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Volatility and risk persistence in black pepper prices: A garch analysis of garbled and ungarbled grades in the Kochi market

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Abstract
Black pepper prices have shown pronounced volatility due to global competition, climatic shocks and structural changes in production and trade. This study analyses and compares price volatility in Malabar Garbled (GBP) and Ungarbled Black Pepper (UBP) using monthly Kochi market prices from January 2001 to December 2024. Log price returns were examined through inter- and intra-annual volatility indices and a GARCH (1, 1) model to capture time-varying and persistent risk. Both grades exhibited substantial price instability, with UBP consistently recording higher inter- and intra-annual volatility, reflecting greater exposure to seasonal and structural shocks. GARCH results revealed extremely high volatility persistence, particularly for UBP, implying slow dissipation of price shocks. This distinction indicated that price shocks in the ungarbled segment have long-lasting effects on volatility compared with the GBP. The findings suggested that quality standardization through garbling provides limited risk mitigation and highlighted the need for grade-specific price risk management and policy interventions.

Keywords: Black pepper, price volatility, GARCH model, volatility persistence, agricultural risk management

1. Introduction

Black pepper (*Piper nigrum),* often revered as "black gold", is among the oldest, most valued and commercially influential spices in the world. Its pervasive culinary use, therapeutic properties and longstanding role in global trade have made it a commodity of enduring economic relevance. India, particularly the southern states, historically dominated the global pepper economy, but this position has weakened as countries like Vietnam and Indonesia have significantly expanded production and export capacities (Jeevan and Lokesha, 2025) [10]. The resulting increase in international competition has heightened India's vulnerability to external price disturbances, making robust analysis of pepper prices increasingly critical for producers, traders, exporters and policymakers.

Kerala, the traditional heartland of black pepper, continues to be the principal centre for cultivation and trade in India. The state's warm climate, rainfall and high humidity provide favourable conditions for pepper vines. Black pepper cultivation contributes substantially to the livelihoods of marginal and smallholder farmers, underpins local spice markets and adds to export earnings. At the same time, the sector confronts several structural challenges, including shifts in land-use (Harilal, 2010; Kuruvila *et al.*, 2012; Sajitha, 2014) [8, 14, 19], declining productivity from aging plantations and recurrent pest and disease outbreaks (Jacob and Job, 2015; Kumar, 2025) [9, 11]. Climatic variability-manifested through irregular monsoon patterns, prolonged dry spells and extreme events such as floods-further intensifies production risk, which is transmitted to both yield and price instability (Jacob and Job, 2015; GoI, 2025) [9, 7]. Within this regional context, the Kochi market functions as a key node for price discovery, linking domestic supply with both national and international buyers. The proximity to major black pepper-growing districts and developed infrastructure for processing, grading and exporting make Kochi a natural reference point for price formation. Price developments in Kochi encapsulate supply chain forces and risk exposures often obscured in national-level analyses.

This market is particularly useful for examining seasonal patterns, structural features and institutional influences on black pepper prices in Kerala.

Black pepper marketed through formal channels is typically differentiated into grades on the basis of physical and chemical quality parameters, including berry size, density, moisture, aroma, biting taste, volatile oil and oleoresin levels. Among these, Malabar garbled and Malabar ungarbled pepper are the most widely traded commercial grades. Garbled pepper consists of cleaned, sorted lots that comply with prescribed quality standards and exhibit higher oleoresin content, whereas ungarbled pepper comprises less processed and more heterogeneous lots of mixed grades (Zachariah, 2000) [20]. These quality and processing differences are reflected in distinct price levels and behaviour, underscoring the need for grade-specific price analysis.

Black pepper prices over the last two decades have been marked by pronounced volatility, shaped by both domestic and global drivers (Sabu and Kuruvila, 2016) [18]. Variations in seasonal output, competition from other major exporting countries such as Vietnam and Sri Lanka, weather-induced supply shocks, pest and disease outbreaks, rising labour costs and shifting demand conditions in local and export markets all contribute to unstable prices. Such volatility has far-reaching implications: it undermines income security for growers, raises inventory and holding risks for traders, complicates marketing and export strategies and poses challenge for policy design in a trade-dependent sector.

Traditional time series models, including ARIMA and classical decomposition-based approaches, have been extensively used but are limited in capturing time-varying volatility and persistence. These techniques commonly assume linear relationships, stationarity and stable seasonal patterns, assumptions that are rarely satisfied in turbulent agricultural markets. When these conditions are violated, model parameters can become unreliable and forecasts can deteriorate. Black pepper prices often display nonlinear dynamics, non-stationary behaviour, variation across multiple time scales and extreme shocks with heavy tails, features that limit the effectiveness of conventional statistical models.

Against this backdrop of market complexity and the limitation of classical statistical models, the present study applies Generalized Autoregressive Conditional Heteroscedasticity (GARCH), supplemented by calculation of inter- and intra-annual volatility indices. The central objective is to quantify and compare the magnitude, time-dependency and persistence of price volatility for Malabar Garbled (GBP) and ungarbled (UBP) pepper in Kochi market, thereby providing grade-wise, evidence-based insights critical for effective price risk management by stakeholders.

2. Materials and methods

2.1 Data source

The study utilizes monthly time series data on average prices (₹ per kg) of GBP and UBP in the Kochi market of Kerala. The dataset spans a 24-year period from January 2001 to December 2024, comprising 288 monthly observations for each grade. Data were sourced from the Spices Board, Kochi and the Directorate of Arecanut and Spices Development (DASD), Kozhikode, ensuring accuracy and consistency.

2.2 Price returns

The analysis is conducted using monthly-log returns $(R_{y,m})$, calculated as the first difference of the natural logarithm of the price series. This transformation ensures the required stationarity for volatility modeling. For price $P_{y,m}$ in year y and month m:

$$R_{y,m} = \ln P_{y,m} - \ln P_{y,m-1}$$

2.3 Preliminary diagnostic and volatility indices

2.3.1 Stationarity test

Stationarity is a fundamental assumption in time series modelling. The Augmented Dickey-Fuller (ADF) test was applied to the price returns to check for the presence of a unit root (Dickey and Fuller, 1979). For a time series $\{y_t\}$, the regression equation of ADF test is presented as:

$$\Delta y_t = \alpha_1 + \alpha_2 t + \delta y_{t-1} + \sum_{i=1}^{h} \beta_i y_{t-i} + \varepsilon_t,$$

where $\Delta y_t = y_t - y_{t-1}$ is the first difference, α_1, α_2 and β_i are parameters of regression model, h is lag length, $\delta = \rho - 1$ and $-1 \leq \rho \leq 1$. The hypotheses are specified as follows:

H_0: $\delta = 0$ (The series has a unit root and is non-stationary)

H_1: $\delta < 0$ (The series is stationary)

2.3.2 Intra-annual volatility index

The intra-annual volatility index measures the short-term, within-year price instability. It is calculated as the standard deviation of the changes in log prices scaled onto an annual basis using the factor $\sqrt{12}$:

$$S_{YM} = \sqrt{\frac{1}{11}\sum_{m=1}^{12}\left(\ln P_{y,m} - \ln P_{y,m-1} - \delta y\right)^2} \text{ for year ‘y’}$$

where $\delta y = \frac{1}{12}\left(\ln P_{y,12} - \ln P_{y,0}\right)$ is the y^{th}year drift and $P_{y,0} = P_{y-1,12}$.

2.3.3 Inter-annual volatility index

The scaled inter-annual range estimates the long-term, year-to-year instability by utilizing the scaled range of prices. The modified Parkinson’s measure (Parkinson, 1980; Garman and Klass, 1980; Kunitomo, 1992) [16, 5, 13] was used in this study as it accounts for the high and low monthly prices within a year and provides a robust measure of volatility:

$$S_y^P = \left(\frac{\left(\ln P_y^H - \ln P_y^L\right)}{2\sqrt{\ln 2}}\right)$$

where, $P_y^H = max_{m-1}^{12} P_{y,m}$, is the highest monthly average price in the year and

$P_y^L = min_{m-1}^{12} P_{y,m}$ is the lowest monthly average price in the year.

2.4 GARCH modelling

Prior to GARCH estimation, the necessary condition of conditional heteroscedasticity was verified using the ARCH-Lagrange Multiplier (ARCH-LM) test. This test confirms if the variance of the residuals from the mean equation is predictable based on past squared residuals, justifying the GARCH structure (Engle, 1982; Bollerslev, 1986) [4, 1].

The GARCH (1,1) model was applied to the return series. The model assumes a mean equation to filter out the linear dependencies and a variance equation to model the time-varying volatility.

Mean equation: $R_{y,m} = \mu + \sum_{i=1}^{h} \phi_i R_{y,m-i} + \varepsilon_{y,m}$

Variance equation: $\sigma_{y,m}^2 = \alpha_0 + \alpha_1 \varepsilon_{y,m-1}^2 + \beta \sigma_{y,m-1}^2$

Here, α_1 captures short-run volatility shocks, while β captures long-run persistence. Their sum $(\alpha_1 + \beta)$ indicates the overall volatility persistence; values close to one imply that shocks dissipate slowly. In practice, a constant mean specification was sufficient, as no significant serial correlation remained in the return series.

The adequacy of this model was assessed using the Ljung-Box Q-statistic on the standardized squared residuals. The non-significance of this test confirms that the model successfully filtered out all remaining conditional autocorrelation, validating the model's suitability for comparative analysis.

3. Results and discussion

3.1 Descriptive statistics

The descriptive statistics for monthly average prices for GBP and UBP are presented in Table 1. The average price for GBP (₹328.90/kg) was consistently higher than that of UBP (₹314.50/kg) over the study period. This is expected, as garbling is a process of value addition which incurs additional cost and results in a premium product commanding higher market price. The difference in the mean price reflects the market valuation of the quality and standardization achieved through garbling process.

Both the grades exhibit a very wide range between their minimum and maximum prices, indicating significant long-term price movement and market risk over the two decades. The highest recorded price for GBP (₹742.50/kg) and UBP (₹714.90/kg) are approximately 12.2 and 12.6 times their respective minimum prices, underscoring the extreme bull and bear cycles characteristic of the black pepper market.

The standard deviation (SD) is higher for GBP than for UBP suggesting that the absolute swings in the price of the higher-value, processed product (GBP) were slightly larger than those of the raw product (UBP). The coefficient of variation (CV) for both grades are remarkably high, signifying high price risk across the entire period. UBP (66.59%) exhibits a marginally higher relative volatility than GBP (66.35%). This small difference suggests that while GBP had larger absolute swings, the raw product (UBP) was slightly more volatile when measured against its lower average price level. The wide range between minimum and maximum prices further underscores the extent of market fluctuations. GBP prices varied from as low as ₹60.90/kg to a peak of ₹742.50/kg, while UBP prices ranged between ₹56.90 and ₹714.90/kg. Such large price swings point to the influence of cyclical supply variations, external market forces and structural changes in the pepper economy over the study period. This observed difference in relative volatility motivates further econometric analysis to assess the persistence and dynamics of price risk.

Table 1: Descriptive statistics of GBP and UBP prices

Statistic	GBP prices	UBP prices
Mean	328.90	314.50
Standard deviation	218.23	209.44
Coefficient of variation	66.35	66.59
Minimum	60.90	56.90
Maximum	742.50	714.90

Inter-annual volatility index

Figure 1 illustrates the inter-annual volatility indices of GBP and UBP prices in the Kochi market for the period from 2001 to 2024. The volatility patterns of both grades exhibit substantial year-to-year variation, reflecting changing market conditions, supply shocks and external influences on black pepper prices.

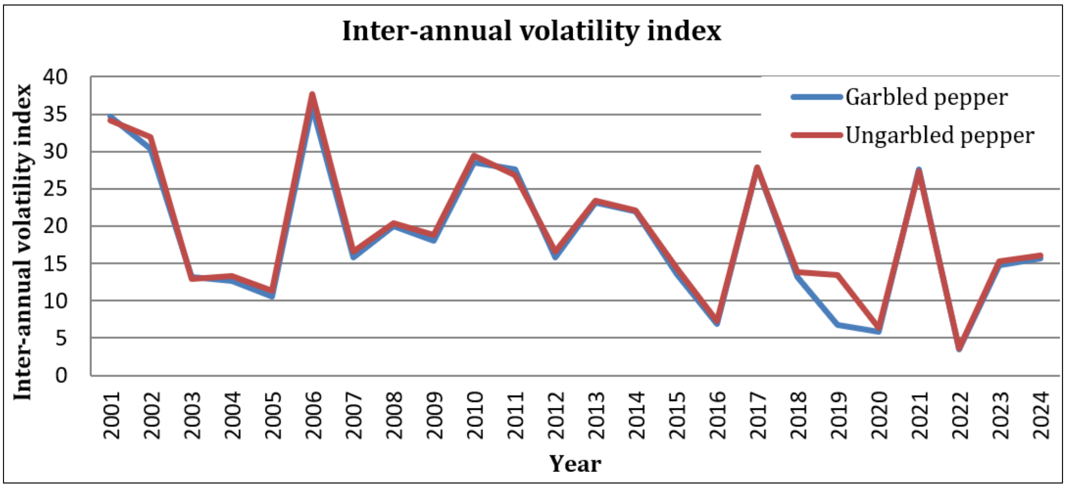

Fig 1: Inter-annual volatility index for GBP and UBP prices

The analysis of the Inter-Annual Volatility Index reveals four key insights:

- **High volatility trend and fluctuation:** The index values for both grades show extreme fluctuations over the 24-year period. Volatility was notably high in the initial years (2001 and 2002) coinciding with the period of intensified international competition following trade liberalization under the Indo-Sri Lanka Free Trade Agreement (ISLFTA) and South Asian Free Trade Agreement (SAFTA) (Cariappa and Chandel, 2020; Sabu, 2022) [2, 17]. Another significant spike in 2006 (GBP: 35.98%, UBP: 37.76%), indicates the sharp fall in international prices coinciding with Vietnam's rapid expansion (Nam, 2008) [15]. Conversely, the market experienced periods of relative stability, with the lowest volatility observed in 2022 (GBP: 3.50%, UBP: 3.65%) and 2020 (GBP: 5.79%, UBP: 6.35%).
- **Comparative risk between grades:** Over majority of the years (19 out of 24), the UBP exhibited a higher Inter-Annual Volatility Index compared to GBP. This suggests that the raw, less standardized product is generally more susceptible to the impact of structural changes and long-term price swings.
- **Role of standardization:** The consistently lower Inter-Annual volatility for GBP indicates that the process of garbling and standardization provides a marginal buffering effect against systemic market risk. The higher quality assurance associated with GBP appears to lend a greater degree of price stability year-over-year compared to the more heterogeneous UBP lots.
- **Trend towards stability:** There is a visible trend of decreasing volatility from the highs of the early 2000s, with multiple years in the last decade registering indices below 15 per cent. However, this long-term stability is interspersed with significant spikes (2017 and 2021), confirming the volatile nature of the commodity.

3.2 Intra-annual volatility index

The intra-annual volatility index measures the magnitude of price instability that occurs within each year, reflecting market exposure to short-term, cyclical factors such as seasonality (peak harvest season and lean season), immediate weather impacts, and localized supply disruptions. The index values for GBP and UBP are presented in Figure 2.

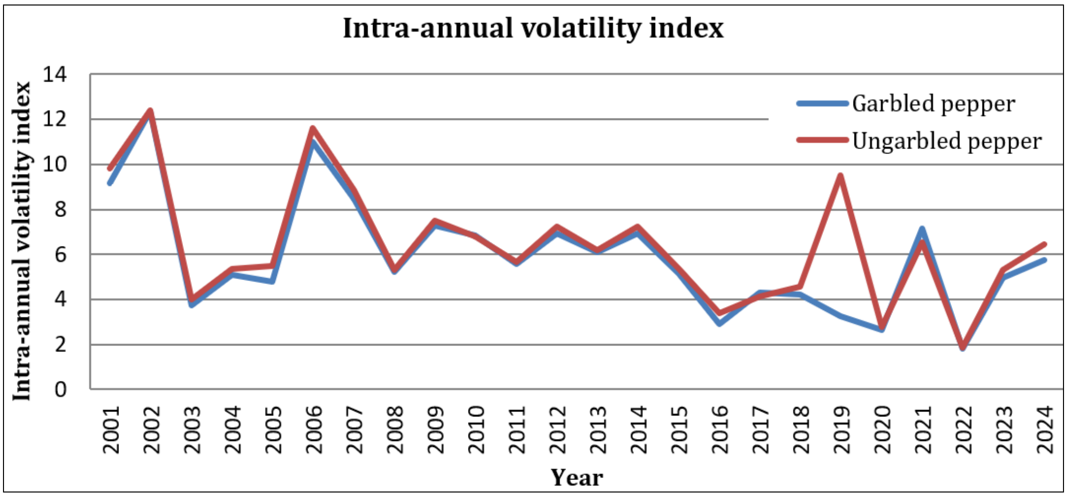

Fig 2: Intra-annual volatility index for GBP and UBP prices

3.3 The key findings are as follows

- **High short-term risk:** Like the inter-annual index, the intra-annual index reveals a high degree of short-term instability. The index often registers above 5 per cent, particularly in the early years (2001, 2002 and 2006), confirming that price fluctuations within a typical 12-month period pose a significant challenge for inventory management and seasonal trading.
- **UBP exhibits higher intra-annual volatility:** Across the majority of the 24 years, UBP consistently recorded a higher Intra-Annual Volatility Index than GBP. This implies that the unprocessed, raw commodity is more susceptible to price instability driven by seasonal supply surges and local market information asymmetry. Since UBP is the primary form in which smallholder farmers sell immediately after harvest, this higher short-term risk directly translates to increased vulnerability and income uncertainty for the growers.
- **Significant volatility events:** The index plot highlights major short-term risk events, such as the peak recorded in 2002 (UBP: 12.39%; GBP: 12.36%) and the high volatility spike in 2006 (UBP: 11.63%; GBP: 10.99%). This volatility often coincides with years of major production uncertainty or external trade shocks.
- **Anomaly in 2019:** A notable divergence occurred in 2019, where the UBP index spiked dramatically to 9.49 per cent while the GBP index remained low at 3.25 per cent. This extreme gap suggests that the ungarbled segment was disproportionately affected by market disturbances associated with the unprecedented floods in 2018 and 2019 (Kumar, 2025), as well as by destabilizing factors such as illegal imports routed through Nepal and Bangladesh and circumvention of trade barriers (Kumar, 2019; GoI, 2019).
- **Comparative risk summary:** Both the inter-annual and the intra-annual analyses point towards the UBP segment bearing a marginally, but consistently, higher volatility risk compared to the standardized GBP.

3.4 Econometric volatility modelling

The final stage of the analysis involved estimating the GARCH model to capture the time-varying nature and persistence of volatility in the price returns of both GBP and UBP. Before fitting any model, a set of preliminary diagnostics was performed.

Table 2: ADF test results for GBP and UBP price returns

Pepper Price	ADF test statistic	Lag order	p-value
GBP	-5.50***	6	< 0.01
UBP	-5.65***	6	< 0.01

Note: *** indicates significance at 1 per cent level

As shown in Table 2, the ADF test statistics for both GBP and UBP price returns strongly reject the null hypothesis of a unit root at the one per cent level. This confirms that both series are stationary satisfying the prerequisite for GARCH modelling.

Table 3: ARCH-LM test results for GBP and UBP price returns

Pepper Price	χ^2 statistic	df	Probability (p-value)
GBP	13.30^{NS}	12	0.35
UBP	15.86 ^{NS}	12	0.20

Note: ^{NS} indicates non-significant

The ARCH-LM test (Table 3) yielded non-significant results for both GBP (p = 0.35) and UBP (p = 0.20). Although the ARCH-LM test does not detect strong linear ARCH effects, volatility clustering and persistence are common features of agricultural commodity prices and motivate the use of GARCH-type models. Given that GARCH models often provide a superior fit and are essential for quantifying volatility persistence—a core objective of this study—the parsimonious GARCH(1,1) model was still estimated to derive comparative risk metrics. The results of the baseline GARCH(1,1) model for both GBP and UBP return series are presented in Table 4.

Table 4: Baseline GARCH model coefficients for GBP and UBP returns

Parameter	GBP returns		UBP returns	
	Estimate	Robust p-value	Estimate	Robust p-value
Omega(α_0)	0	1.00	0	1.00
ARCH effect (α_1)	0.02	0.64	0.02	0.84
GARCH effect (β)	0.97***	< 0.01	0.98***	< 0.01
Shape	3.83***	< 0.01	3.48	0.13
Model fit metrics	**Value**		**Value**	
Log Likelihood	410.33		389.26	
AIC	-2.82		-2.68	
BIC	-2.76		-2.61	

Note: *** indicates significant at 1 per cent level

The coefficient for the short-run shock (α_1) is low and non-significant for both GBP and UBP. This indicates that new information or immediate market shocks have a minimal and statistically negligible direct impact on current volatility after accounting for past volatility. This finding provides context for the non-significant ARCH-LM test. The coefficient for the long-run persistence (β) is highly significant and close to unity for both the series. This signifies a strong market memory where the best predictor of current volatility is the volatility from the previous period.

The persistence for GBP is 0.99, which is extremely close to unity, implying that volatility shocks decay very slowly over several years. The persistence for UBP is 1.00, which suggests near-integrated volatility behaviour. While the raw volatility indices showed UBP as only marginally riskier, the GARCH model reveals that UBP volatility is more persistent and dissipates very slowly, while GBP volatility, though highly persistent, remains technically mean-reverting. This means that a volatility shock in the raw, unstandardized pepper market (UBP) has a much longer-lasting effect on future risk levels compared to the standardized Garbled segment.

Table 5: Post-estimation diagnostics for baseline model residuals

Pepper price	Ljung-Box Q	ARCH-LM
GBP	2.86 ^{NS}	0.42 ^{NS}
UBP	12.06**	0.63 ^{NS}

Note: ^{NS} indicates non-significant and ** indicates significance at 5 per cent level

Model adequacy was checked by analysing the standardized residuals (Tables 5). The model is deemed appropriate if no remaining ARCH effects are found and the residuals are uncorrelated. The high p-values for ARCH LM test on standardized squared residuals confirm that the GARCH(1,1) model has removed remaining conditional heteroscedasticity.

For the Ljung-Box Q statistic, the GBP model residuals are uncorrelated (p = 0.78). For the UBP model, the Ljung-Box test is significant at the five per cent level (p = 0.02), suggesting some residual autocorrelation remains in the variance equation, although the primary objective of adequately modelling conditional variance dynamics was achieved. Overall, the GARCH(1,1) model provides a suitable framework for drawing comparative conclusions on volatility persistence for both grades.

4. Conclusion

This study examined the price behaviour and volatility dynamics of GBP and UBP in the Kochi market over the period from 2001 to 2024 using descriptive statistics, inter- and intra-annual volatility indices and GARCH-based econometric modelling. The results provide a comprehensive picture of both the magnitude and persistence of price risk across the two market segments.

Descriptive statistics confirm that GBP consistently commands a price premium over UBP, reflecting the value addition, quality assurance and standardization achieved through garbling. However, both grades exhibit extremely wide price ranges and high CV, highlighting the inherently risky and cyclical nature of the black pepper market. While GBP experienced slightly higher absolute price fluctuations, UBP showed marginally higher relative volatility when measured against its lower mean price.

The volatility index analysis reinforces these findings. Both inter-annual and intra-annual indices reveal substantial price instability over the study period, driven by international competition, supply shocks, trade policy changes, climatic events and structural shifts. Across most years, UBP recorded higher volatility than GBP, indicating that the raw, heterogeneous product is more exposed to both long-term structural shocks and short-term seasonal fluctuations. The relatively lower volatility of GBP suggests that standardization and quality differentiation provide a modest but consistent buffering effect against market risk.

The GARCH (1,1) model further deepens this understanding by revealing strong volatility persistence in both price series. Short-run shocks were found to be statistically insignificant, while long-run volatility persistence dominated price dynamics. Notably, volatility persistence in UBP was near-integrated, implying that shocks in the raw pepper market have long-lasting effects and dissipate very slowly. In contrast, although GBP volatility is also highly persistent, it remains technically mean-reverting. This distinction indicates that price risk in the ungarbled segment is structurally more entrenched, making smallholders and primary sellers particularly vulnerable to prolonged periods of uncertainty.

Overall, the findings clearly establish that while both GBP and UBP markets are highly volatile, the unprocessed segment bears consistently higher and more persistent risk. Standardization through garbling does not eliminate price volatility, but it reduces both relative instability and the long-run persistence of shocks, thereby offering a partial risk-mitigating mechanism within the pepper value chain.

5. Policy recommendations

1. **Promote on-farm and collective value addition:** Given the lower relative volatility and reduced persistence of shocks in GBP, policies should scale up the existing farmer producer organizations (FPOs) with common processing and grading infrastructure, along with transportable and modular garbling equipment suited to hilly terrain. Such interventions could help smallholders meet minimum quality and standardization thresholds. These initiatives coupled with bundled access to bio-pesticide and need-based training on pest and disease management could ensure consistency in output quality thereby enabling smallholders move up the value chain and reduce their exposure to persistent price risk.
2. **Strengthen market intelligence and price information systems**: The high intra-annual volatility, especially in UBP, underscores the need for enhanced market intelligence systems. While price information systems exist, timeliness and granularity remain problematic, therefore strengthening real-time price dissemination with predictive analytics and early-warning systems for supply shocks would significantly enhance decision-making by farmers, traders and FPOs. Linking domestic price intelligence with futures market signals and export market developments would further improve market transparency and reduce uncertainty arising from abrupt price movements.
3. **Tighten trade regulation and curb illegal imports**: Episodes of disproportionate volatility in UBP prices were linked to illegal imports. Strengthening trade agreements, scaling up the existing United Nations Development Programme (UNDP)-Spices Board pilot initiative by extending block chain traceability system to black pepper and enforcing strict quality and origin standards are essential to protect domestic producers from destabilizing external shocks.
4. **Develop risk management instruments**: The strong volatility persistence revealed by the GARCH(1,1) estimates highlights the need for formal risk management tools. Introducing black pepper-specific price stabilization mechanism can help manage extreme price fluctuations, while hedging can address persistent volatility. Establishing a pepper hedging consortium involving National Bank for Agriculture and Rural Development (NABARD) or cooperative bank for low-cost credit lines, Warehousing Development and Regulatory Authority (WDRA)-registered warehouses for storage and quality certification and National Commodity and Derivatives Exchange Limited (NCDEX) or accredited commodity brokers with dedicated relationship managers for FPOs could also help reduce basis risk and transaction costs.
5. **Enhance climate and disaster resilience:** Extreme volatility events associated with floods and weather anomalies point to the need for climate-resilient production and post-harvest infrastructure. Investments in improved drainage and flood protection measures, resilient pepper varieties and scientific storage facilities can reduce supply disruptions and seasonal price instability.

In sum, reducing price risk in the black pepper market requires a combination of value-chain upgrading, market-based risk management tools, regulatory oversight and institutional support. Policies that facilitate the transition from ungarbled to standardized pepper, while strengthening systemic resilience, can play a crucial role in improving income stability and long-term sustainability of the sector.

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