International Journal of Environment and Climate Change

Volume 13, Issue 9, Page 2983-2992, 2023; Article no.IJECC.104295
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Analysis of Trends in Climate Variables and the Adaptation Strategies Used by Cardamom Growers in Idukki District of Kerala, India

R. S. Devika [a++*], M. Nirmala Devi [a#], C. Karthikeyan [a†], Ga. Dheebakaran [b‡] and R. Gangaiselvi [c^]

[a] Department of Agricultural Extension and Rural Sociology, Tamil Nadu Agricultural University, Coimbatore, 641003, India.
[b] Agro Climate Research Center, Tamil Nadu Agricultural University, Coimbatore, 641003, India.
[c] Department of Physical Science and Information Technology, Tamil Nadu Agricultural University, Coimbatore, 641003, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i92538

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/104295

Original Research Article

Received: 28/05/2023
Accepted: 02/08/2023
Published: 05/08/2023

ABSTRACT

Aim: The study's main goal is to find any significant variations in the climatic variables and to analyze the preferences about adaptation strategies by the farmers to lessen the effects of the same.

++ *M.Sc Scholar;*
# *Professor (Agricultural Extension);*
† *Professor and Head (Agricultural Extension);*
‡ *Associate Professor (Agronomy);*
^ *Associate Professor (Statistics);*
**Corresponding author: E-mail: devikarajeev7560@gmail.com;*

Study Area and Design: An ex-post-facto study was conducted at randomly selected panchayaths in Nedumkandam, Idukki, Kerala.
Methodology: The climate data for 30 years (1991-2021) was analyzed using Mann-Kendall test and sen slope estimator. A sample size of 120 farmers was surveyed for identifying their preferences for adaptation measures. Adaptation strategies proposed by various institutions and experts were ranked using the Response Priority Index.
Results: Throughout the july month every year, the maximum temperature rise by 0.06◦C, and this increase is significant at 1% level. The minimum temperature increased considerably by 0.06◦C at 5% level in December and by 0.04 °C at 10% level in January. For the month of June, there was a 6.15 mm significant decrease at the 0.01 level of significance. March had a rise in precipitation of 0.753 mm, which is noteworthy at the 0.05 level. The increase in rainfall during summer may increase panicle initiation whereas reduction in rainfall during June affects flowering. At the 0.1 criterion, the increase in May was 2.028 mm, which is considerable. And at the 0.1 level of significance, the relative humidity rises by 0.19% and 0.15%, respectively, in March and May. Fluctuation in these parameters resulted in increased pest and disease incidence. 86.66 % of farmers found it important to adopt adaptation measures. The first listed adaptation measure was maintaining a good level of shade. The least effective of the suggested solutions was growing disease and pest-resistant cultivars.
Conclusion: The tests confirmed a shift in climate variables, and it is evident that this change affects cardamom production.

Keywords: Climate change; cardamom; mann-kendall test; sen slope; adaptation strategies; response priority index.

1. INTRODUCTION

Climate change is defined by the Inter-Governmental Panel on Climate Change (IPCC) as a change in the climate's state that can be determined (e.g., using statistical tests) by changes in the mean and/or variability of its properties and that lasts for a considerable amount of time, usually decades or longer. The IPCC (2007) claims that when global warming continues as a result of climate change, people may suffer more [1].

A region's climate is defined as its typical weather over a longer time frame. The average temperatures, daylight hours, and precipitation totals that prevail for a significant period of each season can be used to summarise it. The way of life in a region is influenced by its climate. Climate change is predicted to have a severe negative impact on agriculture, food and water security, and the country's economic growth [2]. Additionally, it is projected to result in changing temperature cycles and long-term alterations in rainfall patterns. The effect of global warming is having its signature in many parts of the world including India causing serious concern for the last few years.

Spice crops are also being negatively impacted by climate change, just like many other horticultural and agricultural crops [3,4,5]. A variety of abiotic elements, particularly temperature, rainfall, photoperiod, daylight hours, wind, etc., have an indirect or direct impact on the physiological growth phases of spice crops, including blooming, fruit set, fruit development, seed set, and the final reproductive or vegetative yield.

Spice crops, especially cardamom have a great role in Kerala's economy. Idukki district of Kerala produces the most cardamom. The quality and quantity of cardamom for domestic consumption and export may change due to changes in weather conditions. Cardamom growers urgently need to pinpoint the trend of climate variables and provide essential actions. To determine the trend of change during the past 30 years, this study examines the climatic data for parameters namely, maximum temperature, minimum temperature, relative humidity, and precipitation. The study's main goal is to find out the positive or negative variations in the climatic factors and identifying the adaptation practices adopted by the cardamom growers.

2. METHODOLOGY

2.1 Study Area

The second-largest district in Kerala is Idukki, which is known as "the spice garden of Kerala".

Nedumkandam block, one of the district's eight blocks, is chosen based on its output of Cardamom for the study. This block belongs to Udumbanchola taluk, which is having greater climate variability concerns. The Nedumkandam block is situated between the latitude 9.8363° N and longitude 77.1571° E (Fig. 1).

2.2 Climate Data

Data on monthly maximum and minimum temperatures, relative humidity, and precipitation were gathered [from https://power.larc.nasa.gov/data-access-viewer/] for the 30 years between 1991 and 2021. (accessed on February 23, 2023). To prevent mistakes that could impact the results, the data quality was visually evaluated by looking for outliers or missing data.

2.3 Trend Analysis

Graphical analysis and non-parametric statistical tests were performed to determine the pattern of change in the variables. Python was used to create a time series of climate factors for 30 years. To identify and estimate trends in the time series of the annual values of atmospheric and precipitation concentrations, the MAKESENS (Mann-Kendall test for trend and Sen's slope estimates) excel template has been adopted.

2.3.1 Mann –Kendall (MK) test

The Mann-Kendall (MK) method was used to come up with a statistically significant trend in the series. It is a non-parametric, rank-based strategy that is unaffected by extremes and can handle skewed variables [6,7]. This method can be used with data that are not normally distributed, filled with outliers, and showing non-linear patterns. The MK test compares the alternative hypothesis of an increasing or declining trend with the null hypothesis of no trend [8]. The 'S' test is used for time series with less than 10 data points, and the normal approximation is used for time series with 10 or more data points. Equation (1) contains the MK test statistic (S).

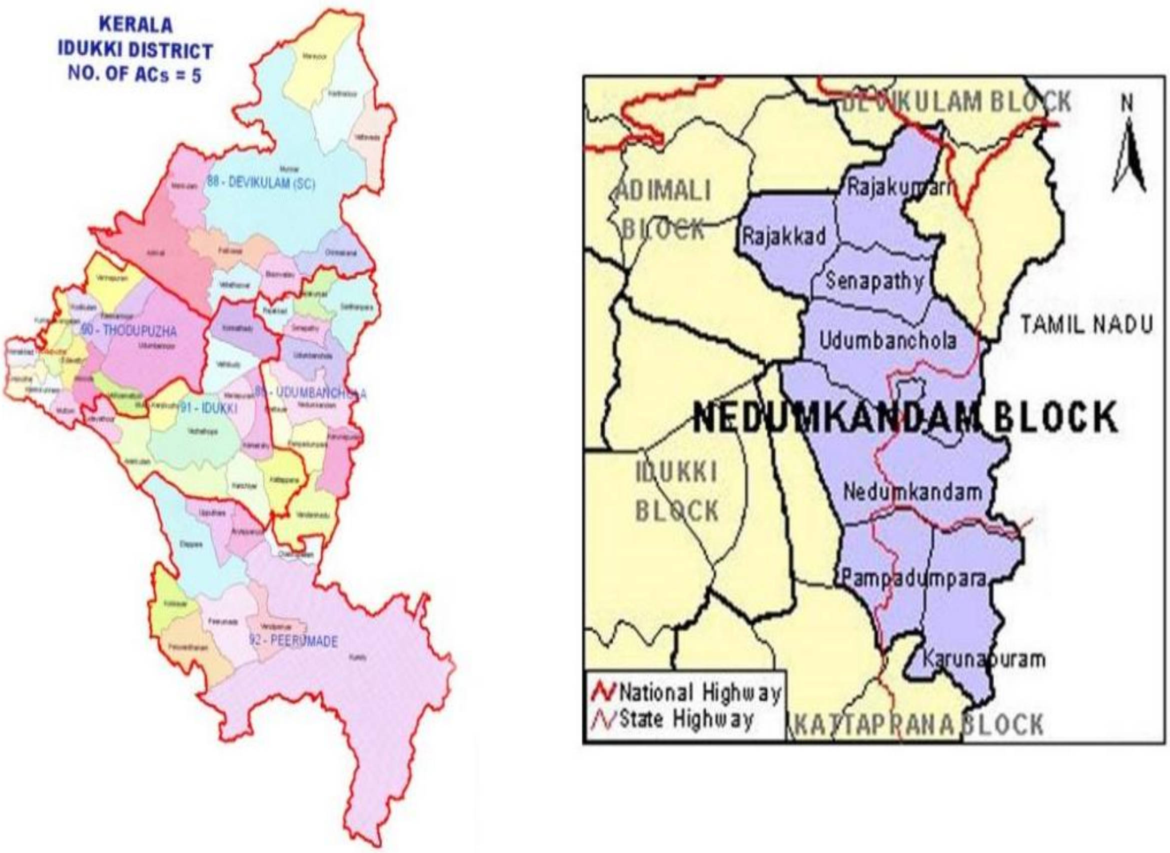

Fig. 1. Map of the study area

$$S= \sum_{k-1}^{n-1}\sum_{j=k+1}^{n} sign(x_j - x_k) \quad (1)$$

Where n is the time series length, x indicates the data point at time j and k, given that (k>j). Equation (2) indicates the sign function.

$$sign\ (x_j\text{-}x_k)= \begin{cases} +1, if\ (x_j - x_k) > 0 \\ 0, if\ (x_j - x_k) = 0 \\ -1, if\ (x_j - x_k) < 0 \end{cases} \quad (2)$$

A positive ‘S’ value indicates an upward trend, while a negative value indicates a downward trend. The mean of S is E[S]=0 and the variance (σ^2) of S is given by equation (3)

$$\sigma^2 = \frac{1}{18}\{n(n-1)(2n+5) - \sum_{j-1}^{p} tj(tj - 12tj+5 \quad (3)$$

where p is the number of the tied groups in the data set and tj is the number of data points in the jth tied group. The normal Z test statistic is calculated by equation (4)

$$Z= \frac{S\pm1}{\sigma^2} \quad (4)$$

This equation uses S-1 if S>0, S+1 if S<0, and Z is 0 if S=0. A positive value of Z indicates an increasing trend. Otherwise, it indicates a downward trend.

2.3.2 Sen slope estimator

A simple non-parametric approach proposed by Sen was also used to assess the magnitude of a time series trend. Equation (5) is used to calculate the trend.

$$\beta = \text{median}\left(\frac{x_j - x_k}{j-i}\right), j > i \quad (5)$$

Where β is Sen’s estimate of the slope. A time series with b >0 shows an upward trend.

2.4 Adaptation Measures

The contingency crop plan for the district and the adaptation techniques suggested by the Cardamom Research Station and Kerala Agricultural University were examined and divided into two categories: crop production measures and soil and moisture conservation measures. These parameters were ranked using the response priority index based on a survey of 120 cardamom growers in the Nedumkandam block.

2.4.1 Response priority index

The response-priority index (RPI) was used for ranking the daptation measures based on the farmers preferences [9]. It was developed by combining the proportion of replies (PR) and priority estimate (PE), where PR for the ith item is the ratio of the number of responses for a particular constraint to the overall number of responses. RPI was suggested as a means to make it clear whether the volume of responses to a particular priority or the highest volume of responses to a limitation in the priority should be the focus. In equation 6, the test statistics are provided.

$$(RPI)_i = \frac{\sum_{j=1}^{k} f_{ij} X_{[(k+1)-j)}}{\sum_{i=1}^{1}\sum_{j=1}^{k} f_{ij}}\ 0 \le \text{RPI} \ge 5$$

Where,

RPI_i = response priority index for i^{th} item,
F_{ij} = Number of responses for j^{th} priority of i^{th} constraint (i= 1,2,………..,I; j = 1,2,3……k)
$\sum_{j=1}^{k} f_{ij}$ = Total number of responses for the i^{th} constraint
K= Number of priorities (1- Strongly agree, 2- Agree, 3-Moderate, 4- Disagree, 5- Strongly disagree),
$X_{[(k=1)-j]}$ = Scores for the j^{th} priority,
$\sum_{i=1}^{1}\sum_{j=1}^{k} f_{ij}$ = Total number of responses to all constraints

3. RESULTS AND DISCUSSION

3.1 Climate Trends

Fig. 2 shows a time series visualization of the relevant variables with a linear trend. The trend for precipitation over time indicates a modest rise. The trend for the maximum temperature is downward, but the trend for the minimum temperature is upward. Additionally improving is the relative humidity.

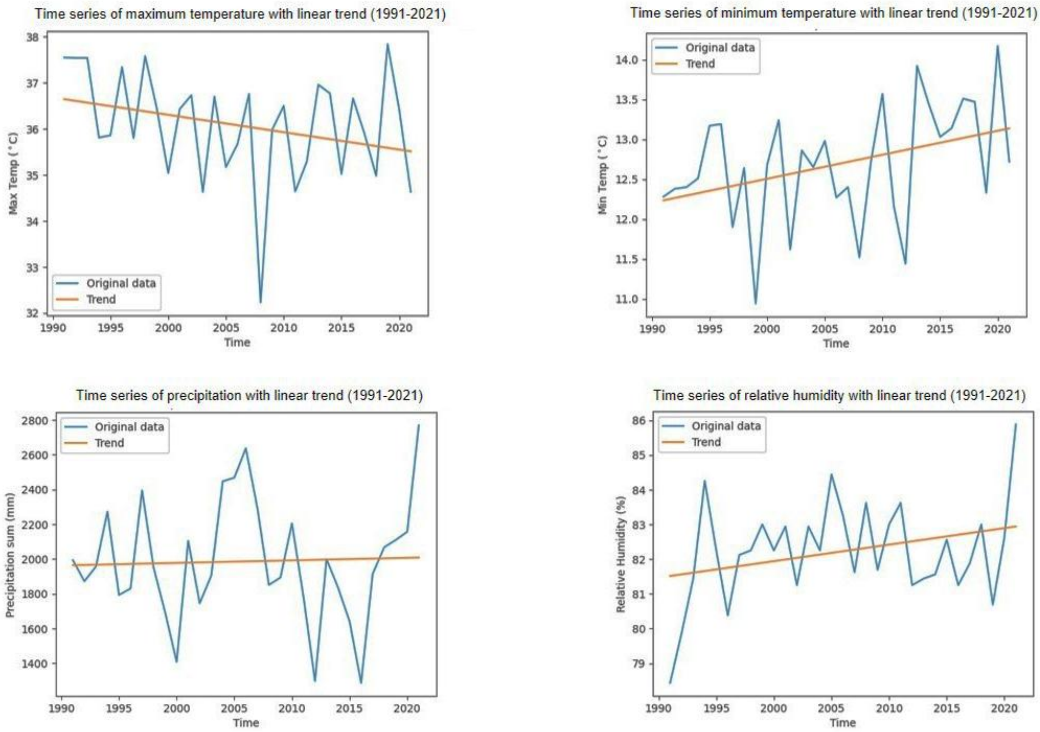

Fig. 2. Time series plots with the linear trend for the variables maximum temperature, minimum temperature, precipitation, and relative humidity for a period of 30 years (1991-2021)

Table 1. Mann- Kendall trend and Sen slope estimate for Maximum temperature (1991- 2021)

Time series	First-year	Last Year	n	Mann-Kendall trend Test Z	Significance	Sen slope estimate (Q)
January	1991	2021	30	0.29	NS	0.009
February	1991	2021	30	0.27	NS	0.009
March	1991	2021	30	-1.31	NS	-0.034
April	1991	2021	30	-0.66	NS	-0.027
May	1991	2021	30	-0.49	NS	-0.015
June	1991	2021	30	-0.20	NS	-0.009
July	1991	2021	30	2.96	**	0.060
August	1991	2021	30	2.48	*	0.043
September	1991	2021	30	1.73	+	0.032
October	1991	2021	30	2.33	*	0.028
November	1991	2021	30	1.41	NS	0.013
December	1991	2021	30	1.75	+	0.015

*** :Trend is significant at α = 0.01 level of significance*
** :Trend is significant at α = 0.05 level of significance*
+ :Trend is significant at α = 0.1 level of significance
NS :Non significant

Even though the plots show a change over time, it is crucial to ensure that the changes are meaningful. Based on monthly data for 30 years, Tables 1, 2, 3, and 4 show MK test and sen slope estimators for each variable, including maximum temperature, minimum temperature, precipitation, and relative humidity. For MAKESENS , the test statistic Z is shown if n is at least 10. The standard normal cumulative distribution is compared to the absolute value of Z to determine whether or not there is a trend at the chosen level of significance. If Z is positive, there is an upward tendency; if Z is negative, there is a downward trend. Sen slope estimate, Q is Sen's estimator for the true slope of linear trend i.e. change per unit period.

The maximum temperature has a discernible trend of fluctuation in some months, as seen in Table 1. Except for the months of March, April, May, and June, the data indicates a tendency in favor of growth. For the month of July, there is a significant increase at the 0.01 level of significance. The Q figure indicates an annual increase of 0.06^{0}C. Between August and October, there is a significant temperature increase at the 0.05 level. In both cases, the temperature rise by 0.04^{0}C and 0.03^{0}C. For September and December, the temperature increase by 0.03^{0}C and .015^{0}C respectively at 0.1 level of significance

Table 2 displays changes in minimum temperature over 30 years. For February and June, it shows a decreasing tendency in minimum temperature, however, for all other months, it shows an increasing trend. In December, there is a substantial rise in the lowest temperature of 0.06^{0}C at the 0.01 threshold of significance. During January, there was also a substantial increase of 0.04^{o}C at the 0.1 threshold of significance.

Estimates of the Mann-Kendall trend and sen slope for precipitation are shown in Table 3. The test results show that, except in January, June, and October, precipitation is on the rise. Every year during the month of June, precipitation decreases significantly by 6.153 mm, which is extremely important for the cardamom crop. Precipitation increased in March by 0.753 mm, which is significant at the.05 level. There was a rise of 2.028 mm in May, with a 0.1 degree of significance.

Table 2. Mann- Kendall trend and Sen slope estimate for Minimum temperature (1991- 2021)

Time series	First-year	Last Year	n	Mann-Kendall trend Test Z	Significance	Sen slope estimate (Q)
January	1991	2021	30	1.73	+	0.040
February	1991	2021	30	-0.10	NS	-0.002
March	1991	2021	30	1.05	NS	0.033
April	1991	2021	30	0.95	NS	0.024
May	1991	2021	30	0.02	NS	0.001
June	1991	2021	30	-0.78	NS	-0.009
July	1991	2021	30	0.22	NS	0.004
August	1991	2021	30	0.70	NS	0.007
September	1991	2021	30	0.10	NS	0.001
October	1991	2021	30	1.19	NS	0.016
November	1991	2021	30	0.99	NS	0.035
December	1991	2021	30	2.60	**	0.058

*** Trend is significant at α = 0.01 level of significance*
+ Trend is significant at α = 0.1 level of significance
NS :Non-significant

Table 3. Mann- Kendall trend and Sen slope estimate for precipitation (1991-2021)

Time series	First-year	Last Year	n	Mann-Kendall trend Test Z	Significance	Sen slope estimate (Q)
January	1991	2021	30	-0.49	NS	0.000
February	1991	2021	30	0.35	NS	0.000
March	1991	2021	30	2.07	*	0.753
April	1991	2021	30	1.00	NS	1.272
May	1991	2021	30	1.84	+	2.028
June	1991	2021	30	-3.18	**	-6.153
July	1991	2021	30	0.14	NS	0.240
August	1991	2021	30	1.09	NS	2.307
September	1991	2021	30	1.40	NS	3.515
October	1991	2021	30	-0.58	NS	-1.319
November	1991	2021	30	0.48	NS	0.878
December	1991	2021	30	0.55	NS	0.329

*** :Trend is significant at α =0 .01 level of significance*
** :Trend is significant at α = 0.05 level of significance*
+ :Trend is significant at α = 0.1 level of significance
NS : Non -significant

Table 4. Mann- Kendall trend and Sen slope estimate for relative humidity (1991-2021)

Time series	First-year	Last Year	n	Mann-Kendall trend Test Z	Significance	Sen slope estimate (Q)
January	1991	2021	30	0.78	NS	0.115
February	1991	2021	30	0.05	NS	0.015
March	1991	2021	30	1.92	+	0.187
April	1991	2021	30	0.76	NS	0.072
May	1991	2021	30	1.96	+	0.155
June	1991	2021	30	-0.34	NS	-0.011
July	1991	2021	30	-1.33	NS	-0.039
August	1991	2021	30	-0.10	NS	0.000
September	1991	2021	30	0.54	NS	0.020
October	1991	2021	30	-0.87	NS	-0.031
November	1991	2021	30	-0.10	NS	-0.010
December	1991	2021	30	1.12	NS	0.063

+ : Trend is significant at α = 0.1 level of significance
NS : Non- significant

The trend in relative humidity is seen in Table 4. The data indicates a declining tendency during the months of June, July, August, October, and November while showing an increasing trend in all other months. During March and May, respectively, there is an increase in relative humidity of 0.19 percent and 0.15 percent at the 0.1 level of significance.

3.2 Impact on Cardamom and Adaptation Strategies Followed by the Cardamom Growers

The production of cardamom is more impacted by changes in temperature, precipitation, and relative humidity. Any alteration to the aforementioned criteria harms the crop's blooming and pod setting. The recommended temperature for the crop's optimum growth is between 15°C and 35°C,[3] however, in practice, it has been shown that the crop grows well between 22°C and 27°C, according to cardamom growers in the study region. Temperature swings cause existing flowers to suffer harm and lessen their ability to blossom [10]. Based on the bloom setting, cardamom can often be harvested three to four times per year. However, a delay in rain and a decrease in rainfall, particularly in June, results in less flowering, which lowers productivity [11,12,13,14,15]. Variations in the climatic variables also lead to an increase in pest and disease incidence. Farmers in the research area reported an increase in the occurrence of sucking and borer pests. *Azhukal* disease, locally known as rotting in the crop, and damping off is caused by irregular rain patterns during the monsoon [5,16,17,18]. The occurrence of pests and illnesses prompts the farmers to use more chemicals, which lowers the soil's fertility and other attributes [19,20]. According to the choices of the farmers, the adaptation options suggested by organizations including the Cardamom Research Centre, Kerala Agricultural University, and the district's Contingency crop plan were enumerated and ranked. Table 5 provides the distribution of farmers for each indicator identified. The RPI method-based ranking of adaptation measures is shown in Table 6. 104 of the 120 farmers agreed that climate change requires special attention and that it is crucial to adopt certain practices to minimize the effects of climate change rather than ignoring them. According to the findings in Table 6, a majority of the respondents named maintaining the shade level as a crucial adaptation measure among the crop production measures. Using varieties that are disease and pest resistant was the least popular method. The most popular technique for soil and water conservation is planting in trenches in muddy places, and the least popular strategy is subsoil irrigation and fertigation.

These findings are also supported by the ranking in Table 6. Using disease and pest-resistant cultivars had the lowest RPI value (1.48) while keeping excellent shade levels in the plantation had the highest (2.71).

Table 5. Distribution of farmers for adaptation measures identified

Adaptation measures	Distribution		
	Not adopted	Partially adopted	Fully adopted
Gap filling	59	43	2
Selection and propagation of location-specific cultivars	8	57	39
New nutrient management techniques	36	62	6
New disease/ pest management	49	51	4
Nursery	14	53	37
Maintaining good shade level in the plantation	75	28	1
Disease/pest-resistant varieties	12	26	66
Planting in trenches	68	36	0
Soil mulching	44	60	0
Mist irrigation for mid-season drought	11	45	48
Construction of shallow ditches to decrease stagnation of water	31	32	41
Digging out ponds for water storage	50	43	11
Subsoil irrigation and fertigation	11	33	60
Bulk organic manure application	26	46	32
Forking	64	37	3

Table 6. Response Priority Index analysis for ranking adaptation measures

Adaptation Measures	Individual priority			Total no.	RPI	Rank
	Adopted	Partially adopted	Not adopted			
Maintaining good shade level in the plantation	75	28	1	104	2.71	1
Planting in trenches	68	36	0	104	2.65	2
Forking	64	37	3	104	2.59	3
Gap filling	59	43	2	104	2.55	4
New disease/ pest management	49	51	4	104	2.43	5
Soil mulching	44	60	0	104	2.42	6
Digging out ponds for water storage	50	43	11	104	2.38	7
New nutrient management techniques	36	62	6	104	2.29	8
Bulk organic manure application	26	46	32	104	1.94	9
Construction of shallow ditches to decrease stagnation of water	31	32	41	104	1.90	10
Nursery	14	53	37	104	1.78	11
Selection and propagation of location-specific cultivars	8	57	39	104	1.70	12
Mist irrigation for mid-season drought	11	45	48	104	1.64	13
Subsoil irrigation and fertigation	11	33	60	104	1.53	14
Disease/pest-resistant varieties	12	26	66	104	1.48	15

4. CONCLUSION

The study looked at climate variables such as maximum temperature, minimum temperature, precipitation, and relative humidity that had a greater impact on the Cardamom crop. The minimum temperature, precipitation, and relative humidity showed an upward trend on the time series plot for these metrics, while the maximum temperature showed a negative trend. Significant change patterns in these parameters were found using the MK test trends and the Sen slope estimator. The maximum temperature increases by 0.06◦C throughout July, and this rise is significant at the 0.01 threshold of significance. In August and October, there was a temperature increase that was statistically significant at the.05 level. In both cases, the temperature rises by 0.04◦C and 0.03◦C. In December and January, respectively, the lowest temperature increased significantly by 0.06◦C at the 0.05 level of significance and by 0.04◦C at the 0.1 level of significance. According to the test results, there was a significant drop of 6.15 mm at the 0.01 level of significance for the month of June.
Precipitation increased in March by 0.753 mm, which is significant at the 0.05 level. There was a rise of 2.028 mm in May, which is significant at the 0.1 threshold. During March and May, respectively, there is an increase in relative humidity of 0.19 percent and 0.15 percent at the 0.1 level of significance.

Crop production will suffer as a result of all these changes to the climate conditions. These modifications will primarily affect flowering. The likelihood of diminished blossoming or flowers dropping before pollination is increased, which will affect the yield. The trend over the past few years has been for there to be less precipitation than usual in June and then a sudden downpour in the following month. Reduced precipitation delays flower emergence, but strong rains cause damping off or the *azhukal disease.*

It is crucial to use specific adaption tactics to deal with the scenario. 104 of the 120 farmers questioned acknowledged the significance of taking extra precautions to combat climate change. Maintaining a decent shade level came in the Initial among the stated adaptation strategies, then planting in trenches. Trees that provide shade reduce the direct impact of sunshine and rain. It aids in preserving humidity and a favorable environment for the development of crops. The least effective of the suggested solutions was growing disease and pest-resistant cultivars. The most popular type among farmers is *njallani*, which was created by a farmer. Due to its superior production compared to all other types, it became a farmer's favorite. The varieties created by research institutes and the extension services offered to farmers did not satisfy them. Farmers were unable to implement the recommendations made by the extension advisory due to their lower degree of satisfaction with them. The next step is to analyze the demands of the farmers and create a viable backup plan for the crop.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Pachauri Rajendra K, Andy Reisinger. IPCC fourth assessment report. IPCC, Geneva 2007. 2007;044023.
2. Prasada GSLHV, Rao VUM, Rao GGSN. Editors. Climate change and agriculture over India. 1st ed. PHI Learning Pvt. Ltd; 2010.
3. Rao GSLHV, Prasada N, Manikandan. Climate variability and cardamom across the Western Ghats of India." Climate Change Adaptation Strategies in Agriculture and Allied Sectors. 1st ed. Scientifc publishers. 2011;281.
4. Muchie Alemnew, Fikirte Assefa. Impact of climate change on horticultural crops production and quality: A review. Amer. J. Biosci. Bioeng. 2021;9(6):156-161.
5. Oommen Manoj, Gopakumar CS, John Jo Varghese, Rema Shree AB. Climate variability and change in the spices and plantation cropping systems in Kerala state, India. J.Plant.Crops.2022;50(3):169.
6. Belay Abrham, Teferi Demissie, John W. Recha, Christopher Oludhe, Philip M. Osano, Lydia A. Olaka et al. Analysis of climate variability and trends in Southern Ethiopia. Climate. 2021;9(6):96.
7. Gupta Nitesh, Ahin Banerjee, Sanjay K. Gupta. Spatio-temporal trend analysis of climatic variables over Jharkhand, India. Earth Systems and Environment. 2021; 5:71-86.
8. Ahmed M, Hoque A, Islam DK. A trend analysis of climatic variables in the Karimganj District of Assam, India. Indian j. Sci Technol. 2022;15(10):442-450.

9. Kalidas K, Mahendran K, Akila K. Constraints in coconut value chain–A framework for analysis using response priority index. Curr. J. appl. Sci. technol. 2020;39(16):76-82.
10. Murugan, Muthusamy, Paddu Krishnappa Shetty, Raju Ravi, Aavudai Anandhi, Arulappan Joseph Rajkumar. Climate change and crop yields in the Indian Cardamom Hills, 1978–2007 CE. Clim. Change 2012;110: 737-753.
11. Das Suddhasuchi, Amit Baran Sharangi. Impact of climate change on spice crops. Indian Spices: The Legacy, Production and Processing of India's Treasured Export, 1st ed. Springer Cham. 2018;379-404.
12. Krishnamurthy KS, Kandiannan K, Srinivasan V, Dinesh R, Ankegowda SJ, Thankamani CK, Nirmal Babu KV, Peter. Climate change impact and water productivity in black pepper and cardamom. Int. J. Innov. Hortic. 2020; 9(1):1-8.
13. Murugan Muthusamy, Alagupalamuthirsolai M, Kaliyaperumal Ashokkumar, Aavudai Anandhi, Raju Ravi J, Rajangam MK Dhanya, et al. Climate change scenarios, their impacts and implications on Indian cardamom-coffee hot spots; one of the two in the world. Front.Sustain.Food syst. 2022;6: 1057617.
14. Farms Small. Production of large cardamom under climate change scenario-findings from Sikkim 385.2022;Econ:67(4).
15. Murugan M, Ashokkumar K, Alagupalamuthirsolai M, Anandhi A, Ravi R, Dhanya MK, et al. Understanding the effects of cardamom cultivation on its local environment using novel systems thinking approach-the case of Indian Cardamom Hills. Front. Sustain. Food Syst. 2022; 6:728651.
16. Posibia M, Daya Ram, Feroze SM. Adaptation strategies of climate change effect and factors affecting the adaptation choices of large cardamom in Sikkim. Indian Res. J. Ext. Edu. 2022;22(5):155-159.
17. Ram Bhavin, Murari Lal Gaur, Patel GR, Kunapara AN, Pampaniya NK, Damor PA, Balas DB. Assessment of diurnal variability and region-specific connection across intensity, depth & duration of rainfall. Int. J. Environ. Clim. 2023;13(9): 595-606.
18. Murugan, Muthusamy, Anil Kuruvila, Aavudai Anandhi, Pooja A, Kaliyaperumal Ashokkumar, Dhanya MK, Subbiah A, et al. Cardamom agro-environmental interrelationships analysis in Indian cardamom hills. Front. Clim. 2023; 5:1107804.
19. Adhikari Deepika, Ram Asheshwar Mandal, Ajay Bhakta mathema. Effects of climatic variability and soil quality on the production of large cardamom in Dhankuta. Agric. For. 2020;4(1):1-10.
20. Murugan M, Ravi R, Anandhi A, Sajan Kurien MK. Dhanya. Pesticide use in Indian cardamom needs change in cultivation practices. Curr. Sci. 2017; 1058-1063.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/104295