International Journal of Frontiers in
Science and Technology Research
Journal homepage: https://frontiersrj.com/journals/ijfstr/
ISSN: 2783-0446 (Online)

(RESEARCH ARTICLE)

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Effects of fruit thinning and some fruit and cladode components on fruit growth and fruit weight of cactus pear *Opuntia ficus-indica* (L.) Mill

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International Journal of Frontiers in Science and Technology Research, 2022, 03(01), 027–037

Publication history: Received on 11 May 2022; revised on 29 June 2022; accepted on 01 Jully 2022

Article DOI: https://doi.org/10.53294/ijfstr.2022.3.1.0041

Abstract

The aim of this paper is to study the effect of fruit thinning and some fruit and cladode components on fruit growth and weight of cactus pear *Opuntia ficus-indica* (L.) Mill. The relationships between the fruit fresh weight and each of the parameters number of fruits per cladode, surface of cladodes and the dry weight of cladodes are studied. Experiments were carried out on an adult plantation of cactus pear in the Agadir area. Fruit thinning treatments used were: T: control without thinning, T1: thinning treatment of 6 fruits per cladode and T2: thinning treatment of 12 fruits per cladode. The size of cladodes used are: the small cladodes (C1), the medium cladodes (C2) and the large cladodes (C3). Obtained results showed that fruit thinning and the surface of cladodes and the interaction of the two factors have a significant effect ($p \leq 0.001$) on fruit growth. On May 10, 2019, the highest rate of growth was obtained with the combination T1/C3 (thinning treatment T1 and large cladodes C3), with 1.6 cm for fruit length and 1 cm for fruit diameter, and the lowest rate of growth was obtained with the combination C1/T (not thinned plants and small cladodes C1) with 0.5 cm for fruit length and 0.3 cm for fruit diameter. The ratio dry weight of cladodes/ number of fruits per cladode has a significant effect ($p \leq 0.001$) on the fruit fresh weight. The increase in the dry weight of cladodes and the reduction in the number of fruits per cladode leads to the production of fruits with large size. Positive linear relationships exist between the fruit fresh weight and the ratio dry weight of cladodes/ number of fruits per cladode, between the fruit fresh weight and the number of fruits per cladode, and between the fruit fresh weight and the surface of cladodes and the coefficient of determination R^2 for each linear relationship is close to 1.

Keywords: Cactus pear; Fruit thinning; Size of cladodes; Fruit growth; Fruit weight

1. Introduction

Fruit weight and size of cactus pear depend on the variety, the duration of the fruit development period, the fruit load of cladodes and the size of cladodes [1, 2, 3, 4, 5, 6]. When the fruit load of cladodes is not reduced by thinning, the fruits are of small size and the loaded cladodes can be damaged [6]. Thinned cladodes produce large size fruits than not thinned cladodes regardless of the number of fruits per cladode [7], and for obtaining large size fruits, Inglese et al. [2] recommended not to leave more than 9 to 12 fruits per cladode. And for determining the number of fruits to be removed by cladode, it is necessary to take into account the size of the cladodes and their load in fruit [8, 9].

Inglese et al. [2] reported that fruit thinning increased the fresh and dry weight of the fruit. The fresh weight of the fruit and pulp increased by 35% and their dry weight increased by 40% when reducing the load of cladodes from 15 to 6 fruits. Fruit dry weight in cladodes bearing 10 to 15 fruits was lower by 16 to 25% than fruit dry weight in cladodes

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bearing 5 fruits [10]. Fruit thinning practice also makes it possible to obtain regular and balanced production over the years, with sufficient yield and good size of the fruits and to avoid the alternation of production [2, 11, 12, 13].

One -year old cladodes are the most fertile cladodes in cactus pear and cladodes exposed to the sun, in particular the peripheral and the terminal cladodes, are the most productive [2, 14, 15]. Several authors also reported that the fertility of cladodes depends on the quantity of dry matter accumulated per unit of surface [16, 17, 18, 19]. Inglese et al. [15] indicated that cactus pear fruits provide only 8-10% of their needs for photosynthetic elements and the rest of their requirements in these elements are provided by the cladodes; and a cladode of 100 cm^2 can only ensure the needs for photosynthetic elements of 5 fruits maximum. The requirements in photosynthetic elements of the fruits of loaded cladodes (10 to 15 fruits) are provided by the lower cladodes.

During the phase of formation of the fruit pulp and the accumulation of carbohydrates, cladodes which are in the lower part of the loaded cladodes with fruits contribute to the increase of the fruit dry weight with 40% in cladodes bearing 10 fruits and 55% in cladodes bearing 15 fruits [10, 20]. When the cladodes are bearing more than 5 fruits, an important part of the assimilated elements is oriented towards neighboring cladodes. This indicates that at a low fruit load of the cladodes, competition between vegetative and floral buds for the carbohydrates is reduced [15]. Reyes Aguero & Valiente Banuet [21] reported that fruit growth in weight and size is faster during the first 20 to 30 days following the anthesis and stops two months after the anthesis. Therefore, when the cladodes are loaded with fruit, fruit growth and size decrease, especially when this load exceeds 6 to 8 fruits [15, 22].

Fruit thinning consists in removing some floral buds and young fruits in order to balance the fruit load of the cladodes with the fruit production of the plant and to minimize the competition between the fruits during their development period [2, 15]. Fruit thinning could be done manually using gloves that protect against spines and glochids and the period which is suitable for the thinning practice extends from two weeks before flowering till three weeks after flowering [2, 8, 23].

Garcia de Cortazar & Nobel [17] and Inglese et al. [24] have shown that the annual allocation of the dry matter of the fruits and cladodes depends on the planting density and Nobel [25] reported that light interception and CO_2 assimilation by cladodes and the productivity of the plant depend on the architecture and the surface of cladodes. A high quantity of biomass is necessary to support fruit growth of a large number of fruits [26] and Nerd & Mizrahi [14] indicated that the fertility of the cladodes is related to the dry matter accumulated by the cladodes.

2. Material and methods

Experiments were carried out on an adult plantation of cactus pear *Opuntia ficus-indica* (L.) Mill. cv 'Aissa' (19 years old) at the experimental station of the Hassan II Institute of Agronomy and Veterinary Medicine in Agadir area, latitude 30 ° 22 'North, longitude 9 ° 39 West and altitude 32 m. Plants have an average length of 2 m and average width of 1.6 m. The planting density is 3 m between rows and 2 m between plants in the rows, i.e. 1666 plants/ha. The soil of the parcel is a moderate alkaline soil with a pH of around 8.4 and electrical conductivity of 0.16 mmhos/cm. It has a sandy-silty texture and an apparent density of 1.4 g/cm^3. It is composed of 4.5% coarse sand, 30.3% fine sand, 28.3% coarse silt, 21.3% fine silt and 15.6% clay. The site of trials is characterized by a semi-arid climate with hot and dry summer and mild and relatively wet winter. The annual rainfall is 207 mm. The mean annual temperature is 22°C, the annual maximum is 31°C and the minimum is 12.5°C.

The aim of this research work was to study the effect of fruit thinning and some components of the fruit and cladode on fruit growth and weight. The effect of fruit thinning on fruit yield and quality has been published in another paper [27]. To meet these objectives we have used two types of fruit thinning: light thinning with 12 fruits per cladode and severe thinning with 6 fruits per cladode. The not thinned plants (control) had an average load of 18 fruits per cladode. Fruit thinning was practiced on three types of one year old cladodes: small cladodes with an area of 509-735 cm^2, medium cladodes with an area of 736-920 cm^2 and large cladodes with an area of more than 920 cm^2. The area of the cladode is determined according to Martin et al. [28]:

$$S = (\frac{W}{2}) \times \frac{L}{2} \times \pi$$

S: cladode area
W: cladode width
L: cladode length
π = 3.14

The experimental design adopted was a randomized block design with 4 blocks. An experimental unit consisted of two plants and studied factors focused on:

- Fruit thinning at the stage of 82% open flowers on one year old cladodes. Fruit thinning was carried out on May 01, 2019 and thinning treatments used were: T1: thinned plants to 6 fruits per cladode; T2: thinned plants to 12 fruits per cladode; and T3: not thinned plants (the control) with 18 fruits per cladode as average number of fruits per cladode.
- Type of thinned cladodes: three types of cladodes are used according to their surface: C1: small cladodes with an area of 509-735 cm^2, C2: medium cladodes with an area of 736-920 cm^2 and C3: large cladodes with an area of more than 920 cm^2.

For each type of cladodes, four cladodes were randomly chosen from the four orientations of the plant (north, south, east, west). Studied parameters focused on:

2.1 Fruit growth: it focused on

- monitoring the evolution of the fruit length and diameter during the fruit development period. It started 10 days after the fruit thinning operation and measurements were carried out every 10 days on a sample of 5 fruits per type of cladode and per experimental unit.
- The rate of growth of the fruit per unit of time: measurements of the rate of growth of the fruit length and diameter every 10 days according to the following formula:

The rate of growth of the fruit length per 10 days (cm) = variation in the growth of the fruit length between dates (i) and (i + n) / n (number of days after the date i)

The rate of growth of the fruit diameter per 10 days (cm) = variation in the growth of the fruit diameter between dates (i) and (i + n) / n (number of days after the date i)

Measurements of the fruit length and diameter are carried out with a caliper.

- The fresh and dry weight of the fruit pulp and peel: they were studied on a sample of 24 mature fruits per type of cladodes and per experimental unit. They were measured with an electronic balance with an accuracy of 0.01 g. The drying of the fruit pulp and peel was carried out in an oven at a temperature of 70 °C during 24 h [29]. Measurement of the fresh weight of the fruit was carried out immediately after harvesting the fruits and measurement of the dry weight of the fruit pulp and peel was carried out at regular time intervals until the dry weight is constant. Measurement of the dry weight is always preceded by cooling the material to be measured after leaving the oven.
- The fresh and dry weight of the cladodes: they were measured with the same electronic balance used in the measurements of the fruits on a sample of four cladodes harvested after the fruit maturation on each type of cladodes and experimental unit. The four cladodes were randomly chosen from the four orientations of the plant at a rate of one cladode per orientation. The harvested cladodes were cleaned with distilled water and measured immediately to determine the fresh weight and then cut into small pieces and dried in the oven at a temperature of 70 °C for 36 hours. Measurements of the dry weight of cladodes were carried out in the same way of the fruits.

2.2 Plant protection of the parcel of trials against the cochineal carmin *Dactylopius opuntia*

Cactus pear plays an important socio-economic role in Morocco where it is considered one of the economy pillars of the arid and semi-arid zones of the country. The development of its cultivation has been the focus of the Morocco Green Plan which is a national agricultural development program for the period 2010-2020. However, in the recent years this culture has experienced an unprecedented infestation of the carmine cochineal which is a specific pest of cactus pear. The Ministry of Agriculture has taken measures to deal with this pest by the implementation of measures to fight this scourge, but the expected result is not achieved and several plantations are infested. The revival of this culture in Morocco and its development through the selection and introduction of resistant varieties to cochineal carmine is part of the priorities of the new agricultural development program '' Green Generation'' for the period 2020- 2030.

Plant protection of the parcel of trials against this pest was carried out with chemical treatment at a frequency of at least once a month during the period of experiments. Five treatments were carried out with an insecticide called ‘Durban 4’

for its trade name. The active material of the insecticide is chlorpyriphos-ethyl with a concentration of 480 g/l; this active matter belongs to the organophosphate organochlorine chemical family. The dose used of the commercial product for the treatment of plants was 150 cc/hl. The product was used for two purposes: preventive treatment for non-infested plants and curative treatment for infested plants to eradicate the pest from the plants. Cactus pear plants are completely wet by the porridge of the product in order to ensure better effectiveness of the product during the treatment.

3. Results and discussion

3.1 Effect of fruit thinning and the type of cladodes on fruit growth

The effects of fruit thinning and the type of cladodes on the growth evolution of the fruit length and diameter are presented in figure 1. This figure shows that fruit length and diameter increase over time in thinned and not thinned plants and on the 3 types of cladodes, and fruit growth is faster from mid-May until mid-June. The difference between the thinning treatments and the type of cladodes is distinguished from May 20, 2019 and statistical analysis of data on this date has shown a significant difference ($p \leq 0.001$) between the fruit thinning treatments, the type of cladodes and the interaction of the two factors. For the three types of cladodes, the evolution of fruit growth of thinned plants was higher than that of not thinned plants and the evolution of fruit growth of thinned plants to 6 fruits per cladode was higher than that of the plants of the other thinning treatments. The T1/C3 combination (thinning treatment T1 and cladodes C3) gave the highest fruit growth evolution and the T/C1 combination (not thinned plants and small cladodes C1) gave the lowest fruit growth evolution.

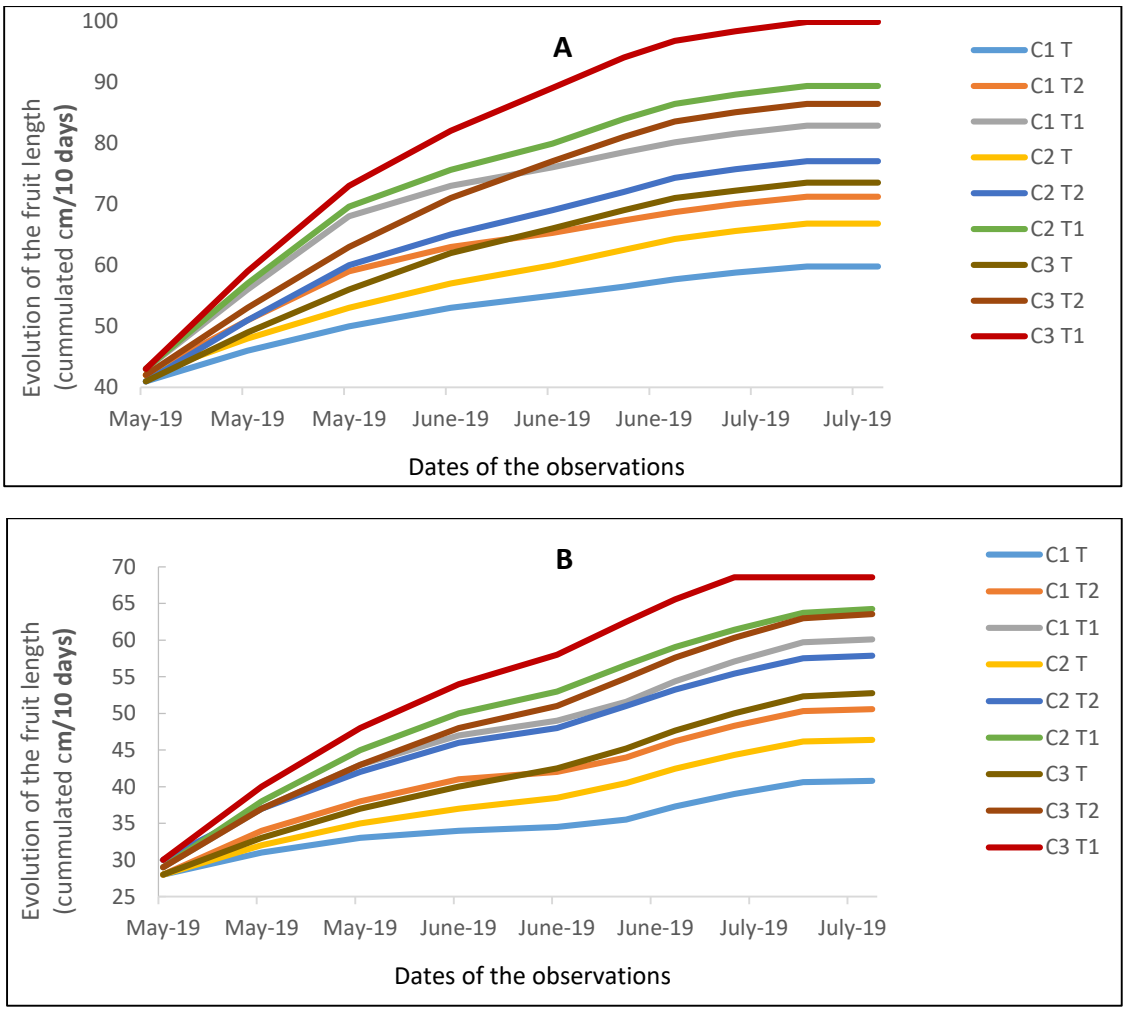

Figure 1 Effect of fruit thinning and the type of cladodes on the evolution of growth of fruit length (A) and diameter (B) of cactus pear *O. ficus-indica* in Agadir area

The effects of fruit thinning and the type of cladodes on the rate of fruit growth of cactus pear per 10 days in thinned and not thinned plants are shown in figure 2. The rate of fruit growth per 10 days is higher in thinned plants than in not thinned plants, and also higher in large cladodes than in small cladodes, and statistical analysis of data has shown a significant difference ($p \leq 0.001$) between the thinning treatments, the type of cladodes and the interaction of the two factors.

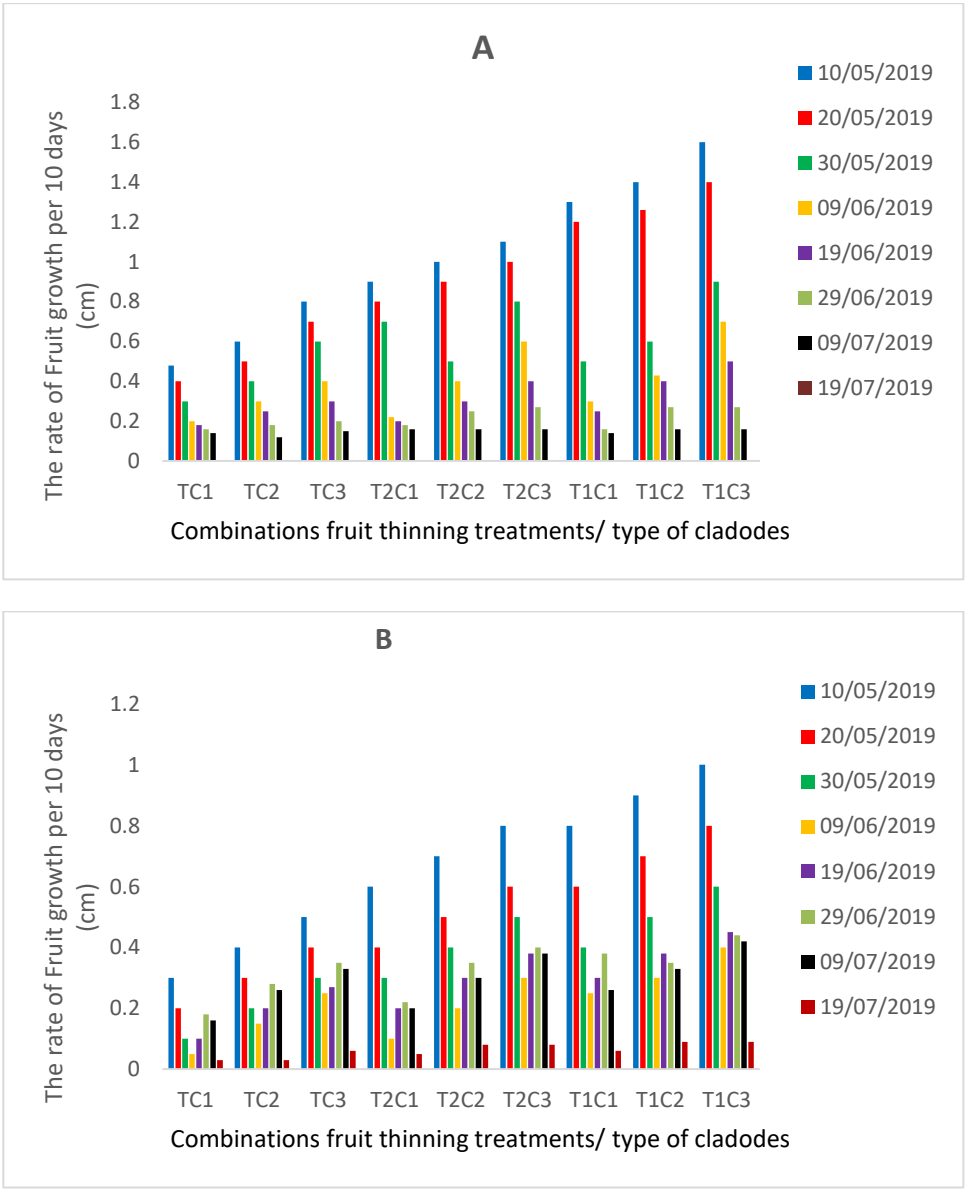

Figure 2 Effect of fruit thinning and the type of cladodes on the rate of growth of fruit length (A) and diameter (B) per 10 days of cactus pear *O. ficus-indica* in Agadir area

The rate of growth of fruit length and diameter per 10 days was higher in thinned plants to 6 fruits per cladode than in thinned plants to 12 fruits per cladode and not thinned plants. In thinned plants to 6 fruits per cladode, the rate of growth of fruit length on 10 May 2019 was 1.6 cm for the cladodes C3, 1.4 cm for the cladodes C2 and 1.3 cm for the cladodes C1. While in thinned plants to 12 fruits per cladode, the rate of growth of fruit length on the same date of May 10, 2019 was 1.1 cm for the cladodes C3, 1 cm for the cladodes C2 and 0, 9 cm for the cladodes C1. In not thinned plants, the rate of growth of fruit length was 0.8 cm for the cladodes C3, 0.6 cm for the cladodes C2 and 0.5 cm for the cladodes C1. The highest rate of growth of fruit length (1.6 cm) was obtained with the combination T1/C3 (figure 2).

In thinned plants to 6 fruits per cladode, the rate of growth of fruit diameter on May 10, 2019 was 1 cm for the cladodes C3, 0.9 cm for the cladodes C2 and 0.8 cm for the cladodes C1, while in thinned plants to 12 fruits per cladode the rate of growth of fruit diameter was only 0.8 cm for the cladodes C3, 0.7 cm for the cladodes C2 and 0.6 cm for the cladodes C1, and in not thinned plants it was only 0.5 cm for the cladodes C3, 0.4 cm for the cladodes C2 and 0.3 cm for the cladodes C1. The best result (1 cm) was obtained with the combination T1/C3 (figure 2).

In thinned plants, the rate of growth of fruit length and diameter was higher during the first month of fruit growth than during the second month of growth. During the first month of growth, the average rate of growth of fruit length was 1.15 cm per 10 days for the cladodes C3, 0.9 cm for the cladodes C2 and 0.8 cm for the cladodes C1; while for the second month of fruit growth, the average rate of growth of fruit length was only 0.3 cm per 10 days for the cladodes C3, 0.25 cm for the cladodes C2 and 0.18 cm for the cladodes C1 (figure 2).

Our results are similar to those of several authors who reported that cactus pear fruits have a higher growth during the first month following the anthesis and stops to grow two months after the anthesis [21]. In our case, the end of fruit growth is also shown in figure 1 where it's visible in around July 10, 2019, two months after May 10, 2019. Other authors indicated that fruit growth decreases when the fruit load of cladodes exceeds 6 to 8 fruits [2, 22].

3.2 Effect of the ratio dry weight of cladodes/ number of fruits per cladode on the fruit fresh weight

The effects of fruit thinning and the type of cladodes on the fruit fresh weight of thinned and not thinned plants are presented in table 1. According to Tukey test for the comparison of the means value, an homogeneous group composed of the combinations T1/C1 and T2/C3 gave an average fruit weight of 138.71 g for the combination T1/C1 and 139.71 g for the combination T2/C3. This result led us to think about establishing a relationship between the dry weight of the cladodes and the number of fruits per cladode in order to explain the origin of this result on the fruit fresh weight which is almost similar in both combinations. Statistical analysis of data have shown that the two combinations T1/C1 and T2/C3 have almost the same ratio dry weight of cladodes/ number of fruits per cladode, with a value of 11.23 g for the combination T1/C1 and 11.17 g for the combination T2/C3 (table 1).

Table 1 Effect of fruit thinning and the type of cladodes on the fruit fresh weight and the ratio dry weight of cladodes/ number of fruits per cladode in cactus pear *O. ficus-indica* in Agadir area

Thinning treatments	**Fruit fresh weight (g)**			**Mean value**
	C1	C2	C3	
T1	138.71 c	162.12 b	180.50 a	160.44
T2	90.93 f	123.58 d	139.71 c	118.07
T	53.22 h	72.06 g	98.31 e	74.53
Mean value	94.29	119.25	139.50	
Thinning treatments	**Ratio dry weight of cladodes/ Number of fruits per cladode (g)**			**Mean value**
T1	11.23 c	18.84 b	30.13 a	20.07
T2	5.84 f	9.12 d	11.17 c	8.71
T	3.56 h	4.8 g	6.82 e	5.06
Mean value	6.88	10.92	16.04	

a, b, c, d, e, f, g, h: Comparison groups according to Tukey test (confidence level of 95%).

Although the dry weight of the cladodes C3 is higher than that of the cladodes C1 (figure 3) the cladodes C1 have a lower number of fruits per cladode (6 fruits per cladode) than the cladodes C3 (12 fruits per cladode). So the increase in the dry weight of cladodes and the reduction in their fruit load leads to the production of fruits with high weight.

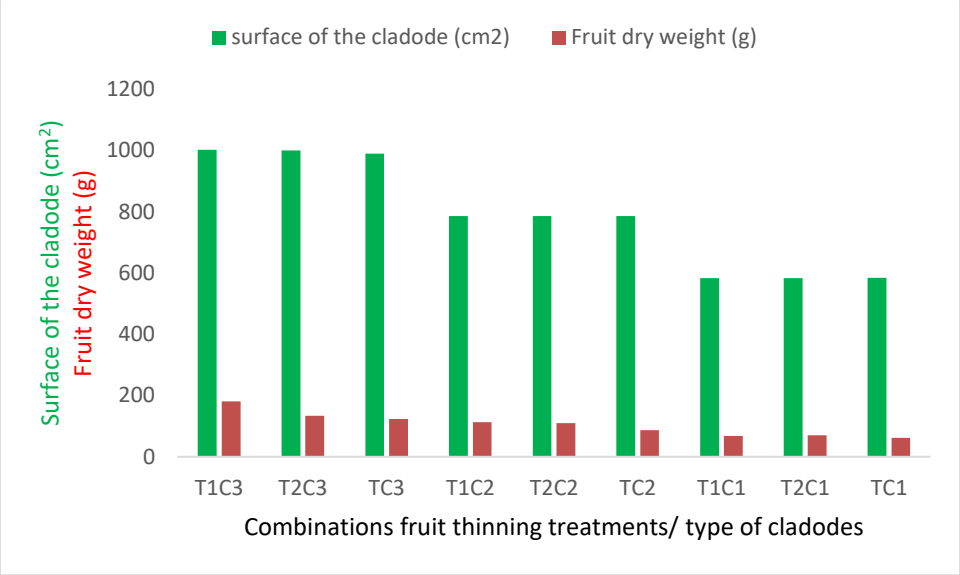

Figure 3 Surface and dry weight of the three types of cladodes C1, C2 and C3 of thinned and not thinned plants of cactus pear *O. ficus-indica* in Agadir area

Several authors reported that fruit weight and size depend on the fruit load and the size of cladodes [1, 2, 3, 4, 5, 6, 7] and when the fruit load of cladodes is not reduced by thinning, the fruit size is small [6]. Other authors indicated that thinned cladodes produce large fruit sizes [2, 7].

Figure 4 shows a significant linear regression relationship between the fruit fresh weight and the ratio dry weight of cladodes/ number of fruits per cladode and the coefficient of determination R^2 is close to 1. Thus, there is a strong positive linear relationship between the fruit fresh weight and the ratio dry weight of cladodes/ number of fruits per cladode.

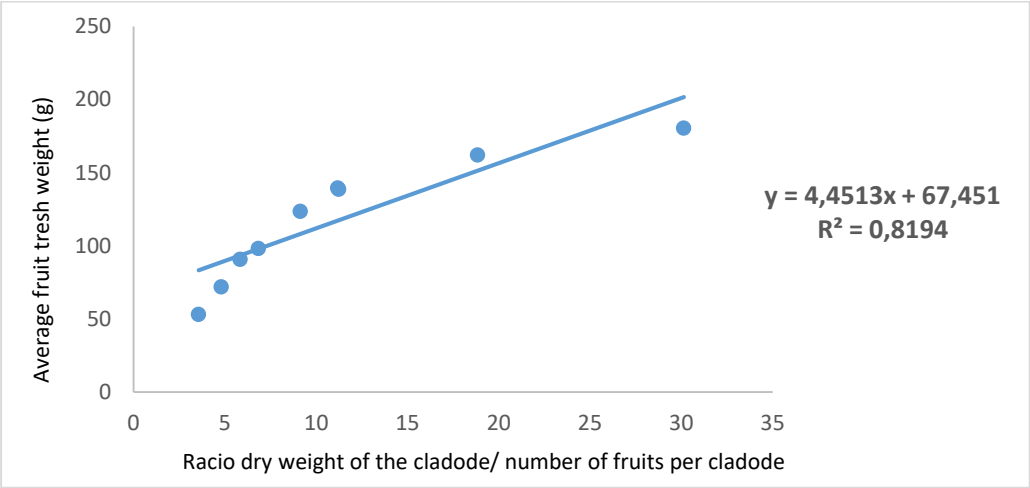

Figure 4 Linear regression relationship between the fruit fresh weight and the ratio dry matter of cladodes/ number of fruits per cladode in cactus pear *O. ficus-indica* in Agadir area

3.3 Effect of the number of fruits per cladode and the surface of cladodes on the fruit fresh weight

Linear regression relationships between the fruit fresh weight and the number of fruits per cladode (A), and between the fruit fresh weight and the surface of cladodes (B) in cactus pear in the Agadir area are presented in figure 5. According to the correlation methods and to figure 5, a significant linear regression relationship ($p \leq 0.001$) exist between the fruit fresh weight and each of the parameters number of fruits per cladode and the surface of cladode. For all these linear regression relationships, the coefficient of determination R^2 is close to 1, what explains that a strong positive linear relationship exists between the fruit fresh weight and each of the parameters number of fruits per

cladode and the surface of cladode. This means that the reduction in the number of fruits per cladode and the increase in the surface of cladodes lead to the increase in the fruit fresh weight.

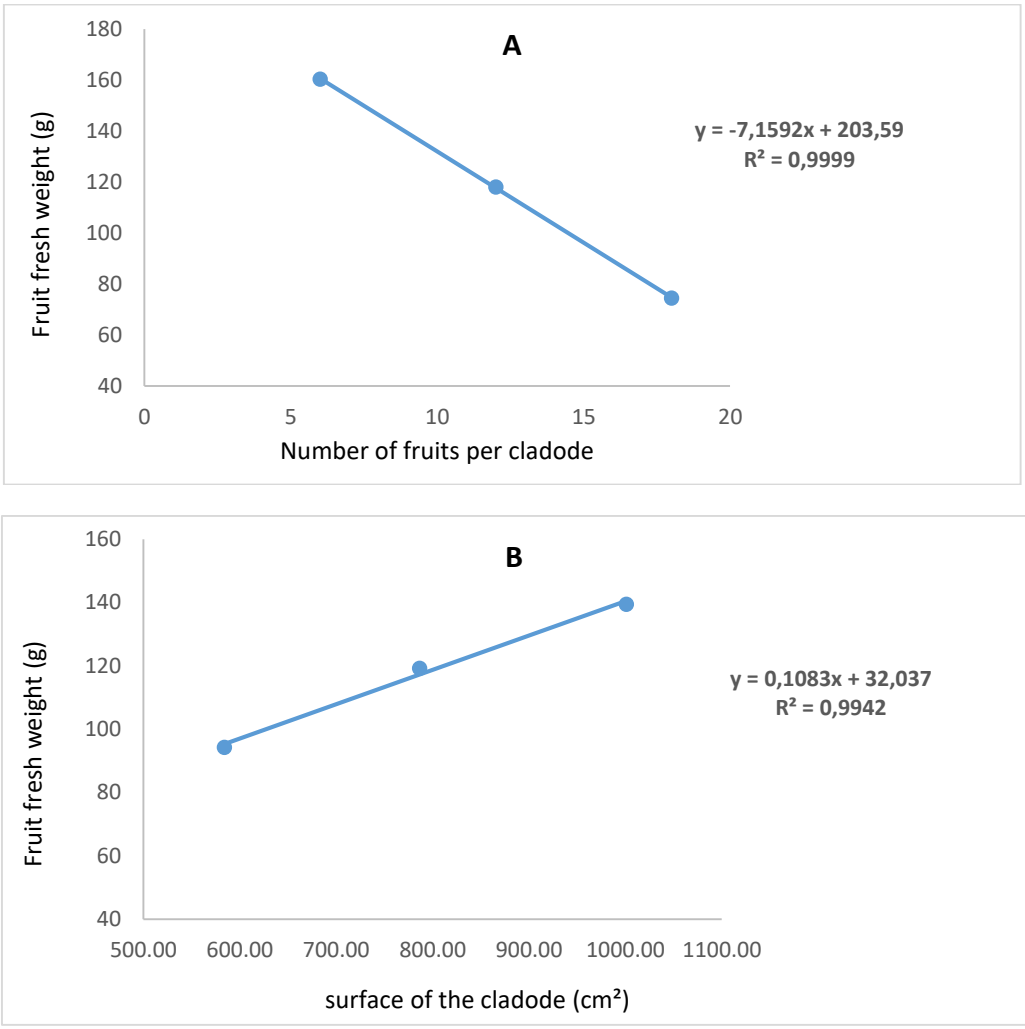

Figure 5 Linear regression relationships and the correlation between the fruit fresh weight and the number of fruits per cladode (A), and between the fruit fresh weight and the surface of cladodes (B) in cactus pear *O. ficus-indica* in Agadir area

Small number of fruits per cladode, in particular with the thinning treatment T1, have a beneficial effect on the three types of cladodes. Indeed, the cladodes C3 gave the best result regarding the fruit fresh weight when they are combined with T1 (low fruit load), with a fruit weight of 180.5 g, what means an increase of 29% compared to the cladodes C3 when combined with T2 (medium fruit load) and 84% compared to cladodes C3 when combined with T (high fruit load: 18 fruits/cladode).

Also, the cladodes C2 gave the best fruit fresh weight (162.12 g) when combined with T1, an increase of 31% compared to the cladodes C2 when combined with T2 and 125% compared to the cladodes C2 when combined with T. This is also the case for the cladodes C1 when combined with T1 with the best fruit fresh weight (139 g) in comparison to other thinning treatments, with an increase of 53 % compared to the cladodes C1 combined with T2 and 161 % compared to the cladodes C1 combined with T.

Our results are similar to those of several authors who reported that the fresh weight of cactus pear fruits increase when the fruit load of cladodes is reduced to 6 fruits per cladode, and fruit weight and size decrease when the fruit load of cladodes exceeds 6 to 8 fruits [2, 10, 22]. Several authors also indicated that the fertility of cladodes depend on the quantity of dry matter accumulated per unit of surface [16, 17, 18, 19]. Other authors reported that fruit weight and size of cactus pear depend on the fruit load and the surface of cladodes [1, 2, 3, 4, 5, 6, 7]. Nobel [25] indicated that the productivity of cactus pear depends on the surface of cladodes, and some other authors have shown that the reduction

in the number of fruits per cladode has increased the dry weight of the fruit [2, 9]. Inglese et al. [10] reported that many photosynthetic elements of cactus pear fruits are provided by the cladodes.

Fruit thinning and the type of cladodes and the interaction of the two factors have a significant effect ($p \leq 0.001$) on the dry weight of the fruit pulp and peel. Thinned plants to 6 fruits per cladode gave the highest dry weight of the fruit pulp with 9.65 g for the three types of cladodes, an increase of 4.98 g compared to T2 thinning treatment and 7.13 g compared to not thinned plants (table 2). The cladodes C3 gave the highest average dry weight of the fruit pulp (7.59 g) for the three thinning treatments, an increase of 1.83 g compared to the cladodes C2 and 4.1 g compared to the cladodes C1. The combination T1/C3 gave the highest dry weight of the fruit pulp with 13.23 g (table 2).

Table 2 Effects of fruit thinning and the type of cladodes on the dry weight of the fruit pulp and peel of cactus pear *O. ficus-indica* in Agadir area

Thinning treatments	**Type of cladodes according to their surface**			**Mean value**
	C1	**C2**	**C3**	
	Fruit pulp dry weight (g)			
T1	5.51c	10.01 b	13.23 a	9.65
T2	3.17 f	4.92 d	5.92 c	4.67
T	1.60 h	2.35 g	3.61 f	2.52
Mean value	3.45	5.76	7.59	
Fruit peel dry weight (g)				**Mean value**
T1	4.68 c	7.99 b	10.23 a	7.63
T2	2.56 f	3.97 d	4.85 c	3.79
T	1.32 h	1.90 g	2.92 e	2.04
Mean value	2.85	4.62	6	

a, b, c, d, e, f, g, h: Comparison groups according to Tukey test (confidence level of 95%).

Thinned plants to 6 fruits per cladode also gave fruits with the highest peel dry weight with an average of 7.6 g for the three types of cladodes, while thinned plants to 12 fruits per cladode and not thinned plants gave an average fruit peel dry weight of 3.79 and 2.04 g respectively. The cladodes C3 also gave the highest fruit peel dry weight of 6 g for the three thinning treatments, while the dry weight of the fruit peel of the cladodes C2 and C1 was only 4.2 g and 2.74 g respectively. The combination T1/C3 gave the highest dry weight of the fruit peel (10. 23 g) (table 2) due to the large size of the fruits of this combination thanks to their highest fruit length and diameter.

Our results are similar to those of several authors who reported that fruit thinning in cactus pear has increased the fruit dry weight with 40% [2, 15]. Other authors indicated that in fruit loaded cladodes, the lower cladodes contribute to the increase of the dry weight of the fruits [10, 20].

4. Conclusion

Fruit thinning and the size of cladodes have a positive effect on the growth of fruit length and diameter and the combination T1/C3 (thinning treatment of 6 fruits per cladode and large cladodes) gave the best result with the highest growth rate. The ratio dry weight of cladodes/ number of fruits per cladode has a significant effect on the fruit fresh weight and a positive linear relationship exists between this ratio and the fruit fresh weight and the coefficient of determination R^2 is close to 1. Positive linear relationships also exist between the fruit fresh weight and the number of fruits per cladode, and between the fruit fresh weight and the surface of cladodes and the coefficient of determination R^2 for each of these linear relationship is close to 1. These linear relationships have shown that the reduction of the number of fruits per cladode and the increase in the surface of cladodes lead to an increase in the fruit fresh weight. Fruit thinning and the surface of cladodes also have a positive effect on the dry weight of the fruit pulp and the peel and the combination T1/C3 of thinned plants to 6 fruits per cladode and large cladodes gave the highest dry weight of the fruit pulp and the peel, while small cladodes in not thinned plants gave the lowest dry weight of the fruit pulp and the peel.

Compliance with ethical standards

Acknowledgments

Many thanks to Hassan II Institute of Agronomy and Veterinary Medicine and its Horticultural Complex in Agadir for their support.

Disclosure of conflict of interest

The authors have no conflicts of interests to declare.

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