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Yield of Syn-1 synthetic varieties of tropical onion resulting from open-pollinated Brazilian populations

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Abstract

Due to technological limitations for the development of onion hybrids, first-cycle synthetic varieties (Syn1-SV) could be an alternative to partially explore heterotic vigor. The growing areas of onion hybrids in Brazil are mainly defined by bulb yield and uniformity. From this perspective, the present study aimed to develop tropical onion Syn1-SV and estimate mid-parent heterosis (Hm), heterobeltiosis (Hp), and standard heterosis (Hs) as an alternative to hybrid development. Six Syn1-SVs, eight open-pollinated (OP) populations, and one commercial hybrid were evaluated in a randomized block design with three replications, in two semesters, for the commercial bulb yield (CBY) and days to bulb harvest (DBH). Significant differences were observed for treatments (T), semesters (S) and the T*S interaction for both variables (p-value<0.05). The OPs 'Alfa SF RT' in the first semester and 'IPA11' in the second semester were the most precocious treatments. The highest CBY was estimated in the commercial hybrid (105.8 t ha^{-1}) and in 'Alfa SF RT' (45.5 t ha^{-1}) in the first and second semesters, respectively. Three Syn1-SVs showed positive Hm values, ranging from 2.0% to 6.3% for CBY. Three Syn1-SV showed positive Hp values in the first semester, ranging from 3.0% to 5.2%, for CBY. Only the Syn1-SV 'Alfa SF RT' × 'BRS Alfa São Francisco' (48.9 t ha^{-1}) showed positive Hs values, surpassing by a small value the control OP population 'IPA11' (48.0 t ha^{-1}), indicating the potential of Syn1-SV as an option for onion hybrids.

Keywords: Allium cepa, Heterobeltiosis, Heterosis, Standard heterosis

Introduction

Onion (*Allium cepa* L.) is a crop with a large growing area and significant economic potential, ranking as the third most important vegetable worldwide and in Brazil (Santos et al. 2015). In 2021, the Brazilian onion production amounted to 1.64 million tons in 49,119 hectares, with an average production per area of 33.4 t ha^{-1} (IBGE, 2021). Onion cultivation is concentrated in the South, Southeast, Central-West, and Northeast regions of Brazil. In the Northeast region, the largest producing states are Pernambuco and Bahia, with mean yields of 29.3 and 37.0 t ha^{-1}, respectively (IBGE, 2021).

The low onion yield observed in northeastern Brazil may be due to the wide use of open-pollinated cultivars (OPs), which have less yield potential than hybrids and rely on low-technology inputs in some areas, whereas the cultivation of hybrids is growing elsewhere (Santos et al., 2015). The reasons for using OPs include the high cost of hybrid seeds, the susceptibility of some hybrids to the pathogen *Colletotrichum gloeosporioides*, and limitations in developing tropical onion hybrids (Santos et al., 2010).

Furthermore, the vigor, uniformity, stress tolerance, and earliness expressed by onion seedlings are some of the reasons to justify the growing use of the F_1 hybrid (Singh et al., 2017). According to Colombo & Galmarini (2017), the cultivation of hybrid seed is increasing worldwide at a fast pace of 8–10% annually in most vegetable crops.

Nunes et al. (2014) reported a yield of 62.3 ton ha^{-1} for the OP onion 'IPA 11', whereas onion hybrids yielded up to 78.7 t ha^{-1} in the semi-arid region of Baraunas, RN, Brazil. However, hybrid development is still technologically challenging, even with the application of marker-assisted selection to identify lines A and B, the basis of onion hybrid production (Ferreira & Santos, 2018).

In this scenario, an alternative to onion hybrids is developing synthetic varieties (SVs), which allows the

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partial utilization of heterotic vigor. A synthetic variety is developed by crossing inbred lines or populations obtained by selection and, in the simplest of cases, a first generation is very similar to an F_1 hybrid, and SVs are labeled as a series of generations (Syn-1, Syn-2,…, Syn-n) from the initial open-pollinated populations (Brown et al., 2014). A more restrictive concept could be adopted by considering SVs as single hybrids, stopping in the first generation, and releasing Syn.1 after intercrossing two OPs or lines.

Studies with SVs have been reported by Musa & Farid (2018) in *Zea mays* and by Saensee et al. (2012) in *Helianthus annuus*. In *A. cepa*, the pioneers of synthetic varieties were Synthetics 1 and 2 and later the Valenciana Synthetics 14 and 15, all developed by INTA in Argentina (Galmarini, 2000). However, onion SVs are still not planted in Brazil, with bulb production relying on OPs or hybrids.

This study aimed to obtain and estimate heterosis in first-generation synthetic varieties (Syn-1) of tropical onion as an alternative to the development of hybrids in northeastern Brazil.

Materials And Methods

Onion bulbs from open-pollinated (OP) populations of the Embrapa Semi-Arid breeding program (Table 1) were vernalized for 100 days in a cold chamber at 8°C and a relative humidity around 60%. Bulks of vernalized bulbs were grown for seed production considering a minimum distance of 600 m between them, including tree barriers to avoid undesirable cross-pollination. The population size was around 25 plants for a single population.

Seeds of Syn-1 synthetic varieties were obtained for the following crosses: 'BRS Alfa São Francisco' × 'IPA11', 'Cascuda T6' × 'Botucatu', 'Alfa SF RT' × 'BRS Alfa São Francisco', 'Cascuda T7' × 'Botucatu ', 'BRS Rio Vale' × 'BRS Carrancas', and 'Botucatu' × 'BRS Carrancas'. 'Alfa SF RT' was derived by recurrent selection from 'BRS Alfa São Francisco', whereas the Valencian populations 'BRS Rio Vale', 'BRS Carrancas', and 'Cascuda T6' resulted from recurrent selections within the CNPH 6400 base population. 'Botucatu' and 'Cascuda T7 ' originated from recurrent selection within the 'Botucatu' population.

Two experiments were conducted in the experimental field of Bebedouro, Embrapa Semiárido, located in the city of Petrolina-PE. According to the Köppen classification, the region has a BSh-type climate (semi-arid, hot, with a well-established dry season), low and irregular rainfall, an average rainfall rate of 470 mm.year^{-1}, and an average annual temperature of 26.2°C. In both experiments, the experimental design was in randomized blocks, with 15 treatments: six synthetic Syn-1 varieties, eight populations, and a commercial hybrid (Table 1), with three replications. The experimental units measured 1.3 m × 1.5 m, with a plant spacing of 0.12 m x 0.10 m.

The soil was plowed, harrowed, and fertilized with 800 kg ha-^{1} of 06-24-12 NPK before the plants were transplanted. Topdressing fertilization was performed with 120 kg ha^{-1} of N, 60 kg ha^{-1} of K_2O, 60 kg ha^{-1} of Ca, and 60 kg ha^{-1} of Mg. Weeds were controlled with commercial herbicides and other crop management practices such as manual weeding and pest and disease control through preventive chemical application. Drip irrigation was adopted for both experiments, and harvest occurred when 70% of the leaves were tipped over, indicating bulb maturity.

The characteristics evaluated were: 1) commercial bulb yield (CBY) - obtained by the weight of bulbs with diameter > 35 mm and < 90 mm, t ha^{-1}; 2) days to bulb harvest (DBH) - obtained by the number of days from sowing to the tipping of 70% of plants. The analyses of variance were performed with the SAS software by analyzing the individual experiments, as well as joint analysis of the two experiments. The treatment means were compared using the Student-Newman-Keuls (SNK) means test ($p < 0.05$).

The estimations of mid heterosis (Hm), heterobeltiosis or better-parent heterosis (Hp), and the standard or check of economic heterosis (Hs), were performed for the commercial bulb yield, as outlined by Naik et al. (2020): 1) mid heterosis (Hm, %) = ((SV1-MP)/MP)*100; 2) heterobeltiosis (Hp, %)=((SV1-BP)/BP)*100; 3) standard heterosis (Hs, %)=((SV1-SCV)/SCV)*100, where: SV1=average of the first generation from the crossing (Syn-1 synthetic variety), MP=mean of parents, BP=p best parent mean, and SCV=standard commercial variety for cultivar IPA 11, which accounts for most of the areas grown with onion in the region.

Results and Discussion

Significant treatment effects were observed in the first (p-value<0.01) and second semesters (p-value<0.05) for the commercial bulb yield and the days to bulb harvest (Table 1). The coefficients of variance ranged from 3.0% to 22.4% (**Table 1**), indicating acceptable experimental errors.

For the commercial bulb yield in the first semester, the commercial hybrid showed the highest yield (105.8 t ha^{-1}), followed by 'Alfa SF RT' (88.9 t ha^{-1}) and the synthetic Syn-1 variety 'Alfa SF RT' × 'BRS Alfa São Francisco' (70.0 t ha^{-1}). In contrast, the lowest yields were observed for

Table 1. Individual and joint analysis of variance for commercial bulb yield (CBY) and days to bulb harvest in six synthetic populations, eight open-pollinated populations (OP), and one onion hybrid. Petrolina, PE, Brazil

Treatment	CBY (t ha^{-1})			DBH (Days)		
	Semester			Semester		
	1°	2°	1° e 2°	1°	2°	1° e 2°
'BRS Alfa Sao Francisco' × 'IPA11' SV-Syn-1	56.9^{cde}	22.9^{bc}	43.3	142^{a}	113^{a}	128
'Cascuda T6' × 'Botucatu' SV-Syn-1	42.0^{e}	15.7^{c}	31.5	128^{bcdef}	108^{a}	118
'AlfaSF RT'×'BRS Alfa Sao Francisco' SV-Syn-1	69.9^{c}	27.9^{bc}	48.9	123^{efg}	112^{a}	118
'Cascuda T7'x 'Botucatu' SV-Syn-1	44.0^{de}	20.8^{bc}	32.5	139^{abc}	110^{a}	124
'BRS Rio Vale' × 'BRS Carrancas' SV-Syn-1	55.6^{cde}	31.1^{ab}	45.8	142^{a}	112^{a}	127
'Botucatu' × 'BRS Carrancas' SV-Syn-1	52.3^{cde}	25.9^{bc}	39.1	142^{a}	112^{a}	127
'BRS Alfa Sao Francisco' - OP	62.7^{cd}	35.1^{ab}	48.9	121^{fg}	109^{a}	115
'IPA11' - OP	62.6^{cd}	33.3^{ab}	48.0	128^{cdef}	97^{b}	112
'Cascuda T6' - OP	42.6^{e}	14.6^{c}	28.6	133^{abcde}	110^{a}	122
'Botucatu' - OP	50.7^{cde}	15.1^{c}	32.9	126^{defg}	109^{a}	118
'Alfa SF RT' - OP	88.9^{b}	45.5^{a}	71.6	117^{g}	110^{a}	114
'Cascuda T7' - OP	53.5^{cde}	19.8^{bc}	36.7	139^{abc}	107^{a}	123
'BRS Carrancas' - OP	55.6^{cde}	30.2^{ab}	42.9	140^{ab}	113^{a}	127
'BRS Rio Vale' - OP	58.6^{cde}	27.1^{bc}	42.9	133^{abcde}	110^{a}	122
Commercial hybrid	105.8^{a}	33.3^{ab}	69.5	137^{abcd}	105^{a}	121
Block	1029**	84^{ns}	608*	56.3^{ns}	27^{ns}	80*
Treatment (T)	892**	180*	786**	210.8**	48*	154**
Semester (S)	-	-	237032*	-	-	124138*
T*S	-	-	233**	-	-	105**
Error	47	35	58	21	11	16
CV(%)	11.4	22.4	17.4	3.5	3.0	3.3
Mean	60.1	26.3	44.0	132	109	121

^{ns}, ** and * = not significant, significant at 1% and 5% probability by the F-test, respectively. Means followed by the same letter in the columns do not differ at the 5% level by the SNK test.

SV- Syn-1s 'Cascuda T6' × 'Botucatu' and 'Cascuda T6' (Table 1). In the second semester, 'Alfa SF RT' showed the highest yield (45.5 t ha^{-1}), followed by 'BRS Alfa São Francisco' (35.1 t ha^{-1}) (Table 1). Genotypes 'Cascuda T6', 'Botucatu', and VS 'Cascuda T6' × 'Botucatu' showed the lowest yields (Table 1), suggesting that the lowest yield of SV- Syn-1 'Cascuda T6' × 'Botucatu' was due to the low parent yield potential.

The means referring to the days to bulb harvest in the first and second semesters corresponded to 132 and 109 days, respectively (Table 1). The populations that stood out with the shortest cycle were Alfa SF RT in the first half and IPA11 in the second, thus being classified as early cultivars according to the classification proposed by Costa et al. (2016).

Significant effects (p-value<0.01) were observed in the joint experiment analysis for the treatments (T), semesters (S), and the T*S interaction (Table 1). The coefficient of variation was lower than 18% (Table 1), indicating that the experimental conditions and errors were acceptable. The synthetic varieties Syn-1s 'BRS Alfa São Francisco' × 'IPA11', 'Alfa SF RT' × 'BRS Alfa São Francisco', 'BRS Rio Vale' × 'BRS Carrancas', and 'Botucatu' × 'BRS Carrancas' showed commercial bulb yield means close to the commercial cultivars 'BRS Alfa São Francisco', 'IPA11', 'BRS Carrancas', and 'BRS Rio Vale' in the average of the two experiments (Table 1).

The difference in the maturation cycle in the joint analysis (1st + 2nd semester) was 16 days, with one commercial cultivar showing greater precocity (112 days), whereas two SV-Syn-1s had a cycle of 118 days, close to the more precocious commercial cultivar (Table 1).

Positive mid-parent heterosis (Hm) for the commercial bulb yield was only observed in the second semester for SV-Syn-1s 'Cascuda T6' × 'Botucatu' (6.0%), 'Cascuda T7' × 'Botucatu' (19.5%), 'BRS Rio Vale' × 'BRS Carrancas' (8.6%), and 'Botucatu' × 'BRS Carrancas' (14.5%) (Table 2). In the joint semester analysis, SV-Syn-1s 'Cascuda T7' × 'Botucatu', 'BRS Rio Vale' × 'BRS Carrancas', and 'Botucatu' × 'BRS Carrancas' showed postive Hm values ranging from 2.0% to 6.3% (Table 2).

Heterobeltiosis (Hp) was negative for all SV-Syn-1s in the first semester and positive for three SV-Syn-1s in the second semester. In the average of the two evaluations, no SV-Syn-1s showed positive values (Table 2). The standard heterosis (Hs) value, with 'IPA 11' as a check, was positive for SV-Syn-1 'Alfa RT' × 'BRS Alfa São Francisco' in the first semester, negative for all SVs in the second semester, and positive for SV-Syn-1 'Alfa SF RT' × 'BRS Alfa São Francisco' in the combined analysis (**Table 2**).

Obtaining onion hybrids is technologically challenging, taking up to 20 years in temperate regions

Table 2. Mid-parent heterosis (Hm), heterobeltiosis (Hp), and standard or economic heterosis (Hs) estimated for commercial bulb yield of synthetic onion varieties. Petrolina, PE, Brazil

SV	Hm			Hp			Hs		
	Semester			Semester			Semester		
	1st	2nd	Mean	1st	2nd	Mean	1st	2nd	Mean
1	-9.1	-33.1	-21.1	-9.2	-34.8	-22.0	-9.1	-31.2	-9.8
2	-9.9	6.0	-1.9	-17.1	4.3	-6.4	-32.9	-52.8	-34.4
3	-7.7	-30.9	-19.3	-21.3	-38.8	-30.1	11.7	-16.2	1.9
4	-15.5	19.5	2.0	-17.8	5.2	-6.3	-29.7	-37.5	-32.3
5	-2.6	8.6	3.0	-5.1	3.0	-1.1	-11.2	-6.6	-4.6
6	-1.9	14.5	6.3	-6.2	-14.3	-10.2	-16.5	-22.2	-18.5
M	-7.8	-2.6	-5.2	-12.8	-12.6	-12.7	-14.6	-27.8	-16.3

1='BRS Alfa São Francisco' × 'IPA11', 2 = 'Cascuda T6' × 'Botucatu', 3 = 'Alfa RT' × 'BRS Alfa São Francisco', 4 = 'Cascuda T7' × 'Botucatu', 5 = 'BRS Rio Vale' × 'BRS Carrancas', 6 = 'Botucatu' × 'BRS Carrancas'. M=mean

to identify 'A' lines (male-sterile lines), 'B' lines (maintainer lines), and 'C' lines (pollinator with acceptable general or specific combining abilities) (Pike, 1986). According to Ferreira & Santos (2018), even with marker-assisted selection, it is expected that three years are required only for the identification of 'A' and 'B' onion lines in tropical environments where the seed-to-seed cycle is one year. In this scenario, using synthetic onion varieties could be an option for farmers with fewer resources, assuming that such varieties could be able to achieve yields close to onion hybrids. In this study, we report a first attempt to develop and evaluate synthetic Syn-1 onion varieties as an alternative to onion hybrids in northeastern Brazil.

The onion SV-Syn-1s evaluated in the present study yielded less than the parents, differing from the results reported by Falk et al. (1998) with synthetic varieties of *Brassica rapa* yielding 23% more than parents, and by Musa & Farid (2018), who reported synthetic corn varieties with higher yield than corn populations. For Faria et al. (2012), from a theoretical point of view, SV should perform better than parents as they are allogamous species and should have higher heterozygosity.

Higher yields for commercial bulb yield were observed in the first semester compared to the second semester, which influenced the ranking and resulted, for the Treatment*Semester interaction, in the 'Alfa SF RT' hybrid showing the highest yield in the 2nd semester, whereas the commercial hybrid had the highest yield in the 1st semester. Temperatures in the region are higher in October, November, and December (Santos, 2011), which interferes with bulb yield. The high temperature also favors increases in the population of *Thrips tabaci*, the main onion pest in the region, and 'Alfa SF RT' is recommended for planting in the second semester due to its resistance to this pest and high temperatures. According to Costa et al. (2016), the absence of climatic conditions that meet the cultivar's requirements results in the formation of bulbs with low commercial value.

Most heterobeltiosis (Hp) estimates were negative in the present study, corroborating some results reported by Evoor et al. (2007), who reported Hp estimates for commercial bulb yield ranging from -30.14% to 45.31%, whereas Abubakar & Ado (2008) reported Hm and Hp values for onion bulb yield ranging from –78.82 to 24.73% and -88.30% to 3.08%, respectively.

A positive heterosis value by itself does not imply superior genotypes as heterosis portrays the superiority (or not) in relation to the parent average, which could be due to lower inbred parent yields. In the present experiment, the SV-Syn-1 with the highest positive heterosis (Hm) value for commercial bulb yield was 'Botucatu' × 'BRS Carrancas' (6). However, this hybrid was not the most yielding and was lower than the other SV-Syn-1s and other commercial cultivars (Tables 1 and 2).

The standard or economic heterosis (Hs) is of greater importance than Hm and Hp as it indicates the possibility that an SV may have a competitive market potential in relation to a cultivar. To Ibarra-Sánchez et al. (2019), parents should be homozygous lines with a high combining ability that have been submitted to selection, resulting in SVs with high genetic variability and heterozygosity, which directly relates to their performance and stability. In the present study, the onion SV-Syn-1s were derived from highly heterozygous parents, reducing the likelihood of developing SVs with high heterozygosity rates (Alves & Santos, 2022). A better SV-Syn-1 performance should be expected with self-fertilization followed by selection for one to two generations before performing new crosses to develop SV-Syn-1.

The negative heterosis values of the SV-Syn-1s in the present study could be associated with high heterozygosity and the presence of intra-population recessive alleles, as reported by Alves & Santos (2022), even for parents derived from the same base population, e.g., 'BRS Rio Vale', 'BRS Carrancas', and 'Cascuda T6' derived from CNPH 6400,' and 'Botucatu' and 'Cascuda T7' derived from the base population 'Botucatu'. Another factor that may have influenced the negative heterosis values was the low cross-pollination rate estimated, ranging from 15% to 71% (Alves & Santos, 2022). From this perspective, we propose developing and evaluating Syn-1 with one to two self-fertilization cycles as an alternative with better chances of outperforming traditional OPs. In this scenario, seed companies retaining SVs parents and farmers should buy onion seeds every year to explore part of the heterotic vigor in case of positive commercial heterosis.

Conclusion

Only the synthetic Syn-1 variety 'Alfa RT' × 'BRS Alfa São Francisco' (48.9 t ha^{-1}) had a positive standard or economic heterosis (Hs), outperforming the 'IPA11' (48.0 t ha^{-1}) check population for commercial bulb yield and indicating the potential of synthetic varieties as options to onion hybrids.

The synthetic Syn-1 varieties 'Cascuda T7' × 'Botucatu', 'BRS Rio Vale' × 'BRS Carrancas', and 'Botucatu' × 'BRS Carrancas' have positive mid-parents heterosis ranging from 2.0% to 6.3% for commercial bulb yield.

No positive heterobeltiosis (Hp) was estimated for any of the SV-Syn-1 in the combined semester analysis, and positive Hp estimates for SV-Syn-1 'Cascuda T6' × 'Botucatu', 'Cascuda T7' × 'Botucatu', and 'BRS Rio Vale' × 'BRS Carrancas' were obtained in the second semester for commercial bulb yield.

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