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Research Article

EFFECT OF TRIGGER WEATHER ON SAFFRON PHENOLOGY UNDER TEMPERATE CONDITIONS OF JAMMU AND KASHMIR, INDIA

F.A. NEHVI[1]*, N.A. DAR[2], B.A. ELAI[2], M.H. KHAN[2], A.M. IQBAL[2], G.H. MIR[2], A. GAUTAM[1] AND Q. SAMEERA[2]
[1]Spices Board (Ministry of Commerce and Industry, Govt of India), Regional office, Srinagar, 190008, India
[2]Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, Jammu and Kashmir, 190025, India
*Corresponding Author: Email - f.nehvi@rediffmail.com

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Abstract: Jammu and Kashmir Union Territory of India is blessed with temperate type of climate with mean annual aerial temperature of 12.99°C, average maximum temperature of 19.55°C, average minimum temperature of 6.43°C, mean relative humidity of 70.56% and precipitation of 1071.15mm received in 91.36 wet days. Weather parameters make J&K pride of being only place in India with successful story of cultivating saffron since aegis. Present study was carried out to study influence of weather parameters recorded over 10 years (2012-2021) on saffron plant development which is divided in to 6 stages *viz*; corm dormancy, flower ontogenesis, bud sprouting, flowering, vegetative phase and plant senescen. Analysis of weather data suggests that with onset of sprouting stage there is decline in average maximum and minimum temperature by 9.29 % & 38.13% respectively, compared to flower ontogenesis stage. However, with decline in mean aerial temperature by 15.29%, there is increase in mean relative humidity by 3.04%. Study has confirmed that saffron flowering is initiated from the sprouted corms either in 2nd fortnight of October or in November depending upon maximum temperature, that has to be around 17°C. For vernalization saffron plant requires 1000-1200 hrs of chilling with mean aerial temperature ranging from 1- 4°C. Weather data pooled over years clearly indicate that during the month of December saffron plant receives 465 chilling hours and during 2nd phase of vegetative cycle (1st January to 15th February) which is also associated with corm development and contractile root formation saffron plant receives 690 chilling hours as mean aerial temperature recorded during this period was recorded to be 2.40°C. This unique weather condition of Jammu and Kashmir from 1st December to 15th February has made saffron cultivation possible. Mean aerial temperature of 8.04°C associated with mean relative humidity of 70.03% is ideal for completion of corm development and foliage growth in saffron. Association of high rainfall with high humidity as evident from data clearly signal build-up of fungal inoculums causing corm rot. Identified weather parameters if used by researchers will help in programming Good Agricultural Practices pertaining to agronomic, disease and pest management capsules to mitigate ill effects of climate change for boosting saffron production.

Keywords: *Trigger weather, Phenological stages, Saffron production*

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Introduction

Kashmir saffron recognized as Globally Important Agricultural Heritage System of India by FAO, Rome and associated with Geographical Indication tag conferred by GI authority of India is a legendary crop of Union Territory of Jammu and Kashmir, being cultivated by 32401 farm operating families from 120 villages. Maximum farm operating families belong to district Pulwama (16140), followed by Kishtwar (7656), Budgam (7225) and Srinagar (1380). Out of 3715 hectares of available saffron area district Pulwama accounts for 84.5 per cent of total saffron area (3200ha) available in 47 villages, followed by 7.9% of area in Budgam (300 ha) from 45 villages, 4.3% of saffron area in Srinagar (165 ha) from 3 villages and 3.2% of area in Kishtwar (50 ha) from 25 villages [Fig-1].

Saffron farming system was under distress as area and production declined by 42.5% and 51.72%, respectively in the year 2008-09. Prolonged drought over the years leading to low production and low market demand and price made farmers despondent about saffron farming system and started giving place to other commercial ventures. In this pursuit about 1992 hectares of traditional saffron area was permanently lost to Industrialization.

National Saffron Mission implemented by Ministry of Agriculture and Farmers Welfare Department stabilized not only saffron area (3715 ha) but also enhanced saffron production (18.05 M.T.) and productivity (4.92 kg ha^{-1}) by 90.7% & 96.8 %, respectively in the year 2020-21 when compared to 2008. (*Source: Directorate of Agriculture & Farmers welfare, Kashmir*).

However, sharp decline in production and productivity during 2014, 2017 and 2018 due to inclement weather in J&K are exception and thus needs to be analyzed for Trigger weather parameters as critical input during phonological stages of saffron crop growth and development to mitigate the ill effects of climate change [Fig-2].

High humidity accompanied with high precipitation is concern of farmers due to build-up of fungal inoculam causing saffron corm rot [1]. Importance of sensitivity of Saffron plant & development towards safe limits of weather parameters *viz*; air temperature, humidity and precipitation available during critical stages of crop growth. have also been reported by several workers [2-5]. Therefore, present study was carried to study and analyze the effect of weather parameters on growth and development of saffron during critical stages of crop growth.

Materials and Methods

The paper is based on ten years field observation records from 2012-2021, which were collected from many farming crops and many field experiments, with plant material of different ages and cultivated at different sites across the heritage site of Pampore, Kashmir (34°01'N / 74°56'E). Relationship of weather parameters *viz*; maximum and minimum temperature, maximum and minimum relative humidity and precipitation was studied as per the biological cycle of saffron plant that starts with the corm in dormancy stage(1st May to 25th June), apparently showing neither

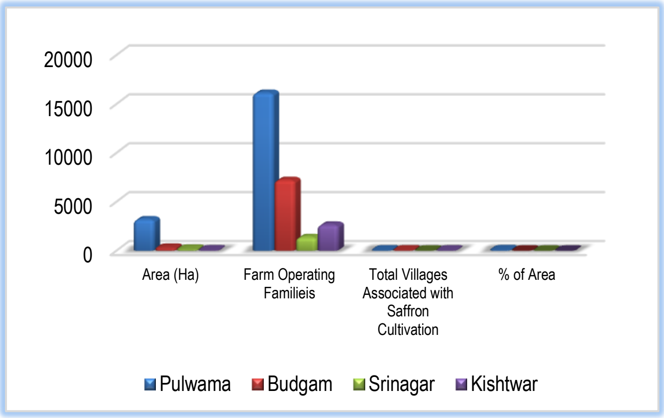

Fig-1 Demography of saffron districts of Jammu & Kashmir (Source APD Kashmir

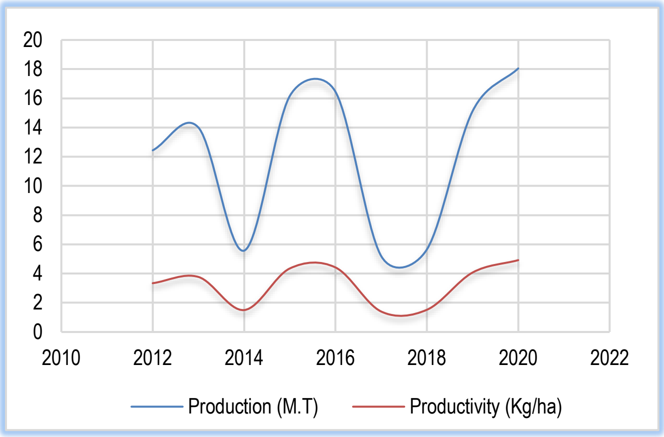

Fig-2 Trends in Production & Productivity of Kashmir Saffron pooled over Years (Source: APD Kashmir)

morphological change, nor external growth, although there do exist internal physiological and morphogenetic changes [6] followed by flower ontogenesis (26th June-25th August), Sprouting (26th August to 30th September), appearance of flower cataphylls (1st fortnight of October), flowering (2nd fortnight of October) and vegetative development (November to April): Leaf development, development of replacement corms and plant senescen [1].

Meteorological data of various weather parameters recorded at Agro-Meteorological Observatory, SKUAST-Kashmir, Srinagar was used in the study. Saffron cultivation and production information has been compiled from Agriculture Production and Farmers Welfare Department Kashmir.

Results and Discussion

Ontogenesis of Kashmir saffron is spread over 6 developmental stages from 1st May to 25th June (corm dormancy), 26th June to 25th August (flower ontogenesis), 26th August to 30th September (bud sprouting), 1st October to 10th November (Flowering), 11th Nov to 31st March (Vegetative) and 1st April to 30th April (Plant senescen). The ontogenesis period of saffron with above ground organs (183 days) is almost similar to period showing non above ground organs (182 days). vegetative phase is the longest period (142 days), followed by flower ontogenesis (61 days), dormancy phase (55 days), flowering (41 days), bud sprouting phase (36 days) and plant senescen (30 days).

Annual weather parameters recorded over 10 years (2012-2021) for aerial temperature, relative humidity and precipitation reveal that saffron phenology under temperate conditions of J&K is under the influence of annual mean aerial temperature of 12.99°C, mean relative humidity of 70.56%, and total precipitation of 1071.15 mm received during 91.36 wet days [Fig-3], [Table-1]. Similar results for average annual maximum temperature (19.55°C), base temperature (6.43°C) total precipitation (1071.15 mm) have also been reported from J&K by Batool, *et al.*, (2020) [7].

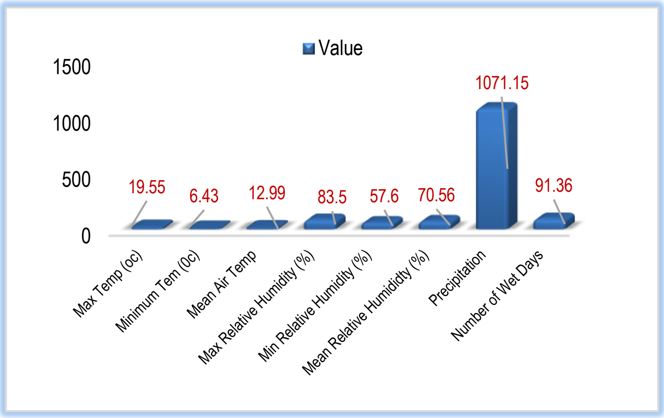

Fig-3 Annual weather parameters of J&K blessed with saffron cultivation

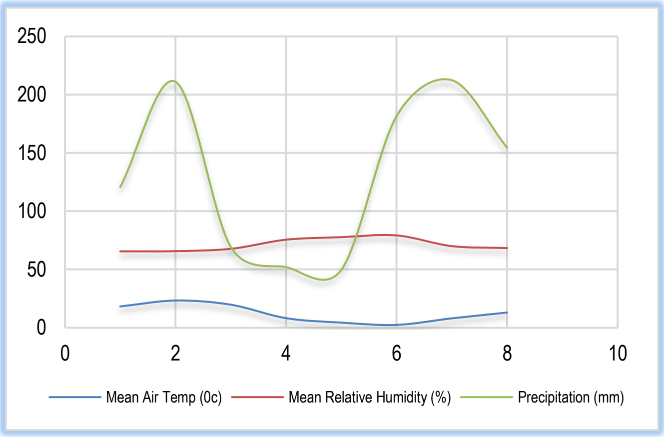

Fig-4 Relationship of weather parameters and saffron phonology- pooled over years

Dormancy and weather

During corm dormancy saffron corms apparently show neither morphological change nor external growth and the apex looks like a resting bud with protective cataphylls. Comparative studies revealed that mean air temperature of 18.28°C associated with mean relative humidity of 65.55% favours corm dormancy under temperate conditions. Similar results for corms dormancy have also been reported [4]. Year wise comparative analysis revealed a significant deviation of ±2°C in terms of maximum and minimum air temperature and ±10% in terms of relative maximum and minimum humidity.

However, rainfall pattern was observed to be erratic over the years suggesting volatility of rainfall during dormancy associated with high humidity and thus can be responsible for build-up of fungal inoculums. Excess early summer precipitation associated with high humidity has become concern of saffron growers as during 2015 saffron growers lost about 30% of corms due to corm rot caused by fungal infestation as saffron area recorded 400% more precipitation from May to July [8,9]. High rainfall therefore warrants efficient cultural management ensuring proper drainage of water from saffron beds as a Good Agricultural Practice to mitigate ill effects of climate change. Corm rot management in saffron has been reported by several workers [10-13].

Flower ontogenesis and weather

Flower ontogenesis stage (26th June to 25th August) is a critical phenological stage of saffron as weather parameters have strong influence on flower formation. During 26th June to 14th July, shoot apex increases in size and leaves differentiate at the flank, followed by Stamen initiation (15th July to 25th July), development of leaf primordial cover base of meristem (26th July to 15th August) and Gynoecium formation (16th August to 25th August). During summer (26th June to 26th August) flower initiation is accelerated on account of earlier rise in average maximum temperature from 25.92°C to 30.1°C, average minimum temperature

Table-1 *Description of annual weather parameters in relation to saffron development stages-Polled over years*

Phenological Stage	Max Temp (°C)	Min Temp (°C)	Mean Air Temperature (°C)	Relative Humidity (Maximum)(%)	Relative Humidity (Minimum)(%)	Mean Relative Humidity (%)	Precipitation (mm)	No of Wet Days
(1st May to 25th June)	25.92±0.35 (24.3-27.9)	10.65±0.23 (9.2-11.5)	18.28 (17.25-19.7)	77.27±1.56 (69.4-89.1)	53.83±1.32 (49.4-62.8)	65.55 (61.3-69.95)	120.76±16.84 (36-189.8)	16.1±08 (11-18)
(26th June to 25th August)	30.1±0.30 (29.0-32.6)	16.59±.0.17 (15.9-17.8)	23.34 (22.85-24.45)	79.25±1.48 (69.2-83.8)	52.17±1.48 (42.9-59.5)	65.71 (56.05-71.35)	211.08±34.19 (86.8-443.4)	16.3±1.78 (10-24)
(26th August to 30th Sept)	27.54±0.52 (24.9-30.4)	12.01±0.38 (10.5-13.9)	19.77 (17.7-21.6)	82.68±1.17 (75.2-87.9)	52.75±2.10 (42-65.1)	67.71 (61.15-76.2)	69.34±16.53 (0-237.7)	7±1.11 (0-13)
(1st October-10th November	21.24±0.72 (19-23.9)	4.05±0.53 (2.2-6.7)	12.64±0.34 (10-60-14.15)	85.0±1.49 (75.9-91.2)	55.5±3.32 (39.1-68)	70.25±2.33 (57.2-78.2)	71.87±24.13 (0-239.1)	5.2±1.28 (0-11)
(11th Nov -31st December)	10.7±0.46 (7.4-12.3)	1.97±0.29 (-3 to- 0.3)	6.33±0.21 (3.1-5.15))	89.7±0.68 (86.3-92.4)	65.7±1.74 (53.1-72.2)	77.71	49.7±15.81 (0-150.6)	6.6±1.42 (0-12)
(1st January to 15th February)	7.4±0.72 (4.9-11.1)	-2.6±0.31 (-4.9 to -1.1)	2.45±0.32 (1.25-4.1)	91±0.39 (89.1-93.5)	67.42±2.77 (57.1-78.8)	79.21 (73.1-84.5)	181.5±36.99 (56.8-438.4)	12±1.44 (4-20)
(16th February-31st March)	13.88±0.58 (10.7-16.8)	2.2±0.19 (1-3.1)	8.04±0.34 (6.2-9.7)	83.52±0.98 (78.3-90.1)	56.5±2.05 (45.4-60.7)	70.03±1.45 (61.85-79.4)	212.4±50.98 (56.7-629.1)	15.6±1.40 (7-23)
(1st April to 30th April)	19.6±0.37 (17.7-21.4)	6.6±0.16 (5.3-7.1)	13.01±0.24 (11.90-14.45)	79.6±1.13 (75.1-87.6)	57.0±1.95 (48.4-68.9)	68.37±1.39 (61.75-78.25)	154.5±21.31 (50.2-321.5)	12.6±0.6 ((10-16)
Pooled over Years	19.55±2.71 (7.4-25.92)	6.43±1.83 (-2.6-16.59)	12.99±2.47 (4.36-19.77)	83.50±1.63 (77.27- 91.0)	57.60±1.92 (52.17-65.7)	70.56±1.72 (65.55-79.21)	1071.15±21.74 (694.4-1383.5)	91.36±1.5c2 (68-110)

Table-2 *Analysis of weather parameters in relation to saffron dormancy, flower ontogenesis and bud Sprouting-Polled over years*

Year	Saffron corm dormancy (1st May to 25th June)			Saffron flower ontogenesis (26th June to 25th August)			Saffron bud Sprouting ((26th August to 30th September)		
	Mean Air Temperature(°C)	Mean Relative Humidity (%)	Precipitation (mm)	Mean Air Temperature(°C)	Mean Relative Humidity (%)	Precipitation (mm)	Mean Air Temperature(°C)	Mean Relative Humidity (%)	Precipitation (mm)
2012	17.6	66.5	58(0.2-8.4)	23.75	66.1	92.4(1-26.4)	20.4	74.75	127.4(1-40)
2013	19	64.1	136.6(0.8-29.8)	23.7	66.9	281(1.5-78.2)	20.35	70.7	31.8(0.6-7.8)
2014	17.75	69.95	84(0.2-27.4)	23.1	63.95	135.2(1.4-33.6)	17.7	76.2	237.7*(1.2 to 53.9)
2015	17.25	68.1	189.8(0.2-68.4)	23.05	71.1	443.4(0.2-56.2)	18.65	66.9	75.4(3.5-37)
2016	19.7	62.95	67.8(0.6-18.5)	22.95	66.5	145.6(0.34-43.2)	19.75	69.1	72.1(3-22)
2017	18.65	65.95	187.1(1-33)	23.35	67.25	130.3(1.2-21)	17.7	63	42.8(1-24)
2018	18.85	61.3	70.8(1-22.6)	22.95	71.35	296.4(0.8-38.2)	20.25	64.8	22.8(5.4-12.4)
2019	16.7	65.6	193(1-47.4)	22.85	66.2	222.6(1-42.4)	21.6	61.15	0
2020	18.5	67.85	148.2(1-51.6)	24.45	56.05	86.8(1-29.8)	19.75	66.05	156.2(0.6-30)
2021	18.85	63.2	72.3(0.4-11.4)	23.3	61.7	277.1(0.8-68)	21.6	64.5	141.2(1-44.2)
Polled over years	18.28±0.28 (17.25-19.7)	65.55±0.80 (61.3-69.95)	120.76±16.84 (36-189.8)	23.34±0.15 (22.85-24.45)	65.71±1.33 (56.05-71.35)	211.08±34.19 (86.8-443.4)	19.77±0.42 (17.7-21.6)	67.71±1.48 (61.15-76.2)	69.34±16.53 (0-237.7)

Table-3 *Analysis of weather parameters during saffron flowering period-Polled over years*

Year	Saffron Flowering (1st October to 10th November)			Saffron Flowering (Date of first flower initiation to final bloom)				
	Mean Air Temperature (°C)	Mean Relative Humidity (%)	Precipitation (mm)	Flowering Period From	Flowering Period To	Mean Air Temperature (°C)	Mean Relative Humidity (%)	Precipitation (mm)
2012	11.85	70.45	8.9(8.9)	5th November	10th November	9.2	72.33	0
2013	14.15	73.6	38(3.2-9.4)	29th October	10th November	8.79	78.24	26.4
2014	12.65	79.6	43(0.4-17.4)	24th October	10th November	9.81	81.21	20
2015	12.3	75.45	126.9(2-27)	19th October	10th November	9.5	78.95	118.8
2016	12.8	61.35	6.4(6.4)	1st November	10th November	9.23	64.8	0
2017	14.6	60.7	0	13th November	20th November	5.78	77.12	15.6
2018	10.6	72.55	140.10.2-61.4)	1st November	10th November	5.42	81.25	129.6
2019	12.15	73.55	239.1(4.4-124.5)	1st November	10th November	6.86	80.8	206.5
2020	12.7	57.2	0	1st November	12th November	9.03	61.45	0
2021	12.65	78.2	116.3(0.8-38)	1st November	10th November	8.67	79.25	3
Polled over years	12.64±0.34 (10-60-14.15)	70.25±2.33 (57.2-78.2)	71.87±24.13 (0-239.1)			8.22±0.47 (5.42-9.81)	75.54±2.12 (61.45-81.25)	51.99±21.89 (0-206.5)

from 10.65°C to 16.59°C, average maximum relative humidity from 77.27% to 79.25%, average rainfall from 120.76 mm to 211.08 mm associated with decline in minimum relative humidity from 55.83 % to 52.17 % [Table-2].61 days of incubation of corms in the average air temperature of 23.34°C (22.85°C - 24.45°C) associated with average relative humidity of 65.71% (56.05% - 71.35%) ensures flower formation. Maximum flower formation in the range of 23-25°C, and with decline in air temperature to 17°C incubated corms form maximum one flower per corm and has also been reported [4], whereas, incubation at 23-25°C results in 2.5-3.0 flowers/corm. To avoid impact of excess rainfall proper management practices for hoeing, corm lifting and corm planting is needed during ontogenesis period. Weather parameters recorded during flower ontogenesis period did not reveal any relationship with saffron production as during the deficit years of 2014, 2017 and 2018 the weather parameters were recorded within the normal range indicating that flower ontogenesis process must have been completed normally in these years.

Sprouting and weather

Saffron bud sprouting (26th August to 30th September) is characterized with sprout initiation, fibrous root development & floral initials are distinctly visible in vascular bundle. In 15 days from 26th August, sprout with floral initials reaches to 4 cm length, which further extends to 12 cm in next 10 days. Between 20th September to 30th September sprouts attain a length of 13 cm and shows floral parts embedded in whorl of tepals. 36 days incubation at mean air temperature of 19.77°C and mean relative humidity of 67.71% facilitates sprout development. Deviation from mean pooled over years for maximum temperature was observed to be ±3°C Analysis of weather data suggests that with onset of sprouting stage there is decline in average maximum and minimum temperature by 9.29 % & 38.13% respectively, compared to flower ontogenesis stage. However, with decline in mean aerial temperature by 15.29%, there is increase in mean relative humidity by 3.04% [Table-2]. In saffron, availability of moisture during sprouting stage is considered the trigger weather to induce saffron flowering on account of development of adventitious roots that helps in better sprout activation. During this period saffron crop should receive 700 m3of water per hectare to ensure quick and timely sprouting leading to high productivity [14,15]. Therefore, deviation from this trigger weather will definitely effect crop production as recommended water availability during sprouting stage ensures 40% yield gain over moisture stress cultivation due to activation of meristematic regions from apicular, axillary and lateral buds. Perusal of [Table-4] reveals that rainfall over 10 years (2012-2021) during bud sprouting period ranged from 0- 237.7 mm with a mean of 69.34 mm.

However, during pre-flowering period (26th August to 26th October) it ranged from (32.6 mm - 261.1mm) with a mean of 121.6 mm, which is in agreement with earlier report of 113 mm rainfall during pre-flowering period [5]. Excess or deficit rainfall observed during the period under study is suggestive of direct impact of abiotic stress on saffron production & productivity. Out of 261.1 mm rainfall received during pre-flowering period of 2014 saffron crop received 71.7% water (187.1 mm) during 1st September to 7th September, resulting in hormonal crosstalk leading to forced sub-hysteranthus characteristics of saffron leading to saffron production loss as during 2014 J&K recorded only 5.57 M.T.

Table-4 *Analysis of weather parameters in relation to saffron corm initiation and leaf development-Polled over years*

Year	Saffron corm initiation and leaf development								
	11th November to 31st December			11th November to 30st November			1st December to 31st December		
	Mean Air Temperature (°C)	Mean Relative Humidity (%)	Precipitation (mm)	Mean Air Temperature (°C)	Mean Relative Humidity (%)	Precipitation (mm)	Mean Air Temperature (°C)	Mean Relative Humidity (%)	Precipitation (mm)
2012	5.15	75.5	57.4(1-26.2)	7.29	67.15	12.8	3.76	80.96	44.6
2013	5.15	77.5	25.2(2.4-12.6)	6.97	74.07	0	3.96	79.83	25.2
2014	4.05	78.6	0	5.9	80.62	0	2.93	77.46	0
2015	4.9	78.7	27.4(0.4-16.5)	7.3	77.52	4.4	3.33	79.51	23
2016	4.6	72.7	4(4)	6.29	69.87	0	3.64	74.67	4
2017	4.6	76.3	65.5(1-28)	5.9	73.57	16.38	3.67	78.44	49.9
2018	4	77.7	14.2(1.4-7)	6.42	78.67	8.6	2.4	77.22	5.6
2019	3.1	82.1	150.6(1.5-38.8)	4.93	85.97	94.4	1.91	79.67	56.2
2020	3.75	80.3	103.1(1-29.2)	4.73	80.97	43	3.1	79.94	60.1
Polled over years	4.36±0.21 (3.1-5.15)	77.71±0.85(72.7-82.1)	49.7±15.81(0-150.6)	6.19±0.29	76.49±1.85	19.9±9.75	3.19±0.21	78.63±0.60	29.84±7.40

Table-5 *Analysis of weather parameters (1st January to 30th March) in relation to saffron corm development, contractile root formation, foliage growth and corm maturation -Polled over years*

Year	Saffron corm development, contractile root formation, foliage growth and corm maturation								
	Saffron corm development and contractile root formation (1st January to 15th February)			Completion of saffron corm development and foliage growth (16th February to 31th March)			Corm maturation (1st April to 30th April)		
	Mean Air Temperature (°C)	Mean Relative Humidity (%)	Precipitation (mm)	Mean Air Temperature (°C)	Mean Relative Humidity (%)	Precipitation (mm)	Mean Air Temperature (°C)	Mean Relative Humidity (%)	Precipitation (mm)
2012	1.55	84.5	124.6(0.6-19.8)	8.15	67	60.4(0.8-23.4)	13.15	68.45	130.5(1-30.4)
2013	3	79.65	132.4(1-55.2)	8.8	65.65	145.6(4.2-36.2)	12.75	69.7	135.6(1-32.6)
2014	2.2	81.95	200.1(0.6-54.2)	6.74	74.35	312.2(0.8-75)	11.9	69.7	124.8(1.4-20.4)
2015	3.85	73.1	75.5(1-24.8)	6.2	79.4	629.1(2-67.6)	13	66.2	186.6(1.8-50)
2016	4.1	75.55	56.8(1.2-20.6)	8.5	69.85	224.9(1-30.6)	12.35	78.25	116.8(0.2-30.4)
2017	1.9	82.1	438.4(1.8-128)	8.25	68.2	197.9(1.5-71)	13.2	70	321.5(1-94)
2018	3.5	70.95	39.5(1.0-24.3)	9.7	61.85	56.7(1.4-15.7)	14.1	64.45	160.3(1.8-54.4)
2019	1.15	84.4	293.6(1.4-56.4)	6.65	71.35	93.1(0.6-17.8)	14.45	64.05	50.2(1-15.2)
2020	2	79.2	250.4(0.6-88)	8.55	72.1	133.4(1-21.4)	13.25	71.15	126(1-20.2)
2021	1.25	80.7	204.5*(1-84)	9.1	70.57	271.2(0.6-60)	12.05	61.75	193.2(3.2-35.8)
Polled over years	2.45±0.32 (1.25-4.1)	79.21±1.38 (73.1-84.5)	181.5±36.99 (56.8-438.4)	8.04±0.34 (6.2-9.7)	70.03±1.45 (61.85-79.4)	212.4±50.98 (56.7-629.1)	13.01±0.24 (11.90-14.45)	68.37±1.39 (61.75-78.25)	154.5±21.31 (50.2-321.5)

Data suggests that excess and deficit rainfall is detrimental for saffron plant development and flowering only if received between 26th August to 30th September as it interacts with the hormonal regulations of saffron. Saffron faces water worries because of the unpredictable dispersion of precipitation all through the protracting time frame [16]. However, downpour during the pre-blooming stage has been reported to have constructive outcomes on saffron yield [17-19].

The suitable development and improvement of saffron is firmly subject to climatic condition particularly precipitation and temperature. Decrease in precipitation is considered as one of the fundamental purposes behind its yield decrease [20]. Study while analyzing relationship between rainfall variability on saffron yield in Kashmir valley for a period from 1995-2015 revealed positive relationship between yearly precipitation and saffron yield [7]. To mitigate the ill effects of deficit rainfall infrastructure for providing water to saffron crop stands already created. 125 borewell with sprinkler distribution system has been created in the major saffron growing areas of Jammu & Kashmir [15].

Flowering and weather

The flowering stage starts when the sprout (usually composed of three sheaths) emerges from the soil surface and is influenced by weather parameters during 41 days period (1st October to 10th November). Perusal of [Table-3] reveal that during 1st October to 10th November, maximum men air temperature of 21.24°C (19°C - 23.9°C) was accompanied with minimum temperature of 4.05°C (2.2°C -6.7°C), & average relative humidity of 70.25%. Further analysis of weather data pertaining to saffron flowering revealed that high temperatures observed during first fortnight of October is responsible for delaying flowering to November as has been observed in all the years under study except 2013, 2014 and 2015, wherein, saffron flowering was initiated on 29th October, 24th October and 19th October, respectively [Table-3]. Data suggest that mean aerial temperature of 8.22°C with a corresponding range of 5.42°C to 9.81°C accompanied with a mean relative humidity of 75.54 % is ideal for saffron flowering under temperate conditions of Kashmir. With corresponding decline in mean aerial temperature by 34.96% (from 12.64°C to 8.22°C), the mean relative humidity increased from 70.25% to 75.54% (7.07%) and thus proves to be important for flower induction. Low mean air temperature by 29.68% in 2017 and 34.06% in 2018 with corresponding high mean relative humidity by 2.09% in 2017 and 7.51% in 2018 has been responsible for low saffron production in these years. However, Giri, *et al*., (2006) [21] did not reveal any clear relationship between productivity and average humidity that ranged from 63% to 67% for 1998-2203. Study clearly suggests that precipitation is important critical trigger weather during flowering as it favours or disfavours saffron production depending on the time of precipitation. If received after completion of 80% flowering then it further helps in activation of more meristematic buds to induce flowering. But if rainfall occurs immediately after flower initiation or during flowering it leads to decline in aerial temperature leading to production loss on account of flower abortion.

Vegetative phase and weather

Vegetative stage is most critical as chilling requirement for vernalization is received by saffron plant during this period. The period is also critical for development of replacement corms which largely depend on efficient translocation of photosynthates from source to sink. Phenological growth stage is completed followed with plant senescen with production of full mature corms showing impression of mother corms in 142 days [1]. Phenological growth stages of saffron have also been reported. During 11th November to 31st December (51 days) leaves from the apicular & lateral bud region are first visible above ground and leaves grow at 80% of final length. This is followed by development of corm, lateral bud and terminal bud contractile roots in 46 days from 1st January to 15th February. In next 45 days (16th February to 31st March) formation of replacement corms associated with 100% leaf growth and corm development is completed. From 1st April to 30th April (30 days) leaves show signs of prominent senescen and fully mature daughter corms are produced. Perusal of [Table-4] revealed that average maximum and minimum temperature of 10.7°C & 1.97°C accompanied with average maximum and minimum relative humidity of 89.7% & 65.7%, respectively favours saffron leaf development. For vernalization saffron plant requires 1000-1200 hrs of chilling with mean aerial temperature ranging from 1-4°C. During first 20 days of vegetative phase (11th November to 30th November) mean aerial temperature was observed to be 6.19°C accompanied with mean relative humidity of 76.49 % [Table-4]. Data clearly suggest that saffron plant does not receive chilling during November period. However, during next 31 days (1st December to 31st December) mean aerial temperature was recorded to the extent of 3.19°C accompanied with mean aerial relative humidity of 78.63% [Table-4].

Weather data pooled over years clearly indicate that during the month of December saffron plant receives 465 chilling hours. Further evaluation revealed that during 2nd phase of vegetative cycle (1st January to 15th February) which is also associated with corm development and contractile root formation saffron plant receives 690 chilling hours as mean aerial temperature recorded during this period pooled over years was recorded to be 2.45°C accompanied with maximum temperature of 7.4°C and minimum temperature of -2.6°C. On an average crop receives 181.5 mm precipitation in terms of rain/snow during this period [Table-5].

Table-6 *Description of trigger weather parameters in relation to saffron development-Polled over years*

Phenological Stage	Max Temp (°C)	Min Temp (°C)	Mean Air Temperature (°C)	Relative Humidity (Maximum) (%)	Relative Humidity (Minimum) (%)	Mean Relative Humidity (%)	Precipitation (mm)	No of Wet Days
Dormancy	25.92±0.35	10.65±0.23	18.28	77.27±1.56	53.83±1.32	65.55	120.76±16.84	16.1±08
(1st May to 25th June)	(24.3-27.9)	(9.2-11.5)	(17.25-19.7)	(69.4-89.1)	(49.4-62.8)	(61.3-69.95)	(36-189.8)	(11-18)
Flower Ontogenesis	30.1±0.30	16.59±.0.17	23.34	79.25±1.48	52.17±1.48	65.71	211.08±34.19	16.3±1.78
(26th June to 25th August)	(29.0-32.6)	(15.9—17.8)	(22.85-24.45)	(69.2-83.8)	(42.9-59.5)	(56.05-71.35)	(86.8-443.4)	(10-24)
Bud Sprouting	27.54±0.52	12.01±0.38	19.77	82.68±1.17	52.75±2.10	67.71	69.34±16.53	7±1.11
(26th August to 30th Sept)	(24.9-30.4)	(10.5-13.9)	(17.7-21.6)	(75.2-87.9)	(42-65.1)	(61.15-76.2)	(0-237.7)	(0-13)
Flowering	15.27±1.04	1.20±0.64	8.22±0.47	86.47±1.38	64.61±3.16	75.54±2.12	51.99±21.89	3.10.87
(From Date of Bloom)	(10.6-19.95)	(-1.58-4.23)	(5.42-9.81)	(75.61-90.8)	(41.8-73.05)	(61.45-81.25)	(0-206.5)	(0-9)
Vegetative-1	10.7±0.46	1.97±0.29	4.36±0.21	89.7±0.68	65.7±1.74	77.71±0.85	49.7±15.81	6.6±1.42
(11th Nov -31st Dec)	(7.4-12.3)	(-3 to- 0.3)	(3.1-5.15))	(86.3-92.4)	(53.1-72.2)	(72.7-82.1)	(0-150.6)	(0-12)
Vegetative-2	7.4±0.72	-2.6±0.31	2.45±0.32	91±0.39	67.42±2.77	79.21	181.5±36.99	12±1.44
(1st January to 15th Feb)	(4.9-11.1)	(-4.9 to -1.1)	(1.25-4.1)	(89.1-93.5)	(57.1-78.8)	(73.1-84.5)	(56.8-438.4)	(4-20)
Vegetative-3	13.88±0.58	2.2±0.19	8.04±0.34	83.52±0.98	56.5±2.05	70.03±1.45	212.4±50.98	15.6±1.40
(16th February-31st Mar)	(10.7-16.8)	(1-3.1)	(6.2-9.7)	(78.3-90.1)	(45.4-60.7)	(61.85-79.4)	(56.7-629.1)	(7-23)
Plant senescen	19.6±0.37	6.6±0.16	13.01±0.24	79.6±1.13	57.0±1.95	68.37±1.39	154.5±21.31	12.6±0.6((10-16)
(1st April to 30th April)	(17.7-21.4)	(5.3-7.1)	(11.90-14.45)	(75.1-87.6)	(48.4-68.9)	(61.75-78.25)	(50.2-321.5)	
Pooled Annual Average	18.80±2.76	6.07±1.98	12.18±2.53	83.68±1.68	58.74±1.99	71.22±1.81	1051.27±22.74	89.3±1.66

This unique weather condition of Jammu and Kashmir from 1st December to 15th February has made saffron cultivation possible as study reveals that saffron crop receives about 1155 chilling hours and is a basic requirement for vernalization. Initial corm weight has been found responsible for increased number of flowers/spathe, more activation of meristematic regions and greater biomass lading to efficient replacement corm production [15].

Perusal of [Table-5] reveals that mean aerial temperature of 8.04°C associated with mean relative humidity of 70.03% is ideal for completion of corm development and foliage growth in saffron. Increase in mean aerial temperature from 2.40°C to 8.04°C (235%) compared to earlier vegetative period helps in faster plant development ensuring 100% of foliage length that helps in better source sink relationship for efficient corm development.

Period is associated with highest rainfall of 212.4 mm and therefore warrents proper management practices. Uniformly circulated winter precipitation has beneficial outcome on saffron yield [22]. Association of high rainfall with high humidity as evident from data clearly signal build-up of fungal inoculums causing corm rot during this period. Several workers have reported appearance of corm rot symptoms during this period of vegetative phase on account of these weather fluctuations [9-11]. Weather parameters between 1st April to 30th April that hastens corm maturation and leaves show signs of prominent senescen are presented in [Table-5]. Mean aerial temperature of 13.01°C associated with mean relative humidity of 68.37% & mean rainfall of 154.5 mm observed in April hastens plant senescen.

Conclusion

61days of incubation of corms in the average air temperature of 23.34°C associated with average relative humidity of 65.71% ensures flower ontogenesis process, whereas as 36 days incubation at mean air temperature of 19.77°C and mean relative humidity of 67.71% favours sprout development. Excess or deficit rainfall observed during the bud sprouting period is suggestive of direct impact of abiotic stress on saffron production & productivity. saffron flowering is initiated from the sprouted corms either in 2nd fortnight of October or in November depending upon maximum temperature that has to be around 17°C. Saffron plant receives chilling during the month of December (465 hours) & during 1st January to 15th February (690 hours) as mean aerial temperature recorded during this period was recorded to be 2.40°C. At present indoor saffron cultivation has been taken on commercial scale by many agro processors.

Application of research: Present study indicating the trigger points for mean aerial temperature and humidity for different plant developmental stages from dormancy to flower production to corm development will help them to upscale their commercial units on desired temperature and humidity to facilitate forced activation of maximum number of flowers from each corm at one time [Fig-4], [Table-6].

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****Principal Investigator or Chairperson of research: Prof Dr F.A. Nehvi**
University: Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, Jammu and Kashmir, 190025, India
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