Zagazig J. Agric. Res., Vol. 52 No. (4) 2025 765-786

Plant Production Science

Available online at http://zjar.journals.ekb.eg
http:/www.journals.zu.edu.eg/journalDisplay.aspx?Journalld=1&queryType=Master

EVALUATING THE IMPACT OF TEMPERATURE AND RAINFALL ON LINSEED PRODUCTIVITY: A CASE STUDY OF INDIA

Ahmed A.A.M. El-Bannan[1]*, A.A. Hassan[2] and A.M. Morsi[3]

1. Nat. Res. Dept., Fac. Graduate Asian Studies, Zagazig Univ., Egypt

2. Agric. Sci. Dept., Coll. Technol. Dev., Zagazig Univ., Egypt

3. Agron. Dept., Agric. Res. Cent., Giza, Egypt

Received: 14/08/2025; Accepted: 26/08/2025

ABSTRACT: India is situated north of the equator between 8°4' north to 37°6' north latitude and 68°7' to 97°25' east longitude. It is the seventh largest country in the world; its total area is 3,287,263 square kilometers. Linseed (*Linum usitatissimum* L.) is one of the most important industrial oilseed crops in India. It is cultivated for the oil extracted from seeds or stem fiber. All parts of the linseed plant are used commercially, either directly or after processing. Temperature and rainfall are exogenous variables beyond the control of farmers, and fluctuations in temperature and rainfall are completely natural. It has been observed that fluctuations in temperature and rainfall lead to fluctuations in production, which in turn leads to changes in prices. Given the importance of temperature and rainfall in determining agricultural production and prices, the study sought to forecast monthly temperature and rainfall in India with the help of time series analysis using monthly rainfall data. This study aims to analyze the impact of temperature and rainfall changes on linseed productivity. To achieve this objective, the distribution of temperature and rainfall in India was evaluated, the current impacts of temperature and rainfall changes on linseed productivity from 1990 to 2025 were studied, and the future impacts of temperature and rainfall changes on linseed productivity from 2026 to 2061 were projected. This study collected monthly climatic data from the World Bank database for India. The variables included air temperature and rainfall. Graphs were created to visualize changes over time. The data were visualized using Boxplot. The temperature shows an overall increasing trend, this indicates that the temperature has been rising at an average rate of approximately 0.0242°C per year, starting from a base of around 20.84°C. The coefficient of determination (R^2 = 0.3136) suggests a moderate level of fit, meaning that about 31.36% of the variability in temperature can be explained by the passage of time., confirming that warming is expected to persist in the coming decades. The extremely low R^2 value indicates that time does not explain any meaningful portion of the variability in rainfall. The productivity has nearly tripled from ~0.29 t/ha in 1990 to ~0.74 t/ha in 2025, showing substantial agricultural development and R^2 = 0.8398

Key words: Temperature, Rainfall, linseed productivity, India

INTRODUCTION

Oilseeds are derived from oil-bearing crops/ plants seeds which are used for the extraction of vegetable oils and are a highly valuable source of proteins, lipids, carbohydrates and functional components **(Bakhytkyzy *et al.*, 2023; Dąbrowski *et al.*, 2025)**. Oilseeds rank sixth among important food commodities after cereals, vegetables, melons, fruits, and nuts, and occupy about 213 million hectares of arable land worldwide **(OECD-FAO, 2020)**. However, the utilization and demand of oil crops continuously increases due to high population pressure, vagaries in dietary choices, cumulative global affluence, and the need for more renewable bio-products

*** Corresponding author: Tel. :+201006143520**
E-mail address: atef98716@gmail.com

(Villanueva-Mejia and Alvarez, 2017). Vegetable oil is used as a biofuel, so it has a great future as an essential energy source **(Lu *et al.*, 2011)**. Due to their specific chemical and physical properties, vegetable oil is an important feedstock used to produce multiple industrial materials, including promising applications such as biofuel and constituting an alternative to petroleum derivatives **(Lu *et al.*, 2011)**. Oilseed crops are a significant source of animal **(Ponnampalam *et al.*, 2019)** and human nutrition **(Rahman *et al.*, 2018a)** and industrial products **(Liu *et al.*, 2018a)**, and biodiesel production **(Mohammad *et al.*, 2018)** has been increasing day by day. The quality and consumption of oilseed crops have been improved through different genetic engineering techniques **(Tan *et al.*, 2011)**.

Across the globe, contemporary agriculture is facing unprecedented environmental pressure and stress due to climatic variability **(Argosubekti, 2020)**. Plants' growth in open environments faces several challenges, including heat, drought, cold, waterlogging, and salinity **(Ashraf *et al.*, 2018)**. Elevated temperature is one of the major concerns for the world as different models have predicted the rise of carbon dioxide (CO_2), causing an increase in the ambient temperature leading to global warming **(NOAA, 2017)**, which would have severe consequences for agriculture production systems across the globe. The Intergovernmental Panel on Climate Change (IPCC) estimates that the global ambient temperature will increase by 1.5°C from 2030 to 2052 **(IPCC, 2018)**. Temperature induced heat stress is articulated as the shift in air temperature exceeding the threshold level for an extended period that could cause injuries or irreversible damage to crop plants in general **(Teixeira *et al.*, 2013)**. Therefore, heat stress has proven to be a great menace and ever-looming threat to fruitful crop production around the globe **(Tariq *et al.*, 2018)**. The consequences of global climate change and spatial, temporal, and regional patterns are of considerable concern in agriculture production **(Porter and Moot, 1998)**. Heat stress speeding up crop growth and not allowing the proper completion of crop growth stages results in immature development **(Rahman *et al.*, 2018a)**, perturbing carbon assimilation. This is an urgent matter, given that the geographical distribution of plant species depends to a large extent on their adaptation to different temperature zones **(Keller and Seehausen, 2012)**.

Additionally, the world population is expected to reach 9 billion by 2050. Agriculture production needs to be enhanced up to 70% regardless of climate change and its impact on agriculture **(Rahman *et al.*, 2018b)**. However, all the growth stages in plants are affected adversely by heat stress right from germination to growth and development, reproductive phase, seed yield **(Ahmad *et al.*, 2016)**, and seed quality in oilseed crops **(Ahmad *et al.*, 2021a)**. The rise in global temperature will ultimately damage the ecosystem comprehensively **(Kanojia and Dijkwel, 2018)**. Specifically, heat stress is a severe threat to oilseed crops as it impairs the production and quality of the yield; for example, the seed yield decreased up to 39% in camelina and 38% in canola under elevated temperature scenarios **(Ahmad *et al.*, 2021b)**.

The temperature fluctuations have made it imperative to develop climate-resilient varieties that display better adaptability for growth under varied environmental conditions **(Bhat *et al.*, 2021; Dąbrowski *et al.*, 2025)**. However, achieving this objective will be complicated by the fact that the performance of oilseeds may be hampered by environmental impacts related to climate change and the associated increase in pests and diseases, which are likely to become more challenging in the near future **(Rahman *et al.*, 2019)**. Therefore, hypothetically, several options can be used to achieve improvements in seed yield and related traits (either alone or in combination), increase seed oil content, or reduce seed yield losses due to abiotic stresses, including high temperature at the sensitive crop stage **(Valantin-Morison and Meynard, 2008)**.

Rainfed agriculture constitutes 80% of global agriculture and plays a critical role in achieving global food security. The importance of rainfed agriculture varies regionally, but it produces most food for poor communities in developing countries. The proportion of rainfed agriculture is 95% in Sub-Saharan Africa (SSA), 90% in Latin America, 60% in South Asia (SA), 65% in East Asia, and 75% in Near East and North Africa **(FAO, 2003)**. India ranks first in rainfed agriculture globally in both area (86 Mha) and the value of produce. Rainfed regions in India contribute substantially towards food grain production including 90% of minor millets, 87% of coarse cereals, 85% of food legumes, 72% of oilseeds, 65% of cotton, and 44% of rice.

Research Problem

Linseed is an important oilseed crop in India, but its productivity often changes from year to year. These changes may be influenced by climate factors such as temperature and rainfall. Until now, there has been limited research that clearly explains how these two factors affect linseed productivity in India. This study, therefore, focuses on examining the impact of temperature and rainfall on the productivity of linseed in India.

Research Objectives

The main goal of this research study was to achieve the following main objectives: (i) determining the extent of influence of temperature and rainfall variability on year-to-year changes in linseed productivity. (ii) Using statistical models such as time-series analysis and linear regression to forecast potential future changes in linseed productivity based on climatic variables. (iii) Providing practical recommendations for policymakers and farmers on adaptive strategies to mitigate climate-related impacts and enhance linseed productivity in India.

MATERIALS AND METHODS

Study Area

India is situated north of the equator between 8°4' north to 37°6' north latitude and 68°7' to 97°25' east longitude. It is the seventh-largest country in the world, with a total area of 3,287,263 square kilometres (1,269,219 sq mi). India measures 3,214 km (1,997 mi) from north to south and 2,933 km (1,822 mi) from east to west. It has a land frontier of 15,200 km (9,445 mi) and a coastline of 7,516.6 km (4,671 mi).

On the south, India projects into and is bounded by the Indian Ocean in particular, by the Arabian Sea on the west, the Lakshadweep Sea to the southwest, the Bay of Bengal on the east, and the Indian Ocean proper to the south. The Palk Strait and Gulf of Mannar separate India from Sri Lanka to its immediate southeast, and the Maldives are some 125 kilometers (78 mi) to the south of India's Lakshadweep Islands across the Eight Degree Channel. India's Andaman and Nicobar Islands, some 1,200 kilometers (750 mi) southeast of the mainland, share maritime borders with Myanmar, Thailand and Indonesia. Kanyakumari at 8°4′41″N and 77°55′230″E is the southernmost tip of the Indian mainland, while the southernmost point in India is Indira Point on Great Nicobar Island. The northernmost point which is under Indian administration is Indira Col, Siachen Glacier. India's territorial waters extend into the sea to a distance of 12 nautical miles (13.8 mi; 22.2 km) from the coast baseline. The northern frontiers of India are defined largely by the Himalayan Mountain range, where the country borders China, Bhutan, and Nepal. Its western border with Pakistan lies in the Karakoram range, Punjab Plains, the Thar Desert and the Rann of Kutch salt marshes. In the far northeast, the Chin Hills and Kachin Hills, deeply forested mountainous regions, separate India from Burma. On the east, its border with Bangladesh is largely defined by the Khasi Hills and Mizo Hills, and the watershed region of the Indo-Gangetic Plain.as shown in Fig. 1.

Data Collection

The study will analyze meteorological data from national meteorological agencies and stations in India, focusing on average temperature, rainfall from (1990 to 2025) using information from the World Bank websites dataset and linseed productivity from (1990 to 2025) using information from FAOSTST websites dataset.

Temporal changes in temperatures, rainfall and linseed productivity

Graphs were created using Microsoft Excel 365 to visualize the changes over time in data to India, specifically average temperatures and rainfall which obtained from the World Bank websites dataset in India, including average temperatures and total rainfall. Average linseed productivity which data obtained from the FAOSTAT websites dataset in India, including average linseed productivity. Boxplot was used to show the data.

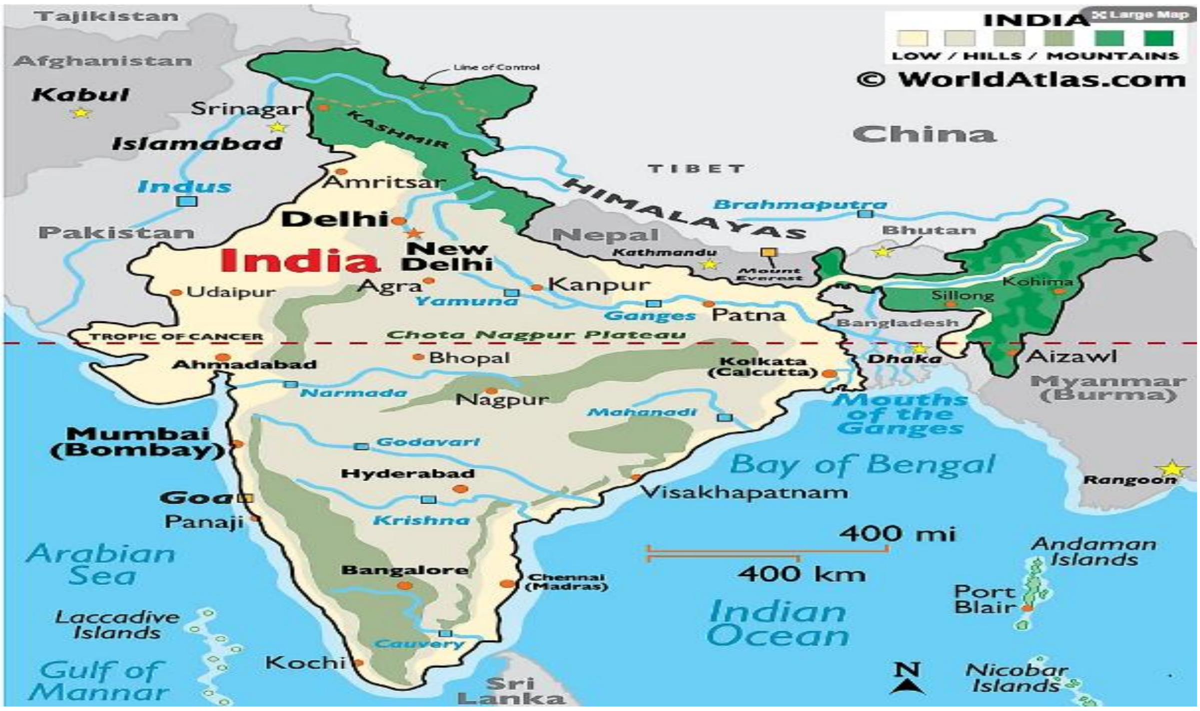

Fig. 1. The geographical location of India

Source: (https://www.worldatlas.com/maps/india)

Correlation Matrix

A correlation matrix is a table that displays the correlation coefficients between multiple variables. The correlation coefficient measures the strength and direction of the linear relationship between two variables, with values ranging from -1 to 1.

A positive correlation coefficient indicates a positive linear relationship, meaning that as one variable increases, the other variable also tends to increase. A negative correlation coefficient indicates a negative linear relationship, meaning that as one variable increases, the other variable tends to decrease. A correlation coefficient of 0 indicates no linear relationship between the variables. (Using SPSS V23 programming, a correlation matrix was created to investigate the relationships between various variables in a dataset, including averages temperatures, averages Rainfall, and linseed productivity. The correlation matrix provides a useful tool for identifying any significant correlations between the variables and exploring the patterns of their relationships.

Multiple linear regression analysis

Multiple linear regression analysis is a statistical method used to examine the relationship between one dependent variable and two or more independent variables, it helps researchers understand how these independent variables, collectively and individually, influence the outcome being studied. This technique is particularly useful when dealing with complex datasets where multiple factors might affect a single outcome. (**Bakst, 1931**). By using SPSS V23 programming, it summarizes the performance of the multiple linear regression model that includes temperature and rainfall as independent variables to predict linseed productivity.

ANOVA for the multiple regression model

In multiple regression, ANOVA (Analysis of Variance) is used to test the overall significance of the model, assessing whether the independent variables collectively explain a significant amount of variance in the dependent variable. The ANOVA table partitions the total variation in the dependent variable into components attributable to the model (explained variation) and to unexplained variation (error or residuals). (**Irwin, 1983**). By using SPSS V23 programming, the variables (temperature and rainfall) together explain the variation in productivity.

Regression coefficients

A regression coefficient is a numerical value that quantifies the relationship between a predictor variable and a response variable in a regression model. It represents the change in the response variable for a one-unit change in the predictor variable, while holding other predictors constant. In essence, it tells you how much the dependent variable is expected to increase or decrease for every one-unit increase in the independent variable. (**Irwin, 1983**). By using SPSS V23 programming, the model aims to quantify the direction and magnitude of two independent variables: average seasonal temperature and annual rainfall, each predictor's effect on productivity while controlling for the other.

Scatter Plot

A scatter plot is a type of graph that displays values for two numerical variables as a set of points. It's used to visually represent the relationship between these variables, showing whether they tend to increase or decrease together (positive correlation), move in opposite directions (negative correlation), or show no clear pattern. Scatter plots help visualize potential relationships between two variables. For example, you can use a model to determine whether there is a relationship between temperature and linseed productivity, or between rainfall and linseed productivity. Using SPSS version 23, the relationship between both is explained: temperature versus yield, and rainfall versus yield.

Air temperature for linseed and forecasting in India

Fig. 2 illustrates the trend of mean surface air temperature during the linseed growing season (November–April) in India from 1990 to 2025. The temperature shows an overall increasing trend, as evidenced by the linear regression equation:

$$y = 0.0242x + 20.84 \text{ with } R^2 = 0.3136$$

Rising temperatures may impact linseed growth cycles – potentially shortening vegetative stages, increasing water stress, and affecting fiber quality. The consistent warming trend since 2015 warrants attention for climate adaptation strategies.

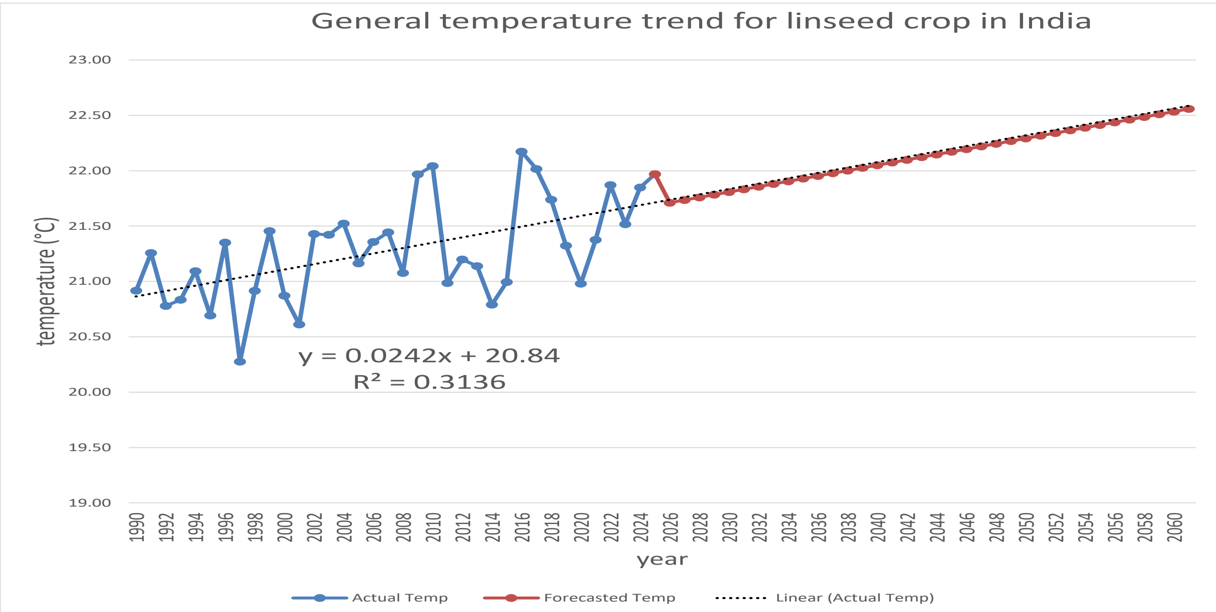

Fig. 2. Time-series trend of average air temperature during the linseed growing season in India (1990–2025), forecast during (2026-2061) from November to April. (Figure created by the researcher using Microsoft Excel 365)

This indicates that the temperature has been rising at an average rate of approximately 0.0242°C per year, starting from a base of around 20.84°C. The coefficient of determination (R^2 = 0.3136) suggests a moderate level of fit, meaning that about 31.36% of the variability in temperature can be explained by the passage of time. This supports the hypothesis that climate change may be influencing the thermal regime during linseed cultivation.

From 1990 to 2025, the average temperature fluctuated around 20.28°C to 22.17°C, showing a general warming trend in Table 1. Forecasted temperatures continue this upward trend, reaching 22.56°C by 2061, confirming that warming is expected to persist in the coming decades. The forecast is based on a simple linear model and should be interpreted with caution, acknowledging its assumption of a constant rate of change.

Rainfall for linseed and forecasting in India

Fig. 3 shows the total seasonal rainfall (November–April) for linseed in India from Coefficient of determination (R^2 = 0.8398) suggests 1990 to 2025. The linear regression equation is: $y = 0.0006x + 155.58$, with $R^2 \approx 0$. This suggests that there is no significant trend in rainfall over the study period. The extremely low R^2 value indicates that time does not explain any meaningful portion of the variability in rainfall, it shows that the linear model fails to explain the observed interannual variability.

The recorded rainfall during the growing season (November–April) in Table 2 ranged between a minimum of 100.52 mm (in 2000) and a maximum of 234.81 mm (in 1998). This wide variability reflects the high inter-annual fluctuation in rainfall. The trend does not suggest any consistent increase or decrease across the years, which aligns with the earlier regression model ($R^2 \approx 0$), indicating that rainfall patterns were not significantly influenced by time. The erratic pattern of rainfall implies that rainfall was not a reliable or stable climatic factor for predicting linseed productivity during the historical period.

The predicted rainfall values are nearly constant, ranging between 155.60 mm and 155.62 mm over the 36-year forecast period. This flat prediction line is a direct result of the insignificant time-related trend observed in the actual data. Such a static forecast highlights the limitations of using linear regression when the independent variable (time) lacks explanatory power ($R^2 \approx 0$).

Productivity for linseed and forecasting in India

Fig. 4 illustrates the general trend in linseed productivity in India over the period from 1990 to 2025, based on annual productivity data (measured in tons per hectare). A simple linear regression model was applied to assess the relationship between year (independent variable) and productivity (dependent variable).

Regression Equation:

$$y = 0.0113\,x + 0.2418 \text{ with } R^2 = 0.8398$$

a strong increasing trend in productivity over time, with 83.98% of the variance explained by the model. This may be attributed to improvements in agronomic practices, seed quality, pest control, or partial adaptation to climatic changes. The productivity has nearly tripled from ~0.29 t/ha in 1990 to ~0.74 t/ha in 2025, showing substantial agricultural development.

The upward slope of the trend line shows a continuous improvement in linseed productivity over the years studied. The absence of extreme fluctuations or irregular patterns in the data supports the suitability of the linear model for this time series. The model is statistically robust and can be used with reasonable confidence to predict future yields, as in Table 3, where forecasts are made up to 2061, assuming stable climatic and agronomic conditions.

Statistical summary and boxplot analysis of temperature, rainfall and linseed productivity in India

The descriptive statistics in Table 4 summarize the central tendency, dispersion, and distribution characteristics of the three study variables over 36 growing seasons (1990–2025). The mean average seasonal temperature was 21.29°C (SD = 0.456°C), with a narrow range (20.28 –22.17 °C), indicating relative thermal stability during the study period. The total seasonal rainfall exhibited substantial variability, with a mean of 155.60 mm (SD = 30.42 mm)

Table 1. Actual temperature from (1990 - 2025) and predicted temperature from (2026 - 2061) during linseed growing season in India

Year	Actual Temp. (ºC)	year	Forecasted Temp. (ºC)
1990	20.92	2026	21.71
1991	21.26	2027	21.74
1992	20.78	2028	21.76
1993	20.84	2029	21.78
1994	21.09	2030	21.81
1995	20.69	2031	21.83
1996	21.35	2032	21.86
1997	20.28	2033	21.88
1998	20.92	2034	21.90
1999	21.46	2035	21.93
2000	20.87	2036	21.95
2001	20.61	2037	21.98
2002	21.43	2038	22.00
2003	21.42	2039	22.03
2004	21.52	2040	22.05
2005	21.16	2041	22.07
2006	21.36	2042	22.10
2007	21.44	2043	22.12
2008	21.08	2044	22.15
2009	21.97	2045	22.17
2010	22.04	2046	22.20
2011	20.99	2047	22.22
2012	21.20	2048	22.24
2013	21.14	2049	22.27
2014	20.79	2050	22.29
2015	21.00	2051	22.32
2016	22.17	2052	22.34
2017	22.02	2053	22.36
2018	21.74	2054	22.39
2019	21.32	2055	22.41
2020	20.98	2056	22.44
2021	21.38	2057	22.46
2022	21.87	2058	22.49
2023	21.52	2059	22.51
2024	21.85	2060	22.53
2025	21.97	2061	22.56

Note: Forecasted temperatures are derived using the regression equation applied to the linear time index. (The table was created by researcher).

Table 2. Actual rainfall from (1990 - 2025) and predicted Rainfall from (2026 - 2061) during linseed growing season in India

Year	Actual rainfall (mm)	year	Forecasted rainfall (mm)
1990	197.58	2026	155.6
1991	168.51	2027	155.6
1992	134.28	2028	155.6
1993	143.6	2029	155.6
1994	180.41	2030	155.6
1995	161.19	2031	155.6
1996	172.47	2032	155.61
1997	166.13	2033	155.61
1998	234.81	2034	155.61
1999	109.69	2035	155.61
2000	100.52	2036	155.61
2001	106.65	2037	155.61
2002	134.30	2038	155.61
2003	170.77	2039	155.61
2004	143.79	2040	155.61
2005	160.12	2041	155.61
2006	135.8	2042	155.61
2007	159.57	2043	155.61
2008	159.84	2044	155.61
2009	119.34	2045	155.61
2010	173.63	2046	155.61
2011	193.77	2047	155.61
2012	124.92	2048	155.61
2013	145.06	2049	155.62
2014	127.14	2050	155.62
2015	209.46	2051	155.62
2016	158.19	2052	155.62
2017	128.18	2053	155.62
2018	116.47	2054	155.62
2019	148.59	2055	155.62
2020	195.86	2056	155.62
2021	130.79	2057	155.62
2022	163.26	2058	155.62
2023	178.46	2059	155.62
2024	178.5	2060	155.62
2025	169.8	2061	155.62

Note: Forecasted rainfall are derived using the regression equation applied to the linear time index. (The table was created by researcher).

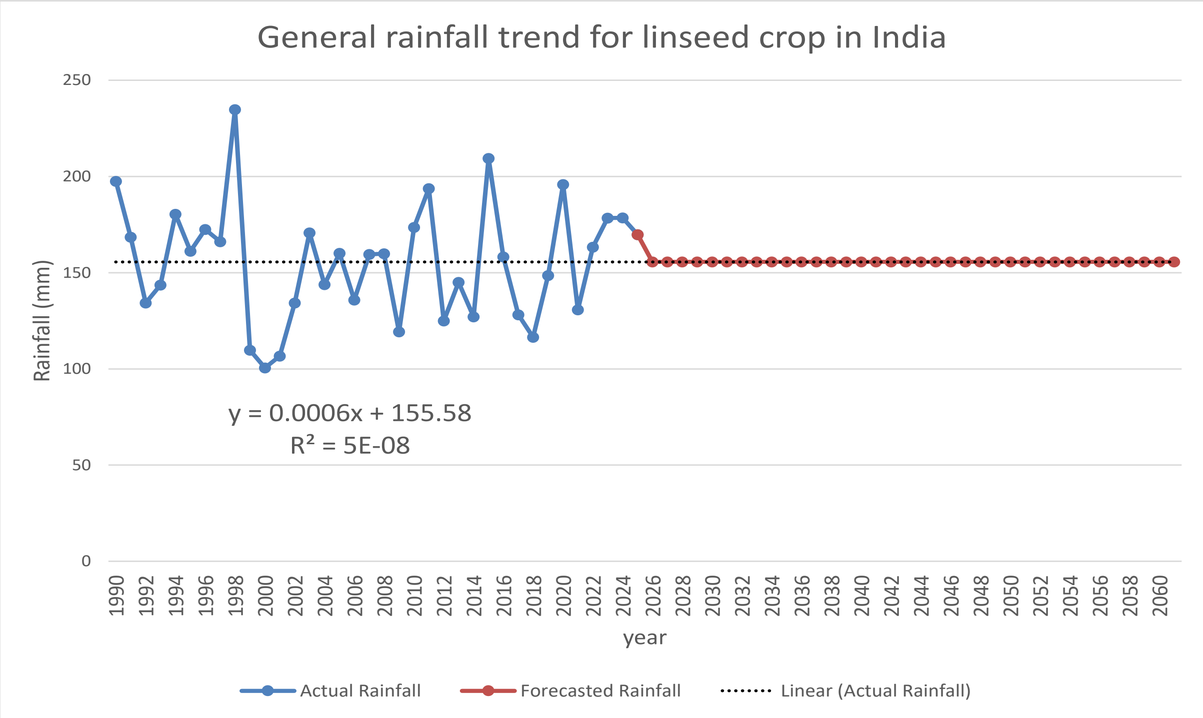

Fig. 3. Time series trend of total rainfall during linseed growing season in India (1990-2025), forecast during (2026-2061) from November to April. (Figure created by the researcher using Microsoft Excel 365)

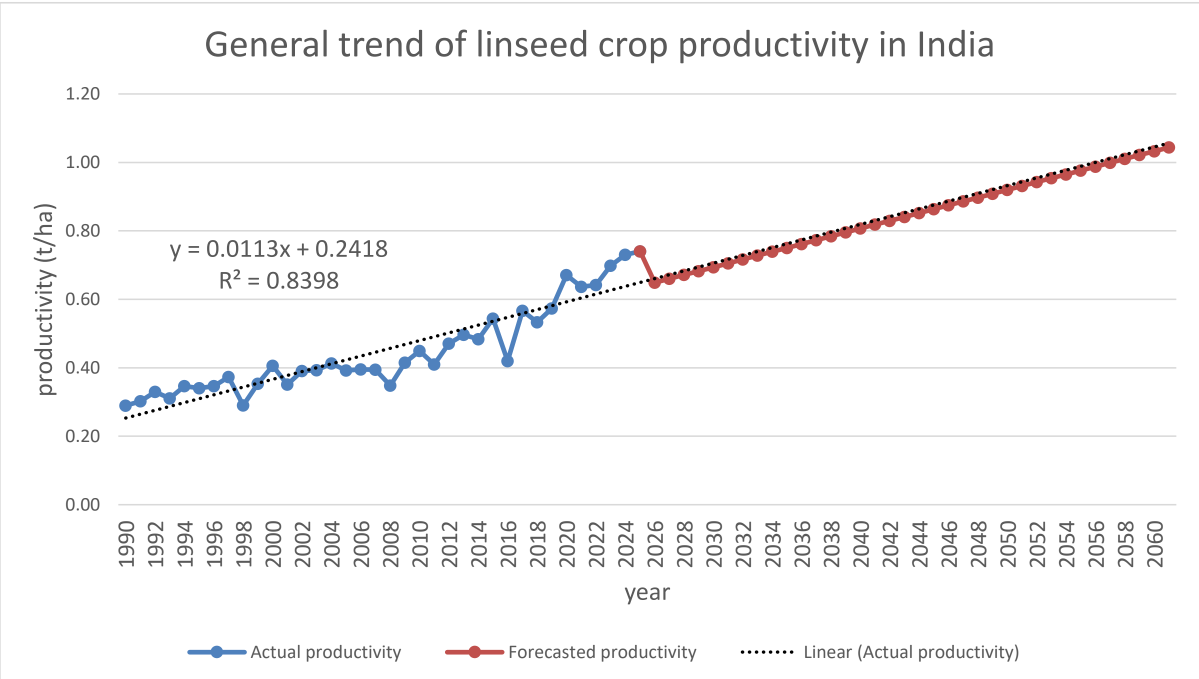

Fig. 4. Time series trend of linseed productivity during growing season in India (1990-2025), forecast during (2026-2061) from November to April .(Figure created by the researcher using Microsoft Excel 365)

Table 3. Actual linseed productivity from (1990 - 2025) and expected productivity from (2026 - 2061) during linseed growing season in India

Year	Actual productivity (t/ha)	year	Forecasted productivity (t/ha)
1990	0.29	2026	0.65
1991	0.30	2027	0.66
1992	0.33	2028	0.67
1993	0.31	2029	0.68
1994	0.35	2030	0.69
1995	0.34	2031	0.71
1996	0.35	2032	0.72
1997	0.37	2033	0.73
1998	0.29	2034	0.74
1999	0.35	2035	0.75
2000	0.41	2036	0.76
2001	0.35	2037	0.77
2002	0.39	2038	0.78
2003	0.39	2039	0.80
2004	0.41	2040	0.81
2005	0.39	2041	0.82
2006	0.39	2042	0.83
2007	0.39	2043	0.84
2008	0.35	2044	0.85
2009	0.41	2045	0.86
2010	0.45	2046	0.87
2011	0.41	2047	0.89
2012	0.47	2048	0.90
2013	0.50	2049	0.91
2014	0.48	2050	0.92
2015	0.54	2051	0.93
2016	0.42	2052	0.94
2017	0.57	2053	0.95
2018	0.53	2054	0.97
2019	0.57	2055	0.98
2020	0.67	2056	0.99
2021	0.64	2057	1.00
2022	0.64	2058	1.01
2023	0.70	2059	1.02
2024	0.73	2060	1.03
2025	0.74	2061	1.04

Note: Forecasted productivity is derived using the regression equation applied to the linear time index. (The table was created by researcher).

Table 4. Descriptive statistics of temperature (°C), rainfall (mm), and linseed productivity (t/ha) in India during the growing season (1990–2025)

		Average seasonal temperature (°C)	Total seasonal rainfall (mm)	Productivity (t/ha)
N	**Valid**	36	36	36
	Missing	0	0	0
Mean		21.2897	155.5958	.4506
Median		21.2900	159.7050	.4100
Mode		20.92[a]	100.52[a]	.35[a]
Std. Deviation		.45564	30.42263	.13030
Variance		.208	925.536	.017
Skewness		.140	.323	.902
Std. Error of Skewness		.393	.393	.393
Kurtosis		-.489	.029	-.259
Std. Error of Kurtosis		.768	.768	.768
Range		1.89	134.29	.45
Minimum		20.28	100.52	.29
Maximum		22.17	234.81	.74
Sum		766.43	5601.45	16.22
Percentiles	**25**	20.9350	131.6625	.3500
	50	21.2900	159.7050	.4100
	75	21.5200	173.3400	.5375

a. Multiple modes exist. The smallest value is shown

(The table was created by the researcher using SPSS V23).

and a wide range (100.52–234.81 mm), reflecting erratic precipitation patterns in the linseed-growing season. Productivity averaged 0.451 t/ha (SD = 0.130 t/ha), with values ranging from 0.29 to 0.74 t/ha, suggesting moderate year-to-year variation. Skewness and kurtosis values for temperature and rainfall were close to zero, indicating approximately normal distributions, whereas productivity showed moderate positive skewness (0.902), suggesting a concentration of values toward the lower end of the distribution with occasional higher-yield seasons. These descriptive measures establish the baseline climatic and yield conditions for subsequent inferential analyses.

The boxplots in Fig. 5 provide the productivity dataset (a) displays a median value of approximately 40, with interquartile range (IQR) extending from ~35 to ~55. The whiskers, spanning ~28 to ~72, suggest moderate variability within the dataset, and the absence of points beyond the whiskers indicates no statistically significant outliers. Productivity showed moderate positive skewness.

The temperature dataset (b) exhibits a narrow dispersion, with a median near 21.5 °C and an IQR from ~21.0 °C to ~22.0 °C. Whiskers range between ~20.0 °C and ~22.3 °C, reflecting low variance and climatic stability. The symmetry of the box and whiskers suggests a nearly normal distribution with minimal heterogeneity.

Conversely, the rainfall dataset (c) demonstrates greater variability, with a median of ~160 mm, an IQR between ~140 mm and ~180 mm, and whiskers extending from ~100 mm to ~210 mm. The presence of a single high-end outlier (~240 mm) indicates an extreme rainfall event, which may exert influence on measures of central tendency and dispersion, potentially reflecting episodic climatic anomalies.

(a) (b) (c)

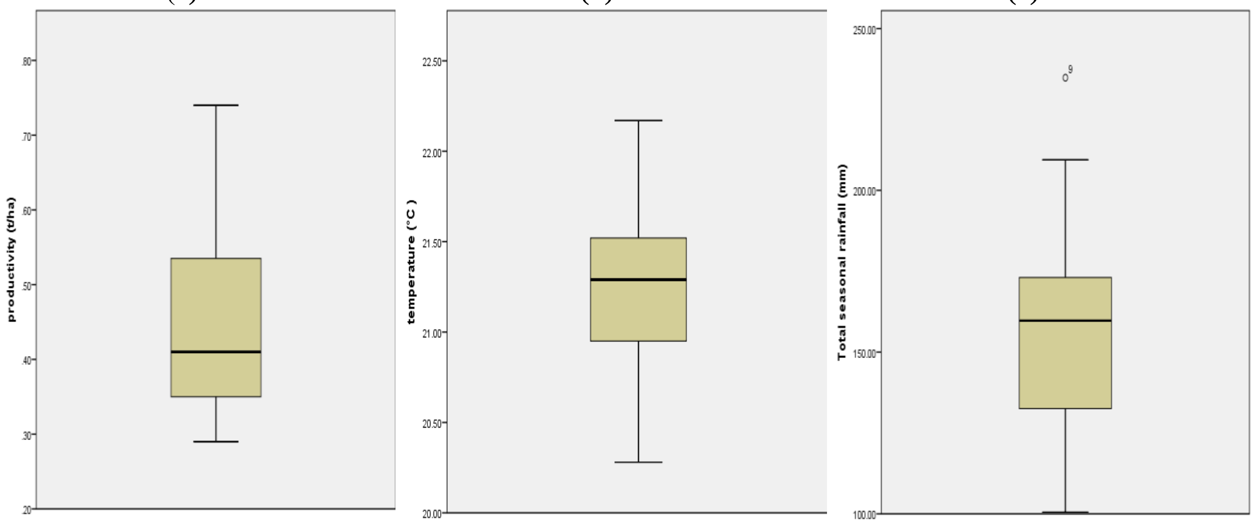

Fig. 5. Comparative boxplots illustrating the distribution of average seasonal temperature, total seasonal rainfall, and linseed productivity in India during (1990–2025). (Figures created by the researcher using SPSS V23)

Simple Correlation Analysis

Simple correlation analysis between study variables for linseed during the growing season in India

Table 5 presents the Pearson correlation coefficients between the three main variables: average seasonal temperature, annual rainfall, and crop productivity.

- There is a moderate positive correlation ($r = 0.468$) and statistically significant correlation between average seasonal temperature and productivity, (p-value = 0.004). This indicates that higher temperatures during the growing season are associated with increased productivity.
- The correlation between rainfall and productivity is very weak ($r = 0.053$) and statistically non-significant (p-value = 0.759), suggesting that rainfall variation did not play a significant role in influencing productivity across the study years.
- The correlation between temperature and rainfall is also weak ($r = –0.087$) and non-significant (p-value = 0.616), indicating that these two climate variables are largely independent within the dataset.

These results underscore the more prominent role of temperature over rainfall in influencing productivity in this context, which may reflect the crop's physiological response to thermal conditions during critical growth stages.

Partial Correlation Analysis

Partial correlation coefficient between temperature and productivity with rainfall control for linseed during the growing season in India

Table 6 displays the partial correlation coefficient between average seasonal temperature and crop productivity, while statistically controlling for the effect of annual rainfall. The purpose is to isolate the direct relationship between temperature and productivity, independent of rainfall. The partial correlation value is $r = 0.475$ with a p-value of 0.004, indicating a moderate and statistically significant positive association even after removing the influence of rainfall.

This result suggests that temperature exerts a substantial independent effect on crop productivity, and its relationship with productivity is not confounded by rainfall levels. The maintained statistical significance strengthens the reliability of temperature as a predictor of productivity in this agro-climatic context.

Table 5. Simple linear correlation analysis between study variables for linseed during the growing season in India (1990–2025)

Correlations				
		Average season of temperature	**Total seasonal rainfall**	**Productivity**
Average season of temperature	**Pearson Correlation**	1	-.087	.468**
	Sig. (2-tailed)		.616	.004
	N	36	36	36
Total seasonal rainfall	**Pearson Correlation**	-.087	1	.053
	Sig. (2-tailed)	.616		.759
	N	36	36	36
productivity	**Pearson Correlation**	.468**	.053	1
	Sig. (2-tailed)	.004	.759	
	N	36	36	36

**. Correlation is significant at the 0.01 level (2-tailed).
(The table was created by the researcher using SPSS V23).

Table 6. Partial correlation coefficient between temperature and productivity with rainfall control for linseed during the growing season in India

Correlations				
Control Variables			**Average season of temperature**	**Productivity**
Total seasonal rainfall	Average season of temperature	Correlation	1.000	.475
		Significance (2-tailed)	.	.004
		df	0	33
	productivity	Correlation	.475	1.000
		Significance (2-tailed)	.004	.
		df	33	0

(The table was created by the researcher using SPSS V23).

Partial correlation coefficient between rainfall and productivity with temperature control for linseed during the growing season in India

Table 7 discusses the relationship between annual rainfall and productivity while controlling for the effect of mean seasonal temperature. The partial correlation coefficient is r = 0.106 with a p-value of 0.544, indicating a very weak and statistically non-significant association between rainfall and productivity once temperature is taken into account.

This implies that, unlike temperature, rainfall does not contribute meaningfully to explaining variability in productivity during the study period. It highlights the lesser importance of rainfall in this model, possibly due to irrigation practices, soil moisture retention, or crop-specific climate adaptability.

Table 7. Partial correlation coefficient between rainfall and productivity with temperature control for linseed during the growing season in India

Correlations				
Control Variables			**Total seasonal rainfall**	**Productivity**
Average season of temperature	Total seasonal rainfall	Correlation	1.000	.106
		Significance (2-tailed)	.	.544
		df	0	33
	productivity	Correlation	.106	1.000
		Significance (2-tailed)	.544	.
		df	33	0

(The table was created by the researcher using SPSS V23).

Multiple Linear Regression Analysis

Multiple linear regression model summary

Table 8 summarizes the performance of the multiple linear regression model that includes temperature and rainfall as independent variables to predict crop productivity.

- The multiple correlation coefficient between temperature, rainfall and productivity is $R = 0.477$, and the $R^2 = 0.227$, indicating that 22.7% of the variation in productivity is explained by the model.
- The Adjusted $R^2 = 0.181$ accounts for model complexity and slightly penalizes the model for the number of predictors.
- The standard error of the estimate (SEE) is 0.11794, indicating the average distance that the observed values fall from the regression line.

Although the R^2 is modest, the model provides a statistically significant explanation of variability in productivity, especially given the relatively small number of predictors.

ANOVA for the multiple regression model

The ANOVA (Analysis of Variance) Table 9 evaluates the overall significance of the regression model. The F-statistic is $F = 4.859$ with a p-value of 0.014, confirming that the model is statistically significant at the 5% level. This means that the independent variables (temperature and rainfall) together significantly explain variance in productivity. The significance of the overall model supports the utility of regression analysis in examining climate-productivity relationships.

Regression coefficients table

Table 10 presents the estimated coefficients of the multiple linear regression model where crop productivity is regressed on two independent variables: average seasonal temperature and annual rainfall. The model aims to quantify the direction and magnitude of each predictor’s effect on productivity while controlling for the other.

Intercept (Constant = –2.509, $p = 0.012$)

While the intercept has theoretical meaning in the regression model, it does not reflect a real-world scenario in agriculture, as both temperature and rainfall are never zero. However, its significance confirms the necessity of including climatic predictors in the model. The negative value suggests that in the absence of any climatic input, the model predicts a baseline of negative productivity. This reinforces the necessity of including climate variables in the model. The p-value indicates that the intercept is statistically significant at the 5% level, meaning it contributes meaningfully to the model's structure.

Table 8. Model summary of multiple linear regression

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	0.477[a]	0.227	0.181	0.11794

a. Predictors: (Constant), Total seasonal rainfall, average season of temperature

(The table was created by the researcher using SPSS V23).

Table 9. Analysis of variance (ANOVA) for multiple linear regression

ANOVA[a]						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	.135	2	.068	4.859	.014[b]
	Residual	.459	33	.014		
	Total	.594	35			

a. Dependent Variable: productivity
b. Predictors: (Constant), Total seasonal rainfall, Average season of temperature
(The table was created by the researcher using SPSS V23).

Table 10. Coefficients of multiple linear regression

Coefficients[a]								
		Unstandardized Coefficients		**Standardized Coefficients**	**t**	**Sig.**	**Collinearity Statistics**	
Model		**B**	**Std. Error**	**Beta**			**Tolerance**	**VIF**
1	(Constant)	-2.509	.950		-2.642	.012		
	Average season of temperature	.136	.044	.476	3.098	.004	.993	1.008
	Total seasonal rainfall	.000	.001	.094	.613	.544	.993	1.008

a. Dependent Variable: productivity
(The table was created by the researcher using SPSS V23).

Average seasonal temperature (=0.136, p= 0.004)

This is the key explanatory variable in the model. The unstandardized coefficient (= 0.136) means that for every 1°C increase in the average seasonal temperature, productivity is expected to increase by 0.136 units, holding rainfall constant.

The p-value of 0.004 confirms that this relationship is highly statistically significant (significant at the 1% level), indicating strong evidence that temperature positively influences productivity.

The standardized beta coefficient (= 0.476) also reinforces its relatively strong contribution compared to rainfall.

This result aligns with agronomic evidence suggesting that rising temperatures, within certain thresholds, can accelerate plant development and enhance yield potential — especially in thermophilic crops.

Total seasonal rainfall (=0.000, p = 0.544)

The coefficient for rainfall indicates a negligible and statistically non-significant effect on productivity. With a coefficient close to zero and a high p-value, there is insufficient evidence to support a meaningful linear relationship between rainfall and productivity in this model.

The standardized beta (= 0.094) is very low, confirming the limited predictive role of rainfall in this dataset.

Several explanations could account for this finding: adequate irrigation systems that reduce dependence on rainfall, rainfall timing mismatch with crop growth stages, or the possibility that the crop is more sensitive to temperature than moisture variations.

Collinearity Statistics (VIF = 1.008 for both predictors). The Variance Inflation Factor (VIF) for both independent variables is close to 1, indicating no multicollinearity. This confirms that each variable contributes unique information to the model, and the regression estimates are stable and reliable. The regression coefficients table highlights that temperature is a statistically significant and practically relevant predictor of crop productivity, while rainfall plays a negligible role in the current model. These findings have important implications for climate-resilient agricultural planning. With no collinearity issues and a strong effect size for temperature, the model provides a robust foundation for forecasting productivity under varying climatic conditions.

Scatter Plot: Temperature vs. Productivity

This scatter plot shown in Fig. 6 visually represents the relationship between average seasonal temperature (x-axis) and linseed productivity (y-axis). Each point represents a seasonal observation within the study period.

The pattern of the data points suggests a positive linear relationship. As temperature increases, productivity tends to increase as well.

The distribution appears moderately linear and consistent, supporting the earlier statistical findings of a moderate positive correlation (r = 0.468) and a significant regression coefficient (p = 0.004) as in Table 5.

The visual trend reinforces the conclusion that temperature plays a substantial and statistically significant role in influencing productivity.

No clear outliers or curvature are apparent, supporting the validity of applying linear regression in this case.

This plot provides compelling visual support for the role of temperature as a primary climatic determinant of linseed productivity.

Scatter Plot: Rainfall vs. Productivity

Fig. 7 displays the relationship between total seasonal rainfall (x-axis) and productivity (y-axis).

The data points show a scattered and diffuse pattern, with no clear linear trend observable between rainfall and productivity.

This visual confirms the weak correlation observed in the statistical analysis (r = 0.053, p = 0.759) as in Table 4 and the non-significant regression coefficient (p = 0.544) as in Tables (7 and 10).

The lack of clustering or directional slope implies that rainfall variation has little to no predictive value in explaining productivity within this dataset.

This may indicate that other factors — such as irrigation, rainfall timing, or crop water use efficiency — play more dominant roles than total rainfall amount.

The plot provides visual support for treating rainfall as a secondary or non-influential variable in this model.

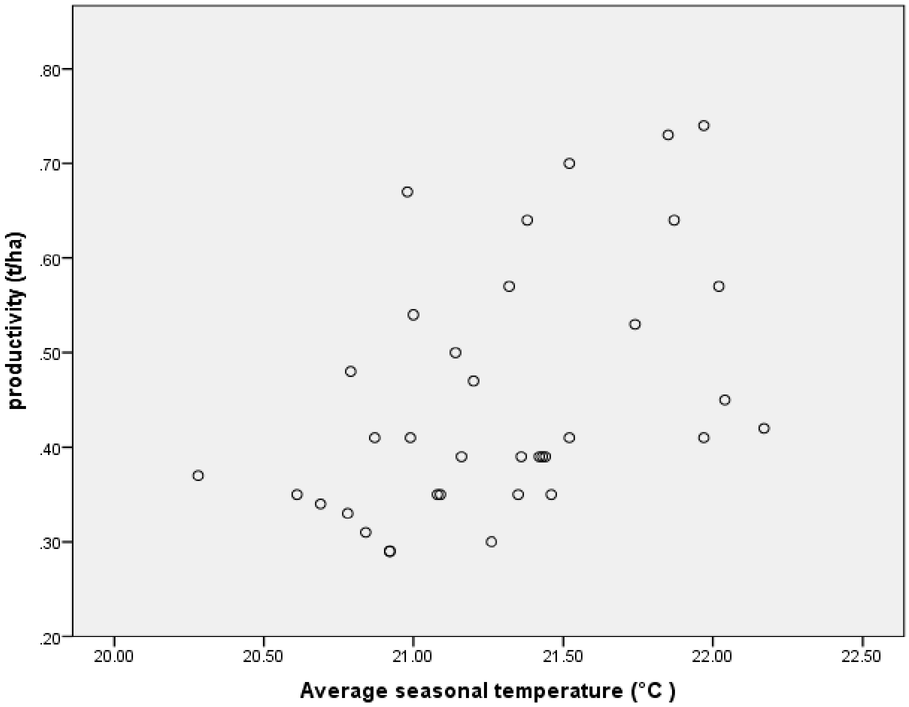

Fig. 6. Scatter plot for temperature vs. productivity for linseed in India (Figure created by the researcher using SPSS V23).

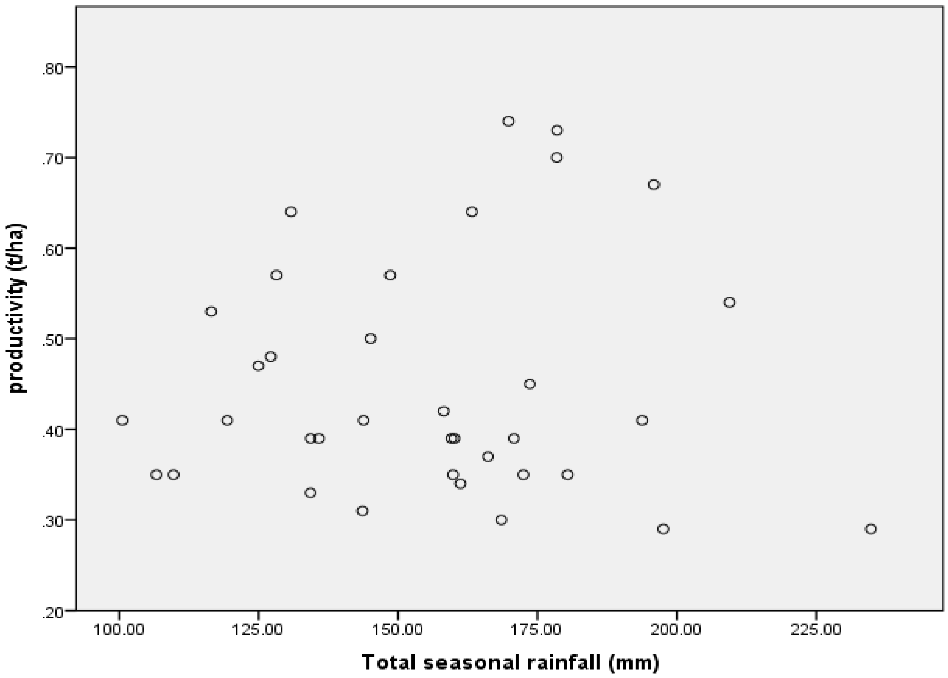

Fig. 7. Scatter plot for rainfall vs. productivity for linseed in India (Figure created by the researcher using SPSS V23)

These two scatter plots in Figs. 6 and 7 are crucial visual diagnostics:

The temperature-productivity plot confirms a meaningful positive relationship, both visually and statistically.

The rainfall-productivity plot reinforces the conclusion of a weak or absent relationship, thereby validating the results from both correlation and regression analyses.

Large recent analyses of Indian surface temperature show positive seasonal and annual warming. For India, **(Kumar *et al.*, 2023)** report seasonal warming rates that vary by season and region (pre-monsoon and post-monsoon trends ~0.1–0.4 °C per decade in many subregions) and note an observed rise of **~0**.24 °C per decade for annual minimum temperature over recent decades — which is numerically the same order as your +0.242 °C/decade. **(Krishnan *et al.*, 2020)** reported that warming over India since late 20th century (seasonal magnitudes differ by dataset and region), so the detected trend (+0.0242 °C/yr) falls within the range reported by those studies (*i.e.*, it is plausible and consistent with Indian seasonal warming reported in the literature).

Multiple Indian analyses conclude that no consistent all-India linear trend in winter/Rabi rainfall emerges when averaged over large spatial scales-results vary strongly by basin/ station and many trends are not statistically significant. **(Jain and Kumar, 2012)** reported that rainfall trends are heterogeneous and a “clear and consistent picture of rainfall trend has not emerged. **(Jain and Kumar, 2012)** emphasize high interannual variability in seasonal rainfall and caution that aggregated seasonal totals can mask important intra-seasonal timing effects (which matter strongly for crops). This supports your observation that the linear model is a poor predictor for rainfall.

Supporting evidence and interpretation from literature and policy reports indicate that national program evaluations and sector analyses — such as those from the National Food Security Mission for Oilseeds (Department of Agriculture & Farmers Welfare, Government of India) and decomposition studies of agricultural growth **(Birthal *et al.*, 2014; Chand *et al.*, 2012; Jain *et al.*, 2017)**-attribute recent productivity increases in oilseeds largely to non-climatic drivers. These include adoption of improved varieties, better crop management practices, enhanced fertilizer application, expanded irrigation, and targeted government programmes. This is consistent with the conclusion that the strong positive trend in linseed productivity likely reflects technical and management improvements as much as, or more than, any direct influence of climate.”

Indian field trials and crop-weather analyses (sowing-date experiments, varietal trials) frequently find that temperature during specific phenophases (emergence → branching → flowering) is strongly associated with linseed yield — sometimes positively when temperature is within the crop’s optimal window, and negatively when terminal heat occurs. Examples: sowing-date correlation studies **(Rokade *et al.*, 2015; Jiotode *et al.*, 2020)** report significant phenophase-specific correlations between T_mean/Tmin/GDD and seed yield.

Controlled experiments on flax show that heat stress during flowering/reproductive stages reduces seed set and yield **(Cross *et al.*, 2003)**, which explains why moderate warming can help (if it moves temps towards optimum) but excessive/terminal heat causes penalties. Thus your positive $r \approx 0.468$ is compatible with agronomic evidence which finds positive relationships inside the optimal thermal window, but strong negative responses to episodic extreme heat.

The partial correlation analysis, controlling for rainfall, showed a positive and statistically significant relationship between mean seasonal temperature and linseed productivity ($r \approx 0.466$, $p<0.01$). This indicates that, even after removing the linear influence of seasonal rainfall, higher mean seasonal temperatures within the observed range were associated with higher yields. Conversely, the partial correlation between seasonal rainfall and productivity, controlling for temperature, was weak and non-significant ($r \approx 0.051$, $p > 0.05$), suggesting that rainfall totals do not independently explain substantial yield variation when temperature is accounted for. Similar patterns have been reported in Indian field studies where temperature metrics explained more yield variability than total seasonal rainfall **(Rokade *et al.*, 2015; Jiotode**

***et al.*, 2017)**. Multi-environment trials under the AICRP-Linseed programme also confirm that rainfall effects are largely stage-specific, and their statistical significance diminishes when aggregated over the season and analysed alongside temperature variables **(AICRP-Linseed, 2019)**.

The multiple regression model using mean seasonal temperature and total seasonal rainfall as predictors yielded R=0.477**,** R^2=0.227 (Adjusted R^2 = 0.181), F = 4.859**,** p = 0.014. The temperature coefficient (β_1 = +0.136, p = 0.004) was statistically significant, whereas the rainfall coefficient ($\beta_2 \approx 0.000$, p = 0.544) was not. This aligns with findings from field-based and statistical studies in India, which report that temperature variables often explain a greater proportion of oilseed yield variability than aggregated seasonal rainfall **(Biswas *et al.*, 2019; Meena *et al.*, 2020)**. This is primarily because rainfall effects are more sensitive to timing and distribution than to seasonal totals, while temperature trends are relatively stable and consistent across years **(AICRP-Linseed, 2019)**.

The multiple regression model using mean seasonal temperature and total seasonal rainfall as predictors yielded R = 0.477**,** R^2 = 0.227 (Adjusted R^2 = 0.181), F = 4.859, p = 0.014. The temperature coefficient (β_1 = +0.136, p = 0.004) was statistically significant, whereas the rainfall coefficient ($\beta_2 \approx 0.000$, p = 0.544) was not. This finding — that a seasonal temperature metric is a significant predictor while aggregated seasonal rainfall is not-is consistent with field-based linseed studies from India which report phenology-dependent and sowing-date–dependent temperature with productivity relationships, and which also show that seasonal rainfall totals frequently fail to capture timing/distribution effects that are critical for yield **(Rokade *et al.*, 2015; Jiotode *et al.*, 2017; AICRP-Linseed, 2019)**. In particular, **(Rokade *et al.*, 2015)** report significant positive correlations between Tmax/Tmean and seed yield for specific growth phases (e.g., emergence → branching) of the Garima cultivar, while **(Jiotode *et al.*, 2017)** show sowing-date dependent crop–weather correlations — all of which explain why a temperature term can be significant in a simple two-variable seasonal model even when seasonal rainfall is not.

REFERENCES

Agarwal S., P. S. Birthal, P. K. Joshi, and D. S. Negi. (2014). Changing sources of growth in Indian agriculture: Implications for regional priorities for accelerating agricultural growth (IFPRI Discussion Paper 01325). International Food Policy Research Institute.

Ahmad A., A. Wajid, M. Hussain, J. Akhtar, and G. Hoogenboom. (2016). Estimation of temporal variation resilience in cotton varieties using statistical models. *Pak. J. Agric. Sci.* 53:4549.

Ahmad M., E. A. Waraich, A. Tanveer, and M. Anwar-ul-Haq. (2021b). Foliar applied thiourea improved physiological traits and yield of camelina and canola under normal and heat stress conditions. *J. Soil Sci. Plant Nutr.* 21, 1666–1678. doi: 10.1007/s42729-021-00470-8.

Ahmad M., E. A. Waraich, U. Zulfiqar, A. Ullah, and M. Farooq. (2021a). Thiourea application improves heat tolerance in camelina (*Camelina sativa* L. Crantz) by modulating gas exchange, antioxidant defense and osmoprotection. *Ind. Crops Prod.* 170:113826.

All India Coordinated Research Project on Linseed (AICRP-Linseed). (2019). Annual Progress Report (2018–19). Project Coordinating Unit (Linseed), Kanpur: ICAR (AICRP Linseed).

Argosubekti N. (2020). A review of heat stress signaling in plants. *IOP Conference Series: Earth Environ. Sci.* 484:012041.

Ashraf M. A., A. Akbar, S. H. Askari, M. Iqbal, R. Rasheed, and I. Hussain. (2018). Recent Advances in Abiotic Stress Tolerance of Plants through Chemical Priming: An Overview. Berlin: Springer.

Bakhytkyzy I., W. Hewelt-Belka, and A. Kot-Wasik. (2023). A comprehensive lipidomic analysis of oilseeds using LC-Q-TOF-MS and dispersive micro-solid phase (D-μ-SPE) extraction techniques. Journal of Food Composition and Analysis, 116, 105037.

.

Bakst A. (1931). A modification of the computation of the multiple correlation and regression coefficients by the Tolley and Ezekiel method. *Journal of Educational Psychology*, 22(8), 629–635. https://doi.org/10.1037/h0075404.

Bhat M.A., R.A. Mir, V. Kumar, A A. Shah, S.M. Zargar, S. Rahman. (2021). Mechanistic insights of CRISPR/Cas-mediated genome editing towards enhancing abiotic stress tolerance in plants. *Physiol. Plant.* 172, 1255–1268. doi: 10.1111/ppl.13359.

Chand R., P. Kumar, and S. Kumar. (2012). Total factor productivity and returns to public investment on agricultural research in India. *Agricultural Economics Research Review*, 25(2). .

Cross R. H., S. A. B. McKay, A. G. McHughen, and P. C. Bonham-Smith. (2003). Heat-stress effects on reproduction and seed set in *Linum usitatissimum* L. (flax). *Plant, Cell and Environment*, 26, 1013–1020. .

Dąbrowski G., M. Tańska, S. Czaplicki, T. Sadowski, B. Rychcik, M. K. Kostrzewska, Z. Antoszkiewicz, and I. Konopka. (2025). Variation in linseed oil composition: Impact of cultivar, cultivation system, and year of cultivation. *Molecules* 30(4): 875. https://doi.org/10.3390/molecules30040875.

FAO. (2003). FAOSTAT. Food and Agriculture Organization of the United Nations, Rome.

IPCC (2018). Fifth Assessment Report. New York, NY: Cambridge University Press.

Irwin, R.D. (1983). Applied Linear Regression Model. Homewood, Illinois, USA.

Jain, R., R. Chand, and A. Singh. (2017). Total factor productivity growth in Indian crop sector. *Indian Journal of Agricultural Economics* 74: 535–554.

Jain, S. K., and V. Kumar. (2012). Trend analysis of rainfall and temperature data for India. *Current Science* 102(1): 37–49.

Jiotode, D. J., D. Patel, and S. R. Patil. (2017). Effect of different dates of sowing and crop–weather on linseed varieties. *Journal of Soils and Crops* 27(1): 232–238.

Kanojia, A., and P. P. Dijkwel. (2018). Abiotic stress responses are governed by reactive oxygen species and age. *Annals of Plant Reviews* 1: 1–32.

Keller, I., and O. Seehausen. (2012). Thermal adaptation and ecological speciation. *Molecular Ecology* 21: 782–799. https://doi.org/10.1111/j.1365-294X.2011.05397.x

Krishnan, R., J. Sanjay, C. Gnanaseelan, M. Mujumdar, A. Kulkarni, and S. Chakraborty, eds. (2020). *Assessment of climate change over the Indian region*. Springer/Ministry of Earth Sciences.

Kumar, R., J. Kuttippurath, G. S. Gopikrishnan, P. Kumar, and H. Varikoden. (2023). Enhanced surface temperature over India during 1980–2020 and future projections: Causal links of the drivers and trends. *npj Climate and Atmospheric Science* 6: 164.

Kumhare, A., K. Kumar, D. J. Jiotode, and S. Thakur. (2022). Effect of sowing dates on yield attributes, yield and economics of linseed (*Linum usitatissimum* L.) varieties. *Journal of Experimental Agriculture International* 44(1): 37–46.

Liu, H., Bean, S. and X. S. Sun, (2018a). Camelina protein adhesives enhanced by polyelectrolyte interaction for plywood applications. Industrial Crops and Products, 124, 343–352. https://doi.org/10.1016 /j.indcrop. 2018.07.068

Lu, C., J. A. Napier, T. E. Clemente, and E. B. Cahoon, (2011). New frontiers in oilseed biotechnology: meeting the global demand for vegetable oils for food, feed, biofuel, and industrial applications. Current Opinion in Biotechnology, 22, 252–259.

Mohammad, B. T., M. Al-Shannag, M. Alnaief, L. Singh, E. Singsaas, and M. Alkasrawi, (2018). Production of multiple biofuels from whole camelina material: a renewable energy crop. BioResources, 13, 4870–4883.

NOAA. (2017). Available online at: https://www.co2.earth/ (accessed January 1, 2018).

OECD-FAO. (2020). Agricultural Outlook 2020–2029. World oilseed projections.

Ponnampalam, E. N., M. G. Kerr, K. L. Butler, J. J. Cottrell, F. R. Dunshea, and J. L. Jacobs. (2019). Filling the out-of-season gaps for lamb and hogget production: Diet and genetic influence on carcass yield, carcass composition, and retail value of meat. *Meat Science* 148: 156–163.

Porter, J. R., and D. J. Moot. (1998). Research beyond the means: Climatic variability and plant growth. In *International Symposium on Applied Agrometeorology and Agroclimatology*, edited by N. R. Dalezios. Luxembourg: Office for Official Publications of the European Commission.

Rahman, M. H., A. Ahmad, A. Wajid, M. Hussain, F. Rasul, W. Ishaque. (2019). Application of CSM-CROPGRO-cotton model for cultivars and optimum planting dates: Evaluation in changing semi-arid climate. *Field Crops Research* 238: 139–152.

Rahman, M. H., A. Ahmad, X. Wang, A. Wajid, W. Nasim, M. Hussain. (2018b). Multi-model projections of future climate and climate change impacts: Uncertainty assessment for cotton production in Pakistan. *Agricultural and Forest Meteorology* 253: 94–113.

Rahman, M. J., A. C. de Camargo, and F. Shahidi. (2018a). Phenolic profiles and antioxidant activity of defatted camelina and sophia seeds. *Food Chemistry* 240: 917–925.

Rokade, B. S., K. T. Madane, J. D. Jadhav, and P. S. Kamble. (2015). Impact of weather parameters in linseed (*Linum usitatissimum* L.) on various genotypes and sowing times. *Asian Journal of Environmental Science* 10 (1): 20–28.

Tan, S. H., R. J. Mailer, C. L. Blanchard, and S. O. Agboola. (2011). Extraction and residual anti-nutritional components in protein fractions of *Sinapis alba* and *Brassica napus* oil-free meals. In *17th Australian Research Assembly on Brassicas (ARAB).*

Tariq, M., S. Ahmad, S. Fahad, G. Abbas, S. Hussain, Z. Fatimal. (2018). The impact of climate warming and crop management on phenology of sunflower-based cropping systems in Punjab, Pakistan. *Agricultural and Forest Meteorology* 256: 270–282. https://doi.org/10.1016/j.agrformet.2018.03.015

Teixeira, E. I., G. Fischer, H. Van Velthuizen, C. Walter, and F. Ewert. (2013). Global hot-spots of heat stress on agricultural crops due to climate change. *Agricultural and Forest Meteorology* 170: 206–215. https://doi.org/10.1016/j.agrformet.2011.09.002

Valantin-Morison, M., and J. M. Meynard. (2008). Diagnosis of limiting factors of organic oilseed rape yield: A survey of farmers' fields. *Agronomy for Sustainable Development* 28: 527–539. https://doi.org/10.1051/agro:2008026

Villanueva-Mejia, D., and J. C. Alvarez. (2017). Genetic improvement of oilseed crops using modern biotechnology. In *Advances in Seed Biology*, 295–317.

تقييم تأثير درجة الحرارة وهطول الأمطار على إنتاجية بذور الكتان: دراسة حالة الهند

أحمد عاطف عبدالنبي محمد البنا[1]، علي عبد الحميد حسان[2]، أمجد محمد مرسي[3]

1- قسم الموارد الطبيعية - كلية الدراسات الآسيوية العليا - جامعة الزقازيق - مصر.

2- قسم العلوم الزراعية ، كلية التكنولوجيا والتنمية ، جامعة الزقازيق ، مصر.

3- رئيس قسم البحوث الزراعية ، مركز البحوث الزراعية ، الجيزة ، مصر.

تركز هذه الدراسة على الهند؛ إذ تقع شمال خط الاستواء بين خطي العرض 8°4' و37°6' شمالًا، وخطي الطول 68°7' و97°25' شرقًا. وهي سابع أكبر دولة في العالم من حيث المساحة. تبلغ مساحتها الإجمالية 3,287,263 كيلومتراً مربعاً. يُعد بذر الكتان (*Linum usitatissimum* L.) أحد أهم محاصيل البذور الزيتية الصناعية في الهند. يُزرع من أجل الزيت المستخرج من البذور أو ألياف الساق. تُستخدم جميع أجزاء نبات بذر الكتان تجارياً، إما بشكل مباشر أو بعد المعالجة. تُعد درجة الحرارة وهطول الأمطار متغيرات خارجية خارجة عن سيطرة المزارعين، كما أن التقلبات في درجة الحرارة وهطول الأمطار طبيعية تماماً. وقد لوحظ أن التقلبات في درجة الحرارة وهطول الأمطار تؤدي إلى تقلبات في الإنتاج، مما يؤدي بدوره إلى تغيرات في الأسعار. ونظراً لأهمية درجة الحرارة وهطول الأمطار في تحديد الإنتاج الزراعي والأسعار، سعت الدراسة إلى التنبؤ بدرجة الحرارة وهطول الأمطار الشهرية في الهند بمساعدة تحليل السلاسل الزمنية باستخدام بيانات هطول الأمطار الشهرية. تهدف هذه الدراسة إلى تحليل تأثير تغيرات درجة الحرارة وهطول الأمطار على إنتاجية بذور الكتان. لتحقيق هذا الهدف، تم تقييم توزيع درجات الحرارة وهطول الأمطار في الهند، ودراسة الآثار الحالية لتغيرات درجات الحرارة وهطول الأمطار على إنتاجية بذور الكتان من عام 1990 إلى عام 2025، وتوقع الآثار المستقبلية لها من عام 2026 إلى عام 2061. جمعت هذه الدراسة بيانات مناخية شهرية من قاعدة بيانات البنك الدولي للهند. وشملت المتغيرات درجة حرارة الهواء وهطول الأمطار. أُنشئت رسوم بيانية لتصوير التغيرات بمرور الوقت. تم تصوير البيانات باستخدام مخطط الصندوق. تُظهر درجة الحرارة اتجاهاً تصاعدياً عاماً، مما يشير إلى أن درجة الحرارة كانت ترتفع بمعدل متوسط يبلغ حوالي 0.0242 درجة مئوية سنوياً، بدءاً من قاعدة حوالي 20.84 درجة مئوية. يشير معامل التحديد ($R^2 = 0.3136$) إلى مستوى توافق متوسط، ما يعني أن حوالي 31.36% من تباين درجات الحرارة يمكن تفسيره بمرور الوقت، مما يؤكد توقع استمرار الاحترار العالمي في العقود القادمة. وتشير قيمة R^2 المنخفضة للغاية إلى أن الوقت لا يُفسر أي جزء ذي دلالة من تباين هطول الأمطار. وقد تضاعفت الإنتاجية ثلاث مرات تقريباً من حوالي 0.29 طن/هكتار عام 1990 إلى حوالي 0.74 طن/هكتار عام 2025، مما يُظهر تطوراً زراعياً كبيراً، وبلغت قيمة معامل التحديد 0.8398

الكلمات الإسترشادية: درجة الحرارة، هطول الأمطار، إنتاجية بذور الكتان، الهند

المحكمـــون:

1- أ.د. علي أحمد إبراهيم أستاذ الاقتصاد الزراعي المتفرغ – كلية الزراعة – جامعة الزقازيق.

2- أ.د. أحمد فؤاد مشهور أستاذ الاقتصاد الزراعي المتفرغ – كلية الزراعة – جامعة الزقازيق.