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Fruit set, yield, and quality of three date palm cultivars influenced by spikelet load variation

Muhammad Munir[1,2]

[1]Date Palm Research Center of Excellence, King Faisal University, Al-Ahsa, Saudi Arabia. [2]Frontier Agriculture, SOYL Precision Crop Production Division, Newbury, United Kingdom. E-mail: mmunir@kfu.edu.sa

Abstract

Date palm is a cross-pollinated perennial tree since it is a dioecious plant. Although natural pollination is feasible, artificial pollination is advised for a significantly higher yield and quality. In this study, the spikelet placement method of pollination was adopted, and different number of spikelets (one, three, five, seven, and nine) were placed in the female inflorescence of three date palm cvs. Khalas, Sheshi, and Barhi. The experiment was based on a two-factorial randomized complete block design with three replications. Although the highest spikelet load (nine) significantly affected all three cultivars' fruit set and yield-related characteristics, seven spikelets placed for pollination followed the higher attributes. The effect of spikelet loads alone did not significantly influence the fruit quality. All three date palm cultivars behaved independently and significantly differently for fruit set, yield, and physicochemical traits. The interaction of spikelet loads and cultivars showed that a higher spikelet load significantly influenced fruit yield and quality.

Key words: Date palm, *Phoenix dactylifera* L., pollination, hand pollination, pollen placement, fruit set, yield and quality

Introduction

The date palm (*Phoenix dactylifera* L.) is a dioecious plant, meaning it has separate male and female trees. Female palm trees bear fruits, whereas male palm trees do not. Pollination takes place when pollen grains from male flowers are transferred to female flowers. (Salomón-Torres *et al.,* 2021). After pollen grains land on the stigma, pollen tube development begins, corresponding to the temperature (Munir *et al.,* 2021). The synergid cells from the female ovule allow the pollen tube to extend down the length of the style, fertilizing the ovule and forming a seed (Cohen *et al.,* 2014; Abd-Elhaleem *et al.,* 2020). Female stimuli precisely guide the tip elongation of the pollen tube to accomplish optimal fertilization (Hoffmann *et al.,* 2020). Several peptides released by females have been identified as species-specific attractants that directly affect pollen tube development orientation (Takeuchi and Higashiyama, 2011; Takeuchi and Higashiyama, 2012; Higashiyama and Takeuchi, 2015; Zhang *et al.,* 2017). The importance of fruit setting and yield characteristics, particularly for a dioecious species, was shown by the molecular mechanism of pollination and fertilization (Li *et al.,* 2018).

Pollination is critical in date palms because pollen significantly impacts date yield and quality, particularly the size and time of fruit ripening. It is one of the most important cultural practices for date palms since it determines the quality and quantity of the fruits produced after harvest. Pollination and fruit set efficiency is influenced by a number of parameters, including male flowering time, pollen source, viability and quantity of pollen grains, pollination time, and female flower receptivity (Munir *et al.,* 2020a; Munir *et al.,* 2020b). If these conditions are fulfilled, the best pollination outcomes can be seen within a few days following pollination (Zaid and de Wet, 2002). In regions where date palm is widely cultivated in the wild, natural pollination by wind and bees takes place. The trees of the wild-grown date palms are largely produced from seeds, with a male population of more than 50%. The Food and Agriculture Organization of the United Nations generally recommends a male-to-female palm ratio of 1:50 for modern plantations for natural pollination. However, this method is inefficient, producing no commercial value parthenocarpic fruits and low palm yield (Zaid and de Wet, 2002; Munir *et al.,* 2020c). Therefore, progressive date palm growers began using artificial pollination techniques, which increased up to 80% fruit set (Awad, 2010; Kadri *et al.,* 2022).

Date palm artificial pollination was a practice of the ancient Mesopotamian Assyrians as early as 4500 BC. (Jaradat, 2015; Halbritter *et al.,* 2018). A variety of artificial date palm pollination methods have been used to gain maximum benefits in terms of fruit development and, ultimately, yield, such as the placement of male spikelets (strands), pollen dusting, and pollen suspension (El-Dengawy, 2017; Munir, 2020; Munir *et al.,* 2020c). Date palm growers have approved these pollination methods based on their personal experience and pollen source availability. Adopting a more appropriate and enhanced pollination method could save pollen grains and increase fruit yield (Awad, 2010). The most common and ancient method of date palm pollination is the hand pollination method or strand placement method. In this technique, four to ten male flower spikelets are inserted by hand between the spikelets of the female inflorescence, depending on the size of the female inflorescence (Zaid and de Wet, 2002). The unavailability of pollinators is the main justification for using hand pollination, followed by the insufficient number or proximity of pollinizers and unbalanced dichogamy or sex ratio. Increased fruit sets and/or improved fruit quality are the primary economic motivations for hand pollination strategies and recommendations. Large- and small-scale farming, home gardens, and greenhouses all use hand pollination. Opportunities for hand pollination include the ability to regulate pollen source and quantity, time, and frequency of pollination, as well as independence from environmental changes (Wurz *et al.,* 2021). However, no precise research has been carried out to specify how many male spikelets are essential to obtain a higher number of fruit set, yield and quality. Therefore, the present research aimed to reveal the effects of different pollen densities on the fruit set, yield, and fruit quality of date palm cvs. Khalas, Sheshi, and Barhi.

Materials and methods

The present study was conducted at the Date Palm Research Center of Excellence, Training and Research Station, King Faisal University, Al-Ahsa, Saudi Arabia, in 2018 and 2019 (Latitude 25° 16' 7.068'' N and Longitude 49° 42' 27.522'' E). Male spikelets for pollination were taken from the second whorl of fourteen-year-old cracked male spathes (inflorescences) in the morning. The protective sheath of male spathes was removed with the help of a sharp knife and placed on Kraft brown paper sheet to dry at ambient room temperature for 48 hours. Pollen viability test was conducted as prescribed by Munir (2021) by staining with acetocarmine, and 91% of pollens were found viable. Male spikelets were inserted on the top side of the female spathe. The experiment included fifteen date palm trees, with five spathes on each palm chosen per replication and the remainder removed. The experiment was laid out on a two-way factorial randomized complete block design with three replicated trees in each treatment as below:

	No. of spikelets (Factor-A)	Date palm cultivars (Factor-B)
T_1	One spikelet	Khalas, Sheshi, Barhi
T_2	Three spikelets	Khalas, Sheshi, Barhi
T_3	Five spikelets	Khalas, Sheshi, Barhi
T_4	Seven spikelets	Khalas, Sheshi, Barhi
T_5	Nine spikelets	Khalas, Sheshi, Barhi

Pollination was carried out at 11 a.m. when the spathes of a fourteen-year-old, uniform female date palm opened. To prevent foreign pollen contamination, all-female pollinated spathes were covered with Kraft brown wax paper bags, which were removed after the fruit set (two weeks after pollination). Around mid-May, each fruit was protected from birds and insects with knitted polyethylene mesh bags (90 × 80 cm). The meteorological data were downloaded from the on-farm wireless weather station, Model WS3083 (Aercus Instruments, West Yorkshire, UK), installed around 25 m away from the experimental orchard (Table 1). Standard doses of straight fertilizers (Urea, SSP, and K_2SO_4) per palm were applied in a one-meter band ring around the stem, *i.e.*, 920 g N, 500 g P_2O_5, and 500 g K_2O (Munir *et al.,* 1992; Munir *et al.,* 1993). All other cultural practices were carried out accordingly.

The data were recorded on the following variables: fruit set, fruit drop, parthenocarpic fruits, bisir fruits, tamar fruits, fruit fresh weight, fruit length, fruit width, fruit surface area, fruit volume, yield per bunch, and yield per palm, seed weight, seed length, seed width, seed volume, pulp weight, pulp:seed ratio, fruit moisture content, total soluble solids, total sugars, reducing sugars, non-reducing sugars, titratable acidity, and TSS:TA ratio according to AOAC standard methods (AOAC, 2005). The collected data were statistically analyzed using Statistical Analysis Software, Release 9.4 (SAS Institute, North Carolina, USA), and the Duncan Multiple Range Test was applied to determine the least significant difference between the means.

Table 1. Meteorological data of the research venue during 2018 and 2019

Year/ month	Temperature (°C)			Relative humidity (%)	Wind speed (km h^{-1})	Air pressure (kPa)	Rainfall (mm)
	Av.	Max.	Min.	Av.	Av.	Av.	
2018							
Jan	15.5	23.9	8.0	30.4	101.79	13.8	0.34
Feb	19.6	27.5	12.2	36.4	101.52	13.3	0.19
Mar	25.1	33.8	16.7	24.6	101.25	12.8	1.45
Apr	28.2	35.5	21.2	29.2	100.9	15.6	2.15
May	33.0	40.5	24.5	18.7	100.62	13.0	0.84
Jun	38.1	45.7	29.8	12.2	99.93	18.8	0.00
Jul	38.8	46.5	30.8	12.4	99.60	19.3	0.00
Aug	37.8	46.0	29.6	14.4	99.82	17.9	0.00
Sep	35.6	43.9	27.2	24.3	100.40	9.3	0.00
Oct	29.5	36.9	22.5	40.6	101.21	10.9	0.00
Nov	23.4	29.1	18.1	56.5	101.55	12.7	1.15
Dec	18.5	24.9	12.8	56.3	101.85	11.7	0.00
2019							
Jan	17.6	25.0	11.0	39.2	101.86	16.5	0.01
Feb	17.7	24.6	11.0	43.9	101.69	15.3	0.07
Mar	20.9	28.0	13.2	33.5	101.36	16.6	0.06
Apr	26.0	33.1	18.9	33.2	101.06	16.8	0.02
May	33.7	41.3	25.2	18.5	100.69	13.1	0.00
Jun	38.2	46.4	29.5	12.5	100.04	15.9	0.00
Jul	38.0	45.9	29.6	14.5	99.68	19.5	0.00
Aug	38.1	46.0	29.6	15.2	99.84	16.4	0.00
Sep	35.2	43.8	27.0	21.8	100.35	12.8	0.00
Oct	31.1	38.7	23.4	33.5	101.00	10.1	0.00
Nov	22.3	28.7	16.5	47.4	101.57	9.9	0.00
Dec	18.0	24.0	12.7	57.8	101.76	11.4	0.02

Results and discussion

Data presented in Table 2 revealed that there was a significant ($P \leq 0.05$) difference among means of different spikelet loads (one, three, five, seven, and nine) regarding fruit set, fruit drop, parthenocarpic fruits, bisir fruits, tamar fruits, fruit fresh weight, fruit length, fruit width, fruit surface area, fruit volume, yield per bunch, and yield per palm. Maximum fruit set (84.37%), tamar fruits (86.57%), fruit fresh weight (10.28 g), fruit length (35.38 mm), fruit width (23.32 mm), yield per bunch (8.66 kg), and yield per palm (43.33 kg) were recorded when nine spikelets were placed in female inflorescence. These attributes were closely followed when seven spikelets were used. Similarly, data regarding fruit fresh weight, length, width, and surface area were higher but statistically at par when seven and nine spikelets were applied. Minimum fruit drop (15.63%) was observed when nine spikelets were applied, followed by seven spikelets (21.67%) treatment. Parthenocarpic and bisir fruits were minimal when five, seven, and nine spikelets were used, and all these treatments statistically behaved alike. Similarly, Table 3 showed a statistically

Table 2. Effects of different number of spikelets on fruit set (FS), fruit drop (FD), parthenocarpic fruits (PF), bisir fruits (BF), tamar fruits (TF), fruit fresh weight (FFW), fruit length (FL), fruit width (FWD), fruit surface area (FSA), fruit volume (FV), yield per bunch (YB), and yield per palm (YP) of three date palm cultivars

Treatments	FS (%)	FD (%)	PF (%)	BF (%)	TF (%)	FFW (g)	FL (mm)	FWD (mm)	FSA (mm^2)	FV (cc)	YB (kg)	YP (kg)
A. No. of Spikelets												
1	32.38^{E}	67.62^{A}	22.80^{A}	11.42^{A}	65.78^{D}	9.54^{C}	32.95^{C}	22.36^{B}	3108.2^{C}	13.05^{C}	3.08^{E}	15.40^{E}
3	54.99^{D}	45.01^{B}	17.43^{B}	8.99^{B}	73.58^{C}	9.82^{BC}	33.84^{BC}	22.80^{AB}	3251.0^{BC}	13.96^{BC}	5.41^{D}	27.07^{D}
5	66.11^{C}	33.89^{C}	10.67^{C}	6.01^{C}	83.32^{B}	10.07^{AB}	34.68^{AB}	23.17^{AB}	3374.0^{AB}	14.71^{AB}	6.66^{C}	33.29^{C}
7	78.33^{B}	21.67^{D}	9.67^{C}	4.88^{C}	85.44^{AB}	10.26^{A}	35.26^{A}	23.42^{A}	3465.3^{A}	15.33^{A}	8.04^{B}	40.20^{B}
9	84.37^{A}	15.63^{E}	8.42^{C}	5.01^{C}	86.57^{A}	10.28^{A}	35.38^{A}	23.32^{A}	3454.7^{A}	15.23^{A}	8.66^{A}	43.33^{A}
LSD$_{(P\leq0.05)}$	3.29*	3.29*	2.51*	1.24*	2.60*	0.38*	0.53*	0.87*	161.02*	1.06*	0.50*	2.48*
B. Cultivars												
Khalas	65.80^{A}	34.19^{B}	12.82^{A}	7.28^{AB}	79.89^{A}	9.96^{B}	37.57^{A}	23.70^{A}	3679.3^{A}	16.60^{A}	6.60^{A}	33.00^{A}
Sheshi	61.42^{B}	38.58^{A}	14.45^{A}	6.63^{B}	78.91^{A}	10.75^{A}	35.99^{B}	23.48^{A}	3520.4^{B}	15.60^{B}	6.68^{A}	33.42^{A}
Barhi	62.49^{B}	37.51^{A}	14.11^{A}	7.87^{A}	78.02^{A}	9.28^{C}	29.70^{C}	21.87^{B}	2792.2^{C}	11.18^{C}	5.83^{B}	29.15^{B}
LSD$_{(P\leq0.05)}$	2.55*	2.55*	1.95^{NS}	0.96*	2.01^{NS}	0.29*	0.84*	0.67*	124.72*	0.82*	0.38*	1.92*
C. No. of Spikelets × Cultivars												
1 × Khalas	37.53^{G}	62.47^{B}	20.90^{AC}	12.06^{AB}	67.03^{E}	9.40^{DE}	35.21^{C}	22.93^{AC}	3365.2^{DE}	14.60^{DE}	3.52^{G}	17.62^{G}
3 × Khalas	57.53^{E}	42.47^{D}	16.24^{D}	10.06^{BC}	73.70^{C}	9.97^{CD}	36.47^{BC}	23.60^{AB}	3575.4^{BE}	15.93^{BE}	5.74^{E}	28.68^{E}
5 × Khalas	68.91^{D}	31.09^{E}	9.94^{EF}	5.26^{FG}	84.80^{AB}	10.01^{CD}	37.80^{AB}	23.85^{A}	3723.1^{AC}	16.87^{AC}	6.90^{CD}	34.49^{CD}
7 × Khalas	81.36^{AC}	18.64^{FH}	8.54^{EF}	4.41^{G}	87.05^{A}	10.19^{BC}	39.14^{A}	24.16^{A}	3885.5^{A}	17.93^{A}	8.30^{B}	41.50^{B}
9 × Khalas	83.70^{A}	16.30^{H}	8.50^{EF}	4.61^{G}	86.89^{A}	10.20^{BC}	39.24^{A}	23.94^{A}	3847.3^{AB}	17.64^{AB}	8.54^{AB}	42.72^{AB}
1 × Sheshi	28.11^{H}	71.89^{A}	22.91^{AB}	9.11^{CD}	67.98^{DE}	10.16^{C}	34.80^{C}	22.85^{AC}	3315.9^{E}	14.26^{E}	2.86^{G}	14.31^{G}
3 × Sheshi	55.94^{EF}	44.06^{CD}	17.02^{CD}	7.62^{DE}	75.36^{C}	10.35^{BC}	36.21^{BC}	23.26^{AB}	3494.9^{CE}	15.39^{CE}	5.80^{E}	28.99^{E}
5 × Sheshi	64.31^{D}	35.69^{E}	11.58^{E}	7.38^{DF}	81.04^{B}	10.82^{AB}	36.28^{BC}	23.49^{AB}	3542.5^{CE}	15.72^{CE}	6.96^{CD}	34.82^{CD}
7 × Sheshi	76.03^{C}	23.97^{F}	11.07^{EF}	4.77^{G}	84.15^{AB}	11.22^{A}	36.31^{BC}	23.94^{A}	3628.1^{AD}	16.33^{AD}	8.53^{AB}	42.66^{AB}
9 × Sheshi	82.68^{AB}	17.32^{GH}	9.69^{EF}	4.29^{G}	86.03^{A}	11.20^{A}	36.40^{BC}	23.86^{A}	3620.6^{AD}	16.27^{AD}	9.26^{A}	46.31^{A}
1 × Barhi	31.51^{H}	68.49^{A}	24.58^{A}	13.11^{A}	62.32^{F}	9.07^{E}	28.83^{D}	21.31^{D}	2643.5^{F}	10.30^{F}	2.85^{G}	14.26^{G}
3 × Barhi	51.51^{F}	48.49^{C}	19.02^{BD}	9.29^{CD}	71.69^{CD}	9.14^{E}	28.85^{D}	21.54^{CD}	2682.9^{F}	10.55^{F}	4.71^{F}	23.54^{F}
5 × Barhi	65.10^{D}	34.90^{E}	10.48^{EF}	5.38^{FG}	84.14^{AB}	9.38^{DE}	29.95^{D}	22.17^{BD}	2856.3^{F}	11.55^{F}	6.11^{DE}	30.56^{DE}
7 × Barhi	77.59^{BC}	22.41^{FG}	9.41^{EF}	5.46^{FG}	85.13^{AB}	9.38^{DE}	30.34^{D}	22.15^{BD}	2882.4^{F}	11.71^{F}	7.28^{C}	36.43^{C}
9 × Barhi	86.74^{A}	13.26^{H}	7.07^{F}	6.13^{EG}	86.80^{A}	9.44^{DE}	30.52^{D}	22.17^{BD}	2896.1^{F}	11.78^{F}	8.19^{B}	40.96^{B}
LSD$_{(P\leq0.05)}$	5.70*	5.70*	4.35*	2.15*	4.50*	0.65*	1.88*	1.50*	278.89*	1.83*	0.86*	4.29*

Means showing a common letter(s) in a column are non-significant statistically at 5% probability using Duncan Multiple Range Test.

significant ($P\leq0.05$) difference among means of different spikelet loads (one, three, five, seven, and nine) regarding seed length, pulp weight, and pulp: seed ratio. However, seed weight, seed width, seed volume, fruit moisture content, total soluble solids, total sugars, reducing sugars, non-reducing sugars, titratable acidity, and total soluble solids: titratable acidity ratio were non-significant statistically. Higher seed length (21.71 mm) was recorded when only one spikelet was applied, which was linearly decreased to nine spikelets (20.75 mm) application. Maximum pulp weight and pulp: seed ratio was recorded when nine and seven spikelets were applied, and both were statistically at par.

The comparative analysis between three date palm cultivars indicated that cv. Khalas had a significantly ($P\leq0.05$) higher fruit set (65.80%), fruit length (37.57 mm), fruit width (23.70 mm), fruit surface area (3679.3 mm^2), and fruit volume (16.60 cc). Fruit drop was higher in cvs. Sheshi (38.58%) and Barhi (37.51%) were a minimum in cv. Khalas (34.19%). There was a non-significant difference among date palm cultivars regarding parthenocarpic and tamar fruit percentage parameters; however, bisir fruit percentage was higher in cv. Barhi (7.87%) followed by cv. Khalas (7.28%) and cv. Sheshi (6.63%). Fruit fresh weight was maximum in cv. Sheshi (10.75 g) followed by cv. Khalas (9.96 g), and cv. Barhi (9.28 g). Similarly, yield per bunch and yield per palm attributes were higher in cvs. Sheshi and Khalas, both were statistically at par (Table 2). Data given in Table 3 indicated that seed weight and seed width were higher in cvs. Khalas and Barhi and both behaved alike. Date palm cv. Khalas had higher total soluble solids and titratable acidity, whereas cv. Sheshi had a higher pulp weight and pulp: seed ratio. Maximum seed length, seed volume, fruit moisture content, total sugars, reducing sugars, non-reducing sugars, and TSS: TA ratio were determined in cv. Barhi.

The interaction data of spikelet loads and date palm cultivars showed that all attributes were significantly different at 5% level of probability (Table 2-3). Maximum fruit set, tamar fruits, fruit fresh weight, fruit length, fruit width, fruit surface area, fruit volume, yield per bunch, and yield per plant were observed in all three cultivars at nine and seven spikelet loads. Minimum fruit drop, parthenocarpic, and bisir fruit percentages were counted at nine and seven spikelet application, whereas these parameters were maximum when only one spikelet was used (Table 2). The interaction data in Table 3 indicated that seed weight, seed width, total sugars, and reducing sugars were higher in cvs. Khalas and Barhi at all spikelet loads. Seed length was higher in cv. Barhi at one to five spikelet loads. Seed volume, fruit moisture content, non-reducing sugars, and TSS: TA ratio were maximum in cv. Barhi at all spikelet loads. Pulp: seed ratio was maximum in cv. Sheshi when seven spikelets were placed, whereas titratable acidity was higher in cv. Khalas at all spikelet loads.

The heat-map of fruit growth and yield traits (Fig.1) revealed that spikelet load was more effective than date palm cultivars. In contrast, the fruit quality traits indicated that the cultivars' difference was more important than the spikelet loads. According

Table 3. Effects of different number of spikelets on seed weight (SW), seed length (SL), seed width (SWD), seed volume (SV), pulp weight (PW), pulp:seed ratio (PSR), fruit moisture content (FMC), total soluble solids (TSS), total sugars (TS), reducing sugars (RS), non-reducing sugars (NRS), titratable acidity (TA), and TSS:TA ratio of three date palm cultivars

Treatments	SW (g)	SL (mm)	SWD (mm)	SV (cc)	PW (g)	PSR	FMC (%)	TSS (Brix)	TS (%)	RS (%)	NRS (%)	TA (%)	TSS:TA ratio
A. No. of Spikelets													
1	0.83^{A}	21.71^{A}	7.84^{A}	1.05^{A}	8.71^{C}	10.83^{B}	16.18^{A}	53.38^{A}	62.02^{A}	60.40^{A}	1.62^{A}	0.170^{A}	367.33^{A}
3	0.83^{A}	21.16^{AB}	7.81^{A}	1.03^{A}	8.99^{BC}	11.23^{AB}	16.00^{A}	53.27^{A}	62.25^{A}	60.65^{A}	1.61^{A}	0.175^{A}	360.67^{A}
5	0.81^{A}	20.92^{AB}	7.75^{A}	0.99^{A}	9.26^{AB}	11.85^{AB}	15.83^{A}	53.52^{A}	62.37^{A}	60.78^{A}	1.59^{A}	0.177^{A}	357.22^{A}
7	0.81^{A}	20.77^{AB}	7.76^{A}	0.99^{A}	9.45^{A}	12.12^{A}	15.84^{A}	53.79^{A}	62.47^{A}	60.86^{A}	1.61^{A}	0.174^{A}	365.33^{A}
9	0.82^{A}	20.75^{B}	7.76^{A}	0.99^{A}	9.46^{A}	11.94^{A}	15.92^{A}	53.51^{A}	62.46^{A}	60.89^{A}	1.57^{A}	0.180^{A}	354.22^{A}
LSD$_{(P\leq0.05)}$	0.049^{NS}	0.94*	0.38^{NS}	0.111^{NS}	0.39*	1.06*	0.65^{NS}	2.44^{NS}	2.66^{NS}	2.65^{NS}	0.47^{NS}	0.015^{NS}	21.62^{NS}
B. Cultivars													
Khalas	0.90^{A}	20.60^{B}	8.05^{A}	1.05^{B}	9.05^{B}	10.05^{B}	15.01^{B}	61.29^{A}	64.52^{B}	63.28^{B}	1.24^{B}	0.243^{A}	254.93^{B}
Sheshi	0.66^{B}	20.53^{B}	7.14^{B}	0.82^{C}	10.09^{A}	15.36^{A}	15.14^{B}	44.10^{C}	54.26^{C}	52.98^{C}	1.28^{B}	0.191^{B}	230.53^{C}
Barhi	0.90^{A}	22.06^{A}	8.17^{A}	1.16^{A}	8.39^{C}	9.37^{B}	17.71^{A}	55.09^{B}	68.17^{A}	65.89^{A}	2.28^{A}	0.092^{C}	597.40^{A}
LSD$_{(P\leq0.05)}$	0.038*	0.73*	0.30*	0.086*	0.30*	0.82*	0.51*	1.89*	2.06*	2.05*	0.36*	0.012*	16.75*
C. Spikelets × Cultivars													
1 × Khalas	0.90^{A}	21.21^{AB}	8.04^{A}	1.08^{A}	8.50^{DE}	9.41^{C}	15.26^{B}	61.20^{A}	64.21^{A}	62.98^{A}	1.22^{B}	0.230^{A}	268.67^{B}
3 × Khalas	0.92^{A}	20.87^{AB}	8.06^{A}	1.07^{AB}	9.06^{CD}	9.89^{C}	15.20^{B}	61.32^{A}	64.35^{A}	63.12^{A}	1.22^{B}	0.243^{A}	252.00^{BC}
5 × Khalas	0.90^{A}	20.41^{B}	8.01^{A}	1.03^{AB}	9.11^{CD}	10.15^{C}	14.94^{B}	61.19^{A}	64.35^{A}	63.15^{A}	1.20^{B}	0.247^{A}	250.67^{BC}
7 × Khalas	0.89^{A}	20.25^{B}	8.09^{A}	1.04^{AB}	9.30^{C}	10.47^{C}	14.75^{B}	61.46^{A}	64.78^{A}	63.44^{A}	1.34^{B}	0.240^{A}	257.33^{BC}
9 × Khalas	0.90^{A}	20.24^{B}	8.06^{A}	1.03^{AB}	9.30^{C}	10.33^{C}	14.91^{B}	61.29^{A}	64.89^{A}	63.70^{A}	1.19^{B}	0.253^{A}	246.00^{BC}
1 × Sheshi	0.67^{B}	21.54^{AB}	7.22^{B}	0.88^{BC}	9.49^{C}	14.13^{B}	15.36^{B}	44.24^{C}	54.02^{B}	52.68^{B}	1.34^{B}	0.190^{B}	232.67^{BC}
3 × Sheshi	0.67^{B}	20.41^{B}	7.11^{B}	0.81^{C}	9.68^{BC}	14.58^{B}	15.07^{B}	43.44^{C}	54.23^{B}	52.86^{B}	1.36^{B}	0.191^{B}	227.33^{C}
5 × Sheshi	0.65^{B}	20.25^{B}	7.13^{B}	0.81^{C}	10.17^{AB}	15.81^{AB}	15.10^{B}	44.22^{C}	54.48^{B}	53.23^{B}	1.25^{B}	0.192^{B}	230.33^{C}
7 × Sheshi	0.65^{B}	20.24^{B}	7.11^{B}	0.81^{C}	10.57^{A}	16.43^{A}	15.04^{B}	44.17^{C}	54.43^{B}	53.24^{B}	1.20^{B}	0.192^{B}	230.67^{C}
9 × Sheshi	0.67^{B}	20.21^{B}	7.11^{B}	0.80^{C}	10.53^{A}	15.85^{AB}	15.14^{B}	44.43^{C}	54.14^{B}	52.89^{B}	1.25^{B}	0.192^{B}	231.67^{BC}
1 × Barhi	0.91^{A}	22.38^{A}	8.24^{A}	1.19^{A}	8.16^{E}	8.95^{C}	17.93^{A}	54.69^{B}	67.83^{A}	65.54^{A}	2.29^{A}	0.091^{C}	600.67^{A}
3 × Barhi	0.90^{A}	22.20^{A}	8.26^{A}	1.20^{A}	8.24^{E}	9.21^{C}	17.73^{A}	55.03^{B}	68.19^{A}	65.95^{A}	2.24^{A}	0.091^{C}	602.67^{A}
5 × Barhi	0.89^{A}	22.08^{A}	8.11^{A}	1.14^{A}	8.49^{DE}	9.59^{C}	17.44^{A}	55.16^{B}	68.27^{A}	65.96^{A}	2.31^{A}	0.093^{C}	590.67^{A}
7 × Barhi	0.90^{A}	21.81^{AB}	8.09^{A}	1.12^{A}	8.49^{DE}	9.46^{C}	17.74^{A}	55.75^{B}	68.19^{A}	65.91^{A}	2.28^{A}	0.092^{C}	608.00^{A}
9 × Barhi	0.89^{A}	21.80^{AB}	8.12^{A}	1.13^{A}	8.55^{DE}	9.65^{C}	17.70^{A}	54.81^{B}	68.34^{A}	66.07^{A}	2.27^{A}	0.094^{C}	585.00^{A}
LSD$_{(P\leq0.05)}$	0.084*	1.63*	0.67*	0.192*	0.67*	1.84*	1.13*	4.23*	4.61*	4.58*	0.81*	0.026*	37.45*

Means showing a common letter(s) in a column are non-significant statistically at 5% probability using Duncan Multiple Range Test.

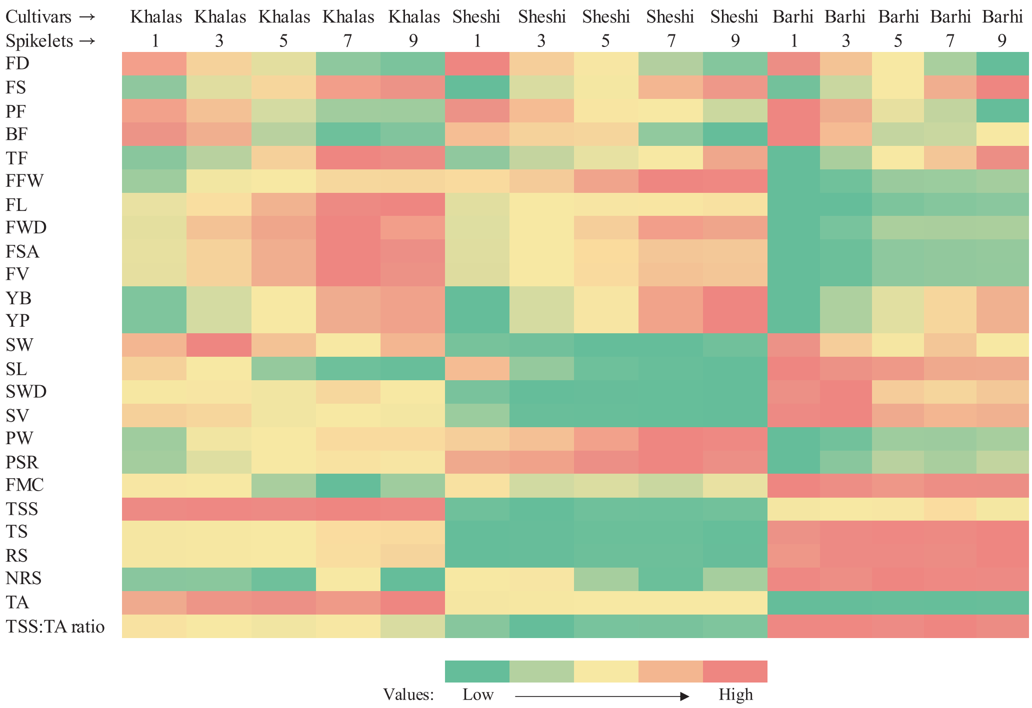

Fig. 1. Heat-map depicting various fruit growth, yield, and quality attributes of three date palm cultivars (Khalas, Sheshi, and Barhi) at different spikelet loads (1, 3, 5, 7, and 9). The heat map was constructed using mean values of three replicates of fruit drop (FD), fruit set (FS), parthenocarpic fruits (PF), bisir fruits (BF), tamar fruits (TF), fruit fresh weight (FFW), fruit length (FL), fruit width (FWD), fruit surface area (FSA), fruit volume (FV), yield per bunch (YB), yield per palm (YP), seed weight (SW), seed length (SL), seed width (SWD), seed volume (SV), pulp weight (PW), pulp:seed ratio (PSR), fruit moisture content (FMC), total soluble solids (TSS), total sugars (TS), reducing sugars (RS), non-reducing sugars (NRS), titratable acidity (TA), and TSS:TA ratio.

to the heat-map, the measured traits such as fruit drop, parthenocarpic, and bisir fruit were maximum at the lowest spikelet load. Higher fruit set, tamar fruits, yield per bunch, and yield per palm were recorded at higher spikelet loads. Although spikelet load affected the fruit fresh weight, fruit and seed size, pulp weight, and pulp: seed ratio, these traits were cultivars dependent. Similarly, fruit quality characteristics were also varied with cultivar irrespective of spikelet loads, such as fruit moisture content, total sugars, reducing sugars, non-reducing sugars, and TSS: TA ratio was higher in cv. Barhi, whereas total soluble solids were higher in cv. Khalas and titratable acidity were maximum in cv. Sheshi.

Pollination is one crucial cultural practice affecting fruit set, productivity, and quality in the plant production chain. For the cultivation of date palms, it is vital to use a viable and sustainable pollination technique that produces sufficient fruit growth, yield, and quality attributes and minimizes the amount of pollen grains applied (Awad, 2010; Munir *et al.,* 2020c).

The results of the present study showed that increased spikelet loads had favourable effects on fruit set, size, and yield attributes; however, fruit quality was cultivar-dependent and unaffected by spikelet loads. In cv. Lulu and most other cultivars, the placement of 5-10 male strands per female bunch increased fruit set between 85-95% (Zaid and de Wet, 2002). The technique of inserting 5-6 strands per bunch in the cv. Halawy also resulted in the highest fruit set (77.13%) (Kumawat *et al.,* 2022).

The maximum yields were obtained for date palms when mulch, fertilizer, and hand pollination were combined (El Mardi *et al.,* 2007). El-Dengawy (2017) found maximum yield in cv. Hayany placed five male strands using the hand pollination technique, which was non-significant to the dusting method. Iqbal *et al.* (2017) placed 2–3 strands and reported good yield and yield-related components in cv. Gulistan. Abdallah *et al.* (2014) revealed that fruit set, yield, and fruit size were statistically similar in the strand placement and dusting pollination methods. Ali-Dinar *et al.* (2021) reported that the placement of nine male strands reduced the abnormal parthenocarpic fruit sets of 13-year-old date palm cv. Barhi trees are raised from either conventional offshoots or through tissue culture technique. Highest fruit set, fruit size, and yield of cv. Dhakki was recorded using the strands placement method compared to dusting and liquid spray methods (Iqbal *et al.,* 2010). Khan and Khan (1993) reported maximum fruit set and yield in cv. Dhakki using the male strands placement method.

It can be concluded that the application of nine spikelets per female bunch greatly enhanced all fruit and yield-related qualities, whereas the application of seven spikelets per female inflorescence was closely followed. Regardless of spikelet loads, the date palm cultivars showed significant variation in fruit quality characteristics. Regarding fruit moisture content, total sugars, reducing sugars, non-reducing sugars, and TSS: TA ratio, the quality of cv. Barhi was superior. Therefore, even though applying nine spikelets per bunch had the best results, applying seven spikelets per bunch can also be practised at a minimal compromise on date palm fruit yield and quality.

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