

Effect of additional lighting for off-season production of dragon fruit

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Abstract

An investigation was carried out on the effects of additional LED lighting on dragon fruit yield, quality, and growth patterns during off-season flushes during 2020–2022. Each LED bulbs of 7, 9 and 12 watts were used during two-time intervals *i.e.* 4.30 to 8.30 pm and 06.30 to 10.30pm constituting 7 treatments including control with four replications. The application of 12W LED lighting from 4:30 pm to 8:30 pm significantly increased the number of fruits, with 10.61 and 10.69 fruits per pillar observed in the first and second flushes, respectively. This lighting regime also resulted in the longest (9.09 cm) and widest (7.18 cm) fruits considering both the flushes. Overall, total yield reached 6.01 kg per pillar, equating to 9.61 tons per hectare. The quickest floral bud formation (15.18 days) and highest ascorbic acid content (up to 7.98 mg/100g pulp) were also observed with the 12W LED lighting in the same time range. Light intensity readings, taken from various distances, peaked at 1002.57 LUX at 30 cm from the source. Additionally, some fruit quality traits, such as total soluble solids and sugar content, showed significant variation with lighting intensity, though titratable acidity and sugar types were unaffected.

Introduction

Dragon fruit (*Hylocereus spp.*), an exotic herbaceous perennial climbing cactus, also widely known as Pitaya is commercially cultivated in Vietnam, Thailand, Malaysia, Indonesia, Australia Mexico, Colombia, Ecuador (Wakchaure et al., 2021). It was introduced in India during the late `90s as a back yard fruit crop and but the area under its commercial cultivation is gradually increasing in rapid pace (Alam et al., 2022). The harvesting season particularly in the eastern part of India is recorded from May to November and therefore this cactus stays unproductive for around five months from December to April (Devi et al., 2023). The persistence of sub-tropical climate in this region might be a constraint limited growing period as it is a photoperiod sensitive crop and long-day in nature. Use of incandescent bulbs, compact fluorescent light (CFL), light emitting diodes (LED) and other forms of additional lighting is capable of inducing off-season flowers in dragon fruit (Y. L. Jiang, 2020; Y. L. Jiang et al., 2016; Kumari et al., 2016; Nguyen et al., 2021; Pascua et al., 2013). Although, it is observed that the LED bulbs cost the least compared to other and consume less electricity without affecting the efficiency compared to other form of light sources (Pascua et al., 2013). The experiment is thus taken up to keep up the production in the regions where the fruiting is unavailable almost half a year. The study is aimed to investigate the effect of duration of exposure and intensity of different LED bulbs in off-season production of dragon fruit.

Materials and methods

The experiment was conducted at a farmer’s field located at Kashtodanga, Haringhata, Nadia, West Bengal, India (22^o58’33.4’’N latitude and 88^o38’43.3’’E) on elevation of 9.75m above mean sea level (MSL) during the years 2020-21 and 2021-22. The soil texture of the field is well drained sandy loam with good water holding capacity. The soil nutrient status of the experimental site is presented here under:

Table 1: Soil nutrient status of the experimental Site

Chemical properties	Values
pH	7.15
Organic carbon (%)	0.46
Available Nitrogen (kg/ha)	253.37
Available P ₂ O ₅ (kg/ha)	31.67
Available K ₂ O (kg/ha)	298.19

The orchard was planted with *Hylocereus costaricensis* cv. Royal Moroccan Red in mop top system of training using concrete pillars spaced at 2.5m × 2.5m. The pillars were 2.13m long with iron ring of 0.6m diameter. The ring is surrounded by thick used rubber tyre of bicycles to prevent the damage to the cladodes from the heat and sharp edges of iron structure. Each pillar consisted of four cuttings. The age of the orchard under experiment was 3 and a half year.

The experiment was conducted using randomized block design (RBD) having seven treatments including control replicated four times. Therefore, twenty-eight number of pillars were considered for conducting the experiment, details are as follows:

Table 2: Treatment details

Sl. No.	Notation	Treatment
1.	T ₁	Additional lighting by 7W LED bulb from 4.30 to 08.30 pm
2.	T ₂	Additional lighting by 7W LED bulb 6.30 to 10.30 pm
3.	T ₃	Additional lighting by 9W LED bulb 4.30 to 08.30 pm
4.	T ₄	Additional lighting by 9W LED bulb from 6.30 to 10.30 pm
5.	T ₅	Additional lighting by 12W LED bulb 4.30 to 08.30 pm
6.	T ₆	Additional lighting by 12W LED bulb 6.30 to 10.30 pm
7.	T ₇	Control

Fertilizer application of NPK @ 450:350:300g and 5kg FYM per pillar were applied following the schedule mentioned below (Perween & Hasan, 2019).

Table 3: Nutrient management schedule for Dragon fruit

Time of application	Urea (g/ pillar)	N (g/ pillar)	SSP (g/ pillar)	P ₂ O ₅ (g/ pillar)	MOP (g/ pillar)	K ₂ O (g/ pillar)	Organic manure (kg/ pillar)
June	125	57.5	500	80	62.5	37.5	5
August	125	57.5	500	80	62.5	37.5	0
October	250	115	500	80	125	75	0
March	500	230	500	80	250	150	0
Total / pillar/ year	1000	460	2000	320	500	300	5

Uniform cultural management was provided for all the plants/pillars along with nutrients, plant protection measures and other parameters. Weeds in the orchard field were controlled by manual hand weeding specially around the base of the pillar, and also by application of herbicides (Glyphosate @ 100ml/15 liter of water) in the inter-row areas. Irrigation was given just after each application of fertilizers and manures. Subsequent irrigation was applied as and when required depending upon the soil moisture and rainfall received. Moisture level at 60-70% field capacity was maintained throughout the production period of dragon fruit. Ants and termites were controlled by spraying of Chlorpyrifos 20% EC @ 4ml/ liter of water.

Light intensity was measured with the help of Lux meter with the increasing distance of 30, 60, 90 and 120 cm from the source of light i.e. 7W, 9W and 12W. The values were observed at four different times to get the mean.

Yield and yield attributing characters

During the observation various observations were taken including number of fruits per pillar, length and width of fruits, number of bracts per fruit, length and width of fruit distal bract, fruit weight and yield. The days taken to the formation of flower bud from the initiation of additional lighting and the days taken to harvest the fruits from the date of flowering were observed.

Chemical composition of fruits

The parameters such as total soluble solids were measured with digital hand refractometer with range of 0-53 °B at 20 °C temperature. The titratable acidity was estimated by titrating the aqueous extract of known quantity of fruit juice

against (N/10) NaOH solution using phenolphthalein as an indicator (A.O.A.C, 2006). Ascorbic acid content of the harvested fruits was estimated by using 2, 6- di chloro indophenol dye titration method (A.O.A.C, 2006) and it was expressed as mg/100g of fruit pulp.

Total sugar content of the fruit was determined by gravimetric procedures. Firstly, the non-reducing sugar content of juice sample was converted into reducing sugar by acid hydrolysis. After conversion, the sugar of the aqueous solution was determined by titrating against the freshly prepared mixture containing equal volumes of Fehling’s solution A and B and using methylene blue as indicator (A.O.A.C, 2006) and expressed in percentage. The reducing sugar content of the aqueous extract was determined by titrating against the Fehling’s solution as stated above (A.O.A.C, 2006) and expressed in percentage. Non-reducing sugar content was determined by the formula: Percentage of non-reducing sugar = (Total sugar – Reducing sugar) × 0.95

As 0.95 gram of sucrose on hydrolysis gives 1 gram of mono saccharides i.e. glucose + fructose (A.O.A.C, 2006).

Results and discussions

Light intensity

The intensity of light with respect to the use of additional lighting for off-season production was determined from four different distances, such as 30, 60, 90 and 120 cm for the source (Tab. 4). The ranges of light intensities were found as 840.72 to 1002.57, 716.98 to 803.22, 596.36 to 705.56 and 184.01 to 301.90 LUX, respectively, at distances of 30, 60, 90 and 120 cm from the light source respectively (Tab. 4). The maximum light intensity of 1002.57 LUX was found with the use of 12W LED bulb from 6.30 pm to 10.30 pm (T₆) at a distance of 30 cm from the source. In contrast, the minimum intensity of 184.01 LUX was recorded with 7W LED bulb from 6.30 pm to 10.30 pm at a distance of 120 cm from the source. However, the differences were statistically *at par* in nature.

The second, third and fourth highest light intensities were recorded 994.07, 993.53 and 985.77 LUX with the provision of additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm (T₅), by 9W LED bulb from 6.30 pm to 10.30 pm (T₄) and by 9W LED bulb from 4.30 pm to 08.30 pm (T₃), respectively, when it was placed at a distance of 30 cm from the source. These values of T₆, T₅, T₄ and T₃ (when provided at a distance of 30 cm from the source) were statistically *at par* with each other.

Table 4: Intensity of the additional lighting for off-season production at different distance from the light source

Treatment	Light intensity at different distance from the source (LUX)			
	30 cm	60 cm	90 cm	120 cm
	from the light source	from the light source	from the light source	from the light source
T ₁ - 7W LED bulb from 4.30 pm to 08.30 pm	847.13	722.09	596.90	192.57
T ₂ - 7W LED bulb from 6.30 pm to 10.30 pm	840.72	716.98	596.36	184.01
T ₃ - 9W LED bulb from 4.30 pm to 08.30 pm	985.77	803.22	696.20	279.75
T ₄ - 9W LED bulb from 6.30 pm to 10.30 pm	993.53	791.09	699.02	278.95
T ₅ -12W LED bulb from 4.30 pm to 08.30 pm	994.07	785.85	699.47	301.90
T ₆ -12W LED bulb from 6.30 pm to 10.30 pm	1002.57	797.00	705.56	292.73
S.Em. (±)	12.306	6.975	4.342	3.567
C.D. (p=0.05)	37.434	21.215	13.209	10.850

Yield and yield attributing characters

The use of additional light resulted in supplementary two flushes of production after the end of normal season and the observational data were recorded for the same. The number of fruits per pillar exhibited significant variation over both the flushes observed. The numbers of fruits per pillar was noted with the range of 8.73 to 10.61 and 8.74 to 10.69 (Tab. 6) in the two flushes respectively. There was a considerable and consistent improvement in the number of fruits per pillar (10.61 and 10.69 fruits/ pillar in first and second flush, respectively) with the utilization of additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm (T₅), followed very closely most remarkably by providing with additional lighting of 12W LED bulb from 6.30 pm to 10.30 pm (T₆) [10.40 and 10.43]. Additional lighting by 9W LED bulb from 4.30 pm to 08.30 pm (T₃) produced 10.29 and 10.37 fruits per pillar, in the two consecutive flushes respectively. However, the values of the treatments T₃, T₅ and T₆ did not differ significantly. A significant improvement in the number of fruits per pillar was observed by using 9 and 12W LED bulb over 7W LED bulb (Fig. 1).

The highest fruit length (8.93 cm) was observed under the influence of additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm (T₅) [Tab. 6 & Fig. 1]. In contrast, the shortest fruit length (8.22 cm) was recorded with the use of additional lighting by 7W LED bulb from 6.30 pm to 10.30 pm (T₂). These two values differed in a significant manner from each other. The second and third highest values for the same were observed 8.75 and 8.61 cm, respectively under the effects of additional lighting by 12W LED bulb from 6.30 pm to 10.30 pm and by 9W LED bulb from 4.30 pm to 08.30 pm (T₆ and T₃). However, these values were statistically *at par* and did not exhibit any significant variations from T₅.

The fruit width ranged from 6.35 to 7.18 cm, producing the maximum value (7.18 and 7.13 cm) by the use of additional lighting with 12W LED bulb from 4.30 pm to 08.30 pm (T₅) and the minimum (6.35 and 6.25 cm) with the 7W LED bulb from 6.30 pm to 10.30 pm (T₂) in the first and second flush respectively. However, T₅ failed exhibit any kind of notable variations from those of T₆ (use of additional lighting by 12W LED bulb from 6.30 pm to 10.30 pm) and T₃ (additional lighting by 9W LED bulb from 4.30 pm to 08.30 pm), having values of 7.16 and 6.98 cm, respectively.

The number of bracts/ fruit failed to create any statistical variation under the influences of the additional lighting for off-season production during both the first and second flushes (Tab. 6). However, the increase in the wattage of light during 4.30 pm to 08.30 pm always resulted in a slight improvement in the number of bracts/ fruit. The highest value (26.89 and 26.20 numbers of bracts/fruit) was recorded with additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm (T₅).

The length of fruit bract behaved in the same manner with the number of bracts/ fruit and it also exhibited statistical difference during the second flush (Tab. 6). The longest fruit bract (of 45.87) was recorded from the use of additional lighting with 12W LED bulb from 4.30 pm to 08.30 pm (T₅). The second and third longest values for the same was recorded 45.74 and 45.73 mm under T₆ and T₃ (the use of additional lighting by 12W and 9W LED bulb from 6.30 pm to 10.30 pm, respectively). The values for length of distal fruit bract in the treatments T₅, T₆ and T₃ were statistically *at par* with each other and differed remarkably with the use of additional lighting by 7W LED bulb from 6.30 pm to 10.30 pm (T₂), having the value of 44.67 mm.

The width of the distal fruit bract failed to exhibit any sort of variation under first flush (Tab. 6), however it resulted into considerable variation during second flush under the direct influence of additional lighting in dragon fruit. The maximum width of distal fruit bract (15.77 and 16.02 mm) was found with the use of additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm (T₅) and the minimum (15.01 and 14.47 mm) with additional lighting by 7W LED bulb from 6.30 pm to 10.30 pm (T₂) in the two consecutive flushes respectively. The difference between T₅ and T₂ was considerable in nature. Remarkably higher values of 15.17 and 14.86 mm had also been obtained with the use of additional lighting by 12W LED and 9W bulb from 6.30 pm to 10.30 pm (under the treatments T₆ and T₃). The treatment T₃ differed significantly from both the T₅ and T₆, whereas T₆ was statistically *at par* with T₅.

The days taken to produce the flower in the dragon fruit plants showed considerable variations under the influences of additional lighting for off-season production. The maximum duration required for flower induction was 17.44 days with the use of additional lighting by 7W LED bulb from 4.30 pm to 08.30 pm (T₁). On the other hand, the quickest floral induction (15.18 days) was recorded with the exposure to additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm (T₅). The difference between T₂ and T₆ were considerable in nature. The second and the third lowest duration for floral induction was 15.53 and 15.62 days, respectively under second and third flush obtained with the use of additional

lighting by 12W LED bulb from 6.30 pm to 10.30 pm (T_6) and by 9W LED bulb from 4.30 pm to 08.30 pm (T_3). The variation between T_6 and T_3 were statistically insignificant. However, all these three showed statistical variation compared to the treatment T_2 .

The time period required between anthesis and final fruit harvesting of dragon fruit did not show any significant variation due to additional lighting for off-season production. However, a close observation of the experimental data indicates the trend that an increase in the wattage of light during 4.30 pm to 08.30 pm resulted into continuous reduction in the time span for fruit maturation. The lowest and the second lowest time span required for harvest was 41.15 and 41.22 days the additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm (T_5) and by 12W LED bulb from 6.30 pm to 10.30 pm (T_6), respectively.

The heaviest fruit of 282.63 and 281.44 g was obtained with the use of additional lighting by 12W LED bulb 4.30 pm to 08.30 pm (T_5), during the consecutive flushes (Tab. 5 & Fig. 2). Fruit weight recorded in T_5 was statistically *at par* with those of T_6 , T_3 and T_4 (the treatments comprised of the use of additional lighting by 12W LED bulb 6.30 pm to 10.30 pm, by 9W LED bulb 4.30 pm to 08.30 pm and by 9W LED bulb from 6.30 pm to 10.30 pm, respectively) and the respective values were 280.30, 274.06 and 271.00 g during first flush and but differed considerably from T_3 and T_4 during second flush, respectively. The lowest figure for the same was observed as 252.78 and 250.44 g, when the additional lighting was provided by 7W LED bulb from 6.30 pm to 10.30 pm (T_2). The treatment T_2 exhibited significant variations from T_5 , T_6 , T_3 and T_4 . The second lowest fruit weight (255.80 and 257.21g) was observed with the additional lighting by 7W LED bulb from 4.30 pm to 08.30 pm (T_1), having the values for the same during both the flushes were 255.80 and 257.21 g.

Yield of fruit showed significant variations in both the flushes. The yield of dragon fruit of 3.00 and 3.01; 2.91 and 2.92; 2.82 and 2.82; 2.73 and 2.68; 2.26 and 2.28 and 2.21 and 2.19 kg/pillar was in ascending order for the treatments as follows: $T_5 > T_6 > T_3 > T_4 > T_1 > T_2$ during first and second flushes, respectively (Fig. 2). Under the first flush, the treatments T_5 and T_6 and T_3 and T_4 were statistically *at par* with each other. The treatments T_2 and T_1 differed significantly from all the other treatments. Whereas, under the second flush the treatments T_5 , T_6 , T_3 and T_4 showed significant variations from each other only in the second flush. However, in both these flushes, the treatments T_2 and T_1 varied remarkably from all the other treatments. It is to mention that the difference between the treatments T_2 and T_1 failed to express any significant variation among them in the first flush. In contrast, the significant variation was observed in the second flush.

Table 5: Effect additional lighting for off-season production on days taken for flower induction and to harvest, fruit weight and yield in dragon fruit

Treatment	Days taken to flower bud formation	Days taken to harvest	Fruit weight (g)		Yield (kg/ pillar/ flush)	
			1 st flush	2 nd flush	1 st flush	2 nd flush
T ₁ - 7W LED bulb from 4.30 pm to 08.30 pm	17.44	42.59	255.80	257.21	2.26	2.28
T ₂ - 7W LED bulb from 6.30 pm to 10.30 pm	18.65	43.76	252.78	250.44	2.21	2.19
T ₃ - 9W LED bulb from 4.30 pm to 08.30 pm	15.62	41.34	274.06	272.19	2.82	2.82
T ₄ - 9W LED bulb from 6.30 pm to 10.30 pm	16.47	42.36	271.00	270.61	2.73	2.68
T ₅ - 12W LED bulb from 4.30 pm to 08.30 pm	15.18	41.15	282.63	281.44	3.00	3.01
T ₆ - 12W LED bulb from 6.30 pm to 10.30 pm	15.53	41.22	280.30	279.98	2.91	2.92
S.Em. (±)	0.121	1.128	2.984	1.800	0.048	0.017
C.D. (p=0.05)	0.367	N.S.	9.078	5.474	0.147	0.050

The use of additional lighting in dragon fruit exerted significantly positive influences over different yield attributes namely, number of fruits, length, width, and weight of fruit, length and width of fruit bracts along with the final yield of this crop. However, the number bracts/fruit failed to show any statistical variation in this respect. With respect to the days taken to harvest and the duration between anthesis and fruit harvest exhibited a marked reduction under the utilization of additional lighting. Consistently and comprehensively the highest values for all these yield related parameters were found with the provision of additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm (T₅), very closely followed by the use of additional lighting by 12W LED bulb from 6.30 pm to 10.30 pm (T₆) and by 9W LED bulb from 4.30 pm to 08.30 pm (T₃) respectively. These results are suggestive to the fact that increase in the power and/or wattage of light, the parameters under study were influenced in a more positive ways, especially, when applied during 4.30 pm to 08.30 pm.

In contrast to this, the time span requirement for floral bud formation as well as fruit maturity decreased considerably with the similar provisions of additional lightings. These experimental findings are supported by strong evidence from the studies of Y. L. Jiang (2020), who observed off-season flowering in a self-compatible red flesh hybrid pitaya (derived from a cross between *Hylocereus undatus* and *H. polyrhizus*) that could be achieved by night-breaking with artificial light in a non-inductive season. To ensure abundant flowering, 4-6 hours of night-breaking is applied and often resulted in over flowering and this consequently led to higher number of fruits per pillar.

The improvement in floral induction as well as in production of number of fruits per pillar with substantial increase in various yield attributes and final yield of this crop in the present investigation could be explained in light of the facts that being a long day crop the flowering in dragon fruit could be induced by the increased day length after the March equinox (Borchert et al., 2005; Garner & Allard, 1920). In pitaya, the meristems located beneath the areoles, which are gray structures with hairs and spines developed on the ribs of a shoot, could differentiate into floral buds in response to increased day length, which in turn help into considerable improvement of majority of the yield attributing parameters in future course (Y. L. Jiang et al., 2012). Day length extension or night-breaking may regulate the vegetative and reproductive growth of cactus plants (Boyle, 1991; Gutterman, 1995).

Yen & Chang (1997) reported the effect of prolonging the light period up to 2200 hour in winter on inducing *H. undatus* plants to flower. The bud development and flowering of a given pitaya plant is supposed to depend on temperature, photoperiod and irradiance (Y. Jiang et al., 2011; Khaimov et al., 2012; Khaimov & Mizrahi, 2006; Luders & McMahon, 2006; Yen & Chang, 1997). In *H. undatus*, the Day Light Integral (DLI) for obtaining optimal CO₂ uptake was between 15 and 25 mol·m⁻²·d⁻¹ (Nobel & Barrera, 2004). These views are conclusively supporting the objective of the present study

with respect to the prominent effect of intensities of additional lighting over the floral induction, fruit quality and final yield of dragon fruit during the non-productive/ off-season period.

Chemical composition of fruits

The total soluble solids (TSS), the most striking fruit quality attributes of dragon fruit failed to show any significant variation during first flush, however, exhibited remarkable variation during the second flush under the influence of additional lighting for off-season production. The maximum TSS content of 17.00 °Brix was found with the use of additional lighting by 9W LED bulb from 4.30 pm to 08.30 pm (T₃) [Tab. 7 & Fig. 3]. In contrast to this, the lowest value (15.44 °Brix) was recorded with the application of additional lighting by 7W LED bulb from 6.30 pm to 10.30 pm (T₂). The difference between the treatments T₃ and T₂ were remarkable in nature. The second and the third highest values for TSS recorded was 16.28 and 16.24 °Brix by providing additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm (T₅) and by 9W LED bulb from 6.30 pm to 10.30 pm (T₄), respectively. The difference between the treatments T₅ and T₄ was insignificant in nature, but both of these varied statistically with T₃ treatment.

The titratable acidity content of dragon fruit failed to display any considerable variation under the present study, during both of the flushes, on account of the influences of additional lighting for off-season production (Tab. 7). This parameter showed a very narrow range of variation and between 0.13 and 0.14% during both the flushes. No specific trend was observed, with respect to the variation over this parameter, during both the flushes.

As a very prominent quality determining parameter, the ascorbic acid content of dragon fruit exhibited considerable variations during both of the flushes under the impact of additional lighting (Tab. 7 & Fig. 3). The value of ascorbic acid content ranged from 7.52 to 7.98 and 7.62 to 7.95 mg/100g pulp under the first and second flushes, respectively. The highest value (7.98 and 7.95 mg/ 100g pulp) in this respect was observed with the additional lighting by 9W LED bulb from 4.30 pm to 08.30 pm (T₃), followed by 7.97 and 7.91 mg/100g pulp with exposure to additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm (T₅). The difference between T₃ and T₅ was, however, statistically insignificant.

The reducing sugar contents of dragon fruit in the current investigation under the specific influences of the provision of additional lighting failed to show variations in any of the flushes under this experimental study (Tab. 7). Although, insignificant in nature still a slight and consistent improvement in reducing sugar content was observed with the use of additional lighting by 9W LED bulb, followed by the use of 12W LED bulb, especially during 4.30 pm to 08.30 pm, (T₃ and T₅), respectively, having the values of 10.93 and 10.90 and 11.06 and 11.06%, respectively, during the first and second flushes. One other hand, lowest values for this character of 10.55 and 10.68% was found with the additional lighting by 7W LED bulb from 6.30 pm to 10.30 pm (T₂).

The non-reducing sugar content also failed to show significant variation during both the flushes under the study due to the effect of additional lighting for off-season production (Tab. 7). This parameter exhibited a range between 1.94 and 2.06 and 1.96 and 2.14% during both of the flushes, respectively. Insignificantly the highest and the lowest values for non-reducing sugar was found with the use of additional lighting by 9W LED bulb from 4.30 pm to 08.30 pm and by 7W LED bulb from 6.30 pm to 10.30 pm (T₅ and T₂, respectively).

Unlike reducing and non-reducing sugar content of dragon fruit, the total sugar content produces a significant variation under the second flush of this experiment. However, the first flush failed to do the same (Tab. 7). The co-efficient of variation for total sugar content was found as 0.852%. The maximum total sugar content (13.34%) was obtained with additional lighting with 9W LED bulb from 4.30 pm to 08.30 pm (T₃) followed by 13.28 and 13.11% in the treatments provided with 12W LED bulb from 4.30 pm to 08.30 pm (T₅) and 9W LED bulb from 6.30 pm to 10.30 pm (T₄), respectively. The differences between T₄ from T₃ and T₅ were significant in nature. The lowest value (12.76%) was estimated with the additional lighting by 7W LED bulb from 6.30 pm to 10.30 pm (T₂) followed by additional lighting by 7W LED bulb from 4.30 pm to 08.30 pm [12.81%] (T₁) during the second flush. The values of T₂ and T₁ differed non-significantly but varied significantly with the treatments T₃, T₅ and T₄.

The various fruit bio-chemical attributes of dragon fruit, in the current investigation, namely, TSS, reducing, non-reducing and total sugar contents, titratable acidity and ascorbic acid content under the provision of additional lighting to extend the day length for off-season production in the present investigation did not exhibit any significant variations among the treatments.

Titrateable acidity, reducing and non-reducing sugar content never varied in a considerable manner, whereas TSS and total sugar content improved very marginally. Only ascorbic acid content showed a notable variation. The very marginal and/or insignificant differences of TSS and different kinds of sugar content of dragon fruit was observed in the present study, due to the influences of use of additional lighting of different duration with various intensities of light.

The results are in conformity with the evidence from the experimental findings of Kumari *et al.* (2016), who also described that there were no significant differences in TSS value along with sugar contents in dragon fruit with additional lighting time from 7-9 pm, 9-11 pm, 11 pm-1 am, 1-3 am, 3-5 am and prolonging the length of days up to 12, 15 and 18 days with twenty watts compact fluorescent bulbs (CFL). However, still a very marginal improvement with respect to TSS, total sugar and ascorbic acid contents, in the current research study, due to the utilization of additional lighting, might be attributed to the fact that the extension of day light by providing additional lighting might have attributed towards more synthesis of carbohydrates along with other metabolites and their translocation to the fruit tissues.

The increased soluble solids and ascorbic acid in the fruits from the plants, received higher night braking (mostly from 4.30pm to 8.30 pm) with more intensities of lightings i.e. 9W and 12W CFL, could also be discussed with the view that the changes took place in the micro-climate might have increased Photosynthetically Active Radiation (PAR) absorption and improved light utilization by the plants canopies, which subsequently caused a greater share of cladode carbohydrates to fruits and a greater cladode : fruit ratio, as the end result, increased in the amount of assimilates supplied from the leaves/ cladodes to the fruits (McArtney et al., 1996; Tustin et al., 1997).

Table 6: Effect of additional lighting for off-season production of dragon fruit on number of fruits/ pillar, length of fruit and width of fruit, number of bracts/fruit, length and width of distal fruit bract

Treatment	Number of fruits/ pillar		Length of fruit (cm)		Width of fruit (cm)		Number of bracts/fruit		Length of distal fruit bract (mm)		Width of distal fruit bract (mm)	
	1 st flush	2 nd flush	1 st flush	2 nd flush	1 st flush	2 nd flush	1 st flush	2 nd flush	1 st flush	2 nd flush	1 st flush	2 nd flush
T₁	8.83	8.88	8.43	8.31	6.40	6.37	25.82	25.13	44.82	45.24	15.34	14.69
T₂	8.73	8.74	8.27	8.22	6.35	6.25	25.63	25.04	44.32	44.67	15.01	14.47
T₃	10.29	10.37	8.73	8.61	6.98	6.99	26.21	25.84	45.12	45.73	15.40	14.86
T₄	10.06	9.92	8.63	8.44	6.89	6.86	25.84	25.58	44.92	45.32	15.40	14.76
T₅	10.61	10.69	9.09	8.93	7.18	7.13	26.89	26.20	45.44	45.87	15.77	16.02
T₆	10.40	10.43	8.84	8.75	7.16	7.07	26.37	25.90	45.28	45.74	15.67	15.17
S.Em. (±)	0.131	0.059	0.338	0.106	0.087	0.312	0.549	0.610	0.365	0.117	0.349	0.083
C.D. (p=0.05)	0.398	0.180	N.S.	0.322	0.263	N.S.	N.S.	N.S.	N.S.	0.357	N.S.	0.252

Table 7: Effect additional lighting for off-season production of dragon fruit on total soluble solids, titrateable acidity, ascorbic acid, reducing sugar, non-reducing sugar and total sugar

Treatment	Total Soluble Solids (°Brix)		Titratable acidity (%)		Ascorbic acid (mg/100g pulp)		Reducing sugar (%)		Non-reducing sugar (%)		Total sugar (%)	
	1 st flush	2 nd flush	1 st flush	2 nd flush	1 st flush	2 nd flush	1 st flush	2 nd flush	1 st flush	2 nd flush	1 st flush	2 nd flush
T₁	15.91	15.96	0.14	0.14	7.70	7.73	10.64	10.72	1.94	1.96	12.83	12.81
T₂	15.62	15.44	0.14	0.14	7.52	7.62	10.55	10.68	1.94	1.93	12.71	12.76
T₃	16.56	17.00	0.13	0.14	7.98	7.95	10.93	11.06	2.06	2.14	13.04	13.34
T₄	16.37	16.24	0.13	0.14	7.81	7.89	10.85	10.93	2.00	2.06	12.96	13.11
T₅	16.42	16.28	0.14	0.14	7.97	7.91	10.90	11.06	2.03	2.08	12.98	13.28
T₆	16.08	16.04	0.14	0.14	7.77	7.87	10.84	10.90	1.99	2.01	12.91	13.05
S.Em. (±)	0.463	0.106	0.006	0.008	0.054	0.060	0.259	0.294	0.062	0.057	0.273	0.079
C.D. (p=0.05)	N.S.	0.321	N.S.	N.S.	0.164	0.183	N.S.	N.S.	N.S.	N.S.	N.S.	0.169

Note: **T₁** -7W LED bulb from 4.30 pm to 08.30 pm, **T₂** -7W LED bulb from 6.30 pm to 10.30 pm, **T₃** -9W LED bulb from 4.30 pm to 08.30 pm, **T₄** -9W LED bulb from 6.30 pm to 10.30 pm, **T₅** -12W LED bulb from 4.30 pm to 08.30 pm, **T₆** -12W LED bulb from 6.30 pm to 10.30 pm

Summary and conclusions

There was a considerable and consistent increase in the number of fruits with the additional lighting by 12W LED bulb 4.30 pm to 08.30 pm (10.61 and 10.69 number of fruits per pillar during first and second flushes, respectively). The longest and widest fruits (8.93 and 7.18 cm) was found with additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm during second and first flushes, respectively (Table 6). The number of bracts/fruit did not vary significantly whereas the length of fruit bract exhibited significant difference only during the second flush. The longest fruit bract (45.87 mm) was observed due to additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm. The maximum width of distal fruit bract was noted with the use of additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm and the minimum with additional lighting by 7W LED bulb from 6.30 pm to 10.30 pm, during the second flush. The heaviest fruit (282.63 and 281.44 g) was obtained with the use of additional lighting by 12W LED bulb 4.30 pm to 08.30 pm during the two consecutive flushes and were *at par* with the use of additional lighting by 12W LED bulb 6.30 pm to 10.30 pm, 9W LED bulb 4.30 pm to 08.30 pm and 9W LED bulb from 6.30 pm to 10.30 pm. The effect of additional lighting for off-season production exhibited significant variation on fruit yield. Individually in both the flushes obtained in the off-season, yield was significantly high (3.00 and 3.01 kg/ pillar/ flush respectively) with the use of 12W LED bulb from 4.30 pm to 08.30 pm, followed by the use of 9W LED bulb from 4.30 pm to 08.30 pm. Total yield was also highest (6.01 kg/ pillar/ off-season) having a value of 9.616 ton/ ha/ off-season considering the consecutive two flushes.

The maximum duration required for flower bud formation observed was 17.44 days with the use of additional lighting by 7W LED bulb from 4.30 pm to 08.30 pm. On the other hand, the quickest floral bud formation was recorded 15.18 days with additional lighting by 12W LED bulb from 4.30 pm to 08.30 pm. However, the time span required between anthesis and final fruit harvesting of dragon fruit did not vary significantly due additional lighting.

The maximum TSS content of 17.00 °Brix was noted with the use of additional lighting by 9W LED bulb from 4.30 pm to 08.30 pm. The titratable acidity content of dragon fruit failed to exhibit any considerable variation under the present study, during both of the flushes. The highest value for ascorbic acid content of 7.98 and 7.95 mg/100g pulp was noted with the additional lighting by 9W LED bulb from 4.30 pm to 08.30 pm, followed by 7.97 and 7.91 mg/100g pulp by 12W LED bulb from 4.30 pm to 08.30 pm. The reducing and non-reducing sugar contents of dragon fruit did not show any

significant effect under the influence of the additional lighting. However, the total sugar content produced a significant variation under the second flush of this experiment having maximum value of 13.34%.

The intensity of light with respect to the use of additional lighting for off-season production was measured during 7.30pm to 08.00pm at a distance from 30, 60, 90 and 120 cm from the source of light and light intensities varied from 840.72 to 1002.57, 716.98 to 803.22, 596.36 to 705.56 and 184.01 to 301.90 LUX, respectively. The maximum light intensity of 1002.57 LUX was noted with the additional lighting by 12W LED bulb from 6.30 pm to 10.30 pm at distance of 30 cm from the source of light compared to the light intensity measured at 12.00 noon.

Declarations

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All the authors, contributors and funding agency are acknowledged.

Author contribution

Md. Abu Hasan: Conceptualization, supervision, visualization, methodology, writing-review. **Mahabub Alam:** Writing-original draft, investigation, data curation, preparation of final version. **Kiran Rathod:** software, formal analysis, writing-review and language.

Abdul Majid Ansari: Review, finalizing the draft.

All authors have read and agreed to the published version of the manuscript.

Consent to publish

Informed consents i.e. consent to participate and consent to publish were obtained from all the participants involved in this study.

Permission to collect the plants/ plant parts

Not applicable.

Source of the plant used in the study

Plant materials (*Hylocereus costaricensis* cv. Royal Moroccan Red) were sourced from the farmer's field located at Kashtodanga, Haringhata, Nadia, West Bengal, India (22⁰58'33.4"N latitude and 88⁰38'43.3"E) on elevation of 9.75m above mean sea level (MSL).

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Data availability

All the data generated or analyzed during the current study were included in the manuscript. The raw data is available from the corresponding author on reasonable request.

Ethics approval and consent to participate

All methods performed in this study including the collection of plant materials were in compliance with the relevant institutional, national, and international guidelines and legislation.

Statement of compliance

The authors confirm that all the experimental research and field studies on dragon fruit plants, including the collection of plant material, complied with relevant institutional, national, and international guidelines and legislation.

Statement specifying permissions

In this study, we obtained permission from the farmer to conduct investigation on the selected dragon fruit plants in the orchard.

Competing interests

The authors declare no competing interests.

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Plate

Plate 1 is available in the Supplementary Files section.

Figures

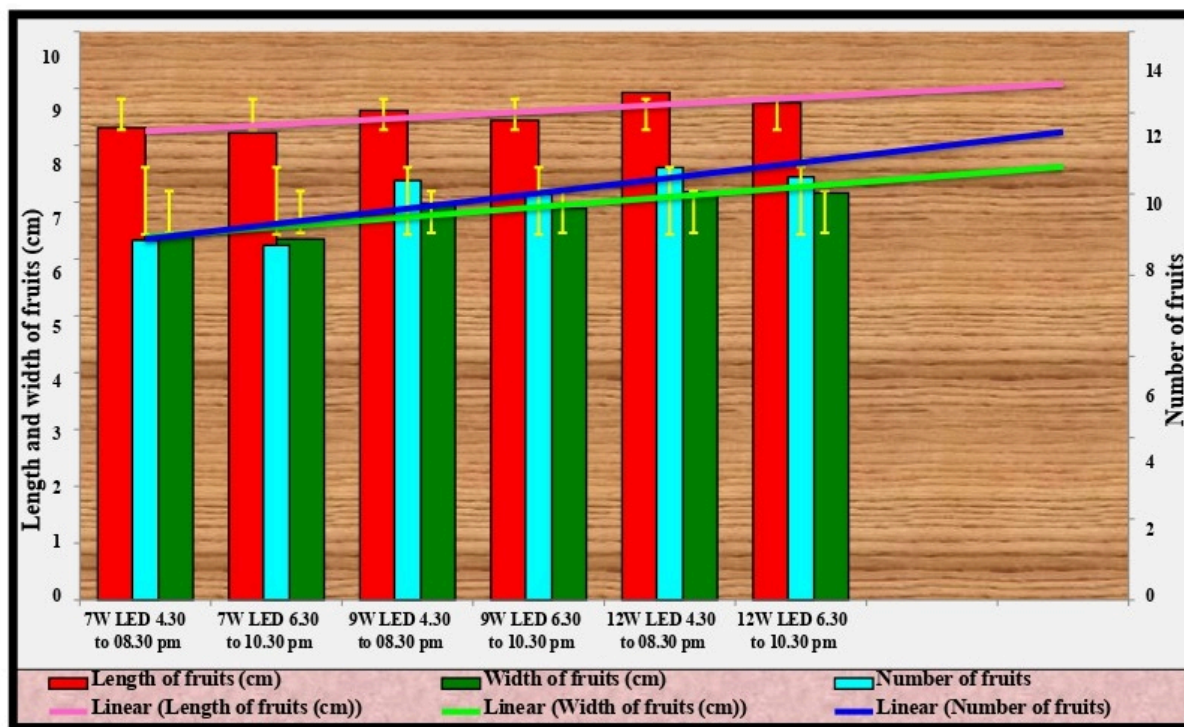


Figure 1

Length and width of fruits and number of fruits per pillar influenced by the additional lighting with varied wattage and duration

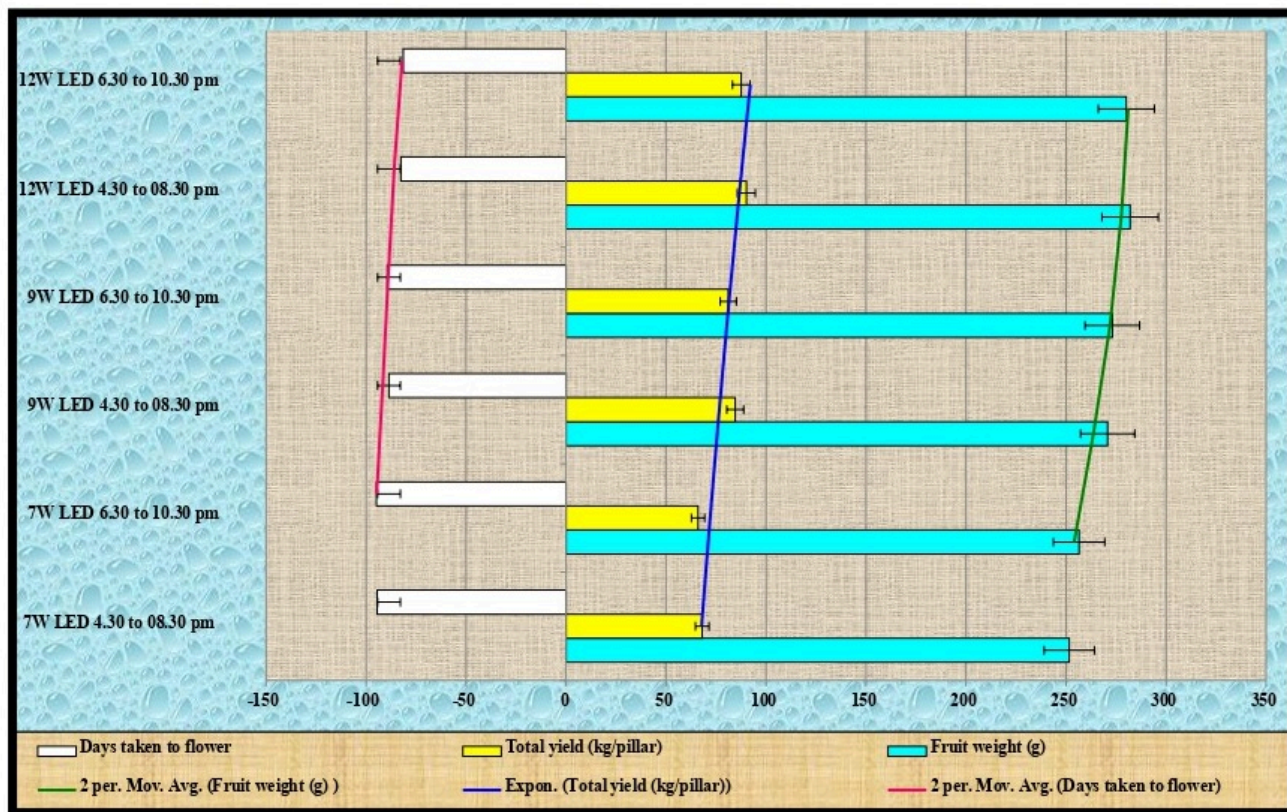


Figure 2

Fruit weight, yield and days taken to flower as influenced by the additional lighting with varied wattage and duration

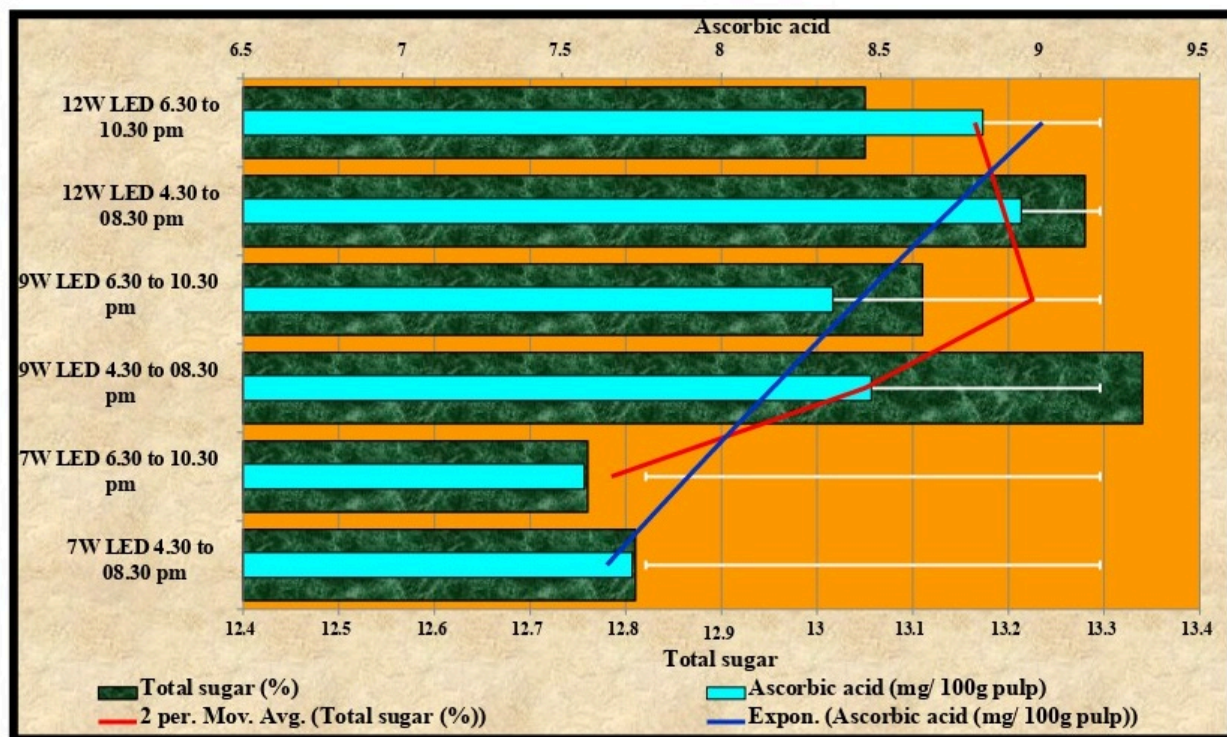


Figure 3

Ascorbic acid and total sugar content influenced by the additional lighting with varied wattage and duration

Supplementary Files

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