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Estimation of Risk Related to Agricultural Crops Using the Value at Risk (VaR) Approach

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Abstract

The present study was conducted with the objective of estimating the risk related to agricultural crops using the widely used and applied measure of risk, i.e., Value at Risk (VaR). Two major crops of Pakistan (wheat and rice) were used, and the data regarding their weekly wholesale prices were collected from the official website of the Pakistan Bureau of Statistics (PBS). The data spanned from the 1st week of January 2013 to the last week of October 2023, yielding 565 observations. The collected data were analyzed using MATLAB 2022a. We used different MATLAB packages for the analysis. The results showed that both price series follow leptokurtic (heavy-tailed) behavior, indicating that a fat-tailed distribution is needed to estimate the true Value at Risk (VaR) for both crops. Mean returns were positive, indicating prices increased over the period. Wheat and rice returns showed very high volatility and volatility clustering, which can be interpreted as riskiness. The returns deviate from normality due to negative skewness, indicating variability in both; using VaR, we found that Rice is riskier than Wheat. Likewise, the prices were calculated through value at risk, historical value at risk and historical predictable shortfall. This shows that normal-distribution VaR can significantly underestimate historical VaR.

Keywords: Value at risk (VaR); agricultural crops; wheat and rice; price volatility; historical var

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Introduction

The word agriculture is derived from the Latin word agricultura, which combines ager, meaning "field" and cultura, meaning "cultivation" or "growing" [1]. Agriculture is the fundamental sector that integrates human livelihood, food production, and economic activities. Agriculture is the backbone of Pakistan's economy and plays a vital role in the country's development, food security, poverty reduction, industrial development, and overall economic growth, particularly in developing countries [2]. In Pakistan, agriculture is a major component of the economy, contributing 21% to GDP and employing 45% of the workforce. Additionally, about 62% of the rural population depends on agriculture for their livelihood, highlighting its importance for the country's economic stability and rural development [3].

Agriculture is exposed to a wide range of uncertainties, which have increased significantly in recent years [4]. These risks arise from various sources and affect agricultural production at different geographic and policy levels. Major agricultural risks include production risks from adverse weather, pests, diseases, and biosecurity threats; market risks from fluctuations in input and output prices; and financial risks related to credit and loan availability. Other important risks include technological changes that affect productivity, institutional risks tied to legal, environmental, and tax policies, and human resource risks linked to farmers' physical and mental health [5]. Effectively managing these risks is essential to ensuring agricultural sustainability and productivity. Risk refers to the possibility of adverse outcomes resulting from uncertainty and imperfect knowledge in decision-making [6, 7]. It encompasses both the likelihood of a harmful event occurring and its potential consequences for human well-being, economic stability, property, or the environment [8]. A hazardous event becomes a risk when it can cause social, environmental, economic, or cultural damage.

Agriculture faces risks from natural, economic, and institutional factors, including weather and climate change, pests, disease, disasters, market fluctuations, policy shifts, and infrastructure limits. Production risk comes from uncertain biological and environmental conditions affecting yields; market risk reflects changing input and output prices [9]. Financial risks involve credit, investment, and cash flow, while strategic and business risks concern long-term planning and operations. Climate change and market volatility have heightened these risks, especially for smallholder farmers [10, 11]. Effective agricultural risk management (ARM) builds resilience, improves decisions, and supports sustainable development. Statistical and econometric methods assess uncertainty and potential losses. Statistical measures also evaluate investment risk and volatility and underpin Modern Portfolio Theory (MPT).

Common risk indicators include alpha, beta, R-squared, standard deviation, and the Sharpe ratio, each offering a distinct perspective on an investment's risk level [12]. From an econometric perspective, particularly in financial risk analysis, market or price risk is commonly measured using Value at Risk (VaR). VaR is a statistical tool that estimates the maximum expected loss of an asset or portfolio over a specified period at a given confidence level. It quantifies the likelihood and magnitude of potential losses arising from market price fluctuations, making it a widely used measure for risk assessment and management [13]. Based on the above, this research will (i) assess agricultural price risk in major Pakistani crops (Wheat and Rice) using the Value at Risk (VaR) approach; (ii) compare the magnitude of price risk between Wheat and Rice using parametric and historical VaR estimates; and (iii) forecast potential future price losses and evaluate downside risk within the VaR framework.

Methodology

.1 *Data description*

This study used secondary data on the weekly average prices of two major agricultural commodities in Pakistan: wheat and rice. The data were obtained from official publications of the Pakistan Bureau of Statistics (PBS). The sample period spans from the first week of January 2013 to the last week of December 2021, comprising 565 weekly observations for each commodity. The collected data were processed and analyzed using MATLAB R2022a. The study used MATLAB's built-in statistical and econometric toolboxes for data management, estimation, and risk analysis.

.2 *Analytical Measures*

The study evaluates market risk in wheat and rice prices using Value-at-Risk (VaR) and Expected Shortfall (ES) within the Extreme Value Theory (EVT) framework. These measures are widely used in financial risk management to quantify potential losses arising from extreme market movements. Value-at-Risk (VaR) is one of the most widely used measures of financial risk. It estimates the maximum expected loss over a specified holding period at a given confidence level. Let X denote the loss (or negative return) of an asset with cumulative distribution function F(X). The VaR at confidence level (p) is defined as:

Where (F) VaR measures the threshold loss that is expected not to be exceeded with probability (p) over a specified time horizon. In financial and commodity markets, portfolio monitoring, capital allocation, and regulatory compliance.

.3 *Expected Shortfall (ES)*

Although VaR indicates the maximum probable loss at a given confidence level, it does not show the magnitude of losses beyond the VaR threshold. To overcome this limitation, Expected Shortfall (ES), also known as Conditional Value-at- Risk (VaR) or tail Conditional Expectation, is employed.

Expected Shortfall is defined as the expected loss conditional on losses exceeding the VaR level:

Unlike VaR, Expected Shortfall satisfies the properties of a coherent risk measure and provides a more comprehensive assessment of tail risk by incorporating the severity of extreme losses. The historical simulation method was employed to estimate Value-at-Risk. This non-parametric method assumes that future market behavior will resemble historical market behavior and therefore does not require any distributional assumptions regarding asset returns.

Under the Historical Simulation framework, a rolling window of historical observations is used to construct the empirical distribution of returns. Within each window, observations are ranked from lowest to highest, and the desired quantile is selected to estimate VaR. Specifically, the 1st and 5th percentiles of the empirical distribution were used to estimate VaR at the 99% and 95% confidence levels, respectively. The Historical Simulation approach is widely used because it is simple, transparent, and can

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capture the non-normal characteristics commonly observed in commodity and financial return series.

Results and discussions

.4 *Descriptive statistics*

It is observed that the numbers on the y-axis change; the prices vary from 2013 to 2021, which means there is a great variation in wheat and rice prices. Both crops show an increasing trend over time, indicating that prices are non-stationary. Rice prices decreased sharply by the end of 2019 due to high production and in 2021 due to COVID-19. Due to the non-stationary structure of the prices of Wheat and Rice, the continuously compounded log-returns were calculated for both price indices, which made them stationary, but they still show non-normal behavior, which means some extreme value allocation is required to model the behavior of returns like Value at Risk, Expected Shortfall, Spectral Risk Measure, etc. Guo and Tanaka [14] also used these measures to calculate extreme losses. In this study, Value at Risk and historical Expected Shortfall were calculated. Fig. 1 shows the time plot of average weekly prices for wheat and rice from the 1st week of January 2013 to the last week of December 2021.

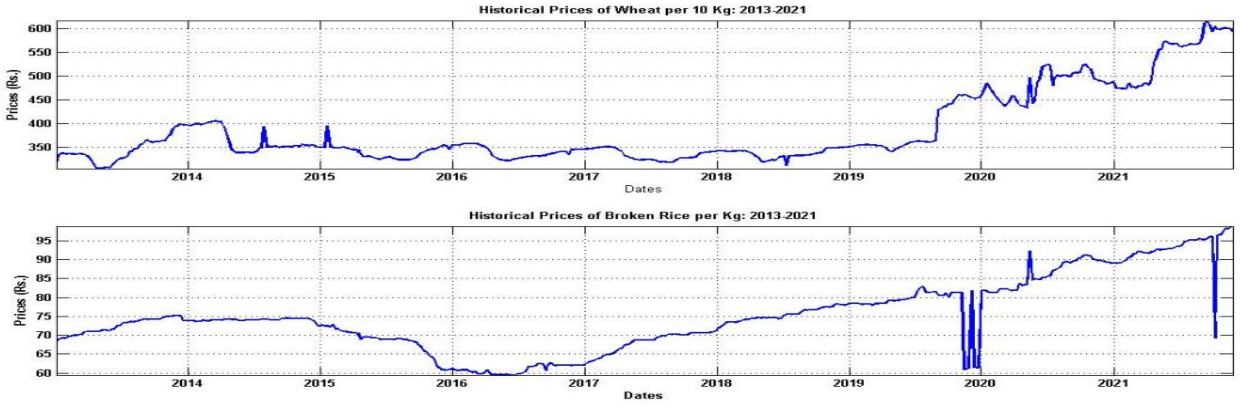

Fig. 1. Time plot of historical prices of Wheat and Rice 2013-2021

Table 1. Summary statistics of historical prices of Wheat and Rice

Measures	Wheat Price	Rice Price
Min	305.070	59.450
Max	617.090	98.900
Mean	383.935	74.951
Variance	5735.243	92.706
Skewness	1.419	0.490
Kurtosis	3.884	2.662

The minimum weekly wheat and rice prices are 305.070 and 59.450, while the maximum is 617.090 and 98.900, respectively. The mean wheat prices are 383.935 and 74.951, while the variance is 5735.243 and 92.706; the large variance indicates greater variability in wheat prices. Similarly, the skewness values are 1.419 and 0.490, and the kurtosis values are 3.884 and 2.662, indicating that prices deviate from normality, with positive skewness and leptokurtic behavior. Fig. 2 shows the continuously compounded log returns (%) calculated using the formula presented in the previous chapter. Firstly, wheat returns, then rice returns and then the combined time plot of % log returns of wheat and rice, 2013-2021. The dotted line in the middle shows the long-term mean (which is also known as the unconditional mean) of the data. The mean and variance are now constant over time, which can be interpreted as returns being a function of lagged values but not a function of time. So, we can say returns are now stationary (with no trend). Furthermore, returns behave similarly to prices, showing high volatility at the end of 2019 and 2021 for Rice and during 2020 for Wheat.

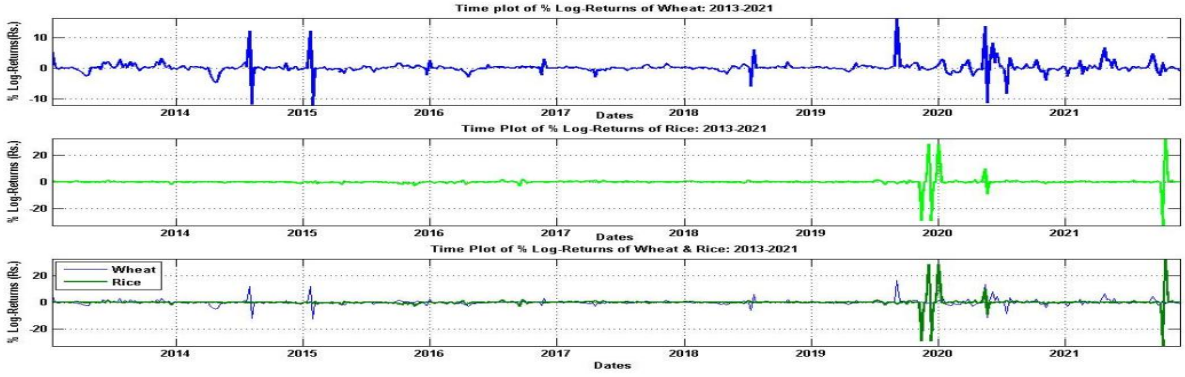

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Fig .2. Time plot of returns from wheat and rice 2013-2021

So far as the summary statistics of log-returns are concerned, it can be seen that the mean of the Wheat and Rice returns is near zero (0.137), (0.080), and there is a large difference between the minimum (-12.185), (-32.637) and maximum (16.469), (32.990) values of the returns. The variance is also high, indicating significant fluctuations in weekly Wheat and Rice returns. There is also evidence that wheat returns are positively skewed, and rice returns are negatively skewed, which shows that the left tail is particularly extreme, which is ultimately an indication of asymmetric returns. Furthermore, the Wheat and Rice returns are leptokurtic or fat-tailed due to their large values of kurtosis (27.681, 70.816), which show that both are away from normality, as the number of bins falls outside the superimposed normality curve, which is a clear indication that both variables' distributions are away from normality.

Table .2. Summary statistics of historical returns from wheat and rice 2013-2021

Measures	Wheat Returns	Rice Returns
Min	-12.185	-32.637
Max	16.469	32.990
Mean	0.137	0.080
Variance	4.232	12.506
Skewness	1.389	-0.015
Kurtosis	27.681	70.816

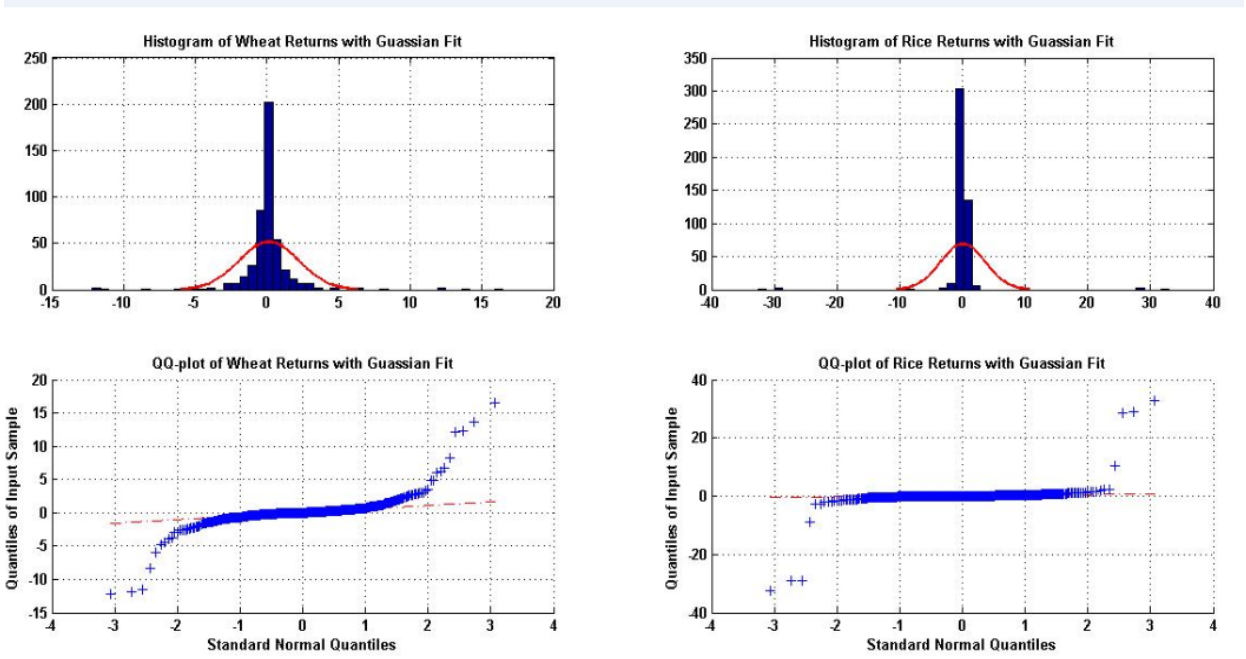

Fig. 3. Histogram and QQ- Plot of returns from wheat and rice

In the histogram in Figure 4.3, we can also see that, in both cases, the bins are away from the superimposed curve, which means they are not normally distributed same thing we can observe in the QQ plot: in the tails, the values show that returns are away from normality.

.5 Value at Risk (VaR)

Table .3. Value at risk at different α-quantile using Normal distribution

Crop	0.1 (10%)	0.05 (5%)	0.01 (1%)
Wheat	-3.2471	-3.895	-5.1622
Rice	-5.7378	-6.8518	-9.0302

On the basis of 465 weekly % return observation for every one of the stated indexes over the time of Jan-2013 throughout November 2021, By using VaR we found that on alpha level 0.1(1%) we have -3.24715% chances to get lose in returns of wheat prices and -5.7378% chances to get lose in Rice returns with alpha level 0.05(5%) level we have 3.895 in wheat and 6.8518 percent chances of getting lose and with 0.01(1%) alpha level we have -5.1622 in wheat and -9.0102 percent chances in rice of getting lose, this also shown in figure .4 with returns and VaR at 10%, 5%, 1% level of significance using normal distribution on first panel with wheat return and on second panel with rice returns. By plotting the historical graph and QQ plot of the value at risk of the normal distribution, we can also see that both histograms' bins are away from the

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superimposed curve, which means they are not normally distributed; the same thing we can observe in the QQ plot: in the tails, the values show us abnormality. It assumes no trading; the portfolio is marked-to-market.

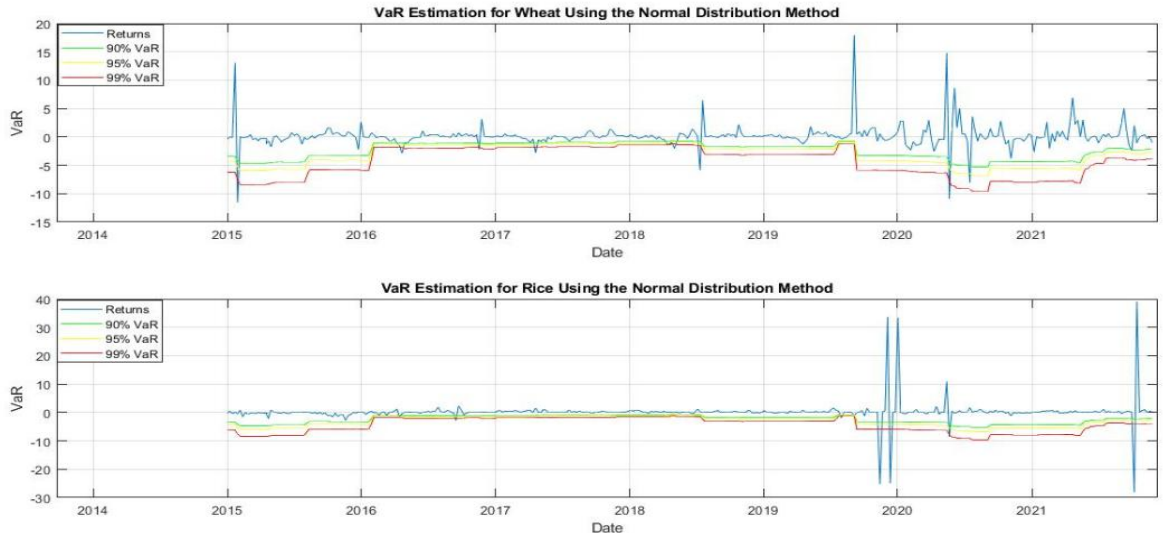
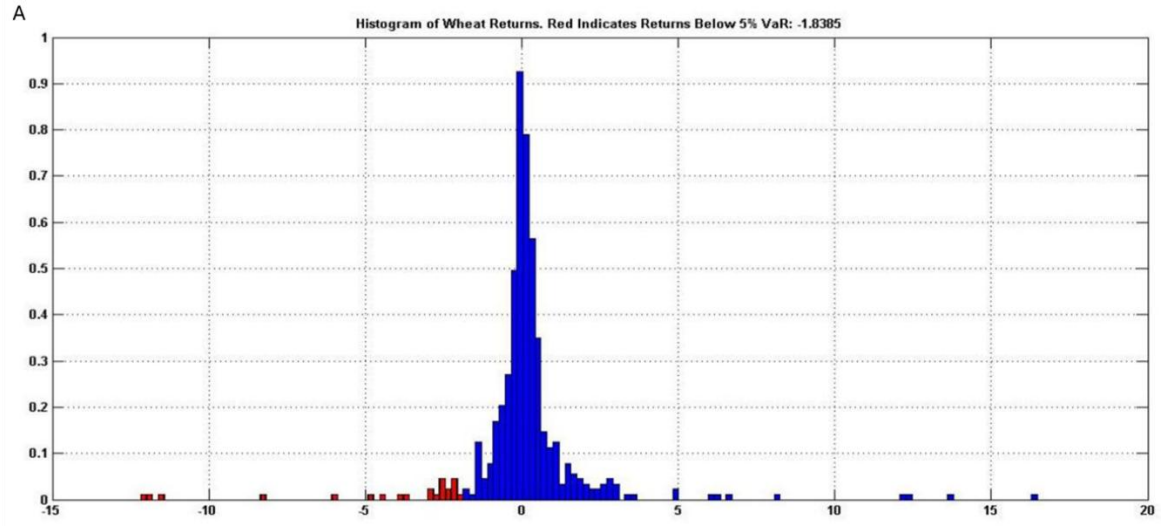


Fig. 4. Plotting of returns and VaR at different α-quantiles using normal distribution

Table .4. Historical value at risk using different α-quantiles

Crops	0.1 (10%)	0.05 (5%)	0.01 (1%)	0.1(10%)	0.05(5%)	0.01(1%)
Wheat	-0.9632	-1.8385	-5.993	-2.847	-4.266	-9.959
Rice	-0.3303	-0.782	-2.7786	-3.024	-5.349	-20.409

On the basis of 464 weekly % return observation for each one of the confirmed over the period of January 2013 throughout November 2021, By using historical VaR we found result at 10% level of significance the chances of getting loss is (-0.9632) of wheat and (-0.3303) of rice, at 5% level of significance the chances of getting loss is (-1.8385), (-0.782) and on 1% level of significance chances the of(-5.993), (-2.7786) of Wheat and Rice, and then by using historical expected short fall at 10% level of significance on Wheat and Rice the chances of loses are(-2.847), at 5% level of significance (-4.266),(-5.349), at 1% level of significance (-9.959),(-20.409) chances of loses, respectively. The descriptive statistics of log-returns showed that the mean of the returns of Wheat and Rice was nearly 0 (0.137), (0.080) with a large variance (4.232), (12.506) showing that there is great variability present in the log returns of Wheat and Rice prices, Similarly, the measures of Skewness is (3.419), (0.490) and kurtosis is (3.884), (2.662) that indicates that returns of both were away from normality but there are more variability in Rice then Wheat or can be said that the Rice were more riskier than Wheat. This shows that rice has more variability than wheat; Fig. 5 also shows the historical VaR of Wheat at the 10%, 5%, and 1% significance levels, where the left tail shows losses. The historical VaR of Rice at 10%, 5% and 1% shows the losses in the tail (Fig. 6). The (p-VaR) can be formally defined as the largest loss possible during that time after excluding any worse events whose combined probability is t most p for a particular portfolio, time horizon, and probability p. Businesses and authorities in the financial sector frequently utilize Value at Risk (VaR) to estimate the amount of assets required to cover potential losses.



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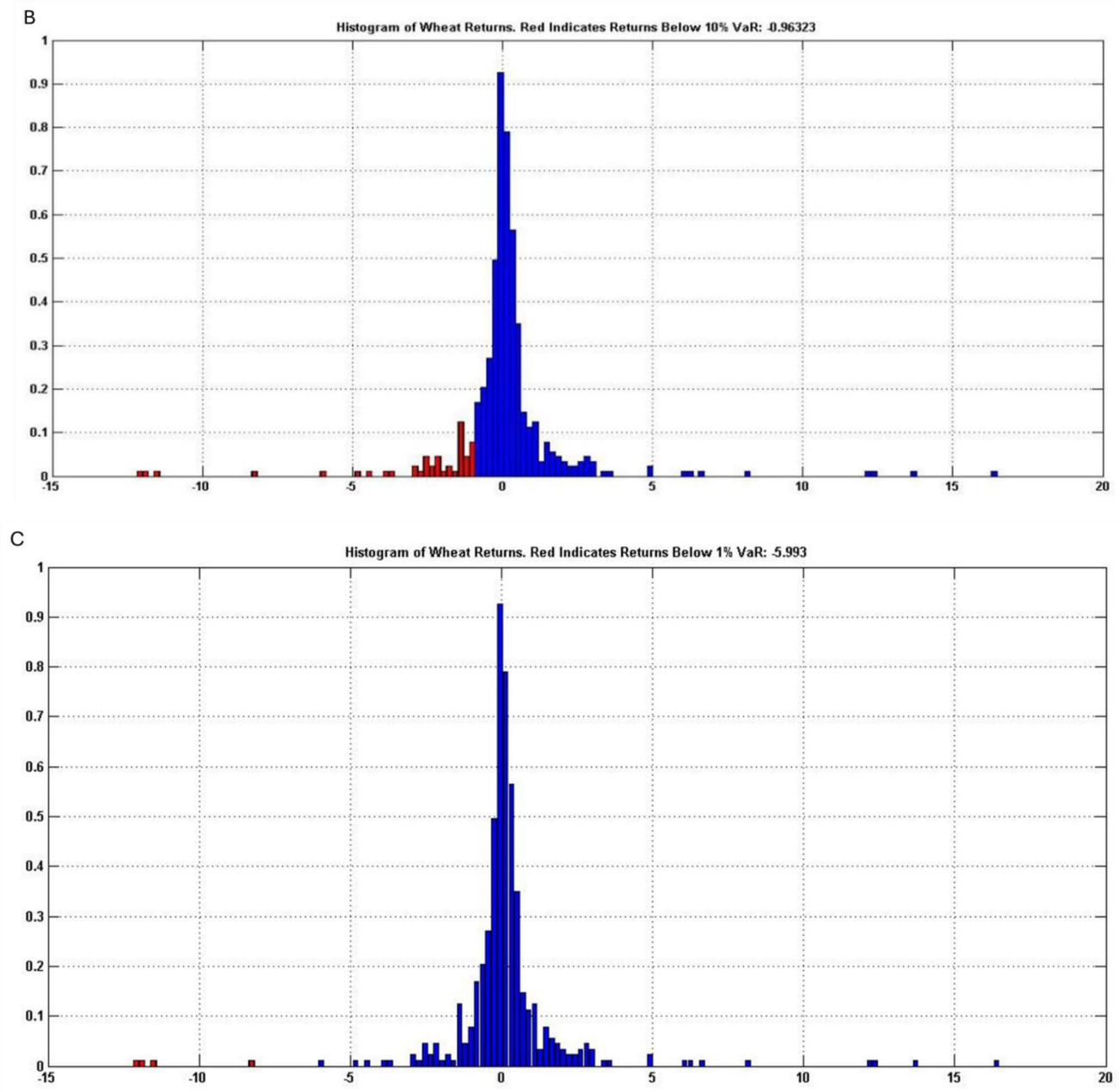
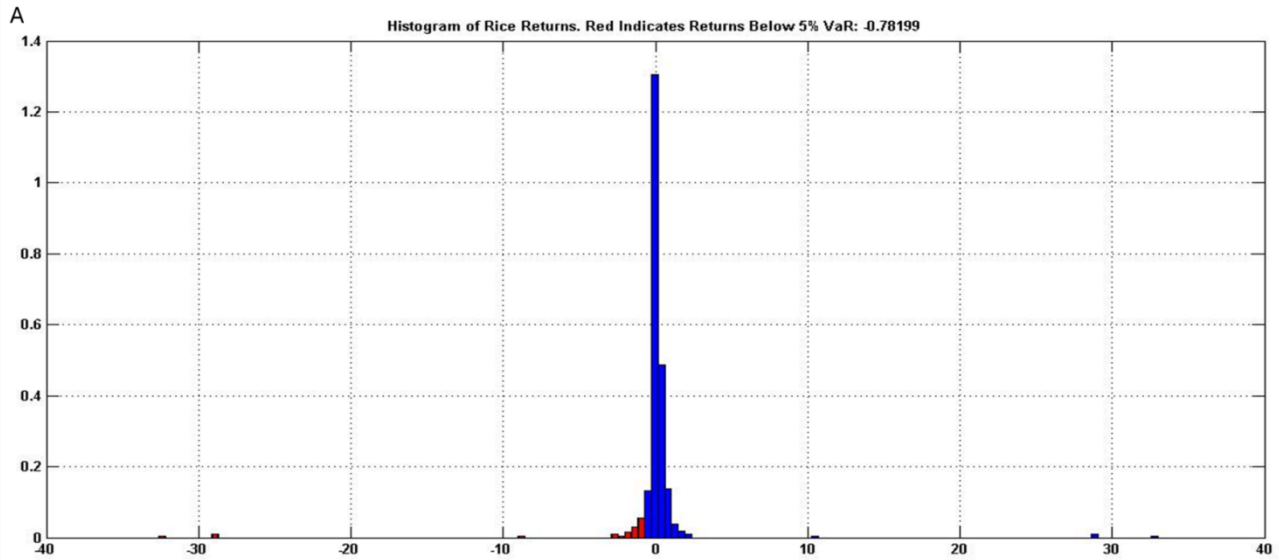


Fig .5. Historical Value at Risk for wheat crop.



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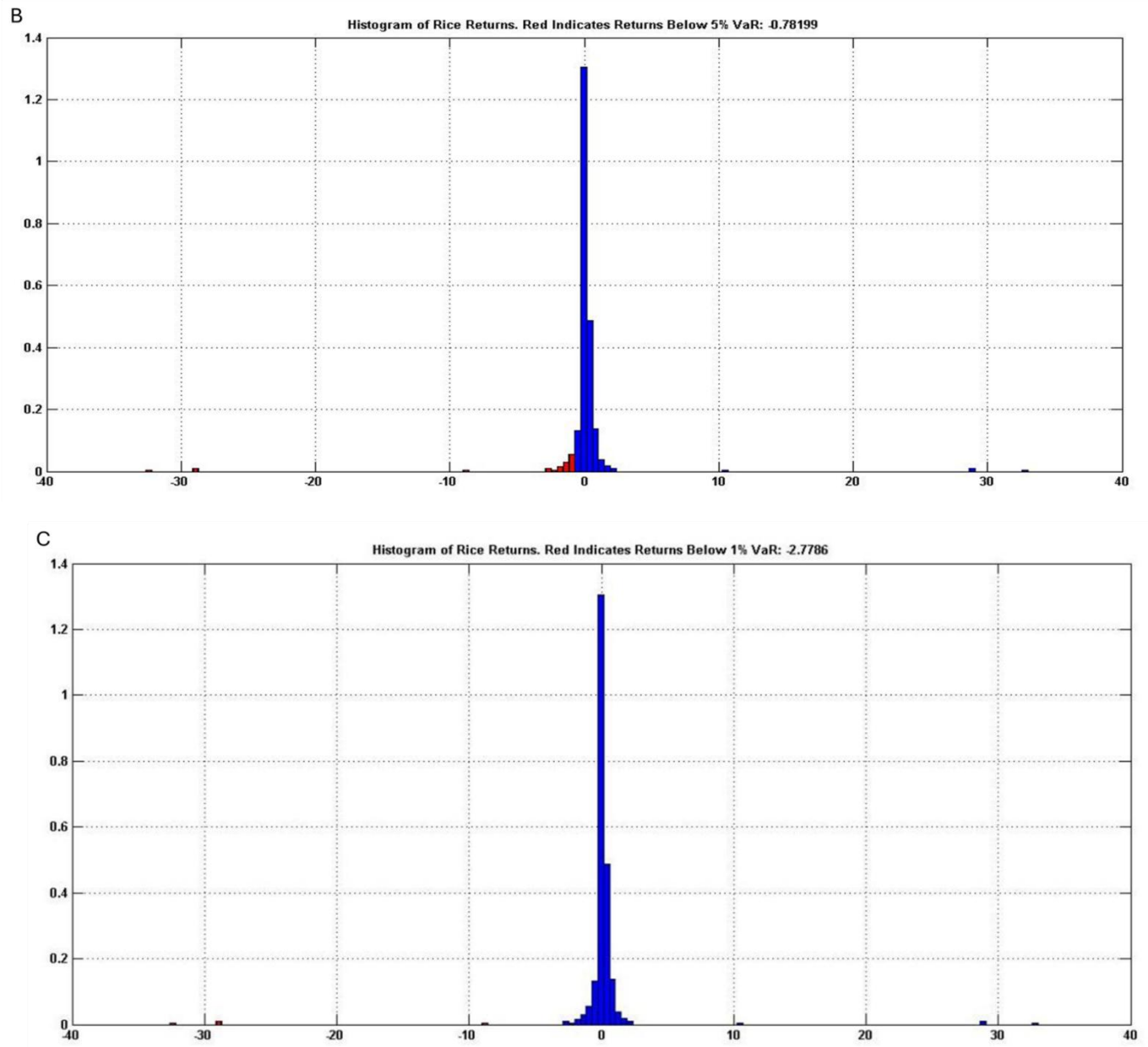

Fig. 6. Historical value at risk for rice crop

Conclusion and recommendations

The study concludes that both wheat and rice generated positive mean returns during the study period, indicating an overall increase in prices; however, their returns also showed substantial volatility and volatility clustering, reflecting considerable financial risk. The negatively skewed returns further indicate that the price series did not follow a normal distribution. Based on VaR, historical VaR, and Historical Expected Shortfall, both commodities were exposed to financial risk, with rice found to be comparatively riskier than wheat. Therefore, farmers, traders, and investors should consider price volatility carefully when making production, marketing, and investment decisions. The findings suggest risk-averse farmers and investors should use historical price information more effectively to understand market behavior and prepare for potential losses. Monitoring price trends, improving marketing decisions, diversifying income sources where possible, and avoiding dependence on a single marketing period can help reduce exposure to price risk. Greater awareness of historical volatility and sound risk-management practices can help agricultural stakeholders make better-informed decisions and better manage unexpected changes in wheat and rice prices. The comparison of risk-measurement methods also shows that Historical VaR was considerably higher than parametric VaR based on the normal distribution for both commodities. This suggests that the normal-distribution approach may underestimate actual market risk when returns are negatively skewed and non-normally distributed. Therefore, farmers, investors, traders, financial institutions, and policymakers should not rely solely on parametric VaR. Historical Expected Shortfall should be used alongside other risk-management techniques to obtain a more realistic assessment of potential losses and support stronger financial planning and stability in agricultural commodity markets.

Declarations

- **Ethics approval and consent to participate**

This study did not involve human participants, human data, or animals, and therefore did not require ethical approval. All experimental procedures were conducted in accordance with institutional and scientific research guidelines.

- **Consent for publication**

Not applicable.

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* **Availability of data and material**

Data and materials will be made available upon request.

* **Competing interests**

The authors declare no competing financial interests or personal relationships that could have influenced the work reported in this paper.

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