Australian Journal of Crop Science AJCS
AJCS 15(04):538-542 (2021) ISSN:1835-2707
doi: 10.21475/ajcs.21.15.04.p2827

Recurrent selection for resistance to *Thrips tabaci* in a tropical onion population

Gleyce de Oliveira Ferreira[1], Carlos Antonio Fernandes Santos[2*], José Adalberto de Alencar[2], Danillo Olegário Matos da Silva[3]

[1]Universidade Estadual de Feira de Santana, Programa de Pós-graduação em Recursos Genéticos Vegetais. Avenida Transnordestina, s/n, Novo Horizonte, CEP 44036-900 Feira de Santana, BA, Brazil
[2]Empresa Brasileira de Pesquisa Agropecuária (Embrapa Semiárido), Rodovia BR-428, km 152, s/n, Zona Rural, CEP 56302-970 Petrolina, PE, Brazil
[3]Uninassau Petrolina, Avenida Clementino Coelho, 714 - Centro, CEP 56308-100 Petrolina, PE, Brazil

***Corresponding author: carlos-fernandes.santos@embrapa.br**

Abstract

Recurrent selection for resistance to onion *Thrips tabaci* has not been well studied by breeding programmes. Onion thrips is a pest of major concern and is controlled by insecticide spraying, raising production costs and potentially damaging the environment. This study aimed to estimate onion bulb yield genetic gain through six cycles in the 'BRS Alfa São Francisco' developed by recurrent selection for *T. tabaci* resistance. Experiments were carried out in a randomised block design, with three replications, in two locations. The degree of infestation in plants was evaluated five times after transplanting, as well as plant architecture traits and bulb yield. The latest selection cycle presented bulb commercial yield of 32.1 $t.ha^{-1}$, while the base population 'Alfa Tropical' and IPA 10 check cultivar 15.9 and 14.0 $t.ha^{-1}$, respectively ($p<0.01$). The broad sense heritability values ranged from 0.65 to 0.74 for bulb yield. The mean genetic gain was 1.0 $t.ha^{-1}$ or 6% per selection cycle, indicating the efficiency of the method to increase the frequency of favourable alleles for thrips resistance and the possibility of onion cultivation in the total absence of insecticide applications to control this pest, or a reduction in their number.

Keywords: *Allium cepa;* heritability; Brazil Northeast; São Francisco Valley; selection response.
Abbreviations: VSF_ São Francisco Valley , DAT_ days after transplanting , DI_ degree of infestation, IYSV_ Iris yellow spot virus, SFV_ São Francisco Valley, DS_ differential of selection, G_ genetic gain, G%_ genetic gain percentage (G%)

Introduction

Thrips tabaci Lindeman, 1889 (Thysanoptera: Thripidae) is the main pest of onion (*Allium cepa* L.), becoming an issue of global concern due to the growing resistance to pesticides and ability to convey other pathogens and to reproduce under high temperatures. This insect feeds on the leaves, causing stains, premature senescence of plants as well as small and twisted bulbs, resulting in a loss of more than 50% in commercial bulbs yield (Diaz-Montano et al. 2011). Thrips becomes even more problematic because it is the main transmitter of the Iris yellow spot virus (IYSV) (family Bunyaviridae, Tospovirus), which may result in a total loss of the bulb (Diaz-Montano et al. 2011). Specifically for control of IYSV, onion breeding programmes consider the identification of a cultivar which is resistant or tolerant to the injuries caused by thrips (Cramer et al. 2014).

The regular control of this pest is done with the application of insecticide. Cultural practices and biological control have not been effective, besides presenting high costs (Gill et al. 2015). In the region of São Francisco Valley (SFV), in Brazil, onion producers often apply three sprayings of insecticides per week, with different active ingredients, in order to minimise the damage caused by thrips, which raises production costs in addition to causing potential damage to the environment and consumers. Onions are produced in Brazil in the Northeast, South, Southeast, and Central-West regions. Production in the Northeast, concentrated in the Vale do São Francisco region (VSF), corresponds to 16% of Brazilian production (IBGE, 2015).

According to Gill et al. (2015), there are no onion cultivars highly resistant to thrips, but some have a low level of resistance or can tolerate the leaf lesions caused by the insect. Onion germplasm evaluations for resistance to thrips has been reported by Loges et al. (2004) and Ferreira et al. (2017) in the region of the SFV, Brazil, by Shaikh et al. (2014) in Gujarat, India, by Silva et al. (2015) in Santa Catarina, Brazil, by Cramer et al. (2014) in New Mexico, USA, and by Diaz-Montano et al. (2010) in the USA. All these studies can be considered as an assessment criterion for resistance of onion accessions and the absence of chemical control for reduction or elimination of thrips. In the same way, the cited studies only considered germplasm evaluations, without reporting the recurrent selection application for increasing the allelic frequency for resistance to pests in a given onion population.

Development of germplasm resistant to onion thrips is the best scenario for overcoming this pest, since this will reduce pesticide application and potential damage to the environment and consumers. The genetic basis of onion resistance to thrips is not well understood. Damon et al. (2014) reported that numbers of adult and immature onion thrips were significantly reduced on glossy and/or semiglossy onion accessions compared to waxy accessions in field and greenhouse cage experiments, indicating that semiglossy plants have intermediate amounts of epicuticular waxes that may protect leaves from diseases or environmental stresses while still conferring resistance to onion thrips. Cramer et al. (2017) reported that leaf colour, and amount of leaf epicuticular wax, were not consistent factors in determining the number of thrips per plant in field evaluation of various cultivars. To Silva et al. (2015), a wider central angle (16.4°), a thinner cuticle, a larger amount of epicuticular waxes, and stomata on the surface of leaves accounted for resistance in the Alfa São Francisco RT cultivar. Other studies, cited by Kamal and Cramer (2018), suggested greater thrip attraction to blue hues compared to green hues.

The use of recurrent selection in the onion breeding programmes for different purposes is well documented in several parts of the world. Gonzalez and Herrera (2012), using this selection method, developed a new 'Valenciana' onion variety, with early maturation. Cramer and Corgan (2012) also made use of recurrent selection to develop the NuMex cultivar Fabian Garcia, with late maturation. Gökçe et al. (2012), aiming at the improvement of quality traits in onion cultivars in Turkey, conducted four recurrent selection cycles applied in commercial cultivars, and reported progress in several traits, including yield of bulbs. To date, no studies were found reporting application of recurrent selection to develop an onion population with medium to high resistance to thrips. Kamal and Cramer (2018) reported progress, with reduced IYUV symptoms and number of thrips per plant, after one selection cycle compared to their original populations in 26 onion accessions evaluated at Las Cruces, NM, USA.

This study aimed to estimate bulb yield in six recurrent selection cycles applied to 'BRS Alfa São Francisco' carried out without insecticide spraying for control of the main onion pest, *T. tabaci*, in order to derive populations able to grow in the absence of insecticide, or with reduction of insecticide application.

Results

Reduced DI of adults at 50 DAT in 'BRS Alfa São Francisco' selection cycles compared to 'IPA 10' and 'Alfa Tropical'

Statistical differences among treatments were found for DI of adult thrips in combined analysis of the two areas, for all dates of evaluation, except at 43 DAT, whereas for nymphs, these differences ($p<0.05$) were found at 15 and 22 DAT (Table 1). No statistical differences were observed between the locations for most evaluation dates, indicating that the populations of nymphs and adults were similar at both sites. Significant location × treatment interactions were observed for the DAT of adults, except at 43 DAT, and for nymphs only at 15 and 22 DAT, indicating different responses of the treatments in the two locations (Table 1).

The coefficients of variation were lower than 27%, except for adults at 15 DAT, indicating good accuracy in population sampling of adults and nymphs in almost all phases. The nymph phase had higher rates of infestation, reaching a peak population near 100% after 43 DAT in all treatments (Table 1). The IPA 10 and Alfa Tropical cultivars had higher DI of adults at 50 DAT in comparison with the recurrent cycles in 'BRS Alfa São Francisco' (Table 1). The lowest levels of infestation of nymphs and adults occurred at 15 DAT, progressively increasing until 50 DAT, when the plant offered ideal feeding and shelter conditions for the insect to reproduce. Percentages close to 100% for nymphs were observed at 50 DAT (Table 1), indicating that the thrip populations had reached the maximum point for all treatments and no further sampling could improve the analysis, as reported also by Ferreira et al. (2017).

Greater onion bulb yield in 'BRS Alfa São Francisco' selection cycles compared to 'IPA 10' and 'Alfa Tropical'

The coefficients of variation for commercial and total bulb yields were below 21% at both sites assessed (Table 1). Statistical differences were found ($p<0.01$) for total and commercial bulb yield in the two areas for all treatments. The selection cycles within 'Alfa São Francisco' showed means of 27.1 t ha^{-1} for commercial bulb yield and 34.5 t ha^{-1} for total bulb yield, whereas the check cultivar Alfa Tropical had a commercial yield of 14.96 t ha^{-1} and IPA 10 had a commercial yield of 13.09 t ha^{-1}. The superiority of the six selection cycles was 1.8× the yield of 'Alfa Tropical' and 2.0× the yield of 'IPA 10' (Table 1).

The highest ratios of commercial bulbs/total bulbs were observed in the cultivar IPA 10, which occupies about 15% of commercial onion plantations in the VSF region, and in 'Alfa SF TT C-IX', whereas 'Alfa Tropical' had the lowest ratio (Table 1). The ratio of commercial bulbs/total bulbs ranged from 0.76 to 0.86 for the six recurrent selection cycles in 'BRS Alfa São Francisco' (Table 1), indicating that there is the possibility of increasing commercial production in subsequent cycles through selection for bulb uniformity .

The coefficients of variation were below 15% in the plant architecture traits evaluated. The central angle of the plant showed no significant differences in different DAT, considering that there was a significant interaction only at 43 DAT (Table 2). For the traits of plant height, pseudo-stem diameter, and number of leaves per plant, the treatments differed, except at 15 DAT for number of leaves (Table 2). No significant interaction was observed for plant height, and significant interaction was observed for pseudo-stem diameter and number of leaves per plant, except at 15 DAT for both traits (Table 2).

'Alfa Tropical' showed the highest averages at 43 DAT for plant height, pseudo-stem diameter, and number of leaves per plant in relation to the six recurrent selection cycles (Table 2), although it had lower commercial bulb production (Table 1). 'IPA 10' had lower means in relation to the six recurrent selection cycles for plant height, pseudo-stem diameter, and number of leaves per plant at 43 DAT (Table 2).

The broad sense heritability values were 0.79 and 0.62 in Petrolina and 0.69 and 0.74 in Juazeiro for commercial and total bulb yields, respectively (Table 3). The biggest genetic gains for commercial yield were estimated for the 'Alfa SF TT C-IX' cycle and the 'Alfa SF TT C-VIII' cycle in Petrolina, whereas the 'Alfa SF TT C-IX' cycle and the 'Alfa SF TT C-V' cycle had the biggest gains in Juazeiro (Table 3). The average genetic gain for commercial yield in relation to the base

Table 1. Total (T) and commercial (C) bulb production, mean squares (MS), coefficient of variation (CV) and degree of infestation (DI) of adults and nymphs of *Thrips tabaci* at 15, 22, 29, 36, 43 and 50 days after transplantation (DAT) in six cycles of recurrent selection for resistance to *T. tabaci* in the onion cultivar BRS Alfa São Francisco and in the control cultivars Alfa Tropical and IPA 10, evaluated in municipalities of Petrolina, PE, and Juazeiro, BA.

		Bulb production (t ha^{-1})			*Thrips tabaci* Adult DIs - DAT						*Thrips tabaci* Nymph DIs - DAT					
Population	Cycle (C)	C	T	C/T	15	22	29	36	43	50	15	22	29	36	43	50
Alfa SF TT	IV	26.94^{A}	34.30^{A}	0.82	43	35	61	78	57	53	26	53	66	92	94	98
Alfa SF TT	V	23.78^{A}	31.28^{A}	0.76	5	50	63	51	50	56	34	53	57	82	97	99
Alfa SF TT	VI	24.18^{A}	32.16^{A}	0.81	10	47	52	78	57	67	26	36	56	85	90	98
Alfa SF TT	VII	26.99^{A}	35.50^{A}	0.79	16	89	50	43	66	64	34	64	66	80	97	98
Alfa SF TT	VIII	28.90^{A}	35.55^{A}	0.85	13	60	71	48	67	50	32	41	59	88	97	95
Alfa SF TT	IX	32.07^{A}	38.40^{A}	0.86	0	74	66	62	69	69	36	42	59	85	98	100
Alfa Tropical		15.87^{B}	24.20^{B}	0.64	37	50	48	47	64	80	19	58	70	80	97	97
IPA 10		13.99^{B}	15.93^{B}	0.86	1	39	83	52	64	73	10	51	57	84	96	98
Trat MS[(1)]		228.6**	303.1**	-	0.33**	0.17**	0.08*	0.16**	0.03	0.07**	0.09**	0.06*	0.01	0.02	0.02	0.02
Local MS[(1)]		20.23	8.43	-	0.13	0.06	0.09	0.44**	0.05	0.24**	0.11*	0.07	0.11*	0.04	0.00	0.00
Trat*Local MS[(1)]		32.84	36.23	-	0.15**	0.13**	0.13**	0.19**	0.02	0.05**	0.15**	0.07*	0.02	0.05	0.03	0.02
CV (%)		20.69	16.73	-	56	21	17	19	15	15	26	19	15	14	10	9
Cycles mean		27.14	34.54		14	59	60	60	61	59	31	48	60	85	95	98
Overall Mean		23.86	30.18	-	15.6	55.5	61.7	57.3	61.7	64.0	27.1	49.7	61.2	84.5	95.8	97.9

[(1)]Original data transformed to arc-sine of the square root for statistical analysis. CV: coefficient of variation. ** and *, significant at 5% and 1% of probability, respectively. Means followed by the same letter do not differ by Student-Newman-Keuls Test at 5% of probability.

Table 2. Average values, mean squares (MS), coefficient of variation (CV) for plant architecture traits at 15, 29 and 43 days after transplanting (DAT) in six cycles of recurrent selection for resistance to *Thrips tabaci* in the onion cultivar BRS Alfa São Francisco and in control cultivars Alfa Tropical and IPA 10 evaluated in the municipalities of Petrolina, PE, and Juazeiro, BA.

Populations	Cycle (C)	Leaves central angle			Plant height (cm)			Pseudo-stem diameter (mm)			Number of leaves		
		15DAT	29DAT	43DAT	15DAT	29DAT	43DAT	15DAT	29DAT	43DAT	15DAT	29DAT	43DAT
Alfa SF TT	IV	12.7	10.5	8.0	16.5	40.5	52.8	2.9	6.2	10.3	3.8	5.0	7.3
Alfa SF TT	V	12.0	10.7	8.9	17.7	38.7	49.3	2.9	6.4	9.7	3.8	5.1	7.1
Alfa SF TT	VI	13.1	11.4	9.0	15.2	34.3	48.7	2.7	5.4	9.4	3.6	4.8	7.2
Alfa SF TT	VII	12.2	11.1	8.9	17.6	38.3	51.9	2.9	6.6	10.0	3.9	5.3	7.4
Alfa SF TT	VIII	13.1	10.7	8.4	16.6	38.0	52.9	3.0	6.3	10.0	3.7	5.0	7.6
Alfa SF TT	IX	13.7	11.3	8.6	20.5	40.7	52.3	3.2	6.7	10.3	3.9	5.5	7.6
IPA 10	-	13.4	11.8	9.0	16.3	33.8	47.7	2.8	4.9	9.4	3.5	4.5	7.0
Alfa Tropical	-	12.3	9.9	8.7	22.6	37.6	56.6	4.0	6.6	11.3	4.0	5.7	7.6
Trat MS (T)		2.12^{ns}	1.9^{ns}	0.7^{ns}	35.2**	35.4**	46.2**	0.92**	2.1**	52.4**	0.13^{ns}	0.8**	0.31**
QMTLocal MS (L)		26.9**	1.0^{ns}	0.14^{ns}	566**	2087**	1928**	6.5**	76**	176**	8.5**	11.7**	14**
T*L MS		4.9^{ns}	1.9^{ns}	4.0**	6.7^{ns}	13^{ns}	7.2^{ns}	0.03^{ns}	2.7**	1.9*	0.05^{ns}	0.5**	0.31**
CV(%)		11.7	14.9	13.0	12.4	7.7	5.1	10.8	12	8.1	8.8	6.7	4.1
Average		12.8	11.0	8.7	17.9	38	51.7	3.1	6.7	10.1	3.8	5.1	7.4

[ns]Non significant; ** and *, significant at 5% and 1% of probability, respectively.

Table 3. Broad heritability (h^2) and genetic gains (GS) for total and commercial bulb production in six cycles of recurrent selection for resistance to *Thrips tabaci* in the onion cultivar BRS Alfa São Francisco in the municipalities of Petrolina, PE, and Juazeiro, BA.

Populations	Cycle (C)	Petrolina						Juazeiro					
		Commercial production			Total production			Commercial production			Total production		
		Average (t ha^{-1})	GS (t ha^{-1})	GS (%)	Average (t ha^{-1})	GS (t ha^{-1})	GS (%)	Average (t ha^{-1})	GS (t ha^{-1})	GS (%)	Average (t ha^{-1})	GS (t ha^{-1})	GS (%)
Alfa SF TT	IV	30.08^{A}	11.94	79.84	36.33^{A}	8.04	34.42	23.80^{AB}	4.83	28.75	32.27^{AB}	5.34	21.33
Alfa SF TT	V	19.38^{AB}	3.49	23.34	25.33^{A}	1.22	5.23	28.18^{AB}	7.85	46.74	37.23^{A}	9.01	35.98
Alfa SF TT	VI	25.25^{AB}	8.13	54.34	31.12^{A}	4.81	20.60	23.10^{AB}	4.35	25.92	33.20^{AB}	6.04	24.11
Alfa SF TT	VII	28.71^{A}	10.86	72.61	35.96^{A}	7.81	33.44	25.27^{AB}	5.84	34.79	35.05^{A}	7.40	29.54
Alfa SF TT	VIII	30.70^{A}	12.43	83.12	35.80^{A}	7.71	33.02	27.10^{AB}	7.11	42.30	35.31^{A}	7.59	30.28
Alfa SF TT	IX	32.96^{A}	14.22	95.05	38.33^{A}	9.28	39.73	31.18^{AB}	9.92	59.06	38.47^{A}	9.93	39.64
Alfa Tropical		14.96^{AB}	0	0	23.36^{A}	0	0	16.80^{B}	0	0	25.05^{AB}	0	0
Average of cycles		27.84	10.17	68.05	33.8	6.47	27.74	26.44	6.65	39.6	35.28	7.5	30.4
h^2		0.79			0.62			0.69			0.74		

Means followed by the same letter do not differ by Student-Newman-Keuls Test at 5% of probability.

population 'Alfa Tropical' was 10.2 t ha^{-1}, i.e., 68%, in Petrolina, PE, and 6.6 t ha^{-1} or 39.6% in Juazeiro, BA. Considering the average of two sites, the gain was 8.4 t ha^{-1} or 53.8%, almost reaching 1.0 t ha^{-1} in the nine selection cycles.

Discussion

Recurrent selection for resistance to onion thrips has not been emphasised by breeding programmes, and this is probably one of the first efforts to concentrate favourable alleles in a Brazilian onion population of regional importance. The efforts of this work may result in the first onion cultivar developed for resistance to the most important pest in onion cultivation. Recurrent selection methods are applied to gradually increase the frequency of favourable alleles, while maintaining genetic variability for future selection (Hallauer, 1985).

The lowest rates of infestation of adults at 50 DAT in the six cycles of recurrent selection in the BRS Alfa São Francisco, compared to IPA 10, suggest the existence of one or more mechanisms of resistance to thrips. The tolerance resistance type to thrips is reinforced by the fact that plants of the six cycles of recurrent selection showed greater plant height, pseudo-stem diameter and number of leaves per plant in relation to cultivar IPA 10, suggesting that vigorous plants can tolerate insect incidence. Boateng et al. (2014) reported that the infestation by thrips increased with an increase in the number of leaves, period of bulb formation and maturity. The authors concluded that plants with a smaller number of leaves attract few insects, reducing the damage caused by thrips feeding on them, but also contributing to a low bulbs yield.

Diaz-Montano et al. (2010) observed that plants with a wider opening angle of leaves are more resistant to infestation of thrips. Silva et al. (2015) also found in the southern region of Brazil that BRS Alfa São Francisco, selected for thrips resistance, showed greater angles of leaves associated with lower insect number.

Non-linear genetic bulb gains were observed from cycle IV to cycle VI. These results could be attributed to a genetic drift that occurred in these recurrent cycles, due to different bulb sampling size and selection intensity. Santos et al. (1999), who evaluated rice genetic improvement for 22 years, and Dudley (2007), who evaluated 106 corn generations for oil content trait, have reported non-linear mean one cycle after other, attributing this fact to genetic drift.

The last cycle of recurrent selection for resistance to thrips in 'Alfa São Francisco' allowed an average yield of 32.9 t ha^{-1}, in the complete absence of insecticides for thrips control. This yield is higher than the regional average of 30.6 t ha^{-1} (IBGE 2015), which is obtained with the massive application of pesticides. The average genetic gain in the nine cycles was 1.0 t ha^{-1} or 6% per selection cycle, indicating that the recurrent selection applied to the fourth cycle of Alfa São Francisco, resulting from the Alfa Tropical, was very efficient in increasing the frequency of favourable alleles for resistance to the most important onion pest.

Pereira and Amaral Junior (2001) have estimated genetic gains of 9.4% for grain yield of popcorn with the use of recurrent selection applied on full sib progenies. Berilli et al. (2013) also reported gains of 12.9% on full sibs maize families subjected to reciprocal recurrent selection. In the present study, the genetic gains were lower than those reported, possibly due to the application of phenotypic recurrent selection, without exploring the general or specific combining ability. However, the high heritability estimated for the present population indicates that genetic progress for commercial bulb yield should continue in the next cycles of selection for resistance to thrips. The total bulb yield observed in the last cycle of selection for resistance reached almost 33 t ha^{-1}, indicating the possibility of onion cultivation in the total absence of insecticides, or with a large reduction in the number of applications of insecticides for control of this destructive pest. The data also indicate that the production of seed for marketing in the SFV region should consider genetic seed from the last selection cycle, and new cycles of selection should be applied in order to increase the competitiveness of this population on onion cropping in the absence of insecticides for control of thrips.

Materials and Methods

Plant material and experimental conditions

The experiments were conducted in two field areas of Embrapa Semiárido, one in the municipality of Juazeiro, BA (09° 24' S, 40° 26' W, 350 m asl) and another in the municipality of Petrolina, PE (09º09'S, 40º22'W, 365.5 m asl). Onion plant transplanting was carried out 30 days after sowing, when seedlings presented from 15 to 20 cm tall. The experimental design was a randomised complete block with three replications. The experimental plot was 3.5 m^2, with planting space of 0.15 m x 0.15 m, corresponding to around 440,000 plants ha^{-1}. The treatments consisted of six cycles of recurrent selection applied in the 'BRS Alfa São Francisco' for resistance to thrips, the base population 'Alfa Tropical', and 'Franciscana IPA 10'. The Alfa São Francisco cultivar was developed from 'Alfa Tropical', an open-pollinated cultivar. 'Franciscana IPA 10' is an important open-pollinated purple cultivar developed for the Brazilian tropical semi-arid region.

The cycles of phenotypic recurrent selection in cultivar BRS Alfa São Francisco were carried out in the absence of insecticide application for control of thrips or other pests, both at the bulb production stage and in the phase of seed production. Harvested onion bulbs were classified in order to select those with diameter between 35 mm to 70 mm. The number of selected bulbs per selection cycles was not the same, ranging from 600 to 1,200 bulbs. Selected bulbs were vernalised in a cold chamber at 8°C, relative air humidity around 60%, during 90 days. The three initial cycles of selection were not included due to the loss of germination of their seeds.

The soils for transplantation were prepared by ploughing, harrowing, raising beds and fertilisation with 800 kg ha^{-1} of the formula 06-24-12 NPK. There was an additional fertilisation with 100 kg of N ha^{-1}, divided in five doses at 15, 22, 29, 36 and 43 days after transplanting (DAT), and three applications of 60 kg of K_2O ha^{-1} divided in three doses at 30, 40 and 50 DAT. The irrigation was done by micro-sprinkler during the production of seedlings, and after transplantation by dripping. The other cultural practices were those more commonly adopted for onion cropping in the region of SFV.

The experiments were also conducted without the application of insecticides for the control of thrips or other insects. Onion assessments for resistance to thrips in the absence of chemical control have been reported by Loges et al. (2004), Diaz-Montano et al. (2010), Cramer et al. (2014), Shaikh et al. (2014) and Silva et al. (2015).

Variables assessed and statistical analysis

For assessment of resistance to thrips, populations of the insect were quantified in field at 15, 22, 29, 36, 43 and 50 DAT, always in the morning, using a manual magnifying glass. On each date, nymphs and adults of the insect were counted and evaluated in five plants, randomly chosen from each plot, through the application of a five-point scale as described by Ferreira et al. (2017).

In addition to the degree of infestation (DI) of thrips, the following traits associated with plant architecture were assessed: 1) angle between the two central leaves fully developed – measured with a protractor from the central axis formed by the leaves; 2) plant height (cm) – from the sheath to the apex of the tallest leaf with the aid of a graduated ruler; 3) pseudo-stem diameter (mm) – measured using digital calipers; 4) number of leaves. For these variables, the measurements were performed at 15, 29 and 43 DAT, in five plants randomly taken per plot, in each evaluation. The harvest was performed manually between 100 and 120 DAT, when more than 50% of the onion plant tops per plot naturally fell over and browned. The bulb yield, in $t.ha^{-1}$, was quantified to commercial and total bulbs harvested in each plot. Commercial bulbs were defined as those with a diameter greater than 35 mm.

The data were submitted to analysis of variance for each experiment, and then to a joint analysis. Data from the DI, in percentage (%), were transformed to arc-sine of the square root for statistical analyses. All data were submitted to statistical analyses with support of SAS, using the procedure GLM. Estimates of heritability in broad sense (h^2) were obtained based on the mean square (MS) of variance components for each area: [(TreatmentMS – ErrorMS / r)] / (TreatmentMS / r), where *r* is the number of replication. Genetic parameters as differential of selection (DS), genetic gain (G), and genetic gain percentage (G%) also were estimated for each population in two areas, according to the equation: $G = DS*h^2$. The DS was considered the difference in bulb yield means of each cycle of recurrent selection in relation to the base population, Alfa Tropical.

Acknowledgements

Carlos A F Santos is also a CNPq researcher.

References

Alimousavi SA, Hassandokht MR, Moharramipour S (2007) Evaluation of Iranian onion germplasm for resistance to thrips. Int J Agr Biol. 9:897-900.

Berilli APCG, Pereira MG, Trindade R, Santos, Costa FR, Cunha KS (2013) Response to the selection in the 11th cycle of reciprocal recurrent selection among full-sib families of maize. Acta Sci Agron. 35:435-441.

Boateng CO, Schwartz HF, Havey MJ, Otto K (2014) Evaluation of onion germplasm for resistance to Iris yellow spot (*Iris yellow spot virus*) and onion thrips, *Thrips tabaci.* Southwest Entomol. 39: 237-260.

Cramer CS, Singh N, Kamal N (2014) Screening onion plant introduction accessions for tolerance to onion thrips and Iris yellow spot. HortScience. 49:1253-1261.

Cramer CS, Corgan JN (2012) 'NuMex Fabian Garcia' onion. HortScience. 47:1369-1371.

Cramer CS, Kamal N, Singh N (2017) Evaluating Iris yellow spot disease incidence and severity in onion germplasm of varying leaf characteristics. HortScience. 52:527–532.

Damon SJ, Groves RL. Havey, MJ (2014) Variation for epicuticular waxes on onion foliage and impacts on numbers of onion thrips. J Amer Soc Hort Sci. 139:495–501.

Diaz-Montano J, Fuchs M, Nault BA, Shelton AM (2010) Evaluation of onion cultivars for resistance to onion thrips (Thysanoptera: Thripidae) and Iris yellow spot virus. J Econ Entomol. 103:925-937.

Diaz-Montano J, Fuchs M, Nault BA, Shelton AM (2011) Onion thrips (Thysanoptera: Thripidae): A global pest of increasing concern in onion. J Econ Entomol. 104:1-13.

Dudley J (2007) From means to QTL: the Illinois long-term selection experiment as a case study in quantitative genetics. Crop Sci. 47.

Ferreira GO, Santos CAF, Oliveira VR, Alencar JA, Silva, DOM (2017) Evaluation of onion accessions for resistance to thrips in Brazilian semi-arid regions. J Hortic Sci Biotechnol. 92: 1-9.

Gill HK, Garg H, Gill AK, Gillett-Kaufman JL, Nault BA (2015) Onion thrips (Thysanoptera: Thripidae) biology, ecology, and management in onion production systems. J Integr Pest Manag. 6:1-9.

Gökçe AF, Basar N, Candar A, Kaderlioglu E, Akbudak N (2012) Onion breeding program in Turkey. Acta Hortic. 969:93-94.

Gonzalez MI, Herrera P (2012) Valinia INIA, a new early storage onion variety for central south Chile. Chil J Agr Res. 72:16-20.

Hallauer AR (1985) Compendium of recurrent selection methods and their applications. Crit Rev Plant Sci. 3:1-33.

IBGE Indicadores IBGE - produção agrícola 2015. Retrieved from ftp://ftp.ibge.gov.br/Producao_Agricola/Fasciculo_Indicadores_IBGE/estProdAgr_201608.pdf. Accessed on December 7, 2019.

Kamal N, Cramer S (2018). Selection progress for resistance to Iris yellow spot in onions. Hortscience. 53:1088-1094.

Khan IA, Shah RI, Said F (2015) Distribution and population dynamics of *Thrips tabaci* (Thysanoptera: Thripidae) in selected districts of Khyber Pakhtunkhwa province Pakistan. J Entomol Zool Stud. 3:153-157.

Loges V, Lemos MA, Resende LV, Menezes D, Candeia JA, Santos, VF (2004) Resistência de cultivares e híbridos de cebola a tripes. Hortic Bras. 22:222-225.

Pereira MG, Amaral Júnior AT (2001) Estimation of genetic components in popcorn based on the nested design. Crop Breed Appl Biot. 1:3-10.

Santos PG, Soares PC, Soares AA (2014) Avaliação do progresso genético obtido em 22 anos no melhoramento do arroz irrigado em Minas Gerais. Pesq Agropec Bras. 34:1889-1896.

Shaikh RR, Acharya MF, Rode NS (1999) Screening of onion varieties against onion thrips, Thrips tabaci Lind. J Entomol Zool Stud. 2:91-96.

Silva VCP, Bettoni MM, Bona C, Foerster (2015) Morphological and chemical characteristics of onion plants (*Allium cepa* L.) associated with resistance to onion thrips. Acta Sci Agron. 37:85-92.