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Impact of climatic variables on cumin productivity of north Gujarat districts

Sevak Das^{1*} and A.M. Shekh²

¹Department of Agricultural Meteorology, C.P. College of Agriculture, SDAU, Sardarkrushinagar-385506

²Anand Agricultural University, Anand- 388110

*Correspondence address: dasagmet86@gmail.com

ORCID: <https://orcid.org/0000-0001-7520-0451>

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ABSTRACT

To quantify the impact of climatic factors on cumin productivity of three districts viz. Banaskantha, Mehsana and Sabarkantha of north Gujarat, weekly weather data of cumin growing season (45th to 10th SMW) for 30 years (1991-92 to 2020-21) were analysed. The cumin yield was obtained from Directorate of Agriculture, Gujarat state, Gandhinagar. For each weather variables, simple and weighted weather indices were generated and used to develop stepwise regression equations. The results revealed that generated indices using temperature, relative humidity and bright sunshine play significantly role to determine cumin productivity. The developed yield forecasting models exhibited $R^2 = 0.51$ to 0.70 , index of agreement 0.80 to 0.90 and RMSE 73.26 to 105.01 in different districts. The models validated with two years i.e. 2021-22 and 2022-23 independent data sets elucidated that percent deviation between observed and predicted yields varied from 14.4 to 26.8% in different districts.

Keywords : Weather variables, Cumin yield, Forecasting model

INTRODUCTION

Cumin (*Cuminum cyminum* L.) belongs to family Apiaceae is one of the important seed spice crop commonly known as “zeera”. It is successfully grown in tropical and sub-tropical climate. Being one of the most important crop extensively used as seed spices worldwide. It is the second most popular spice after black pepper. It is probably a native of the southern mediterranean region to deserts of Egypt and other Arabian countries and to Central Asia (Turkestan). It is grown widely in China, India, Indonesia, Iran, Japan, Morocco, Southern Russia, Syria and Turkey.

India is the leading country for area, production, consumption and export of cumin. In India, during 2022-23, the area and production of cumin were 7.14 lakh ha and 4.62 lakh tones respectively with an average productivity of 647 kg/ha (Anonymous, 2023^a). The major seed spices growing area in India is concentrated in arid and semi-arid regions of Gujarat and Rajasthan. These states contribute more than 80 percent of total seed spices production in the country and thus, both states together are known as “Seed Spices Bowl of India”. In Gujarat, during 2022-23, area under cumin cultivation was reported 2.76 lakh ha and production of 2.14 lakh tonnes with an average productivity of 777 kg/ha. Similarly, the area and production of cumin in Banaskantha district were reported 0.37 lakh ha and 0.31 lakh tonnes

respectively with productivity of 833 kg/ha (Anonymous, 2023^b).

The cumin export was highest during 2018-19 for Vietnam (4.05 lakh tonnes) in terms of quantity followed by Bangladesh, USA, Egypt, Pakistan, Nepal, and UAE. The export of cumin has increased by 454% in terms of quantity from the year 2010 to 2019. The continuous increase in export of the cumin may be due to globalization and free trade policy leading high demand of Indian seed spices in the global market. Consequently, interest of the farmers for more profit popularized the cultivation of cumin (Kumar *et al.*, 2021). Timely and reliable yield forecast of cumin crop is essential for the country like India where cumin is a major export commodity production mainly depends on weather conditions. Weather based yield forecasting is one of the important tools in taking policy decisions on export-import and trade as well as developing storage and marketing.

MATERIAL AND METHODS

Yield and weather data collection

Daily weather data on maximum temperature (Tmax), minimum temperature (Tmin), morning relative humidity (RH1), afternoon relative humidity (RH2), rainfall (mm) and sunshine (BSS) corresponding to growing period of cumin (45th SMW to 10th SMW) of last 30 years (1991-92 to

2020-21) for Banaskantha have been collected from Department of Agricultural Meteorology, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar. The daily weather data for Mehsana and Sabakantha district was collected from NASA website (<https://power.larc.nasa.gov>). These daily weather was converted into weekly basis and finally various weather indices (weighted and un-weighted) were generated through excel command. The data on cumin yield (kg/ha) of Banaskantha, Mehsana and Sabarkantha districts for the corresponding years were also collected from the portal of Government of Gujarat (<https://dag.gujarat.gov.in>).

Statistical approach for yield forecasting

The ICAR-Indian Agricultural Statistical Research Institute, New Delhi modified the existing model developed by Hendricks and Scholl (1943) by expressing the effects of weather on yield in successive weeks as a quadratic function of the respective correlation coefficients between yield and weather parameters, instead of using the week number. To quantify the long term impact of weather variables on cumin productivity of Banaskantha, Mehsana and Sabarkantha districts, two weather indices were developed for each weather variable, one as simple total of weather variables in different weeks (un-weighted index -Z_{i0}) and another as weighted total (weighted index-Z_{i1}) weights being correlation coefficients between de-trended yield (if trend is present) and weather variable in respective week (Table 1). The first index represents the total amount of weather parameter received by the crop during the period while the

other one takes care of distribution of weather parameters with special reference to its importance in different weeks in relation to the de-trended yield. Statistical Package for Social Science (SPSS) computer software version 20 was used for the regression analysis in present investigation. The developed forecast model was as follows:

$$Y = A_0 + \sum_{i=1}^p \sum_{j=0}^1 a_{ij} Z_{ij} + \sum_{i \neq i'=1}^p \sum_{j=0}^1 a_{ii'j} Z_{ii'j} + cT + e$$

Where,

$$Z_{ij} = \sum_{w=1}^m r_{iw}^j X_{iw} \quad \text{and} \quad Z_{ii'j} = \sum_{w=1}^m r_{ii'w}^j X_{iw} X_{i'w}$$

Where,

Y= Forecasted yield (kg/ha)

A₀ = Constant

a_{ij}, a_{ii'j} and c are partial regression coefficients associated with Z_{ij}, Z_{ii'j} and time trend, respectively (ii' = 1, 2, ..., p and j = 0, 1)

r_{iw} is correlation coefficient of yield with ith weather variable in wth period

r_{ii'w} is correlation coefficient (adjusted for trend effect) of yield with product of ith and ith weather variables in wth period

m is period of forecast+

p is number of weather variables used

e is random error distributed as N(0, σ²)

T is technological factor

Table 1: Generated weather indices used in model using composite weather variables

Weather variables	Simple weather indices						Weighted weather indices					
	BSS	Tmax	Tmin	RF	RH1	RH2	BSS	Tmax	Tmin	RF	RH1	RH2
BSS	Z10						Z11					
Tmax	Z120	Z20					Z121	Z21				
Tmin	Z130	Z230	Z30				Z131	Z231	Z31			
RF	Z140	Z240	Z340	Z40			Z141	Z241	Z341	Z41		
RH1	Z150	Z250	Z350	Z450	Z50		Z151	Z251	Z351	Z451	Z51	
RH2	Z160	Z260	Z360	Z460	Z560	Z60	Z161	Z261	Z361	Z461	Z561	Z61

3. Validation of model

Model validation is a comparison between predicted and observed values. There are several statistical measures to evaluate the association between predicted and observed values. Among them the coefficients of determination (R²) are widely used. Willmott (1982) pointed out that the magnitudes of r

and R² are not consistently related to the accuracy of prediction where the accuracy is defined as the degree to which model predictions approach the magnitudes of their observed counterparts.

Test criteria have been separated into two groups viz., summary measures and difference measures. The summary measures describe the quality of prediction

while, the difference measures try to locate and quantify the errors. Willmott (1982) calculated an index of agreement (d) as per the following formulas follow:

$$d = 1 - [\sum (P_i - O_i)^2] / [\sum (P_i - \bar{O})^2 + \sum (O_i - \bar{P})^2]$$

Where, d= Index of agreement

O_i= Observed value for ith observation

P_i= Predicted value for ith observation

$\bar{O}$ = Mean of observed value

$\bar{P}$ = Mean of predicted value

Later include the mean absolute error (MAE), the mean bias error (MBE) and the root mean square error (RMSE). They were calculated according to Willmott (1982) as following based on the terms P_i – O_i:

$$MAE = \sum |P_i - O_i| / n$$

$$MBE = \sum (P_i - O_i) / n$$

$$RMSE = \sum [(P_i - O_i)^2 / n]^{1/2}$$

MAE and RMSE indicate the magnitude of the average error, but provide no information on the relative size of the average difference between (P) and (O). The statistic MBE describes the direction of the error bias. The value of MBE is related to the magnitude of the values under investigation. A negative MBE indicates that the predictions are smaller than the corresponding observations.

RESULTS AND DISCUSSION

Yield forecast for Banaskantha district

The yield forecasting equation for Banaskantha district (Table 2) and (Figure 1). The results revealed that temperature, relative humidity and sunshine hours play an important role to determine the cumin yield. The weather variables like weighted RH1 (Z51), weighted cross product of BSS and RH1 (Z151), weighted BSS (Z11), un-weighted RH1 (Z50) and un-weighted cross product of BSS and Tmax (Z120) found most influencing parameters to determine the productivity of cumin in Banaskantha district. The stepwise multiple regression equation developed with these indices exhibited high coefficient of multiple determination ($R^2 = 0.701$). The Root Mean Squared Error (RMSE) and Index of Agreement (d) were 105.01 and 0.903 respectively (Table 2). The productivity of cumin positively affected by weighted RH1, weighted BSS and unweighted RH1 while the impact of cross product of

BSS and RH1 and cross product of un-weighted BSS and Tmax was negative. An increase in unit coefficient of weighted RH1, weighted BSS and un-weighted RH1, there was increase in yield by 24.67, 157.03 and 0.62 kg/ha, respectively whereas, decrease in unit coefficient of weighted cross product of BSS and RH1 and across product of unweighted BSS and Tmax, there was increase in yield by 2.11 and 0.20 kg/ha respectively. The percent contribution of weighted RH1, weighted cross product of BSS and RH1, weighted BSS, un-weighted RH1 and un-weighted cross product of BSS and Tmax was 18.9, 34.4, 24.5, 13.2 and 9.0%, respectively (Table 3). The graphical presentation of observed and predicted yields also indicated that model fairly captured the yield variability (Figure 1).

Yield forecast for Mehsana district

In Mehsana, maximum temperature (Tmax), bright sunshine (BSS) and morning relative humidity significantly affected cumin productivity. The weighted indices of Tmax (Z21), weighted indices of cross product of BSS and RH1 were most influencing weather variables to determine the district's cumin productivity. The regression equation exhibited $R^2 = 0.586$, RMSE 73.26 and agreement index 0.850 (Table 2). The productivity of cumin was positively affected by the combination of weighted Tmax, weighted cross product of BSS and RH1 and weighted BSS. An increase in unit coefficient of weighted Tmax, weighted cross product of BSS and RH1 and weighted BSS, increased cumin yield by 14.91, 0.14 and 27.40 kg/ha respectively. The percent contribution of weighted Tmax, weighted cross product of BSS and RH1 and weighted BSS was 40.1, 33.7 and 26.2%, respectively to the total variability in the yield (Table 3). The forecasted yield was more or less in good agreement with observed one in the district (Figure 2).

Yield forecast for Sabarkantha district

Maximum temperature (Tmax) and morning relative humidity (RH1) had significant impact on cumin productivity of Sabarkantha district. The un-weighted indices of Tmax (Z20) and weighted indices of RH1 were key determinant of the cumin productivity in this district. The regression equation had $R^2 = 0.505$ with RMSE value of 98.93 and index of agreement 0.803 (Table 2). The decrease in unit coefficient of un-weighted Tmax, increased cumin yield by 3.64 kg/ha while, increase in unit coefficient of weighted RH1, increased in yield by 6.49 kg/ha. The percent contribution of un-weighted Tmax and weighted

RH1 was 50.5 and 49.5% to the total yield variability, respectively (Table 3 and Figure 3).

The developed forecasting models were validated with two years (2021-22 and 2022-23) independent data sets. The observed and predicted yields deviation varied from 14.4 to 18.4% for Banaskantha district, 22.1 to 26.8% for Mehsana district and 22.5 to 24.1% for Sabarkantha district (Table 4). Overall, the models provided reliable forecast of cumin yield with reasonable accuracy. Das and

Kumar (2019) also developed yield forecasting model for wheat in Banaskantha district of Gujarat using weighted RHI, weighted cross product of Tmax and Tmin and un-weighted cross product of BSS and RHI. Decrease in coefficient of estimation of these weather indices explained 67% yield variability. Similar studies were also carried out in various crops by Chaurasia and Minakshi (1997), Varnora *et al.* (2004), Chaudhari *et al.* (2015), Gupta *et al.* (2018), Vaghasiya *et al.* (2016), Diwan *et al.* (2018) and Mishra *et al.* (2018).

Table 2 : Forecasting models of cumin yield for different districts

District	Regression Equation	R ²	d	RMSE
Banaskantha	Y = -550.56 +24.67Z51** -2.11Z151** +157.03Z11** + 0.62Z50* -0.20Z120*	0.701	0.903	105.01
Mehsana	Y = 1792.16 +14.91Z21* +0.14Z151* +27.40Z11*	0.586	0.850	73.26
Sabarkantha	Y= 2669.51 -3.64Z20* +6.49Z51*	0.505	0.803	98.93

Note: Z51= Weighted RH1, Z151= Weighted BSS*RH1, Z11= Weighted BSS, Z50= Un-weighted RH1, Z120= Un-weighted BSS*Tmax, Z21= Weighted Tmax, Z20= Un-weighted Tmax

Table 3: Percent contribution of different weather indices to the total variability in yield

Weather indices	Percent contribution		
	Banaskantha	Mehsana	Sabarkantha
Weighted RH1	18.9	-	49.5
Weighted BSS*RH1	34.4	33.7	-
Weighted BSS	24.5	26.2	-
Un-weighted RH1	13.2	-	-
Un-weighted BSS*Tmax	9.0	-	-
Weighted Tmax	-	40.1	-
Un-weighted Tmax	-	-	50.5

Table 4 : Observed and predicted yield (kg/ha) of cumin of during validation

District	2021-22			2022-23		
	Observed	Predicted	Percent deviation	Observed	Predicted	Percent deviation
Banaskantha	734	599	18.4	833	713	14.4
Mehsana	721	572	22.1	777	610	26.8
Sabarkantha	721	547	24.1	777	602	22.5

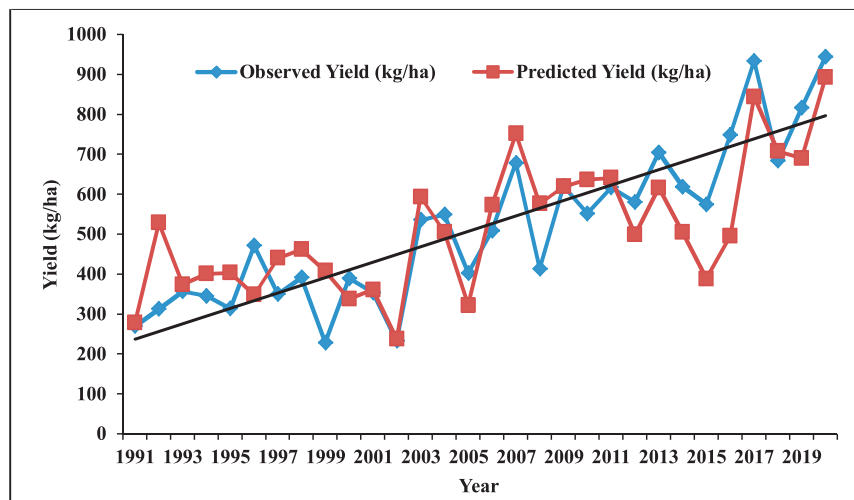


Figure 1: Comparison between observed and predicted yield of cumin of Banaskantha

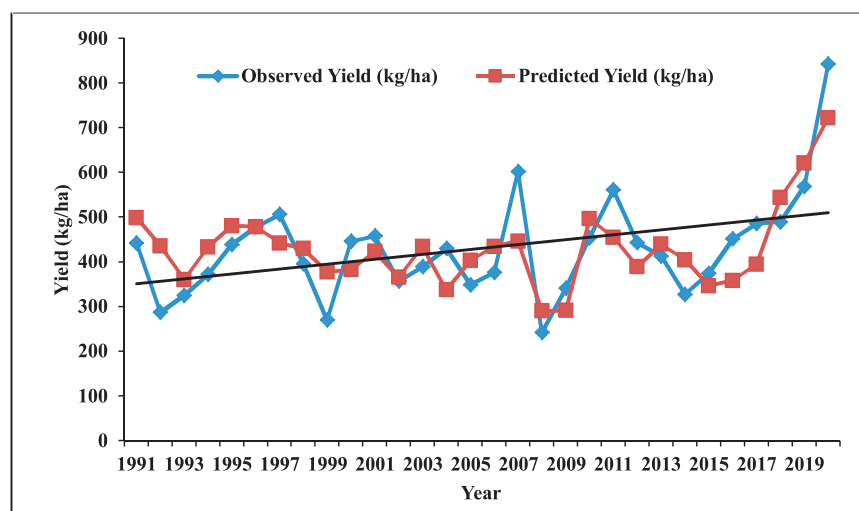


Figure 2: Comparison between observed and predicted yield of cumin of Mehsana

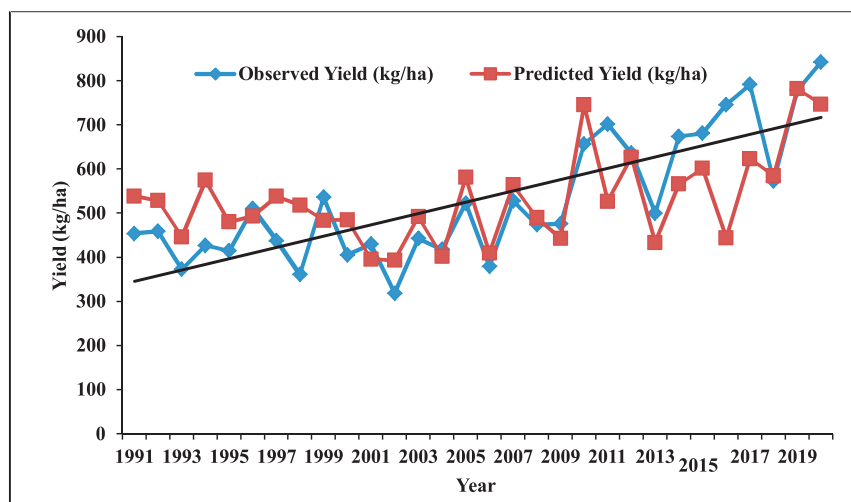


Figure 3: Comparison between observed and predicted yield of cumin of Sabarkantha

CONCLUSION

The long term relationship between climatic factors and yield of cumin indicated that, maximum and minimum temperatures, relative humidity and sunshine hours were most influencing parameters. The developed models using such weather variables provided reasonable forecast of cumin yield and explained 50.5 to 70.1% variation in the yield under different districts.

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