <sub>t-1</sub>  | 0.359**               | 0.018 |
| Lag length               | ARDL (1,1,0,01)       |       |
| R <sup>2</sup>           | 97                    |       |
| Adj. R <sup>2</sup>      | 96                    |       |
| F-Stats                  | 118.98                |       |
| Prob (F-Stats)           | 0.000                 |       |

Source: Own calculations; \*, \*\*, and \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively.

TABLE 5 Error correction model results.

| Variables                | ln(PROD) <sub>t</sub> |       |
|--------------------------|-----------------------|-------|
|                          | Coefficient           | Prob. |
| Constant                 | 0.243***              | 0.006 |
| ECT <sub>T</sub>         | -0.101***             | 0.000 |
| <b>Long-run results</b>  |                       |       |
| ln(AREAH) <sub>t</sub>   | 0.768***              | 0.000 |
| ln(FUSE) <sub>t</sub>    | 0.003***              | 0.000 |
| ln(PRI) <sub>t</sub>     | -0.092***             | 0.002 |
| ln(AARF) <sub>t</sub>    | 0.253***              | 0.002 |
| <b>Short-run results</b> |                       |       |
| Δln(AREAH) <sub>t</sub>  | 0.681*                | 0.090 |
| Δln(AARF) <sub>t</sub>   | 0.149**               | 0.018 |
| R <sup>2</sup>           | 98                    |       |
| Adj. R <sup>2</sup>      | 97                    |       |

Source: Own calculations; \*, \*\*, and \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively.

high climate sensitivity of South African wheat systems (Mphateng, 2022). Input cost inflation has a significant adverse effect. The long-term elasticity of PPI (-0.092;  $p < 0.01$ ) shows that sustained

TABLE 6 Diagnostic test results.

|                                   | Statistics/p-value | Decision              |
|-----------------------------------|--------------------|-----------------------|
| Durbin-Watson                     | 1.91               | No serial correlation |
| Breusch-Godfrey test              | 0.041 (0.839)      | No autocorrelation    |
| White's test (Heteroskedasticity) | 33 (0.418)         | No heteroskedasticity |
| Jarque Bera (Normality)           | 0.323 (0.851)      | Normal distribution   |

Source: Own calculations.

increases in input prices consistently hinder production. This aligns with the structural dependence on imported fertilizer and agrochemicals, whose dollar-linked prices amplify global shocks (Halecki and Bedla, 2022). Fertilizer use has a small but positive long-term elasticity (0.003;  $p < 0.01$ ). The modest size is explained by (i) national fertilizer figures that conceal variation in wheat-specific use, (ii) diminishing marginal returns to nitrogen in high-potential areas, and (iii) production decisions being more strongly influenced by land and rainfall than by marginal nutrient adjustments (Dadrasi et al., 2023).

Together, these results characterize wheat production as a system governed by structural land constraints, climatic variability, and upstream input-pricing pressures, with fertiliser's role statistically identifiable but secondary in magnitude.

### 4.4 Diagnostics and stability

Diagnostic tests (Table 6) confirm that the ARDL-ECM is well-specified. The Durbin-Watson statistic (1.91) and the Breusch-Godfrey test ( $p = 0.839$ ) indicate no serial correlation. White's test ( $p = 0.418$ ) suggests homoscedastic residuals, while the Jarque-Bera statistic ( $p = 0.851$ ) affirms normality.

Stability is confirmed by the CUSUM plot (Figure 3), with recursive residuals staying within the 5% confidence band. This shows that the relationships among variables stay stable despite multiple stress events, including EL Niño 2015-2016, COVID-related import disruptions, and recent global fertilizer price increases, during the sample period.

### 4.5 Integrated discussion and policy implications

The empirical results reveal a clear causal hierarchy within South Africa's wheat sector: land allocation exerts the most decisive

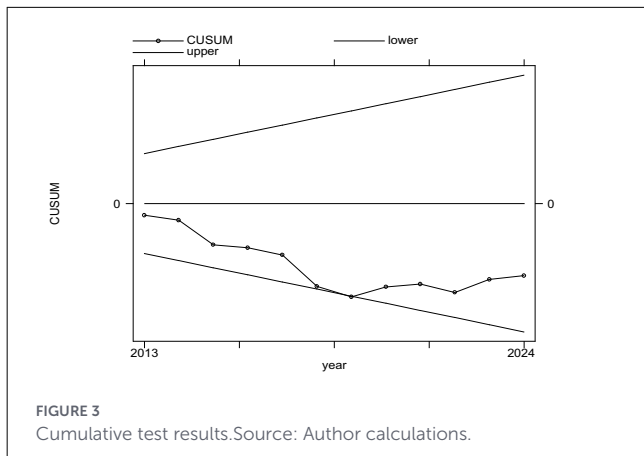


FIGURE 3  
Cumulative test results. Source: Author calculations.

influence on production outcomes, followed by climatic moisture conditions, input-price inflation, and, lastly, fertilizer use. This hierarchy captures the structural architecture of wheat supply and aligns with global findings that land availability and climatic conditions dominate cereal yield variation in semi-arid agricultural systems (O'Leary et al., 2018; Dadrasi et al., 2023; Chen et al., 2025). At its core, the evidence suggests that wheat production is shaped less by incremental input adjustments and more by broader institutional, climatic, and economic forces that govern land utilization, hydrological stability, and the affordability of key inputs.

The dominance of harvested areas underscores the centrality of land use incentives in driving supply responsiveness. Producers adjust land allocation based on expected profitability, risk perceptions, and competition from alternative crops, consistent with established agricultural supply-response theory (Ouattara et al., 2019; Zhao and Yue, 2020). The results support the literature showing that land-use constraints such as tenure insecurity, variable profitability, and conversion costs remain binding in South Africa's cereal sector (Everard, 2011; Farooq et al., 2023). Rainfall's strong short and long-run effects reinforce its role as a critical climatic determinant of wheat output, consistent with agronomic research demonstrating that South African wheat yields are highly sensitive to rainfall distribution, soil moisture dynamics, and seasonal heat stress (Shew et al., 2020; Hossain et al., 2021; Ajilogba and Walker, 2023). The significance of lagged rainfall confirms the presence of hydrological memory, in which cumulative soil-moisture conditions shape both planting decisions and yield formation, consistent with findings in semi-arid wheat-producing regions worldwide (Miranda Oliveira, 2024; Xing and Wang, 2024).

The negative long-run influence of input cost inflation reflects structural vulnerabilities in South Africa's fertilizer and agrochemical markets, which are heavily import-dependent and dominated by a small number of firms (Lotriet et al., 2017; Roberts et al., 2023). International research similarly documents that fertilizer price spikes impose disproportionately large constraints on cereal producers in import-dependent economies (Stanberry and Fletcher-Paul, 2024). The small elasticity of fertilizer use does not contradict this structural picture; rather, it reflects diminishing marginal returns to nitrogen, inefficiencies in nutrient utilization

under variable moisture regimes, and the limitations of aggregate fertilizer statistics that do not distinguish crop-specific application rates (Ruark et al., 2018). The empirical narrative is therefore consistent: input markets matter primarily through pricing power and cost transmission, not through marginal adjustments in physical quantities applied.

These findings carry direct implications for both domestic reform and South Africa's engagement in multilateral governance. The quantified hierarchy of determinants provides an empirical basis for advancing South Africa's position within the G20 Agriculture Working Group and the Food Security Task Force, which prioritize transparency in fertilizer markets, improved climate-risk surveillance, and strengthening of global grain market information systems (Mohylnyi et al., 2022). Rainfall sensitivity supports the G20's commitments to enhance early warning systems and climate adaptation monitoring. At the same time, the input-price constraint underscores the importance of global cooperation in addressing fertilizer supply disruptions and export restrictions, issues repeatedly highlighted in AMIS bulletins and OECD trade-restrictions reports (Kubayi et al., 2024; Rudloff et al., 2024). At the same time, the overwhelming influence of land availability confirms that some structural levers, such as land reform, land-use conversion, and incentive frameworks, remain primarily domestic responsibilities.

Taken together, the integrated evidence shows that strengthening wheat production requires a dual approach: reducing exposure to climatic and trade-related volatility through international cooperation, and addressing domestic structural constraints that limit land expansion and drive up input costs. This aligns with the broader lesson in agricultural economics that resilience comes not from isolated actions but from coherent policy frameworks that coordinate land-use incentives, input-market competition, and climate adaptation (Pillot and Dugue, 2018). The findings, therefore, provide not only an understanding of historical production trends but also an empirically grounded framework for future policy development. South Africa's engagement in G20 platforms such as AMIS can be most effective when paired with domestic reforms that improve land allocation efficiency, enhance competition in input markets, and invest in climate-resilient farming systems. These measures collectively support long-term stability of the wheat sector and national food security.

## 5 Conclusions

This study quantified the influence of structural, climatic, and cost-related factors on South Africa's wheat production using an ARDL-ECM framework. The results reveal a clear hierarchy of determinants: land availability is the primary long-term driver, rainfall variability has a substantial climatic impact, input-price inflation in concentrated upstream markets suppresses output, and fertilizer use, although statistically significant, has only a marginal economic effect. The existence of a stable long-run cointegrating relationship and a moderate adjustment speed confirms that production responds to both immediate shocks and deeper structural conditions. These findings contribute to the literature by providing an integrated estimate of the relative

strength of these constraints within a unified dynamic model, addressing a gap in the empirical understanding of wheat-sector resilience in semi-arid economies. Recognizing that nationally aggregated fertilizer and rainfall measures limit spatial precision, the results nonetheless offer clear implications: improving land-use efficiency, moderating input-cost pressures, and strengthening adaptation to rainfall variability remain crucial for stabilizing wheat output. As South Africa engages in broader food-system governance platforms, including G20 processes, these empirical insights provide a strong evidence base for aligning domestic reform with international resilience priorities. Ultimately, the study shows that long-term wheat stability will depend on coordinated responses to the underlying structural, climatic, and market forces identified here.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

BD: Conceptualization, Formal analysis, Project administration, Writing – original draft, Writing – review & editing. NM: Formal analysis, Writing – review & editing. ML: Investigation, Methodology, Validation, Writing – review & editing. SM: Methodology, Software, Writing – review & editing. JK: Conceptualization, Data curation, Writing – review & editing. LM: Writing – review & editing.

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## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest

## In memoriam

We honour the memory of our late co-author, Mr Lucas Moswane, whose passion for agricultural economics, climate research, and South Africa’s rural development continues to inspire this work. Though young, he approached scholarship with uncommon dedication, clarity of purpose, and a deep commitment to strengthening the country’s food systems. This paper stands as part of the impact he hoped to make, and we are grateful for the insight, discipline, and spirit he brought to the project.

## Generative AI statement

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