Article

Phenology and content of capsaicinoids in chili fruits produced under greenhouse conditions

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Abstract

In the present investigation, the development and yield of 10 chili genotypes were evaluated under greenhouse conditions and in the laboratory the content of capsaicinoids in fruits with different stages of maturity was determined, coming from seven municipalities in the state of Puebla. The work was carried out at the Faculty of Agrohydraulic Engineering of the Benemerita Autonomous University of Puebla, San Juan Acateno, Teziutlan, Puebla. The experimental design used was complete random blocks with four repetitions. Phenology variables were recorded and the content of capsaicin and dihydrocapsaicin was determined by high performance liquid chromatography (HPLC). The Cera Amarillo chili had the highest growth cycle (4 360 degrees day, $p \leq 0.05$) among all genotypes, while Cera Rojo registered the maximum weight of the fruit (795 g, $p \leq 0.05$), attributed to its greater diameter and average weight. The highest content of capsaicin, dihydrocapsaicin and total capsaicinoids (2.65, 0.49 and 2.99 mg g^{-1}, respectively) was presented in the state of commercial maturity of the fruits. The Mirasol chilli showed greater stability in the content of capsaicin, dihydrocapsaicin and total capsaicinoids when changing from the state of physiological maturity to commercial.

Keywords: *Capsicum* spp., capsaicin, dihydrocapsaicin, growth, total capsaicinoids, yield.

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Introduction

The chilli *Capsicum* genus is native to South America and is made up of approximately 30 species, of which *C. annuum*, *C. frutescens*, *C. chinense*, *C. baccatum* and *C. pubescens* have been domesticated. It is considered the second most popular vegetable in the world only after tomato (Benson *et al*., 2014) and in many countries, it is essentially valued for its pungent flavor, nutrition, and pigment content in fruits (Tian *et al*., 2014). The *annuum* species is the most economically important, it is widely cultivated in the world (Hernandez, 2018) and presents great variation in its phenology and in the content of bioactive compounds (Martínez-Damián *et al*., 2019).

Phenology comprises the analysis of biological phenomena linked to certain periodic rhythms or phases and the relationship with the environment where they occur (Mundarain *et al*., 2005) and its study is essential to achieve maximum performance in cultivated plants (Morales-Fernández *et al*., 2018), since it allows determining the factors that directly affect crop productivity (Prabhakar *et al*., 2007).

In the cultivation of *Capsicum*, five development phases can be identified, ranging from the transplantation of the plants to the floral initiation, full bloom, fruit tie, physiological maturity and commercial maturity (Soto-Ortiz and Silvertooth, 2008). Other studies consider the time in which the first, second, third and fourth stem bifurcation, flowering, fruiting and color change of the fruit occur (Moreno-Pérez *et al*., 2011).

An efficient way of measuring the duration of the development phases has been with the physiological time calendar method (accumulation of heat units), since this allows the modeling and prediction of the phases to be generated in a normalized way, compared to the variants number of days (Soto-Ortiz *et al*., 2006).

Capsaicinoids are phenolic compounds (Bae *et al*., 2014), amides derived from vanillylamine, that are synthesized and accumulate in the tissue of the placenta (Cázares-Sánchez *et al*., 2005). They are responsible for the hot in the chili fruits, caused by at least one of the 20 identified compounds. Capsaicin [(E)-N(4-hydroxy-3-methoxybenzyl)-8-methyl-6-nonenamide)] and dihydrocapsaicin (its analog 6,7-dihydro) represent more than 90% of the total content of capsaicinoids present in chilies (Vázquez-Flota *et al*., 2007).

From a genetic point of view, the production of capsaicinoids is inherited as a dominant character and is controlled by the Pun1 locus (Blum *et al*., 2002), whereas under pun1 / pun1 recessive conditions, they are not produced by chilies. The degree of hot is also regulated by the environment and the genotype-environment interaction (Gurung *et al*., 2011), which generates a high variation in the level of hot between and within the genotypes (Zewdie and Bosland, 2000).

The variation in hot can be attributed to the high cross-pollination rates (7 to 90%), causing genetic differences in the cultivars (Bozokalfa *et al*., 2009), the presence of high temperatures during the crop cycle (González-Zamora *et al*., 2013), water stress due to drought or flooding (Sung *et al*., 2005) and imbalances in crop fertilization (Monforte-González *et al*., 2010).

Some studies related to the evaluation of the capsaicinoid content in chili fruits have reported significant variations, depending on the genotypes and production environments (Gurung *et al*., 2011). Cazáres-Sánchez *et al*. (2005) reported in Habaneros chilies values of 60 901 Scoville units, while in sweet chilies only 1 519.

Likewise, Borges-Gómez *et al*. (2010) working with the same species obtained 8.4 g kg^{-1} of capsaicin and 4.7 g kg^{-1} of dihydrocapsaicin, in fruits harvested 126 days after transplantation, when studying the accumulation of capsaicinoids during the development of wild chiltepin fruit, found 8.22 mg g^{-1} of capsaicin and 4.24 mg g^{-1} of dihydrocapsaicin in mature fruits, and 4.24 and 0.53 mg g^{-1} in immature fruits.

In Mexico, studies of phenology and capsaicinoid content have focused on chili species with the highest demand; however, in those of lower demand such as the native ones, they are scarce, due to the above, and with the purpose of generating available information for producers and researchers interested in cultivation, the objective of this work was to evaluate the development and yield of 10 genotypes of chilli and determine the content of capsaicinoids in fruits with different stages of maturity.

Materials and methods

Greenhouse genotype evaluation

The research was carried out at the Faculty of Agrohydraulic Engineering of the Benemerita Autonomous University of Puebla (19° 52' north latitude and 97° 22' west longitude, at 1 676 masl), between the months of December (2017) and November (2018), under greenhouse conditions (120 m^2). Ten chili genotypes from seven municipalities in the state of Puebla (Table 1) were selected, selected for their origin, production area, crop cycle and type of species.

Table 1. Characteristics of the chili genotypes studied in the investigation.

Common name	Species	Origin	Ripe fruit[z]		
			Color	Length (cm)	Weight (g)
Chilli type habanero (G1)	*chinense*	Zacapoaxtla	Orange	3.8	93.1
Chilli cera amarillo (G2)	*pubescens*	Tlatlauquitepec	Yellow	4.4	312.5
Chilli loco (G3)	*annuum*	Cholula	Purple	16.4	375
Chilli medium creole type serrano (G4)	*annuum*	Cuetzalan	Red	3.5	15.8
Chilli of arbol (G5)	*annuum*	Tetela de Ocampo	Orange	7.8	41.9
Chilli cera rojo (G6)	*pubescens*	Tlatlauquitepec	Red	4.5	395
Chilli creole type jalapeño (G7)	*annuum*	Hueyapan	Red	5.5	106.6
Chiltepin (G8)	*annuum*	Cuetzalan	Red	1	5.2
Chilli Mirasol (G9)	*annuum*	Hueyapan	Red	4.9	14.4
Chilli creole type serrano (G10)	*annuum*	Teziutlán	Red	12.4	136.7

[z]= average values of 10 fruits; the length of the fruits was made from the basal to the apical part.

The seeds of the 10 chili genotypes were extracted from the mature fruits and dried in the shade. In the first week of December 2017, sowing was carried out in 200-cavity polystyrene germination trays with the mixture of peat, perlite and forest soil substrates in relation (1:1:1 v/v/v), depositing two seeds per cavity to produce a total of 20 plants of each species, under greenhouse conditions.

Once the seedlings of the different chili genotypes had 6 to 8 leaves, they were transplanted into 600 caliber polyethylene bags (40 x 40 cm), using the same ratio of the substrate mixture as in the germination trays. The bags were placed 50 and 20 cm apart between rows and rows, respectively.

Fertilization was performed 20 days after transplantation with the formula 200-75-100-20-10 of N, P, K, Ca and Mg and 4.6 g of the mixture was applied to each bag. Irrigation was applied according to the water needs of the crop through a drip irrigation system with an average cost of 2.49 liters per plant per day, throughout the growth cycle of the genotypes.

From the transplant and until the commercial maturity of the 10 chili genotypes, the maximum and minimum air temperatures (ºC) were recorded with a Taylor® model 5 458 mercury column thermometer, with these data the average temperature was obtained.

A randomized complete block experimental design with four replications was used and the experimental unit consisted of a bag with a chili plant. Postharvest capsaicinoid analysis was under the same experimental design, for which the factorial arrangement was used with the genotype factors with 10 levels and maturity stages with two levels.

From the transplant in the bags, the number of days (D) and degrees day (G) accumulated until the beginning of each phenological stage of the culture was determined with the classical residual method, which consists of adding the difference of the daily average temperature and the base temperature, which in this case used a value of 5 ºC (Pérez and Castro, 2008). The floral initiation stage (IF) was determined at the time when the first flower bud was presented in all genotypes, the fruit tie (AF) when wilt, drying and detachment of the flower corolla was observed, remaining only the gyneceus developing.

Physiological maturity (MF) occurred when the maximum accumulation of dry matter of the first fruit was presented and which was visually identified by the characteristic green color and maximum growth in length and thickness, while commercial maturity (MC) was identified at the time the first fruit showed a change in coloration other than green, but without losing turgidity.

The vegetative period (PV) was considered as the time elapsed from the transplantation of the genotypes in the bags to the appearance of the first flower bud, a state characterized by the growth of the aerial part and the establishment of the root system. The reproductive period (RP) considered the interval between the appearance of the first flower bud and the commercial maturity of the first fruit, and that was when fruit formation and growth occurred.

At commercial maturity, the length of the fruit (LF, cm) was determined, which was considered from the basal part to the apical part. The equatorial diameter of the fruit (DF, cm) was made in the middle part of the fruit, between the basal and apical part. Fruit weight (PF, g) was performed on 20 fruits from each experimental unit. The average fruit weight (PPF, g) was obtained by dividing the weight of fruits by the number of fruits harvested.

Laboratory evaluation of capsaicinoids

Extraction

The capsaicin and dihydrocapsaicin content of the 10 chili genotypes was determined by high-performance liquid chromatography (HPLC), in whole fruits, harvested in the stages of physiological maturity and commercial maturity, according to the methodology proposed by Cruz-Pérez *et al*. (2007). 5 ±0.5 g of freshly ground fruits and 10 mL of HPLC grade acetonitrile were taken from Eppendorf tubes. The tubes were in a water bath for 5 h at 60 °C, stirring the content every hour. From the supernatant, 2 mL were filtered with a 25 mm diameter acrodisk and 0.45 µm pore (Millipore Co.) and placed in 2 mL vials.

Analysis

A high resolution liquid chromatography equipment, Agilent Technologies, 1260 infinity, was used, consisting of an auto sampler, quaternary pump, degasser, refractive index detector and column oven. A Hypersil ODS® column (25 cm x 4.6 mm, 5 µm) was used, according to Collins *et al*. (1995). As a mobile phase, the gradient consisting of acetonitrile: water, HPLC grade in 45:55 ratio was used. The flow rate was 1.5 mL min^{-1}, the sample volume injected was 20 µL and the run time was 20 min. The column temperature was maintained at 26 °C.

Capsaicin and dihydrocapsaicin standards (Sigma, MN) were prepared in acetonitrile at a concentration of 1 mg mL^{-1} each, with these, the chromatograph calibration curve was elaborated. The content of capsaicin and dihydrocapsaicin (mg) was calculated from the official method 995.03 of the AOAC (1995), where 0.001 mg of capsaicinoids g^{-1} is equivalent to 15 Scoville Units of hot. Total capsaicinoids resulted from the sum of the content of capsaicin and dihydrocapsaicin. The data obtained were statistically analyzed through analysis of variance and Tukey's mean comparison tests ($p\leq 0.05$) using the Statistical Analysis System package (SAS, 2004).

Results and discussion

Culture phenology

The knowledge of the phenology allows to identify the critical periods of development that affect the crop yield. In Table 2, it was observed that the Cera Amarillo chili (G2) required a greater number of days and degrees day ($p\leq 0.05$) in the stages of floral initiation (DIF and GIF), fruit tie (DAF and GAF) and maturity. Physiological (DMF and GMF) compared to the creole chili type Jalapeño (G7).

In general, the G7, Chiltepin (G8) and Mirasol (G9) chilies required 20 and 23% fewer days and degrees day in the DMF and GMF stage than G2, so they were characterized as the earliest of all the studied materials, which indicates the great differences in the phenological behavior exhibited by the genotypes due to their genetic origin (Soto-Ortiz and Silvertooth, 2008; Moreno-Pérez *et al*., 2011) and development environment (Mundarain *et al*., 2005; Gurung *et al*., 2011).

Table 2. Accumulated days and degrees day in the phenological stages of 10 chili genotypes (*Capsicum* spp.), grown under greenhouse conditions.

Genotypes	DIF	GIF	DAF	GAF	DMF	GMF
G1	175.5 a[z]	2 927 a	189.7 a	3 230.3 a	214 ab	3 712 ab
G2	175.2 a	2 921.8 a	189 a	3 215.5 a	223.7 a	3 901 a
G3	142 bcd	2 237.8 bcd	150.5 cd	2 401.5 bc	185 bc	3 133.5 bc
G4	140.2 bcd	2 205.5 bcd	154.2 bcd	2 471.5 bc	185.7 bc	3 150.8 bc
G5	155.7 abc	2 503.5 abc	169.2 abc	2 790 ab	201 abc	3 455.8 abc
G6	161 ab	2 615.5 ab	177 ab	2 957.8 a	213.5 ab	3 702 ab
G7	128.7 d	1 997.5 d	136.7 d	2 142 c	176.2 c	2 942 c
G8	138 cd	2 162.5 bcd	150 cd	2 386.8 bc	179.3 c	3 012.4 c
G9	132.5 d	2 069.3 cd	142.2 d	2 241.5 c	181 c	3 045 c
G10	136.3 cd	2 136.8 cd	148 cd	2 355.5 bc	184 bc	3 112.5 bc
DMSH	22.7	454.4	23.9	486.2	31.1	633.28

[z]= values with the same letter within columns are the same according to Tukey's test at $p \leq 0.05$. DMSH= honest minimal significant difference; DIF and GIF= days and degrees day to flower initiation; DAF and GAF= days and degrees day to fruit mooring; DMF and GMF= days and degrees day at physiological maturity; G1= chilli type habanero; G2= chilli cera amarillo; G3= chilli loco; G4= chilli medium creole type serrano; G5= chilli of arbol; G6= chilli cera rojo; G7= chilli creole type jalapeño; G8= chiltepin; G9= chilli mirasol; G10= chilli creole type serrano.

The commercial maturity stage and the duration of the vegetative and reproductive periods were differential (Table 3). The G7, G8 and G9 genotypes required 19 and 20% less time (days and degrees day) for commercial maturity (DMC and GMC) compared to G2. The G7 and G9 genotypes had the least number of days and degree days ($p \leq 0.05$) during the vegetative period (DPV and GPV) compared to the chili Type Habanero G1 and G2; that is, they had a difference of 45 days and 891 degrees day. The reproductive period required 28 and 18% fewer days (DPR) and degrees days (GPR) in the G1 genotype than in the chili Cera Rojo (G6).

These results generally indicate that the number of DPV and GPV was greater than the number of DPR and GPR in all genotypes, a situation that can occur when competition for space is generated, causing a delay in flowering and fruiting (Lujan and Chavez, 2003) as occurred in the present investigation, although the type of species (Montes *et al*., 2004), the growth habit and the number of cuts can affect the length of the reproductive period of the genotypes (Vázquez-Vázquez *et al*., 2011).

Table 3. Accumulated days and degrees day in the commercial maturity stage, vegetative and reproductive periods of 10 chili genotypes (*Capsicum* spp.), grown under greenhouse conditions.

Genotypes	DMC	GMC	DPV	GPV	DPR	GPR
G1	234.2 ab[z]	4026.5 abc	175.5 a	2927 a	58.7 b	1099 b
G2	249.6 a	4360.3 a	175.2 a	2921.8 a	79 ab	1538 ab
G3	211 bc	3653.3 bcd	142 bcd	2237.8 bcd	76.3 ab	1555 a
G4	211.7 bc	3668.3 bcd	140.2 bcd	2205.5 bcd	71.5 ab	1462.8 ab
G5	218.5 bc	3799.5 bcd	155.7 abc	2503.5 abc	67.6 ab	1388.7 ab
G6	237.5 ab	4144.5 ab	161 ab	2615.5 ab	81.5 a	1639 a
G7	203.5 c	3508.8 cd	128.7 d	1997.5 d	71 ab	1441.3 ab
G8	201 c	3462 d	138 cd	2162.5 bcd	63 ab	1299.5 ab
G9	202.2 c	3483.5 cd	132.5 d	2069.3 cd	73 ab	1427.7 ab
G10	213.3 bc	3699.3 bcd	136.3 cd	2136.8 cd	77 ab	1562.8 a
DMSH	27.6	552.5	22.7	454.4	22.55	452.8

[z]= values with the same letter within columns are the same according to Tukey's test at $p \leq 0.05$. DMSH= honest minimal significant difference; DMC and GMC= days and degrees day to commercial maturity; DPV and GPV= days and degrees day during the vegetative period; DPR and GPR = days and degrees day during the reproductive period; G1= chilli type habanero; G2= chilli cera amarillo; G3= chilli loco; G4= chilli medium creole type serrano; G5= chilli of arbol; G6= chilli cera rojo; G7= chilli creole type jalapeño; G8= chiltepin; G9= chilli mirasol; G10= chilli creole type serrano.

Yield and its components

The performance of the genotypes expressed in fruit weight (PF) was varied (Table 4). The G6 genotype had the highest yield per plant ($p \leq 0.05$) among all the materials studied, that is, it surpassed G2 and the chilli Loco (G3) 18%, who were the closest in this character. This parameter was associated with the largest diameter of the fruit (DF) since, together with the average weight of the fruit (PPF), they were the main components that contributed to the yield of chili, which is consistent with what was reported by Moreno-Pérez *et al.* (2011), although according to López-Gomez *et al.* (2020) in addition to these characters, the number of fruits per plant also influences the final weight. The length of the fruit (LF) in the G3 genotype was 21% greater than in the red chilli type Serrano (G10).

Table 4. Yield characters in 10 chili genotypes (*Capsicum* spp.), grown under greenhouse conditions.

Genotypes	PF (g)	LF (cm)	DF (cm)	PPF (g)
G1	137.27de[z]	3.5 de	3.13 b	6.86 de
G2	631.6b	4.43 de	4.73 a	31.56 b
G3	673 b	14.6 a	3.17 b	33.65 b
G4	28.3 f	3.15 e	1.07 d	1.42 f

Genotypes	PF (g)	LF (cm)	DF (cm)	PPF (g)
G5	65.95 ef	7.57 c	0.97 de	3.3 ef
G6	795 a	4.45 de	4.6 a	39.75 a
G7	185.65 d	5.3 d	2.05 c	9.3 d
G8	10.97 f	1.03 f	0.63 e	0.56 f
G9	30.55 f	4.02 de	0.77 de	1.55 f
G10	276.2 c	11.5 b	1.8 c	13.8c
DMSH	71.47	1.87	0.4	3.75

[z]= values with the same letter within columns are the same according to Tukey's test at $p \leq 0.05$. DMSH= honest minimal difference; PF= fruit weight; LF= length of the fruit; DF= diameter of the fruit; PPF= average weight of the fruit; G1= chilli type habanero; G2= chilli cera amarillo; G3= chilli loco; G4= chilli medium creole type serrano; G5= chilli of arbol; G6= chilli cera rojo; G7= chilli creole type jalapeño; G8= chiltepin; G9= chilli mirasol; G10= chilli creole type serrano.

Capsaicinoid content

The capsaicinoids responsible for hot in chili fruits (González-Zamora *et al*., 2013), showed significant variation between genotypes and stages of maturity. The content of capsaicin (CAP), dihydrocapsaicin (DIH) and total capsaicinoids (CTOT) in chili fruits fluctuated from 0.03 to 1.95 mg g^{-1} in the state of physiological maturity and from 0.04 to 2.99 mg g^{-1} at maturity commercial (Table 5), which agrees with that reported by Montoya-Ballesteros *et al*. (2010) indicating that in some chili species, the highest concentrations of capsaicinoids occur in mature fruits, a situation that reflects the differential behavior of the genotypes in the accumulation of capsaicinoids during fruit development (Rahman and Inden, 2012).

Table 5. Capsaicinoid content in fruits of 10 chili genotypes (*Capsicum* spp.), grown under greenhouse conditions.

Genotypes	Physiological maturity (mg g^{-1} pf)			Commercial maturity (mg g^{-1} pf)		
	CAP	DIH	CTOT	CAP	DIH	CTOT
G1	1.7 a[z]	0.25 b	1.95 a	2.65 a	0.34 b	2.99 a
G2	0.36 b	0.23 bc	0.59 b	0.09 d	0.16 cd	0.25 d
G3	0.1 b	0.05 e	0.15 b	0.1 d	0.08 de	0.18 d
G4	0.15 b	0.03 e	0.18 b	0.33 cd	0.04 e	0.37 cd
G5	0.5 b	0.07 de	0.57 b	0.38 cd	0.06 de	0.44 cd
G6	0.42 b	0.21 bc	0.63 b	0.09 d	0.07 de	0.16 d
G7	0.29 b	0.09 de	0.38 b	0.17 cd	0.08 de	0.25 d
G8	0.41 b	0.15 cd	0.56 b	0.8 bc	0.25 bc	1 .06 bc
G9	1.22 a	0.48 a	1.7 a	1.18 b	0.49 a	1.67 b
G10	0.07 b	0.03 e	0.1 b	0.11 d	0.05 de	0.16 d
DMSH	0.53	0.08	0.62	0.63	0.11	0.74

[z]= values with the same letter within columns are the same according to Tukey's test at $p \leq 0.05$. DMSH= honest minimal difference; PF= fruit weight; CAP= capsaicin; DHI= dihydrocapsaicin; CTOT= total capsaicinoids; G1= chilli type habanero; G2= chilli cera amarillo; G3= chilli loco; G4= chilli medium creole type serrano; G5= chilli of arbol; G6= chilli cera rojo; G7= chilli creole type jalapeño; G8= chiltepin; G9= chilli mirasol; G10= chilli creole type serrano.

At physiological maturity, the G1 and G9 genotypes had 81 and 79% higher CAP and CTOT content than the rest of the materials. Likewise, it was the G9 that registered the highest content of DIH (Table 5). At commercial maturity, it was observed that the G1 genotype was the one that presented the highest values of CAP and CTOT ($p \leq 0.05$), since, on average, it had 82 and 83% greater content in these studied characters than in the other materials.

These results indicate that the degree of hot between the different materials was varied, since there were differences of 2.83 mg g^{-1} of CTOT between the genotypes with the highest and lowest pungency in commercial maturity. In this regard, Gurung *et al*. (2011) indicate that the genetics of the species still, over the environmental conditions, is the one that assumes the main role in the synthesis and accumulation of capsaicinoids, in addition, other studies have reported that some materials of the *chinense* species tend to be more pungent that *annuum* (Sanatombi and Sharma, 2008), as occurred in the present investigation, in which Habanero (G1) was generally the most hot among all the species studied.

The analysis of the 10 genotypes in the two stages of maturity of the chili fruits indicated that the content of CAP and CTOT in G1 and G8, exhibited significantly greater variation when changing from one condition of maturity to another (Table 6). A similar behavior was observed in DIH for G6 and G8, which indicates the degree of response that some materials show when evaluated under different conditions (Gurung *et al*., 2011), although also, the accumulation of capsaicinoids depends on the age and stage of fruit development (Estrada *et al*., 1998), as observed in this work, where the content of CAP and CTOT in the G1 genotype was 36 and 35% higher during commercial maturity than in the physiological one.

Table 6. Capsaicinoid content in fruits of 10 chili genotypes (*Capsicum* spp.) By effect of genotype and state of maturity, under greenhouse conditions.

Capsaicinoids (mg g^{-1} PF)				
Genotypes	Maturity stage	CAP	DIH	CTOT
G1	MF	1.7 b[z]	0.25 bc	1.95 b
G1	MC	2.65 a	0.345 b	2.995 a
G2	MF	0.365 de	0.235 cd	0.595 de
G2	MC	0.095 e	0.165 cde	0.255 e
G3	MF	0.106 e	0.055 fg	0.155 e
G3	MC	0.105 e	0.085 efg	0.19 e
G4	MF	0.15 e	0.035 g	0.185 e
G4	MC	0.335 de	0.045 g	0.375 e
G5	MF	0.505 de	0.07 efg	0.575 de
G5	MC	0.385 de	0.065 fg	0.445 de
G6	MF	0.425 de	0.215 cd	0.635 de
G6	MC	0.09 e	0.07 efg	0.16 e
G7	MF	0.295 de	0.09 efg	0.385 e
G7	MC	0.175 e	0.085 efg	0.255 e

Capsaicinoids (mg g^{-1} PF)				
Genotypes	Maturity stage	CAP	DIH	CTOT
G8	MF	0.415 de	0.15 def	0.565 de
G8	MC	0.805 cd	0.255 bc	1.06 cd
G9	MF	1.22 bc	0.48 a	1.7 bc
G9	MC	1.185 bc	0.495 a	1.675 bc
G10	MF	0.07 e	0.03 g	0.105 e
G10	MC	0.115 e	0.05 g	0.165 e
DMSH		0.571	0.099	0.669

[z]= values with the same letter within columns are the same according to Tukey's test at $p \leq 0.05$. DMSH= honest minimal difference; PF= fresh weight; CAP= capsaicin; DIH= dihydrocapsaicin; CTOT= total capsaicinoids; MF= physiological maturity; MC= commercial maturity; G1= chilli type habanero; G2= chilli cera amarillo; G3= chilli loco; G4= chilli medium creole type serrano; G5= chilli of arbol; G6= chilli cera rojo; G7= chilli creole type jalapeño; G8= chiltepin; G9= chilli mirasol; G10= chilli creole type serrano.

The G9 genotype was the one that presented the smallest variation ($p \leq 0.05$) in the content of CAP, DIH and CTOT when changing from physiological maturity to commercial maturity, a characteristic that could be of importance in hot genetic improvement programs, since that the objective of the breeder is to develop uniform and stable genotypes with specific levels of hot (Zewdie and Bosland, 2000). Two conditions indicate that G9 is a promising material for a breeding program, its minimal variation in capsaicinoid content and its highest content after G1.

The G2 and G6 genotypes had an average 76% higher CAP content in physiological maturity than in commercial maturity, a result that may have been due to the competition that exists in the synthesis of metabolites in the same metabolic pathway, including capsaicin, which led to a decrease during fruit maturity (Gurung *et al*., 2011).

Other studies indicate that the greatest accumulation of capsaicinoids in some chili species may occur before commercial maturity (Cruz-Pérez *et al*., 2007), although the variation in the content of capsaicinoids in the different stages of development of the fruit is attributed to the genotypic expression of the species (Rahman and Inden, 2012).

Conclusions

The longer duration of the biological cycle in the chili Cera Amarillo was not reflected in a greater weight of the fruit. The yield components that contributed the most in the chilli Cera Rojo, the one with the highest fruit weight, were the diameter and average weight of the fruit. The content of capsaicin and total capsaicinoids varied according to the state of maturity of the fruit.

The highest concentrations were found in the Habanero and Mirasol type genotypes at physiological maturity and in Habanero at commercial maturity. In general, the highest concentrations of capsaicin, dihydrocapsaicin and total capsaicinoids, occurred in the state of commercial maturity of the fruits.

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