POSTHARVEST CONSERVATION OF STRUCTURAL LONG SHELF LIFE TOMATO FRUITS AND WITH THE MUTANT RIN PRODUCED, IN EDAPHOCLIMATIC CONDITIONS OF THE SOUTHERN STATE OF TOCANTINS

Conservação pós-colheita de frutos de tomateiro longa vida estrutural e com mutante *rin*, produzidos nas condições edafoclimáticas do sul do estado do Tocantins

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ABSTRACT

The high temperature of growth environment can affect the postharvest quality of tomato fruits. In this situation, an alternative for the farmers is the use of hybrid cultivars that produce long shelf life fruit with longer postharvest shelf life when compared to normal varieties of fruits. The objective of this research was to compare the postharvest conservation of fruits of structural long shelf life tomato hybrids and with the mutant *rin*. The fruits evaluated were from fifteen tomato genotypes produced under the edaphoclimatic conditions of the southern State of Tocantins, being four of them long shelf life type hybrids (with *rin* allele) which were: Tyler, Rebeca, Carmem and AF 13527; nine of them structural long shelf life hybrids: Lumi, Débora Max, Michelli, Tammy, AF 12525, AF 11097, AF 13363, AF 13364 and AF 13525; and two normal fruit cultivars: Santa Clara and Drica. The fruits were harvested at the breaker stage and stored in a controlled environment (20 °C and relative humidity of 60%). The half-life firmness of fruits of genotypes with a structural genotypic long shelf life background ranged from 6.25 to 13.44 days for the genotypes Tammy and AF13525, respectively, not differing from the long shelf life genotypes with *rin* allele. Despite the fact that daytime temperatures are higher than those recommended for the tomatoes crops, it was observed that if the fruits are stored in appropriate conditions (20 °C and relative humidity of 60%), the color and firmness of the fruits with a long shelf life genotypes with *rin* allele and structural genotypic background evolve more slowly than the fruits of normal genotypes. Under these conditions, it took the fruits 7 to 8 days to acquire a red color on more than 80% of the surface after being harvested.

Index terms: *Solanum lycopersicon*; hybrids; firmness; color**.**

RESUMO

A temperatura elevada do local de cultivo pode afetar a qualidade pós-colheita dos frutos do tomateiro. Nessa situação, uma alternativa para os produtores, é o uso de cultivares híbridas que produzem frutos longa vida com maior tempo de conservação em pós-colheita, quando comparado com cultivares de frutos normais. Neste trabalho, objetivou-se avaliar a conservação em pós-colheita de frutos de híbridos de tomateiro longa vida estrutural e com mutante *rin* cultivados em duas épocas sobre ambiente protegido na região Sul do estado do Tocantins. Os tratamentos foram constituídos de 15 genótipos, sendo quatro híbridos com frutos tipo longa vida (com alelo *rin*) que foram: Tyler, Rebeca, Carmem e AF 13527; nove híbridos com frutos tipo longa vida estrutural: Lumi, Débora Max, Michelli, Tammy, AF 12525, AF 11097, AF 13363, AF 13364 e AF 13525 e duas cultivares de frutos normais: Santa Clara e Drica. Os frutos foram colhidos no estádio de *breaker* e armazenados em ambiente controlado (20 ºC e umidade relativa de 60%). A meia vida da firmeza dos frutos dos genótipos com *background* genotípico longa-vida estrutural variou de 6,25 a 13,44 dias nos genótipos Tammy e AF13525, respectivamente, não diferindo dos genótipos longa-vida com alelo *rin*. Apesar das temperaturas diurnas terem sido superiores às recomendadas para o cultivo do tomate, observou-se que, se os frutos forem colhidos no estádio de "breaker" a coloração e firmeza dos frutos nos genótipos longa-vida *rin* e *background* genotípico estrutural evolui mais lentamente que os frutos de genótipo normal, necessitando de 8 dias depois de colhidos para estarem com mais de 80% da superfície do fruto vermelha.

Termos para indexação: *Solanum lycopersicon*; híbridos; firmeza; cor.

INTRODUCTION

Tomatoes (*Solanum lycopersicon* L.) are widely consumed and grown in practically all of the geographic regions in Brazil (Andreuccetti et al., 2007; Matos; Shirahige; Melo, 2012) and all over the world. It plays an important role in the national economy, as it is one of the main vegetable products (Shirahige et al., 2010). It is characterized for being a climacteric fruit whose ripening usually begins with an alteration in the color of the distal

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portion, migrating to the neighboring regions by the free diffusion process, until the maturation process reaches the whole of the fruit (Moura et al., 2005).

In most tomato crop systems aiming the market *in natura*, the fruits are harvested at the "mature green stage" or at the "breaker " stage. The purpose of this is to prevent postharvest losses caused by several biotic and abiotic factors. In this situation the fruits ripen in storage places before commercialization and due to this, they do not reach the quality required by consumers. Moreover, other factors either positively or negatively influence the quality attributes of fresh tomatoes at the maturation phase, in which both the firmness and shelf life of the fruits are included. An alternative to improve the quality of tomato fruits is to develop cultivars with longer shelf life, which can be easily made with a good understanding of both the maturation process and the genetic and physiological factors (Foolad, 2007).

The firmness is a critical aspect of the quality of the tomato (Lana et al., 2007). It is determined by a certain number of factors, including the cell wall structure, turgor (Saladié et al., 2007) and cuticle properties (Chaïb et al., 2007). The fruit firmness may also be a function of both the genetic background and the mutant alleles which can act during the ripening process (Andrade Junior et al., 2005), varying according to the maturation stage.

There are some possibilities to obtain the long shelf life tomato plant, by increasing the frequency of favorable alleles for greater firmness of the fruit pericarp, the structural long shelf life type, and also by the use of ripening mutants, which are simple mutant alleles with multiple effects (pleiotropic) that affect the ripening of the tomato fruit. Regarding the use of ripening mutants, the allele *rin* (ripening inhibitor) is the most used allele in modern cultivars (Cá et al., 2006). These alleles delay ripening and prolong shelf life, interfering mainly on the firmness and carotenoid pigments synthesis, in addition to being useful for a better understanding of the processes which regulate the maturation and the development of new cultivars with longer shelf life (Dias et al., 2003; Faria et al., 2006; Cá et al., 2006).

The aims of the breeding programs within the different regions that grow tomatoes in Brazil are: the development of hybrids with better agronomic traits related to both fruit yield and quality (Souza et al., 2012) and; to make them available to the consumer by producing tomato types with better taste quality and distinct in terms of size, color, shape, texture and firmness.

Although the local average temperature is higher than the ideal temperature required by the tomatoes, during autumn-winter it may be possible to crop adopting appropriate cultivars for those conditions.

The objective was to evaluate the postharvest conservation of tomato hybrids fruits with structural long shelf life and ripening mutant allele, cropped in the edaphoclimatic conditions of the southern State of Tocantins.

MATERIAL AND METHODS

The experiments were conducted in the field and in the Plant Physiology laboratory of the University Campus of Gurupi - CAUG of the Federal University of Tocantins (altitude of 280 m, coordinates 11°43'45" of latitude and 49°04'07" of longitude).

The following fifteen tomato genotypes were evaluated. Four commercial and pre-commercial hybrids of the long shelf life type, carriers of the ripening mutant *rin* in heterozygosis (*rin*+/*rin*): Tyler, Rebeca, Carmen and AF13527; nine commercial and pre-commercial hybrids of structural long shelf life type: Lumi, Débora Max, Michelli, Tammy, AF12525, AF11097, AF13363, AF13364 and AF13525; and two cultivars as a control: Santa Clara, which is the most widely planted in Brazil, and Drika, the cultivar improved due to the State of Tocantins conditions.

Two field experiments were conducted in randomized block design, with three replications between 2008 and 2009. They were conducted in a greenhouse in summer (December to March), and in the open field during the winter (June to September). The average temperatures of the two crop environments are shown in Figure 1.

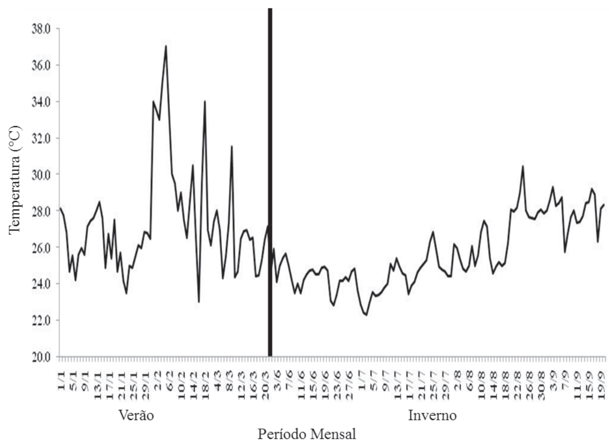

Figure 1: Average temperature of the crop period of long shelf life and normal type tomato cultivars, in two growing seasons in the state of Tocantins.

Each plot consisted of a row of eight plants spaced 0.42 m inter-plants and 0.85 m inter-rows. The fertilization was performed according to the recommendation for the culture (Alvarenga, 2004), based on the chemical properties of the soil, in both seasons. The cultivation was done in stake system, using drip irrigation. Every week, the plants were pruned to maintain single and individually staked stem.

Six fruits of each genotype per plot were selected as to the uniformity of size, absence of defects and maturity stage. For the selection of the six maturity stages evaluated, the fruits were visually separated according to the color scale suggested by the United States Standard United States Standard for Grades of Fresh Market Tomatoes - USDA (1976), as follows: stage 1 - fruits with maximum growth and still without a sign of red color on the epidermis (breaker stage); stage 2 - less than 10% of the surface with red color; stage 3 - 11 to 40% of red color; stage 4 - 41 to 80% of red color; stage 5 - more than 80% of red color, but not yet fully red; stage 6 - 100% of red color. During the evaluations, only fruits harvested at stage 1 which were stored on shelves, in rooms with controlled temperature (20 ºC and 60% relative humidity), were considered.

The traits evaluated were: relative size of the peduncle scar, whose measurement was performed with the use of a digital caliper; fruit shape obtained through the ratio between the measurements of the longitudinal length (C) and transverse or width (L), in which C/L<1, C/L=1 and C/L>1, indicate the shape flattened, round or oblong, respectively; rate of loss of firmness during the storage period. The firmness ($N\ m^{-2}$) was measured on the equatorial surface of each fruit, individually, by means of the non-destructive flattening technique described by Calbo and Nery (1995). The firmness readings were taken from the first ripening stage (day zero) with a two-day interval, until the fruits reached the firmness $3.0x10^4$ N m^{-2} (Andrade Júnior et al., 2005).

Nonlinear models were employed to adjust the march of the loss of fruit firmness over time. The half-life of firmness (T) was obtained by means of the regression of firmness data (A) of each plot, on the number of days elapsed (X), by the statistical model: $A = A_0(1/2)X/T$, wherein: A_0 is the fruits with initial firmness ($N\ m^{-2}$), at stage 1 (day 0); X is the number of days after harvest, at breaker stage; T is the half-life of the firmness (measured in days); A is the firmness ($N\ m^{-2}$) after X days. The curves were fitted with the resource of the Sigma Plot 10.0 statistical package. On the basis of the fitted equation, the following items were determined for each plot: the half-life of the firmness (which corresponds to the period in days for the fruits to have their firmness reduced to half in relation to the initial firmness) and the number of days elapsed for the fruits to reach the firmness of $3.0.10^4\ N.m^{-2}$ and $2.0.10^4\ N.m^{-2}$.

The number of days for the fruits to reach the red color was also evaluated by means of a score scale, where: 1 - few stripes or spots of red color on the region of the stylar scar of the fruit (breaker stage); 2 - 20% to 40% of the fruit surface area with red color; 3 - 41% to 60% of the fruit surface area with red color; 4 - 61% to 80% of the fruit surface area with red color; 5 - more than 80% of the fruit surface area with red color.

An individual and joint analysis of the variance of the studied traits and their due decompositions was performed by the statistical package SAS. The average of the treatment was compared by the Scott-Knott test (p = 0.05) through the GENES program (Genes; V. 3.0) (Cruz, 2006). Non-orthogonal contrasts were calculated to compare the treatment groups, evaluate and quantify the effects of the *rin* mutant at heterozygosis, of the structural and normal genetic backgrounds, on the evaluated traits.

RESULTS AND DISCUSSION

There was a significant effect of sowing date on most of the evaluated characteristics. The interaction 'genotype x growing season' was not significant for all the characteristics, indicating that there was no inversion of the behavior of the fruits regarding the postharvest characteristics due to the different growing seasons, and thus, the results were presented in the average of the two seasons (Table 1).

According to Faria et al. (2006), the fruit shape is determined by the ratio between the longitudinal and transverse lengths, being a mark to classify different tomato cultivars as to morphoanatomical group (Santa Cruz or Salada). Significant differences were found in Table 1 among the average of treatments, distinguished by the Scott-Knott (p = 0.05). The genotypes evaluated showed average values of the length/width ratio being smaller than an unit**,** characterizing the tomato fruits as salad type, with the exception of the structural long-life hybrid Deborah Max and the normal cultivar Santa Clara, which had that relationship greater than an unit, indicating oblong fruits and belonging to the Santa Cruz group. The average values of the relative size of the fruits' peduncle scar of the 15 evaluated genotypes are shown in Table 1. High values for this characteristic are considered undesirable. The variance analysis allowed me to detect significant differences among the treatments, the average of which were distinguished by the Scott-Knott test (p = 0.05) (Table 1). It was detected that all the genotypes had similar values for this characteristic through the average of both seasons, with the exception of two long shelf life genotypes of structural type that presented higher values statistically differing from the others.

A significant effect was found in the contrast 'structural versus normal' for average size of the peduncular scar, becoming evident that normal genotypes tend to produce fruit with higher values for this characteristic (Table 1). Araújo et al. (2002) related the smallest water loss at post-harvest and the longest shelf life of the long shelf life tomato fruits attributed to the reduction of the peduncular scar size. According to Faria et al. (2006) the reduction of peduncular scar of the fruits may be due to both the effects of allele mutants and the genetic background. Leal and Shimoya (1973) state that this characteristic is directly related to the decay process of the fruit.

The fruits were evaluated as for firmness on harvest day (stage 1). From the results of the average of the growing seasons, it was found that the genotypes have similar average (Table 1), 4.08 N m^2. The group of long shelf life type heterozygous *rin* and structural genotypes showed the highest values estimated for the initial firmness, though the estimates of the contrasts were not significant (Table 1).

Table 1: Estimates of average for length/diameter ratio (shape) of the fruits, peduncular scar, fruit firmness at the *breaker* stage, half-life of firmness, number of days for the fruits to reach the firmness 3.10^4 $N.m^{-2}$ and 2.10^4 $N.m^{-2}$, average number of days to reach red coloration and estimates of non-orthogonal contrasts of interest of 15 tomato genotypes fruits with long shelf life and normal type, at post-harvest, in two growing seasons at Gurupi - TO. Gurupi, UFT, 2009.

Genotypes	Background	Fruit shape	Peduncular scar size	Initial stage 1	Half-life of firmness	Days to reach firmness 2.10^4 $N.m^{-2}$	Days to reach firmness 3.10^4 $N.m^{-2}$	Days to reach the red coloration
Tyler	rin	0.78b	0.2576c	4.57	9.18b	3.53b	8.90b	6.66
Lumi	structural	0.88b	0.2547c	3.89	15.19a	4.83a	13.72a	6.98
Débora Max	structural	1.10a	0.2283c	4.12	7.84b	2.45b	7.04b	7.02
Michelli	structural	0.87b	0.2807b	3.89	8.16b	2.38b	7.15b	5.33
Tammy	structural	0.89b	0.2289c	3.99	6.25b	2.40b	6.05b	5.66
Rebeca	rin	0.91b	0.2243c	3.94	16.56a	5.50a	15.19a	6.68
Carmem	rin	0.84b	0.2318c	3.99	14.11a	3.97b	12.22a	6.68
AF12525	structural	0.87b	0.2038c	4.24	9.56b	3.10b	8.70b	8.16
AF11097	structural	0.89b	0.2621c	4.45	10.20b	3.91b	9.87b	6.01
AF13363	structural	0.87b	0.2443c	4.20	10.92b	4.94a	11.32a	6.38
AF13364	structural	0.88b	0.3330a	4.11	11.92a	2.97b	9.95b	5.66
AF13525	structural	0.88b	0.2378c	3.89	13.44a	3.75b	11.61a	7.38
AF13527	rin	0.88b	0.2221c	3.90	11.47a	2.92b	9.63b	7.55
Sta Clara	normal	1.14a	0.2225c	4.27	7.45b	2.18b	6.54b	5.02
Drica	normal	0.97b	0.2139c	3.89	11.97a	1.23a	10.04b	5.41
Average		0.91	0.243	4.08	10.95	3.46	9.86	6.44
Estimates of contrast of interest								
rin vs structural			-0.0186^{ns}	0.028^{ns}	2.44*	0.57^{ns}	1.99^{ns}	0.39^{ns}
rin vs normal			0.0158^{ns}	0.029^{ns}	3.12*	1.37*	3.19*	1.69*
structural vs normal			0.0344*	0.001^{ns}	0.68^{ns}	0.8*	1.2^{ns}	1.3*

Average followed by the same small letters in the column do not differ from each other by the Scott-Knott test at 5%. * Significant at 5% de probability by the t test.

The half-life of the firmness corresponds to the postharvest period that the fruit takes to reduce its firmness to half compared to the initial firmness. For the evaluated hybrids, this characteristic varied from 6.25 days for the structural genotype Tammy to 16.56 days for the *rin* genotype Rebecca (Table 1).

The fruits of long shelf life type genotypes, especially *rin* type, presented the highest values for half-life firmness in general, statistically differing from the other genotypes, with an average difference of 10 days (Table 1). The increased half-life of the firmness of fruit genotypes with mutant alleles may be related to the delay in the increase of polygalacturonase activity, which is enhanced in fruits when they are at stages 2 and 3 (Moura et al., 2005).

Santos Junior et al. (2005) report that the *rin* allele mutant at heterozygosis significantly increased the half-life of fruit firmness by 2.2 days as compared to the normal isogenic genotype in Floradade x Tropic background. Benites et al. (2010) found that rin^{+}/rin e $rin^{+}/rin\ nor^{+}/nor^{A}$ genotypes promoted increases of 5.7 days and 7.7 days, respectively, in the half-life of fruit firmness in relation to the isogenic control Floradade. Andrade Júnior et al. (2005) report that the *rin* allele showed a similar magnitude effect in the sense of increasing the half-life of fruit firmness by 2.9 days in relation to the normal genotype on hybrid background (Floradade x Mospomorist).

Significant differences were observed between the contrasts while comparing the firmness half-life of the fruits of mutant *rin* allele genotypes to the ones coming from structural and normal genotypes (Table 1). The longest half-life of fruit firmness is dependent on the environmental condition of the fruit pericarp apoplast (Moura et al., 2005). According to Moura et al. (2002), mutant fruits present less electrolyte leakage during ripening as compared with normal fruits at stage 3 of maturation. Under these conditions, even the pH of *rin,* normal and structural fruits are similar, in mutant fruits, the ionic conditions in the apoplast due to the level of K^{+} can act as a limiting factor, causing delay in the increase of polygalacturonase activity in the pericarp of mutant fruits.

The stage of fruit firmness, which corresponds to the limit below those tomatoes that are no longer considered suitable for consumption, experimentally relates to a value situated between $3{,}0.10^4$ N m^{-2} and $2{,}0.10^4$ N m^{-2}, of which is why the elapsed time after harvest that is needed for the firmness to reach these values was sought to be estimated. Those times, however, represent the fruit conservation capacity (shelf life).

The values corresponding to the average number of days that the fruits remain stored, from harvest until their firmness has been reduced to $2{,}0.10^4$ N m^{-2} (Table 1) showed that most of long shelf life genotypes, highlighting those long-life *rin* Rebeca, Carmen and structural Lumi and AF13363, were effective in slowing the loss of fruit firmness.

Evidently, the fruits of normal genotypes were the ones presenting a faster noticeably softening among genotypes. The range of variation of the average obtained for this trait (Table 1) confirms the efficiency of the use of long-life *rin* genotypes on postharvest conservation of fruits in the region. Estimates of the contrasts *'rin versus* normal' indicate that, on average, the genotypes of the *rin* group promoted a delay of 1.37 days in the period for fruits to reach firmnesses of $2{,}0.10^4$ N m^{-2} (Table 1). Nevertheless, it was not found to be significant.

The number of days from harvest until the fruits have their firmness reduced to 3,0 10^4 N m^{-2} varied from 1.23 in the normal genotype Drica to 15.19 in the *rin* genotype Rebecca (Table 1). The long shelf life *rin* genotypes Rebecca and Carmen, and structural Lumi and AF13525, were those that took the greatest average number of days for the local produced fruits not to be considered suitable for consumption.

The significant estimate of the contrast that compares the group of the structural type of genotypes in relation to the normal group showed an average increase of 3.19 days in relation to the normal group on the postharvest conservation of fruits (Table 1). From these results, the favorable contribution of long shelf life *rin* genotypes on the increment of days to reach the limit value of firmness, is being a characteristic that regardless of the weather condition where the fruit is produced, requires only that the fruit is harvested at stage 1 of maturation. Faria et al., (2006) report that the advantage that the genotypes carrying the mutant allele present on the normal genotype is quite significant from the standpoint of post-harvest storage. For marketing, this aspect starts to have greater importance when the fruits are produced in locations distant from the places of consumption.

Araújo et al. (2002) studying the effect of ripening mutant alleles upon the reduction of peduncle scar, ascribe to them a part of the greatest post-harvest storage of fruits. Leal and Mizubuti (1975) attributed the smaller mass reduction of tomatoes to the smaller size of the peduncle scar. Such a mass decrease based on the water loss of the fruits is due to the high respiration rate of the tomato plant provided by the peduncle scar (Shirahige, 2010). The loss of water, besides the action of polygalacturonase and pectinmethylesterase enzymes (Resende et al., 1997), contributes to make the tomato fruits less consistent. Thus, fruits with smaller peduncle scar associated to ripening mutant alleles, may present smaller mass reduction, favoring increased postharvest preservation (Shirahige, 2010). Thus in the selection of genotypic background with mutant allele promoter greatest average number of days being reached, when the goal is the longest longevity of fruits.

The average values corresponding to the average number of days for the fruits to reach the red color on over 80% of the surface (5.0 score) are in Table 1. Overall, no significant differences were observed with respect to the score of fruit color, with lower average ascribed to the cultivars Santa Clara and Drica, both of normal type fruits, reaching the red color more rapidly when compared with the others (Table 1).

In spite of the lack of statistical differences among the treatments, significant estimates of the contrasts '*rin* versus normal' and 'structural versus normal' indicate that the fruits, delayed 1.69 and 1.3 days, respectively, achieved the score of 5 in color relating to the group of normal maturing genotypes (Table 1). The contrast 'structural versus *rin'* was not significant either (Table 1), demonstrating minimal difference between the long-life genotypes for that characteristic. It is evident that in the long shelf life *rin* and structural genotypes, the external fruit color evolved more slowly when compared to normal genotypes (Table 1).

It is important to highlight that the color is a quality attribute that serves as attractiveness to consumers. Thus, the choice, upon purchase, always falls on the fruit whose color is more attractive. So, this characteristic can be used as a parameter to indicate the genotypes for cropping, depending on the market, as there are markets that prefer pinkish ripe tomato and others that prefer red or reddish and quite firm fruits (Marcos; Jorge, 2002).

For conventional tomato**,** the ideal genotypes are those that take the longer to reach an intense red color, such as AF12525, AF13525, AF13527, Lumi and Deborah Max that took about 7 to 8 days after harvest to be with more than 80% of the surface in red.

It follows that the firmness half-life of the fruits of the genotypes with structural long–life genotypic background ranged from 6.25 to 13.44 days in the genotypes Tammy and AF13525, respectively, not differing from the long-life genotypes with *rin* allele.

CONCLUSIONS

The firmness half-life of the fruits of the genotypes with genotypic background structural long shelf life ranged from 6.25 to 13.44 days for the genotypes Tammy and AF13525, respectively, not differing from the long shelf life genotypes with *rin* allele.

Despite daytime temperatures being higher than those recommended for tomato crop, it was observed that if the fruit is stored on appropriate conditions (20 °C and relative humidity of 60%), the color and firmness of fruits in the long shelf life genotypes with *rin* allele and structural genotypic background evolves more slowly than the fruits of normal genotypes. Under these conditions, the fruits took from 7 to 8 days after harvested to reach more than 80% of its surface in red color.

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