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Indigenous *bahar* management practice for improving quality of pomegranate under hot arid climate of *Thar* Desert

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Pomegranate is an ancient fruit renowned for its exceptional nutritional value and is deeply rooted in traditional health-care systems. In hot arid climate, pomegranates exhibit three distinct flowering seasons, traditionally known as "*ambe, mrig* and *hasta bahar*". The choice of *bahar* to be regulated depends on irrigation water availability, market demand and pest/disease incidence. The present investigation was undertaken to optimize *bahar* management and induce synchronized flowering during optimal climatic conditions to enhance fruit quality while minimizing fruit cracking through indigenous horticultural techniques such as water stress, pruning, de-blossoming and defoliation using ethephon. Data revealed that indigenous horticultural techniques and ethephon had a significant positive impact on fruit quality and marketable yield of pomegranate. Among horticultural techniques (P), the most favorable results were observed with water stress during June with pruning and de-blossoming, which yielded maximum fruit weight of 216.58 g, 64.58 fruits/plant, and marketable yield of 11.59 kg/plant, all while minimizing fruit cracking to 11.51%. The horticultural techniques in combination with ethephon applications (PxC) involving water stress during June, pruning, de-blossoming, and ethephon (2 mL/l) demonstrated remarkable improvements. This treatment resulted in improved fruit weight of 223.58 g, a marketable yield of 13.63 kg/plant, and the lowest incidence of fruit cracking of 9.42%. These findings allowing synchronized flowering, enhanced fruit quality and market value. These insights contribute to the sustainable pomegranate cultivation in rural areas of *Thar* desert and further support its role in traditional health-care system.

Keywords: *Bahar* management, Ethephon, Fruit cracking, Pomegranate, Quality, Water stress

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Pomegranate (*Punica granatum* L.) is a rapidly emerging fruit crop in the hot arid region of *Thar* Desert. This fruit, known for its vibrant ruby-red arils and distinctive flavour, has gained commercial prominence across several Indian states. With cultivation spanning approximately 2.72 lakh hectares[1], it has established a robust presence in Maharashtra, Karnataka, Gujarat, Telangana, Andhra Pradesh, Madhya Pradesh and Rajasthan states. It has ability to survive adverse climatic conditions of heat, cold and drought stresses. The acreage under pomegranate crop in *Thar* Desert is increasing continuously on account of its hardy nature, regular demand, better yield and keeping quality with immense therapeutic importance. It has huge nutritional value and one of the powerful sources of natural antioxidants. Every part of pomegranate like root, bark, wood, sprouts, leaves, flowers, fruits, rind, and seeds have economic value[2]. The fresh fruits are mainly meant for table purpose and also utilized for making juices, syrup and jelly. The dried aril of sour type pomegranate is known as anardana which is used traditionally as acidulant for making curries and chutney etc. Besides culinary purpose it improves mouth feel and digestion[3]. The aril juice is rich in vitamins, minerals and health promoting phytochemicals and is suggested for patients suffering from gastric troubles. Dried arils, seeds and rind used in different ayurvedic preparations[4]. Pomegranate rind extracts is also effective against some phytopathogenic bacteria and its organic waste materials can be used as a substitute to synthetic drugs and thus, prevent toxic substance pollution[5]. Its rind powder used as antimicrobial agents in a fixed proportion for application on linen fabric[6]. It has been used in traditional health-care systems. Owing to several health, nutritional and therapeutic benefits it is known as 'super food'[7] and also famous in hindi idiom as "Ek Anar Sau Bimar". Jalore Seedless is a popular cultivar of the arid region of Rajasthan and it

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showed its superiority with respect to vegetative growth, yield, fruit size, juice content, and softness of seeds over other cultivars.

Indian farmer's practicing *bahar* management in pomegranate long back through withholding of irrigation for 1-2 month, root exposure, pruning and plant growth regulators application which varies from region to region. Pomegranate flowers thrice in a year traditionally known as *ambe* (February-March), *mrig* (July-August) and *hasta bahar* (September-October) which may not be advantageous owing to staggered harvesting of crop with inferior fruit quality. To maintain the productivity of the plants, only a particular *bahar* flowering and fruiting are managed to get quality yield at desired time. Under hot arid climate fruit cracking is very burning problem. Maximum cracking was reported in advance stage of harvesting during December owing to diurnal temperature variation prevailed in the arid zone[8]. The monetary loss due to fruit cracking problem varied from 10% to 40%, but the cracking is further severe (70%) in adverse climatic condition of hot arid regions[9,10].

Major indigenous horticultural techniques such as water stress, root exposure and canopy engineering (pruning & de-blossoming) along with plant hormones and nutrient management significantly affected flowering, fruit set, fruit and aril quality in pomegranate. Water stress manipulates physiology of plants by synthesis of stress metabolites and induces flowering in a required period which enhance quality fruits with minimal fruit cracking. Similarly, pruning induces flowering, improves fruit set for quality fruit harvest by diverting photosynthetic material to reproductive buds. Ethylene is commercially employed as defoliant which causes a wide range of physiological changes in plants *i.e.*, dormancy breaking, senescence, flower induction and late flowering, modification of sex forms, leaves defoliation and colour improvement[11]. The main problems under hot arid climate of *Thar* Desert are high fruit cracking, low yield and inferior quality due to lack of standardized *bahar* management treatment in pomegranate. Hence, the present investigation was conducted for flowering initiation during optimal climatic condition in such an approach that plant produce quality yield with minimum fruit cracking incidence through water stress, pruning, de-blossoming and defoliation using ethephon.

Materials and Methods

Basic information

The present study was conducted on indigenous pomegranate cultivar Jalore Seedless eight year old trees planted at 5 m × 2.5 m spacing during 2017 to 2019. The experimental field is situated at an altitude of 215.60 m above mean sea level and latitude of 28°06′45.0″ N and longitude of 73°20′52.4″ E. The soil is loamy sand with 8.32 pH and 0.27 dSm^{-1} EC. The organic carbon is 0.15%, available nitrogen106.4 kg/ha, available phosphorus 11.51 kg/ha and available potassium 214.5 kg/ha.

Experimental design and treatment details

The experiment was carried-out in Factorial RBD with three replications. The experiment comprised of twenty treatment combinations with five levels of horticultural techniques (water stress during March and June with/without pruning and de-blossoming) and four levels of ethephon concentrations. These factors with their level and symbols are given in Table 1 and their treatment combinations are presented in Table 2.

Treatment application

Water stress was imposed by stopping irrigation water during whole month of March and June as per the treatment plan. In pruning, 20 cm annual growth was removed after water stress period. The de-blossoming was carried out manually prior to and during water stress period and flowers induced after treatment imposition were retained and advanced to quality fruit harvest. Ethephon (40%) was applied foliar spray after water stress imposition, pruning and de-blossoming, whereas in control (P_0) treatments, ethephon was sprayed during May end. Five gram DAP per litre of water was also applied in all ethephon treatment to improve efficacy.

Table 1 — Details of factors with their levels and symbols

First factor –Horticultural techniques for *bahar* management	Symbol
Control (Natural flowering)	P_0
Water stress during March	P_1
Water stress during March + pruning +de-blossoming	P_2
Water stress during June	P_3
Water stress during June + pruning +de-blossoming	P_4
Second factor –Ethephon treatments for *bahar* management	
Control (Without ethephon)	C_0
Ethephon 1 mL/l	C_1
Ethephon 2 mL/l	C_2
Ethephon 3 mL/l	C_3

Observation recorded

Data on important fruit yield and quality attributes were recorded. The fruit juice TSS was measured using digital refractometer (Model Atago PAL II). The juice acidity was measured by titration with 0.1N sodium hydroxide[12]. The ascorbic acid was estimated using 2, 6, dichlorophenol indophenol dye[13]. Total anthocyanin content of juice was measured by the pH-differential method[14]. The total antioxidant activity of juice extract was determined by the CUPRAC method[15]. The average monthly weather parameters were collected from Agromet Observatory, ARS, Bikaner and presented in (Fig. 1).

Table 2 — Treatment combinations and their details

Treatments	Details
P_0C_0	Control (Natural flowering without ethephon) *i.e.* absolute control
P_0C_1	Natural flowering + ethephon 1 mL/l
P_0C_2	Natural flowering + ethephon 2 mL/l
P_0C_3	Natural flowering + ethephon 3 mL/l
P_1C_0	Water stress during March without ethephon
P_1C_1	Water stress during March + ethephon 1 mL/l
P_1C_2	Water stress during March + ethephon 2 mL/l
P_1C_3	Water stress during March + ethephon 3 mL/l
P_2C_0	Water stress during March + pruning + de-blossoming without ethephon
P_2C_1	Water stress during March + pruning + de-blossoming + ethephon 1 mL/l
P_2C_2	Water stress during March + pruning + de-blossoming + ethephon 2 mL/l
P_2C_3	Water stress during March + pruning + de-blossoming + ethephon 3 mL/l
P_3C_0	Water stress during June without ethephon
P_3C_1	Water stress during June + ethephon 1 mL/l
P_3C_2	Water stress during June + ethephon 2 mL/l
P_3C_3	Water stress during June + ethephon 3 mL/l
P_4C_0	Water stress during June + pruning + de-blossoming without ethephon
P_4C_1	Water stress during June + pruning + de-blossoming + ethephon 1 mL/l
P_4C_2	Water stress during June + pruning + de-blossoming + ethephon 2 mL/l
P_4C_3	Water stress during June + pruning + de-blossoming + ethephon 3 mL/l

Statistical analysis

The data recorded on different fruit quality and yield attributes were analyzed statistically using a factorial randomized block design methods[16]. The treatment main effect and their interaction effect were compared at 5% level of significance.

Results and Discussion

The perusal of data (Table 3) showed that horticultural techniques, ethephon applications and their interaction significantly affected fruit yield parameters. Among horticultural techniques, significantly highest fruit weight and diameter (216.58 g and 8.18 cm) was recorded in the water stress during June + pruning + de-blossoming (P_4) treatment as against lowest fruit weight and diameter (202.42 g and 6.80 cm) registered in natural flowering (P_0) control, respectively. Among ethephon treatments, highest fruit weight and diameter (213.57 g and 7.58 cm) was recorded in ethephon 2 mL/l (C_2), while lowest fruit weight and diameter (203.01 g and 7.30 cm) registered in control without ethephon (C_0) application, correspondingly.

In horticultural techniques and ethephon interaction, highest fruit weight and diameter (223.58 g and 8.43 cm) were observed in water stress during June + pruning + de-blossoming + ethephon 2 mL/l

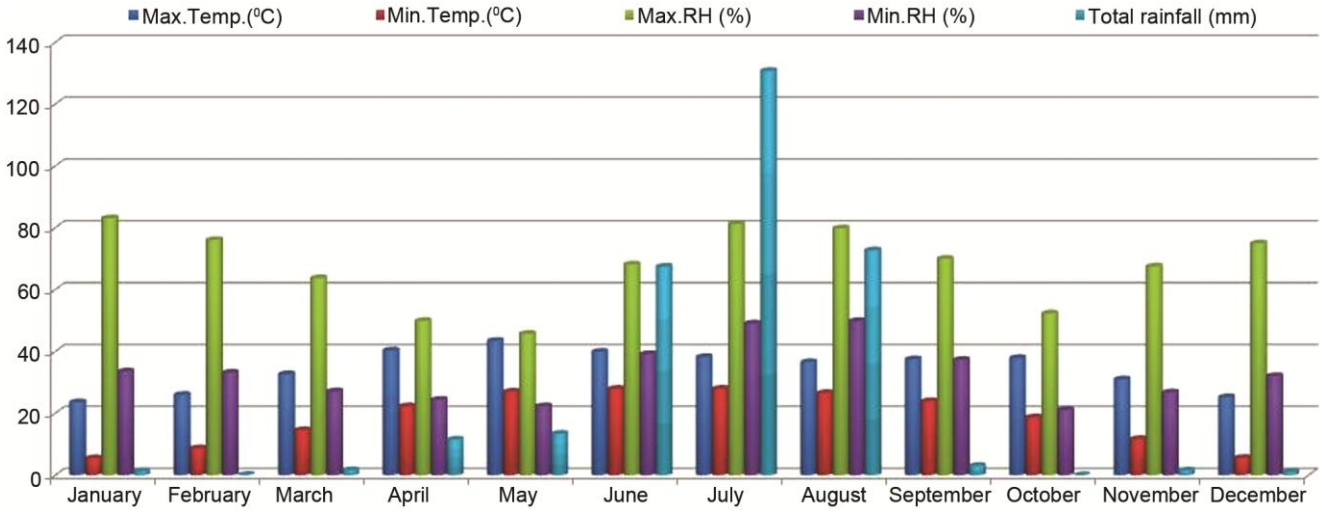

Fig. 1 — Average monthly weather data measured during experiment period

(P_4C_2) as against minimum fruit weight and diameter (196.79 g and 6.66 cm) recorded in natural flowering without ethephon (P_0C_0) applications, respectively. The improved fruit weight/size might be attributed to congenial weather condition during fruit development and maturity period from January to March (max. temperature 32.68 ºC and min. temperature 5.46 ºC) and more flow of nutrients and water to fruit due to pruning. The fruits weight and size was significantly improved by pruning and maximum fruits diameter and volume were recorded in higher pruning intensity[17,18]. Ethephon application increased fruit weight and size of pomegranate[19].

Among horticultural techniques**,** significantly highest fruits/plant (64.58) was obtained in water stress during June (P_3) in comparison to least fruits/plant (58.44) registered in natural flowering (P_0) control. Among different ethephon concentrations, highest fruits/plant (64.60) was recorded in ethephon 2 mL/l (C_2) in comparison to least recorded in control without ethephon (C_0) treatment (57.33). Among horticultural techniques and ethephon combinations, highest fruits/plant (70.17) was registered in water stress during June with ethephon 2 mL/l (P_3C_2) application while least fruits/plant (55.33) was recorded in water stress during March + pruning + de-blossoming without ethephon (P_2C_0) application. The increase in number of fruits/plant in water stress during June might be attributed to higher fruit set under optimal climatic

Table 3 — Effect of *bahar* management on fruit yield attributes of pomegranate

Treatments	Horticultural techniques (P)				
	Fruit weight (g)	Fruit diameter (cm)	Number of fruits/plant	Fruit yield (kg/plant)	Marketable yield (kg/plant)
P_0	202.42	6.80	58.44	11.83	9.15
P_1	203.07	7.06	61.58	12.51	9.93
P_2	212.66	7.76	59.54	12.67	10.50
P_3	206.31	7.45	64.58	13.33	11.00
P_4	216.58	8.18	60.29	13.08	11.59
SEm±	0.35	0.02	0.32	0.07	0.06
CD (5%)	0.99	0.05	0.89	0.19	0.16
			Ethephon applications (C)		
C_0	203.01	7.30	57.33	11.63	9.15
C_1	210.00	7.51	62.15	13.05	10.79
C_2	213.57	7.58	64.60	13.80	11.90
C_3	206.25	7.41	59.47	12.26	9.91
SEm±	0.31	0.02	0.28	0.06	0.05
CD (5%)	0.89	0.05	0.79	0.17	0.15
			Horticultural techniques x Ethephon applications (PxC)		
P_0C_0	196.79	6.66	57.33	11.28	8.30
P_0C_1	203.58	6.82	58.75	11.96	9.28
P_0C_2	208.80	6.90	59.50	12.42	10.17
P_0C_3	200.50	6.81	58.17	11.66	8.86
P_1C_0	197.28	6.97	58.50	11.54	8.67
P_1C_1	205.12	7.12	62.83	12.89	10.37
P_1C_2	207.62	7.14	64.50	13.39	11.20
P_1C_3	202.28	7.02	60.50	12.24	9.49
P_2C_0	208.39	7.65	55.33	11.53	9.15
P_2C_1	214.34	7.81	61.67	13.22	11.08
P_2C_2	217.77	7.83	62.50	13.61	11.79
P_2C_3	210.17	7.76	58.67	12.33	9.99
P_3C_0	202.77	7.32	59.83	12.13	9.64
P_3C_1	207.26	7.49	65.67	13.60	11.15
P_3C_2	210.06	7.58	70.17	14.73	12.70
P_3C_3	205.15	7.42	62.67	12.86	10.53
P_4C_0	209.85	7.91	55.67	11.68	10.01
P_4C_1	219.72	8.33	61.83	13.59	12.05
P_4C_2	223.58	8.43	66.33	14.84	13.63
P_4C_3	213.17	8.04	57.33	12.22	10.67
SEm±	0.70	0.04	0.63	0.14	0.12
CD (5%)	1.98	0.11	1.78	0.39	0.33

condition while increase in numbers of fruit in ethephon probably due to stimulation of more bisexual flowers by induced stress. The number of fruits/plant varied significantly with pruning intensity and maximum number of fruits was produced in un-pruned plants as against minimum in higher pruning intensity[17]. The ethephon application increased number of fruits/plant in pomegranate in comparison to lowest in control[19].

The horticultural techniques significantly enhanced fruit yield and highest fruit yield (13.33 kg/plant) was registered in the water stress during June (P_3) as compared to lowest (11.83 kg/plant) registered in natural flowering (P_0) control. Amongst ethephon concentrations, highest fruit yield (13.80 kg/plant) was observed in ethephon 2 mL/l (C_2) application while minimum fruit yield (11.63 kg/plant) recorded in without ethephon (C_0) control. In conjoint treatments, maximum fruit yield (14.84 kg/plant) was recorded in water stress during June + pruning + de-blossoming + ethephon 2 mL/l (P_4C_2) which was at par with water stress during June + ethephon 2 mL/l (P_3C_2) treatment (14.73 kg/plant) while minimum fruit yield (11.28 kg/plant) was registered in natural flowering without ethephon (P_0C_0) control.

Among horticultural techniques, significantly maximum marketable yield (11.59 kg/plant) was registered in the water stress during June + pruning + de-blossoming (P_4) as compared to minimum marketable yield (9.15 kg/plant) was registered in natural flowering (P_0) control. Among different ethephon applications, maximum marketable yield (11.90 kg/plant) was found in ethephon 2 mL/l (C_2) as compared to the lowest marketable yield (9.15 kg/plant) registered in without ethephon (C_0) control. In combination treatments, highest marketable yield (13.63 kg/plant) was recorded in water stress during June + pruning + de-blossoming + ethephon 2 mL/l (P_4C_2) followed by water stress during June + ethephon 2 mL/l (P_3C_2) treatment (12.70 kg/plant) in contrast to lowest marketable yield (8.30 kg/plant) found in natural flowering without ethephon (P_0C_0) control. The enhanced yield in water stress during June + pruning + de-blossoming + ethephon 2 mL/l (P_4C_2) may be because of optimal climatic condition which improved photosynthetic efficiency, fruit-set and weight. Pruning and de-blossoming encouraged more flow nutrients and water to fruits whereas ethephon increased numbers of bisexual flowers which improved fruit set and retention. The cumulative effect of season, pruning, de-blossoming and ethephon application had improved fruit yield and reduced fruit cracking. The ethephon application increased fruit yield in pomegranate[18]. In pomegranate maximum superior grade/size fruits were observed in severe pruning intensity. The ethephon application significantly improved fruit size, yield and reduced fruit cracking in pomegranate[17,18].

In hot arid climatic conditions of *Thar* Desert fruit cracking is a challenging problem which is significantly minimized by horticultural techniques, ethephon concentrations and their interaction (Fig. 2). In horticultural techniques, significantly least fruit cracking (11.51%) was observed in the water stress during June + pruning + de-blossoming (P_4) as compared to highest fruit cracking (21.78%) was noticed in natural flowering (P_0) control. In ethephon applications, significantly minimum fruit cracking (15.46%) was recorded in ethephon 2 mL/l (C_2) in contrast to maximum fruit cracking (20.52%) found in without ethephon (C_0) control. With respect to interaction combinations, minimum fruit cracking (9.42%) was observed in water stress during June + pruning + de-blossoming + ethephon 2 mL/l (P_4C_2) which was followed by water stress during June + pruning + de-blossoming + ethephon1 mL/l (P_4C_1) treatment (11.05%) whereas maximum fruit cracking (26.16%) observed in natural flowering without ethephon (P_0C_0) control. The lower fruit cracking in water stress during June + pruning + de-blossoming + ethephon 2 mL/l (P_4C_2) may be due to fruit growth and development during congenial weather condition, low day-night temperature fluctuation, low pest and disease incidence mainly fungal spot and mite in hot arid climate. The lowest fruit splitting was noticed in severe pruning in comparison to highest in un-pruned pomegranate plants[17]. The ethephon (2 mL/l) application reduced fruits cracking in pomegranate[20].

The data (Table 4) revealed that horticultural techniques, ethephon and their interaction significantly influenced rind thickness, aril and seed content, total sugar as well reducing sugar. With respect to horticultural techniques, significantly high rind thickness (3.88 mm) was recorded in water stress during June + pruning + de-blossoming (P_4) treatment as against low rind thickness (3.09 mm) measured in control natural flowering (P_0) treatment. Among ethephon treatments, significantly high rind thickness (3.60 mm) was measured in ethephon 2 mL/l (C_2) treatment as against lowest recorded in control (C_0)

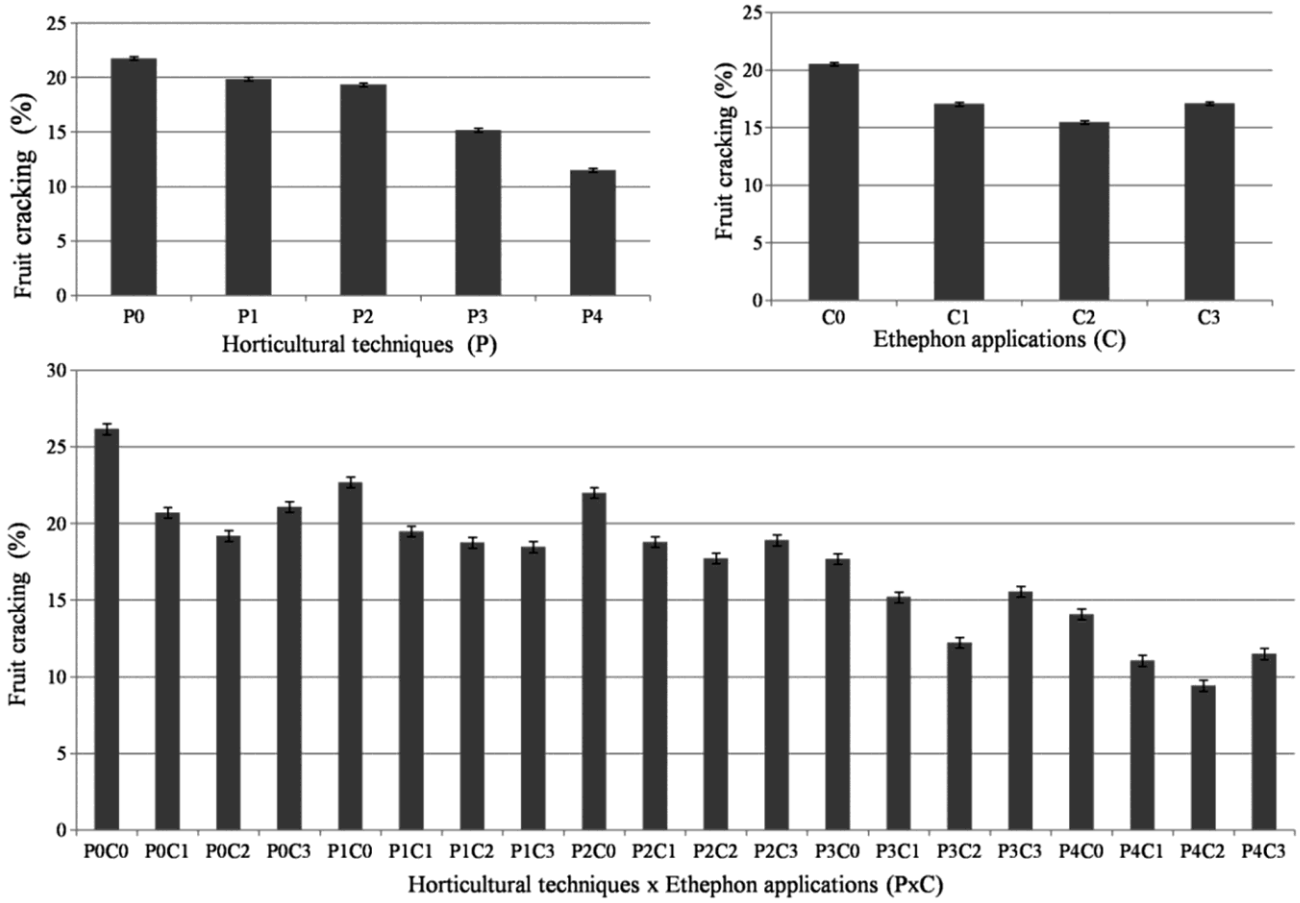

Fig. 2 — Effect of *bahar* management treatments on fruit cracking of pomegranate

treatment (3.25 mm). The interaction effect of horticultural techniques (P) and ethephon treatments (C) was found non-significant. The maximum rind thickness (3.98 mm) was found in water stress during June + pruning + de-blossoming + ethephon 2 mL/l (P_4C_2) treatment. The minimum rind thickness (2.86 mm) was recorded in absolute control (P_0C_0) treatment. The higher rind thickness in water stress during June + pruning + de-blossoming (P_4) treatment may be due to optimal condition for growth, higher photosynthetic efficiency and diversion of water flow and nutrients to fruit caused by pruning. In pomegranate rind percentage was increased with increasing pruning intensity[18,21]. The higher rind weight of pomegranate was recorded with ethephon application (0.2%) in contrast to control because of growth promoter effect of ethephon at lower concentration[20].

Aril content significantly enhanced by horticultural techniques and registered maximum aril weight/fruit (137.01 g) was obtained in water stress during June + pruning + de-blossoming (P_4) treatment. The minimum aril weight per fruit (118.94 g) was found in control (P_0) treatment. Among ethephon treatments, significantly highest aril weight/fruit (133.04 g) was recorded in ethephon 2 mL/l (C_2) as against lowest registered in control without ethephon (C_0) treatment (121.34 g). Among combined treatments, maximum aril weight/fruit (147.27 g) was registered in water stress during June + pruning + de-blossoming + ethephon 2 mL/l (P_4C_2) followed by water stress during June + pruning + de-blossoming + ethephon1 mL/l (P_4C_1) treatment (138.72 g), however minimum aril weight/fruit was recorded (110.58 g) in absolute control (P_0C_0) treatment. The higher aril weight in water stress during June + pruning + de-blossoming (P_4) treatments was probably owing to increased fruit size, higher photosynthetic efficiency and more flow nutrients/water to arils due to pruning and de-blossoming effect. The enhanced aril weight content was reported in ethephon (0.2%) application owing to its growth promoter effect at lower concentration[20].

Among different horticultural techniques, significantly low seed content (9.11%) was recorded in water stress during June + pruning + de-blossoming

Table 4 — Effect of *bahar* management on fruit quality attributes of pomegranate

Treatments	Horticultural techniques (P)				
	Rind thickness (mm)	Aril weight/fruit (g)	Seed (%)	Total sugar (%)	Reducing sugar (%)
P_0	3.09	118.94	12.09	12.58	11.55
P_1	3.28	123.28	11.57	11.47	10.62
P_2	3.60	130.30	10.58	11.74	10.78
P_3	3.38	126.35	10.55	12.80	11.73
P_4	3.88	137.01	9.11	13.17	12.05
SEm±	0.04	0.65	0.12	0.02	0.02
CD (5%)	0.11	1.82	0.35	0.05	0.05
	Ethephon applications (C)				
C_0	3.25	121.34	11.35	12.17	11.18
C_1	3.52	128.83	10.54	12.39	11.38
C_2	3.60	133.04	10.30	12.55	11.54
C_3	3.41	125.49	10.94	12.30	11.29
SEm±	0.04	0.58	0.11	0.02	0.02
CD (5%)	0.10	1.63	0.31	0.05	0.05
	Horticultural techniques x Ethephon applications (PxC)				
P_0C_0	2.86	110.58	13.08	12.38	11.37
P_0C_1	3.18	121.12	11.72	12.62	11.56
P_0C_2	3.28	125.43	11.36	12.81	11.79
P_0C_3	3.04	118.64	12.19	12.50	11.46
P_1C_0	3.13	118.39	12.21	11.17	10.38
P_1C_1	3.34	125.25	11.09	11.58	10.74
P_1C_2	3.37	127.34	10.96	11.78	10.87
P_1C_3	3.27	122.15	12.02	11.36	10.49
P_2C_0	3.36	126.19	10.94	11.54	10.63
P_2C_1	3.66	131.46	10.45	11.78	10.78
P_2C_2	3.78	135.23	10.33	11.91	10.95
P_2C_3	3.60	128.31	10.62	11.75	10.75
P_3C_0	3.16	122.34	10.80	12.70	11.56
P_3C_1	3.48	127.58	10.47	12.79	11.72
P_3C_2	3.59	129.93	10.34	12.96	11.92
P_3C_3	3.29	125.53	10.60	12.77	11.71
P_4C_0	3.75	129.22	9.72	13.07	11.95
P_4C_1	3.94	138.72	8.97	13.19	12.08
P_4C_2	3.98	147.27	8.50	13.31	12.15
P_4C_3	3.83	132.83	9.25	13.13	12.03
SEm±	0.08	1.29	0.25	0.04	0.04
CD (5%)	NS	3.64	NS	0.11	0.11

(P_4) treatment as compared to higher seed content (12.09%) recorded in control natural flowering (P_0) treatment. Among ethephon treatments, lowest seed content (10.30%) was observed in ethephon 2 mL/l (C_2) treatment whereas high seed content recorded in control without ethephon (C_0) treatment (11.35%). Among interaction treatment, seed content ranged from 8.50% in water stress during June + pruning + de-blossoming+ ethephon 2 mL/l (P_4C_2) treatment to 13.08% in absolute control (P_0C_0) treatment.

In horticultural techniques, significantly maximum total and reducing sugar (13.17 and 12.05%) was observed in water stress during June + pruning + de-blossoming (P_4) treatment. Significantly minimum total and reducing sugar (11.47 and 10.62%) was recorded in water stress during March (P_1) treatment, respectively. Among ethephon treatments, significantly maximum total and reducing sugar (12.55 and 11.54%) was recorded in ethephon 2 mL/l (C_2) treatment as compared to minimum total and reducing sugar (12.17 and 11.18%) observed in control (C_0) treatment, respectively. In combined treatments, maximum total and reducing sugar was recorded (13.31 and 12.15%) in water stress during June + pruning + de-blossoming + ethephon 2 mL/l (P_4C_2) treatment as compared to minimum recorded in water stress during March without ethephon (P_1C_0) treatment (11.17 and 10.38%), respectively. The improved sugar might be attributed to favourable climate; diversion of photosynthetic assimilates to fruits due to pruning, de-blossoming and

hydrolysis of starch to sugar by ethylene application. Ethephon induced stress might also enhanced water soluble osmolytes which increased total and reducing sugars. These findings are in agreement with Yadav *et al.*[22] in guava and Kacha *et al.*[23] in phalsa. The differences in fruit quality parameters are owing to maturity of fruits at different time[24]. Pruning significantly increased sugar in pomegranate and maximum total and reducing were recorded in higher pruning intensities[17,18,25,26]. The ethephon 0.2% application significantly increased total and reducing sugar in pomegranate[20].

The horticultural techniques, ethephon applications and their combination significantly influenced TSS, acidity, ascorbic acid and total anthocyanin content of pomegranate fruit juice (Table 5). Among different horticultural techniques, significantly maximum TSS (16.16°Brix) and minimum acidity (0.358%) were registered in water stress during June + pruning + de-blossoming (P_4) in comparison to minimum TSS (12.66°Brix) and maximum acidity (0.443%) were recorded in water stress during March (P_1). Among ethephon applications, maximum TSS (14.65°Brix) and minimum acidity (0.384%) were observed in ethephon 2 mL/l (C_2) as against minimum TSS (13.80°Brix) and maximum acidity (0.411%) recorded in control without ethephon (C_0). In combined treatments, maximum TSS (16.43°Brix) and minimum acidity (0.344%) were observed in water stress during June + pruning + de-blossoming +

Table 5 — Effect of *bahar* management on fruit quality attributes of pomegranate

Treatments	TSS (°Brix)	Acidity (%)	Ascorbic acid (mg/100 g)	Total anthocyanin (mg/100 mL)	Total antioxidant activity (mg AAE/mL)
			Horticultural techniques (P)		
P_0	14.03	0.391	10.21	27.84	8.54
P_1	12.66	0.443	9.55	31.58	9.28
P_2	12.87	0.417	9.72	28.50	9.05
P_3	15.44	0.374	11.20	27.02	7.34
P_4	16.16	0.358	11.35	25.51	6.32
SEm±	0.03	0.001	0.011	0.08	0.02
CD (5%)	0.09	0.002	0.032	0.23	0.05
			Ethephon applications (C)		
C_0	13.80	0.411	10.27	25.54	7.88
C_1	14.38	0.392	10.46	29.09	8.20
C_2	14.65	0.384	10.52	30.37	8.35
C_3	14.10	0.400	10.38	27.35	8.01
SEm±	0.03	0.001	0.010	0.07	0.02
CD (5%)	0.08	0.002	0.029	0.20	0.05
			Horticultural techniques x Ethephon applications (PxC)		
P_0C_0	13.50	0.405	9.93	25.96	8.34
P_0C_1	14.24	0.386	10.32	28.58	8.60
P_0C_2	14.44	0.381	10.41	30.19	8.73
P_0C_3	13.93	0.394	10.18	26.63	8.49
P_1C_0	12.13	0.451	9.48	28.11	9.01
P_1C_1	12.82	0.440	9.56	33.00	9.36
P_1C_2	13.12	0.433	9.61	33.81	9.58
P_1C_3	12.57	0.447	9.54	31.38	9.18
P_2C_0	12.64	0.430	9.64	25.45	8.87
P_2C_1	12.92	0.414	9.76	29.47	9.12
P_2C_2	13.27	0.406	9.83	30.66	9.23
P_2C_3	12.66	0.420	9.67	28.42	9.00
P_3C_0	14.83	0.393	11.05	24.94	7.10
P_3C_1	15.67	0.371	11.27	27.88	7.52
P_3C_2	15.98	0.358	11.34	29.52	7.60
P_3C_3	15.30	0.375	11.17	25.75	7.15
P_4C_0	15.89	0.374	11.23	23.24	6.07
P_4C_1	16.26	0.348	11.39	26.54	6.40
P_4C_2	16.43	0.344	11.43	27.69	6.59
P_4C_3	16.07	0.366	11.34	24.59	6.22
SEm±	0.06	0.001	0.02	0.16	0.04
CD (5%)	0.17	0.004	0.06	0.45	0.11

ethephon 2 mL/l (P_4C_2). The improved TSS and reduced acidity were probably because of most favorable growth condition, pruning and de-blossoming effect. The maximum TSS was recorded in higher pruning intensity[18]. The ethephon application significantly improved TSS and reduced acidity of pomegranate[20]. The minimum acidity was observed in higher pruning intensity[17,25].

Among horticultural techniques, significantly highest ascorbic acid (11.35 mg/100 g) was found in water stress during June + pruning + de-blossoming (P_4) against lowest ascorbic acid (9.55 mg/100 g) measured in water stress during March (P_1). In different ethephon applications, ascorbic acid was ranged from maximum (10.52 mg/100 g) in ethephon 2 mL/l (C_2) to minimum (10.27 mg/100 g) in without ethephon (C_0) control. Among interactions, the highest ascorbic acid (11.43 mg/100 g) was observed in water stress during June + pruning + de-blossoming + ethephon 2 mL/l (P_4C_2) as against minimum ascorbic acid (9.48 mg/100g) recorded in water stress during March without ethephon (P_1C_0). Pruning[17,25] practice and ethephon[20] application significantly increased ascorbic acid content in pomegranate fruits.

Among horticultural techniques, significantly maximum total anthocyanin (31.58 mg/100 mL) was registered in water stress during March (P_1) as compared to lowest total anthocyanin (25.51 mg/100 mL) measured in water stress during June + pruning + de-blossoming (P_4). Among ethephon applications, significantly highest total anthocyanin (30.37 mg/100 mL) was measured in ethephon 2 mL/l (C_2) as compared to lowest total anthocyanin (25.54 mg/100 mL) registered in without ethephon (C_0).

Among combination treatments, maximum total anthocyanin (33.81 mg/100 mL) was observed in water stress during March with ethephon 2 mL/l (P_1C_2) as against lowest total anthocyanin (23.24 mg/100 mL) observed in water stress during June + pruning + de-blossoming without ethephon (P_4C_0). The anthocyanin content in pomegranate arils changes contrarily to the prevailed temperatures[27]. Anthocyanin content in pomegranate fruit was usually low in June-July harvested fruits and high in November-December harvested fruit[28]. The decline in anthocyanin might be owing to high temperature and sunlight intensity observed during March-April which caused anthocyanins degradation. The ethephon application in pomegranate significantly increased anthocyanin content[20].

The data showed that horticultural techniques significantly influenced total antioxidant activity of pomegranate juice. The significantly maximum total antioxidant activity (9.28 mg AAE/mL) was registered in water stress during March (P_1) treatment as compared to minimum total antioxidant activity recorded in water stress during June + pruning + de-blossoming (P_4) treatment (6.32 mg AAE/mL). The different ethephon treatments significantly improved total antioxidant activity of pomegranate juice. Significantly maximum total antioxidant activity (8.35 mg AAE/mL) was observed in ethephon 2 mL/l (C_2) treatment while minimum (7.88 mg AAE/mL) was registered in control without ethephon (C_0) treatment.

The interaction effect of horticultural techniques (P) and ethephon treatments (C) on total antioxidant activity was found significant. The maximum total antioxidant activity (9.58 mg AAE/ml) was registered in water stress during March + ethephon 2 mL/l (P_1C_2) treatment. The minimum total antioxidant activity was recorded (6.07 mg AAE/mL) in water stress during June + pruning + de-blossoming without ethephon (P_4C_0) treatment. The higher total antioxidant activity in water stress during March + ethephon 2 mL/l (P_1C_2) treatment might be owing to cold stress during fruit development increased levels of antioxidants and non-degradation of anthocyanin at lower temperature. Ethephon application might be up-regulated biosynthesis of anthocyanin which increased its concentration.

In pomegranate, TSS: acidity ratio is an important quality index which is significantly improved by horticultural techniques, ethephon applications and their interaction (Fig. 3). Among horticultural techniques, significantly highest TSS: acidity ratio (45.23) was registered in the water stress during June + pruning + de-blossoming (P_4) treatment which was followed by water stress during June (P_3) treatment (41.35). Significantly lowest TSS: acidity ratio (28.61) was registered in water stress during March (P_1) treatment. Among ethephon applications, significantly highest TSS: acidity ratio (38.69) was registered in ethephon 2 mL/l (C_2) treatment which was followed by ethephon1 mL/l (C_1) treatment (37.25) in comparison to lowest TSS:acidity ratio (33.97) observed in control without ethephon (C_0) treatment. Among interaction treatments, highest TSS: acidity ratio (47.81) was registered in water stress during June + pruning + de-blossoming with ethephon 2 mL/l (P_4C_2) treatment followed by water stress during June + pruning + de-

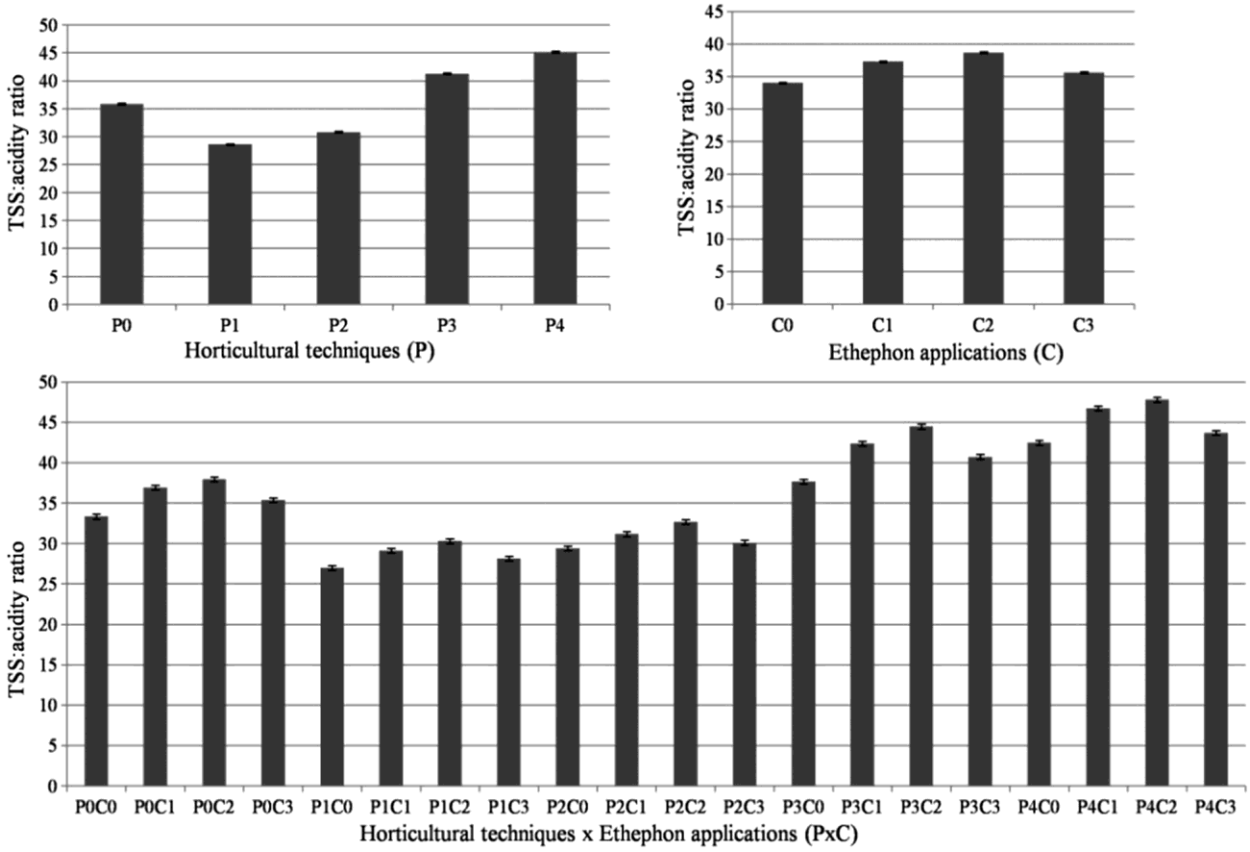

Fig. 3 — Effect of *bahar* management treatments on TSS: acidity ratio of pomegranate

blossoming with ethephon1 mL/l (P_4C_1) treatment (46.75). While lowest TSS:acidity ratio (26.88) registered in water stress during March without ethephon (P_1C_0) treatment.

The higher TSS: acidity ratio in water stress during June + pruning + de-blossoming + ethephon 2 mL/l (P_4C_2) treatment possibly owing to high TSS and low acidity owing to favourable climate, diversion of nutrients & assimilates to growing fruits caused by pruning and de-blossoming treatments. The juice TSS was significantly affected by pruning and highest TSS was recorded in severe pruning intensity[18,21,26]. The ethephon application significantly improved TSS and reduced acidity of pomegranate as compared to minimum in control[20].

Conclusion

Bahar management, encompassing a range of horticultural practices such as water stress, pruning, de-blossoming and ethephon application, found highly effective approach in pomegranate cultivation. The strategic combination of indigenous techniques, specifically water stress during June, coupled with pruning, de-blossoming, and the ethephon application (2 mL/l), yields remarkable improvements in the quality of pomegranate fruits. This technique not only induces synchronized flowering but also enhances fruit development during favorable climate with minimal fruit cracking. These insights contribute to the sustainable pomegranate cultivation in *Thar* Desert and further support its role in traditional health-care system.

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Conflict of Interest

Authors have declared that there is no conflict of interest regarding present study.

Author Contributions

RK-Conceptualization, experiment implementation in field, data recording, writing and review; JSG-Data recording and editing; MKB-Biochemical analysis and editing; CR-Statistical analysis and proof reading.

Data Availability

The authors approved that the data supporting the findings of this study are available within the manuscript or may be requested from the corresponding author.

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