Article

Yield and quality of habanero chili in response to driving pruning and nutritional regime

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Abstract

Habanero chili is traditionally produced in soil and in the open sky, so that information on its hydroponic cultivation in greenhouse conditions is scarce, especially with regard to plant management and nutrition. For this reason, in a greenhouse of the experimental field of the Faculty of Agricultural Sciences of the Autonomous University of the State of Morelos, an experiment was carried out in the hydroponic system in order to evaluate the growth, yield and quality of fruits of the habanero chilli in response to conduction pruning (2, 3, 4 stems per plant and without pruning) and the nutritional regime [RN1: universal nutrient solution (Steiner, 1984) supplied throughout the crop cycle; RN2: specific nutrient solution for each phenological stage of habanero chilli (López-Gómez *et al*., 2017)]. There were eight treatments, each with four repetitions, distributed in experimental design completely random. The experimental unit was three plants, each placed in a black polyethylene container with a capacity for 15.14 L, with red tezontle gravel as a substrate. The nutritional solutions were supplied with the drip irrigation system. The results indicated that the treatment 'without pruning-RN2' increased 29.5% and 35.5% dry biomass and number of fruits respectively, compared to the treatment plants 'without pruning-RN1'. The yield was 616.9 g plant in six fruit cuts with the treatment 'without pruning-RN2', 22.8% higher than the one obtained from the treatment '4 stems-RN2'. By effect of the pruning of conduction (2, 3 and 4 stems) the size of the fruits was increased.

Keywords: nutrition, phenological stage, pruning.

Reception date: January 2020
Acceptance date: March 2020

Introduction

Habanero chili (*Capsicum chinense* Jacq.) Is traditionally produced in the Yucatan Peninsula in the open sky (Macías *et al*., 2013); however, with this system the crop is negatively affected by various environmental factors, capable of reducing the product quality, yield and profitability of the crop (Lugo-Jiménez *et al*., 2010), in addition to the characteristics habanero chilli such as the flavor, aroma, pungency, color and shelf life depend on the weather, soil and location of the region (Borges-Gómez *et al*., 2014).

Some recommendations of the nutritional requirements of *Capsicum chinense*, especially when the crop is established in the open, indicate the use of fertilization doses to obtain the best yields (Borges-Gómez *et al*., 2010; Noh-Medina *et al*., 2010). However, the results of field fertilization are not entirely satisfactory since it depends on the type of soil (Borges-Gómez *et al*., 2014).

On the other hand, information on nutrient solutions for greenhouse-grown habanero chilli is scarce. Tucuch-Haas *et al*. (2012) have used the universal nutrient solution (SNU, Steiner, 1984), modifying concentrations of N-NH_4^+: N-NO_3^-, indicate that with the ratio 0% NH_4^+:100% NO_3^- plants of greater height and of stem diameter until the end of the crop cycle and that the ratio 20% NH_4^+:80% NO_3^- provides better results in yield and fruit quality.

However, it has been reported that habanero chili can be nourished according to the phenological stage of the crop. López-Gómez *et al*. (2017) evaluated three concentrations of nitrate in the vegetative stage (10, 12 and 14 meq L^{-1}), each combined with three ratios of nitrate: phosphate: sulfate in the flowering stage (14:1.25:4.75, 12:1:7 and 14:1.25:4.75 meq L^-) and with three nitrate ratios: potassium in the fruiting stage (14:5, 14:5 and 12:7 meq L^{-1}).

The results indicated that due to the nutritional regime of 14 meq L^{-1} of NO_3^- (vegetative stage), 14:1.25:4.75 meq L^{-1} of NO_3^-:$H_2PO_4^-$:SO_4^{2-} (flowering stage) and 14:5 meq L^{-1} de NO_3^-:K^+ (fruiting stage), there was an increase in the number of flowers plant^{-1}, number of fruits plant^{-1} and yield, which was 1054 g plant^{-1} in six fruit cuts, 33% higher than the yield obtained from plants that are fed with SNU during the entire crop cycle, while the accumulation of dry matter was also higher 20.3%. In plants of the *Capsicum* genus, information about the effect of pruning on yield is scarce.

In the chilli (*Capsicum annuum*) different recommendations are indicated (Jaimez *et al*., 2002). According to Cruz *et al*. (2009), in the north of Europe and America the production of chilli in greenhouse conditions is generally based on the 'Dutch' type pruning, which consists of the use of undetermined cycle cultivars that are driven to two stems until reaching 2 to 3 m high, which can increase the yield.

Similarly, Villegas *et al*. (2004) point out that, in the tomato crop of undetermined growth habit, the plants are pruned to two stems when the first inflorescence begins and they are allowed to grow freely until they reach 2 m in height, eliminating the lower leaves and sprout lateral.

However, information on the types of pruning that the crop requires is scarce in habanero chilli. According to Macías *et al*. (2013), in the production of habanero chili in the greenhouse, the plants are pruned to three stems during the whole crop cycle. On the other hand, Jaimez *et al*. (2002), when evaluating the effect of different pruning intensities (at 10 and 15 knots) carried out in habanero chilli plants (*Capsicum chinense*).

On the dynamics of production of flowers and fruits, they observed that an increase in the weight of the fruits can be achieved, obtaining fruits of greater commercial quality, although this can cause decreases between 12-14% in the total yield. The importance of pruning is that sometimes a rapid increase of some organ can compete with the leaves for nutrients that can easily be translocated, which causes foliar senescence and reduction in its photosynthetic capacity. There is also competition between the bodies whose growth and development are simultaneous; such is the case of apex growth with foliar differentiation.

In general terms, pruning can influence the number and quality of flowers and fruits. Such is the case of Ponce *et al*. (2012), who report that, in the cultivation of peel tomatoes, if the number of fruits is reduced, they will be of greater size and quality; however, excessive apical pruning can further promote vegetative growth and suppress flowering.

Based on the above, it is convenient to analyze the effects of the nutrition provided in accordance with the phenological stage of the crop along with the type of conduction pruning on the yield and physical quality of the fruit of habanero chili grown under plastic cover in a system hydroponic.

Materials and methods

The experiment was carried out in a greenhouse of the experimental field of the Faculty of Agricultural Sciences (18° 58’ 51” north latitude, 99° 13’ 57” west longitude, 1 868 masl) at the Autonomous University of the State of Morelos, Cuernavaca, Morelos, Mexico.

Vegetal material

Habanero chili seeds ‘Jaguar’ were used. This variety has plants with a height of 80-90 cm in the open field and up to 1.8 m in protected farming systems with tutoreo, from 70 to 85 days to flowering and from 115 to 120 days to the first harvest. It has one to three flowers per knot, which can give the same amount of fruits.

It presents uniform emerald green fruits in physiological maturity that turn to deep orange at total maturity, reaching a hue value (Hue) of 54. The fruits have a length of 3.8 to 5.5 cm, diameter of 2.5 to 3.0 cm and of 6.5 to 10 g of weight, with yields ranging from 18.3 to 36 t ha^{-1} (Ramírez *et al*., 2012).

Experiment management

To obtain the seedlings, the seeds were sown in 72-cavity black polyethylene trays with a Sunshine3® commercial substrate. In post-transplant, the experimental unit consisted of three black polyethylene bags 25.5 cm in diameter by 30 cm high with a capacity for 15.14 L.

Distributed in a topological arrangement 'tres bolillo', it was used as a red tezontle substrate, considered chemically inert (Ojodeagua *et al*., 2008). In each bag a habanero chili seedling was placed, and for the evaluation of the response variables only the central plant was considered.

The treatments were generated from the factorial combination of the levels of the two study factors: conduction pruning (two, three and four stems per plant and without pruning) and the nutritional regime [RN1: universal nutritional solution (Steiner, 1984) supplied throughout the crop cycle; RN2: specific nutrient solution for each phenological stage of habanero chilli (López-Gómez *et al*., 2017)] (Table 1).

Table 1. Treatments generated by the factorial combination of driving pruning and nutritional regimes for hydroponic production of habanero chilli in the greenhouse.

Treatments	Driving pruning	Nutritional regime
1*	Without pruning	RN1
2	Without pruning	RN2
3	4 stems	RN1
4	4 stems	RN2
5	3 stems	RN1
6	3 stems	RN2
7	2 stems	RN1
8	2 stems	RN2

*= control treatment. RN1= supply of the universal nutrient solution (Steiner, 1984) throughout the crop cycle; RN2= supply of specific nutrient solution for each phenological stage of habanero chilli (López-Gómez *et al*., 2017).

Table 2 describes RN2. In both regimens, the concentrations of salts that contributed micronutrients were kept constant: Fe-EDTA (5 mg L^{-1}); H_3BO_3 (2.88 mg L^{-1}); $MnCl_2$ (1.81 mg L^{-1}); $ZnSO_4$ (0.22 mg L^{-1}); $CuSO_4$ (0.18 mg L^{-1}) and H_2MoO_4 (0.02 mg L^{-1}). From the transplant, the supply of the nutritional regimens began according to what is indicated in Table 1. The plants without pruning with the RN1 was the control treatment. A completely randomized experimental design with four repetitions per treatment was used.

Table 2. Alternative nutritional regime (RN2) for the production of habanero chili in a hydroponic and greenhouse system (López-Gómez *et al*., 2017).

Phenological stage	Chemical composition of nutrient solutions (meq L^{-1})					
	NO_3^-	H_2PO_4	SO_4^{2-}	K^+	Ca^{2+}	Mg^{2+}
Vegetative	14	0.75	5.25	7	9	4
Flowering	14	1.25	4.75	7	9	4
Fructification	14	0.75	5.25	5	10.39	4.61

The vegetative stage lasted from the transplant until 50% of the plants presented the first flower. The flowering stage covered from 50% of the plants presented the first flower until 50% of the plants had the first fruit with a length of 10 ±1 mm. The fruiting stage included from 50% of the plants presented the first fruit with a length of 10 ±1 mm until the end of the harvest.

From the transplant the supply of the nutritive solutions began according to the treatments indicated in Table 1 by means of drip irrigation system. Nine daily irrigations were applied, with a duration of 1 min each irrigation the first days after transplantation and increasing the irrigation time according to the growth of the plant.

To prevent the attack of pests and diseases, chemical products were used. Confidor® (ai Imidacloprid) was applied at a dose of 2 mL L^{-1} to prevent the appearance of possible pests such as whitefly or thrips (*Bemisia* sp., *Trialeurodes* sp., *Frankliniella* spp., *Liryomisa* sp.) and Promyl® (ai Benomilo) 2 g L^{-1}, to prevent diseases such as ashtray (*Oidium* spp.), anthracnose (*Colletotrichum phomoides*), leaf spot (*Septoria lycopersici*) and rot (*Botrytis cinerea*), among others.

Response variables

The height of the plant was measured with a tape measure, from the base of the stem to its longest apex; the diameter of the stem was measured with a vernier of dial type clock and was obtained from the base of the main stem, 2 cm above the substrate; the relative chlorophyll content was measured with SPAD (Minolta) on the fifth and sixth leaf of the apex down each plant; the leaf area was determined with a leaf area integrator (Li-Cor LI3100C).

The mechanical resistance of the stem was obtained with a Shimadzu Ez Test texturometer, taking as a point for measurement the last internode of the main stem of each plant and a 3 mm penetration with a conical strut; the dry matter weight of leaf, stem and root was obtained with an Adam Core CQT5000 digital scale.

To obtain the weight of dry matter, the different organs of the plant were put in brown paper bags and placed in a forced air circulation oven at a temperature of 70 °C until the weight of the dry matter remained constant. To count the number of flowers per plant, the first six bifurcations of each secondary stem were taken as a parameter for all plants and from there the percentage of floral abortion was obtained.

The root volume was measured with a graduated test tube of 2 L, setting the test tube to 1 L, introducing the root and obtaining the record of the volume of the same with the increase in the volume of water inside the test tube. Destructive variables were analyzed at 156 days after transplantation (DDT). The fruits began to be harvested at 103 DDT when they had an intense orange color, making six cuts in a period of 49 days of harvest. In each cut, the fruits of each plant were counted and weighed on an EKS 402SI digital scale.

Subsequently, the total weight was divided by the number of fruits of each plant and its individual average weight was obtained. The yield per plant was obtained with the sum of what was harvested during the six cuts, as well as the number of total fruits. The length of the fruit was measured from the peduncle to its apex with a vernier of clock-like cover as well as the diameter in the middle part of the fruit. The variance analysis was performed with the SAS program (Version 9.0) and the Tukey multiple means comparison test ($p \leq 0.05$) was applied to the data with treatment effect.

Results and discussion

The plants with 2, 3 and 4 stems nourished with RN2 were of greater height and with more resistant stems; however, the development of the plants in most of the evaluated variables was better because of RN2 without pruning. The flower abortion was greater when the plants were not pruned (Table 3).

Table 3. Variables of growth, number of flowers and abortion of flowers in plants of habanero chilli due to the effect of driving pruning and nutritional regime.

Driving pruning	Nutritional regime	AP (cm)	DTP (mm)	AF (cm^2)	RMT (N cm^{-2})	CRC (SPAD)	NFP	ADF (%)
S/pruning	RN1*	104.6 d	19.7 a	12886 a	65.4 ab	66.5 e	127.2 b	61.5 ab
S/pruning	RN2	113.3 cd	21.8 a	15367 a	67.1 ab	75.2 bd	163.2 a	67.5 a
4 stems	RN1	139 ab	16.8 ab	5134 b	67.7 ab	77.5 ac	52 cd	49.7 ac
4 stems	RN2	139 ab	16.8 ab	6306 b	70.1 a	78.9 a	60.7 c	43.9 ac
3 stems	RN1	140 ab	14.6 b	3561 b	63.2 b	78 ab	51.5 cd	30.8 c
3 stems	RN2	149.3 a	14.6 b	4763 b	70.7 a	76.6 ac	48.5 cd	37.7 bc
2 stems	RN1	126.6 bc	13.7 b	3495 b	69.7 a	72.9 d	33.7 d	25.6 c
2 stems	RN2	146.6 a	13.5 b	4095 b	64.2 b	74.2 cd	49 cd	27.5 c
CV		4.94	10.73	20.8	2.86	1.71	7.6	24.13

AP= plant height; DTP= main stem diameter; AF= leaf area; RMT= mechanical resistance of the stem; CRC= relative chlorophyll content; NFP= number of flowers per plant =; ADF= flower abortion =; RN1, supply of the universal nutrient solution (Steiner, 1984) throughout the crop cycle. RN2, supply of specific nutrient solution for each phenological stage of habanero chilli (López-Gómez *et al.*, 2017); *= control treatment; CV= coefficient of variation. Means with the same literal are statistically equal according to the Tukey test ($p \leq 0.05$).

Ramírez-Luna *et al*. (2005) report more than 40% of flower abortion, while Medina-Lara *et al*. (2008) have described up to 85% of flower abortion in this crop. On the other hand, Cruz *et al*. (2012) indicate that high temperatures cause physiological disorders in habanero chili plants (*Capsicum chinense* Jacq.) causing a high abortion of flowers.

Patiño-Torres and Jaimez-Arellano (2016) point out that high temperatures cause an increase in ethylene production, which causes abortion of flowers, also mentioning that high densities of plants per surface induces floral abortion due to a low intensity of light. Similarly, Jaimez *et al*. (2010) attribute to the high temperatures the same effect on paprika (*Capsicum annuum*), but argue that the phenomenon is due to an affectation of the germination process of the pollen and of the pollen tube, in addition to the fact that this process can also be different between cultivars .

On the other hand, when the plants were treated with RN2, but not pruned, the highest values were obtained in terms of root volume and dry matter weight of the plant organs (leaf, stem and root) as well as of total dry matter (Table 4).

Table 4. Root volume and fresh matter weight of habanero chilli plants due to the effect of driving pruning and nutritional regime.

Pruning driving	Regime nutritious	VR (cm^3)	PMSH (g)	PMST (g)	PMSR (g)	PMSTotal (g)
Without pruning	RN1*	413.3 ab	83.3 ab	141.6 b	71.6 ab	298.3 b
Without pruning	RN2	443.3 a	111.6 a	226.6 a	85 a	423.3 a
4 stems	RN1	336.6 bc	55 bc	103.3 bc	66.6 a-c	225 bc
4 stems	RN2	423.3 ab	65 bc	103.3 bc	70 a-c	238.3 bc
3 stems	RN1	270 c	38.3 c	55 c	51.6 cd	145 c
3 stems	RN2	416.6 ab	51.6 c	85 bc	55 b-d	191.6 bc
2 stems	RN1	340 bc	40 c	53.3 c	45 d	138.3 c
2 stems	RN2	286.6 c	41.6 c	60 c	45 d	146.6 c
CV		9.5	18.3	23.45	11.17	16.95

VR= root volume; PMSH= weight of dry matter of leaf; PMST= stem dry matter weight; PMSR= root dry matter weight; PMSTotal= total dry matter weight; RN1= supply of the universal nutrient solution (Steiner, 1984) throughout the crop cycle; RN2= supply of specific nutrient solution for each phenological stage of habanero chilli (López-Gómez *et al.*, 2017); *= control treatment; CV= coefficient of variation. Means with the same literal are statistically equal according to the Tukey test ($p \leq 0.05$).

The total dry matter weight of the plants (leaf + stem + root) nourished with the RN2 and without pruning was 29.5% higher than the weight of the plants that were nourished with RN1 and also did not receive pruning. The percentage of dry matter of the aerial part of the plants nourished with the treatment without pruning/RN2 was 79.9% while the production of dry matter of root corresponded to 20.1%. Due to the same treatment, the highest yield was also obtained (Figure 1).

These results seem to be related to what Peña and Zenner (2015) point out, who state that high percentages of dry matter from the aerial part of *Capsicum annuum* plants indicate a greater number of leaves, source and production of photoassimilates for filling demanding organs. In addition, Peil and Gálvez (2005) show that, under the conditions of cultivation in artificial substrates under greenhouse, with a contribution of water and nutrients close to the optimum, maximum growth of plants with a reduced radical system can be achieved.

In the case of cucumber, this fraction varies between 8 and 15%, in the vegetative growth stage and between 3 and 7% during the reproductive stage. In the case of tomato, the fraction of dry matter destined for the roots varies between 17 and 20% in the vegetative stage; and between 1 and 10% in the reproductive stage. In terms of yield, the highest value was 616.9 g per plant in six fruit cuts due to the treatment without pruning/RN2, exceeding 22.8% of the yield of the plants pruned to four stems and fed with the regime.

On the other hand, Tucuch-Haas *et al*. (2012) reported yield of habanero chili of 302 g/plant in three fruit cuts, providing the Steiner solution with an NH_4^+/NO_3^- ratio of 10/90%, respectively, in combination with a mixture of coconut fiber tezontle substrate (75-25% respectively) and with 10-20 mm tezontle granulometry.

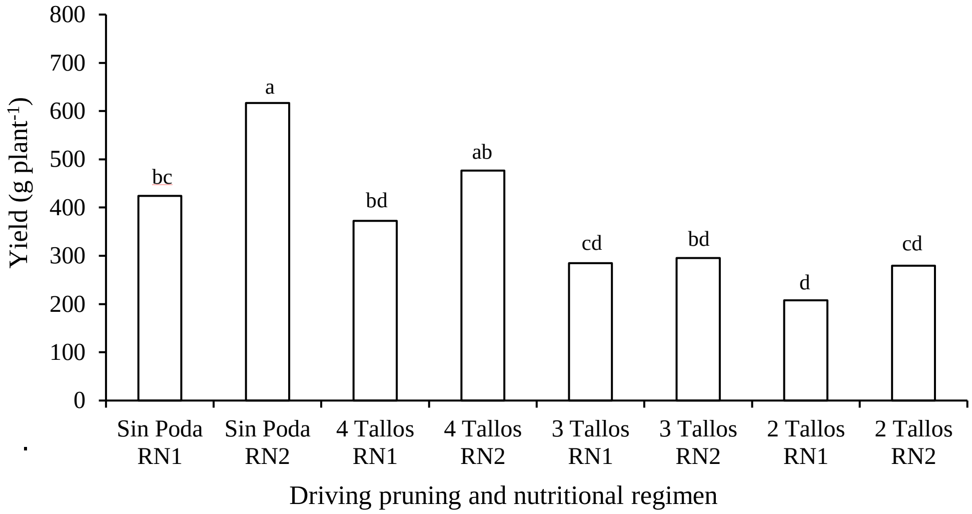

Figure 1. Yield of habanero chilli due to the effect of driving pruning and the nutritional regime. RN1= supply of the universal nutrient solution (Steiner, 1984) throughout the crop cycle. RN2= supply of specific nutrient solution for each phenological stage of habanero chilli (López-Gómez *et al*., 2017). Means with the same literal are statistically equal according to the Tukey test ($p\leq 0.05$).

On the other hand, Alejo-Santiago *et al*. (2015) evaluated four concentrations of NO_3^- in the nutrient solution (5, 10, 15 and 20 meq L^{-1}), based on what was proposed by Steiner and Van Winden (1970). They point out that by increasing the concentration of NO_3^- in the nutritive solution, the production of dry matter in the different organs of the habanero chili plant var. 'Big Brother', increased significantly, observing that with the dose of 20 meq L^{-1}, the dry matter corresponding to leaves, stems and flowers was the highest with respect to the other treatments, while the highest total dry matter production was recorded in the treatment of 15 meq L^{-1}.

This is due to the fact that from 20 meq L^{-1}, the production of dried fruit matter decreases. As a consequence, they also observed that the increase in the concentration of NO_3^- in the nutrient solution, up to a dose of 15 meq L^{-1}, caused an increase in yield. However, from the dose of 20 meq L^{-1}, the yield decreases. This increase in organ dry matter and yield coincides with the results obtained in the present investigation, since the applied RN2 had a higher concentration of nitrate (14 meq L^{-1}) in all the phenological stages of the culture, unlike the solution Steiner (12 meq L^{-1}).

Due to the effect of RN2 without the need to prune the plant, the highest number of fruits per plant was also obtained (Table 6), surpassing with 35.5% more fruits than the plants nourished with RN1 without pruning and up to 61% the amount of fruits produced by plants pruned to 4 stems regardless of the nutrition applied. However, from the plants that were pruned to two main stems nourished with RN2, fruits 47.1% heavier than those obtained from plants without pruning plus RN2 were obtained (Table 6).

As for the length and diameter of the fruit, the highest values were presented in most of the treatments where pruning was performed unlike the plants that were not pruned (Table 6). However, a trend is observed, especially in the diameter of the fruits, that when the plants are pruned and also receive RN2, the diameter is larger.

Table 6. Average weight, size and number of fruits per habanero chilli plant by set effect of driving pruning and nutritional regime.

Driving pruning	Nutritional regime	Average weight per fruit (g)	Fruit length (mm)	Equatorial fruit diameter (mm)	Fruits plant^{-1}
Without pruning	RN1*	1.43 c	19.2 c	17.4 c	179.6 b
Without pruning	RN2	2.04 bc	20.9 bc	17.7 bc	278.6 a
4 stems	RN1	2.57 abc	27.3 ab	21.3 ab	103.6 bc
4 stems	RN2	2.92 ab	30.8 a	22.8 a	111 bc
3 stems	RN1	2.72 abc	28.1 a	21.8 a	61.3 c
3 stems	RN2	2.05 bc	29.9 a	21.9 a	68.6 c
2 stems	RN1	2.59 ac	28.3 a	21.3 ab	59.3 c
2 stems	RN2	3.86 a	29.4 a	23.5 a	60.6 c
CV		20.3	8.54	6.29	12.49

RN1= supply of the universal nutrient solution (Steiner, 1984) throughout the crop cycle. RN2= supply of specific nutrient solution for each phenological stage of habanero chilli (López-Gómez *et al*., 2017); *= control treatment; CV= coefficient of variation. Means with the same literal are statistically equal according to the Tukey test ($p \leq 0.05$).

According to Ramírez-Luna *et al*. (2005) habanero chili plants developed in the greenhouse have a greater number of flowers and fruits, but with small fruit size, in contrast to the production in the field, where larger fruits are obtained, attributing the smaller fruit size, to the low intensity of light in the greenhouse. Condition that favors larger plants, thinner stems, but small fruits.

However, in tomato cultivation (*Lycopersicon esculentum* Mill.), Aldana *et al*. (2007) state that the size of the fruit depends directly on the amount of pollen grains deposited in the stigma; that is, with less pollen, smaller, deformed fruits or with few seeds are produced. This problem is of great importance since increasing the quality parameters can increase the shelf life; therefore, their economic value (Chamu-Baranda *et al*., 2011).

Conclusions

The fruit size of habanero chili is increased by the effect of pruning to 2, 3 and 4 stems together with the nutritional regimens RN1 or RN2 compared to the simultaneous effect of unpruned plants with the same regimes. The number of fruits and yield per plant of habanero chili was favored by the joint effect of not pruning the plant with the nutritional regime two (RN2), although the yield was statistically similar to that of plants driven to four stems with the same regime.

The nutritional regime based on the phenological stage of the crop (RN2) together with the driving pruning does affect the yield and quality of the fruits of habanero chilli.

The yield of habanero chilli was higher when the alternative nutritional regime (RN2) was applied without pruning the plant.

The size and weight of the fruits of habanero chilli is greater when the plants are nourished based on their phenological stage (RN2) and are pruned to 4, 3 and 2 stems; however, with this pruning the total yield decreases from 22.8% to 53.7%, compared to unpruned plants.

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