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RECURRENT SELECTION AS A BASIS FOR THE WIDESPREAD DISSEMINATION AND CULTIVATION OF ONIONS: EXAMPLES FROM NORTHEASTERN BRAZIL

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ABSTRACT

Goal: This study aimed to review phenotypic recurrent selection (PRS) in the onion development for northeastern Brazil.

Theoretical Framework: Domesticated in the Central Asia (35°N and 50°N), onion is one of the main vegetable species widely cultivated around the globe. PRS methods are efficient for genetic gains (GG), maintaining variability in the population.

Method: Cultivars of two onion-breeding programs for the Brazil Northeast region were analyzed to evaluate the PRS efficiency.

Results and discussion: 1. PRS resulted in the development of cultivars Valeouro Ipa 11 and Franciscana IPA 10, at Belém do São Francisco (08°45'S, 38°57'W), replacing 70% of imported cultivars. 2. PRS for resistance to *Thrips tabaci* (09°09'S, 40°22'W), a pest of global importance, in the 'BRS Alfa São Francisco' resulted in GG of 6%/cycle, with a bulb yield of 32.1 ton.ha^{-1}, contrasting with 15.9 and 14.0 ton.ha^{-1} of 'Alfa Tropical' and 'IPA 10', respectively ($p<0.01$). In direct planting and high population density, BRS Alfa São Francisco produced 60 ton.ha^{-1} in the second semester. 3. The PRS for external brownish or purplish cataphylls and greater thickness (09°09'S, 40°22'W), in the CNPH 6400, resulted in GG/cycle of 6.83% and 11.54% in the brownish population and 7.84% and 10.92% in the purplish population, evaluated in two locations.

Research implications: These examples emphasize the efficiency of PRS for accumulating favorable alleles, allowing the recommendation of onion cultivars in areas different from the domestication region.

Originality/Value: The adopted approach have distinguished the massal selection from recurrent selection.

Keywords: *Allium cepa*, Genetic-Gain, Open Pollination.

SELEÇÃO RECORRENTE COMO BASE PARA DIFUSÃO E CULTIVO DE CEBOLAS: EXEMPLOS DO NORDESTE BRASILEIRO

RESUMO

Objetivo: Este estudo teve como objetivo rever a seleção fenotípica recorrente (PRS) no desenvolvimento da cebola para o Nordeste do Brasil.

Estrutura teórica: Domesticada na Ásia Central (35°N e 50°N), a cebola é uma das principais espécies vegetais amplamente cultivadas em todo o mundo. Os métodos PRS são eficientes para ganhos genéticos (GG), mantendo a variabilidade na população.

Método: Foram analisadas cultivares de dois programas de cultivo de cebola para a região Nordeste do Brasil para avaliar a eficiência do PRS.

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Resultados e discussão: 1. O PRS resultou no desenvolvimento das cultivares Valeouro Ipa 11 e Franciscana IPA 10, em Belém do São Francisco (08°45'S, 38°57'W), substituindo 70% das cultivares importadas. 2. PRS para resistência ao Thrips tabaci (09°09'S, 40°22'W), praga de importância global, no 'BRS Alfa São Francisco' resultou em GG de 6%/ciclo, com rendimento de bulbo de 32,1 ton.ha-1, contrastando com 15,9 e 14,0 ton.ha-1 de 'Alfa Tropical' e 'IPA 10', respectivamente (p<0,01). No plantio direto e alta densidade populacional, a BRS Alfa São Francisco produziu 60 ton.ha-1 no segundo semestre. 3. O PRS para catafílicas externas acastanhadas ou arroxeadas e maior espessura (09°09'S, 40°22'W), na CNPH 6400, resultou em GG/ciclo de 6,83% e 11,54% na população acastanhada e 7,84% e 10,92% na população roxa, avaliada em dois locais.

Implicações da pesquisa: Estes exemplos enfatizam a eficiência do PRS para acumular alelos favoráveis, permitindo a recomendação de cultivares de cebola em áreas diferentes da região de domesticação.

Originalidade/valor: A abordagem adotada distinguiu a seleção em massa da seleção recorrente.

Palavras-chave: *Allium cepa*, Ganho Genético, Polinização Aberta.

SELECCIÓN RECURRENTE COMO BASE PARA LA DIFUSIÓN Y EL CULTIVO GENERALIZADO DE CEBOLLAS: EJEMPLOS DEL NORESTE DE BRASIL

RESUMEN

Objetivo: Este estudio tuvo como objetivo revisar la selección fenotípica recurrente (PRS) en el desarrollo de cebolla para el noreste de Brasil.

Marco teórico: Domesticada en Asia Central (35°N y 50°N), la cebolla es una de las principales especies vegetales ampliamente cultivadas en todo el mundo. Los métodos de PRS son eficientes para las ganancias genéticas (GG), manteniendo la variabilidad en la población.

Método: Se analizaron cultivares de dos programas de mejoramiento de cebolla para la región noreste de Brasil para evaluar la eficiencia del PRS.

Resultados y discusión: 1. PRS dio lugar al desarrollo de los cultivares Valeouro Ipa 11 y Franciscana IPA 10, en Belém do São Francisco (08°45'S, 38°57'W), reemplazando el 70% de los cultivares importados. 2. La SPR para la resistencia a Thrips tabaci (09°09'S, 40°22'W), una plaga de importancia mundial, en el 'BRS Alfa São Francisco' resultó en GG de 6%/ciclo, con un rendimiento de bulbo de 32.1 ton.ha-1, en contraste con 15.9 y 14.0 ton.ha-1 de 'Alfa Tropical' e 'IPA 10', respectivamente (p<0.01). En siembra directa y alta densidad de población, BRS Alfa São Francisco produjo 60 ton.ha-1 en el segundo semestre. 3. El PRS para catafilos externos parduscos o morados y de mayor espesor (09°09'S, 40°22'W), en el CNPH 6400, resultó en GG/ciclo de 6.83% y 11.54% en la población pardusca y 7.84% y 10.92% en la población morada, evaluados en dos lugares.

Implicaciones de investigación: Estos ejemplos enfatizan la eficiencia de PRS para acumular alelos favorables, permitiendo la recomendación de cultivares de cebolla en áreas diferentes de la región de domesticación.

Originalidad/Valor: El enfoque adoptado ha distinguido la selección masiva de la selección recurrente.

Palabras clave: *Allium cepa*, Ganancia Genética, Polinización Abierta.

1 INTRODUCTION

Onion (*Allium cepa*: Amaryllidaceae) is cultivated in 141 out of 193 countries, in both low and high latitudes and altitudes, and in regions with varying temperatures (Cramer et al., 2021). India, China, Egypt, the United States of America, and Bangladesh are the five largest global producers. Meanwhile, the highest yields for this crop have been recorded in the Republic of Korea, Guyana, the United States, Botswana, and Australia (FAO, 2022). In this scenario, Brazil ranks 12th in onion production (1.65 million tons) and 36th in yield (33.9 ton.ha^{-1}) (FAO, 2022), with its Northeast region contributing approximately 20% of the national production.

Central Asia is considered the probable region of domestication for *A. cepa*, situated between 35°N and 50°N, with average winter temperatures ranging from -3°C to 20°C and summer temperatures from 20°C to 40°C (Yusupov et al., 2020). Archaeological evidence suggests that onion was among the first plants to be domesticated, approximately 4700 years ago (Ochar & Kim, 2023). According to these authors, domestication involved the cultivation of wild onion species, followed by the selection of specific genotypes based on desired traits by early farmers.

Furthermore, Fritsch and Friesen (2002) state that the Romans introduced the onion to northern regions beyond the Alps and to western and central Europe at the beginning of the Christian era, cultivating it in special gardens (cepinae). They also note that onions were among the first plants brought by Europeans to the Americas and the Caribbean during the early periods of colonization.

Azorean immigrants brought onion varieties to the Rio Grande region (latitude 32°02'), Rio Grande do Sul, and Itajaí (latitude 26°54'), Santa Catarina, in the 18th century. From the basic germplasm 'Garrafal,' three main populations resulted from selections made by growers: Baia Periforme, Pera Norte, and Crioula (Barbieri, 2008).

Onion breeding in the Northeast region of Brazil began in 1972. This initiative introduced germplasm from the Baia Periforme group, from the ESALQ-USP program in Piracicaba (22°42'S, 47°38'), to the experimental station in Belém do São Francisco (08°45'S, 38°57'W), managed by the Pernambuco Research Company (Costa et al., 1999).

Onion cultivars require a specific number of light hours per day for bulb formation. They are classified into short-day (SD) types, needing 12-14 hours of light; intermediate-day (ID) types, needing 12-14 hours; and long-day (LD) types, needing 14-16 hours. Long-day cultivars do not bulb satisfactorily under short-day conditions. When an LD cultivar is subjected to SD conditions, bulb formation does not occur. Conversely, an SD cultivar subjected to LD conditions will bulb prematurely, resulting in non-commercially viable bulbs. Additionally, cultivars with the same photoperiod requirements will accelerate bulb formation and plant maturation under high temperatures (Havey, 2024). The onion cultivars in Northeast Brazil are of the SD type.

Despite being a temperate species, onion seed production is feasible in the Brazilian semi-arid region, where minimum temperatures rarely reach 15°C. To achieve this, bulb vernalization, or a cold period for transitioning bulbs from the vegetative to the reproductive phase, is conducted in cold chambers at temperatures between 4°C and 8°C for up to 150 days. In the Brazilian semi-arid conditions, the seed-to-seed cycle can be completed in up to 12 months, including bulb production, cold chamber vernalization, and bulb planting for seed production. In temperate regions, the seed-to-seed cycle can take up to 24 months, presenting an advantage for breeding programs in the Brazilian semi-arid region (Santos et al., 2010).

2 THEORETICAL FRAMEWORK

Recurrent selection is defined as a group of plant breeding procedures consisting of repetitive cycles of selecting exceptional genotypes for a specific objective in a heterozygous population. The selected group of plants is subsequently subjected to genetic recombination (open pollination), enhancing the phenotypic performance of the selected population segment (Hallauer et al., 2010). According to these authors, the primary virtue of recurrent selection methods is that they increase the frequency of favorable alleles for quantitatively inherited traits, e.g., grain yield and bulb weight, while maintaining variability for subsequent cumulative genetic gains.

Mass selection (MS) is often mistakenly cited in some breeding programs as similar to phenotypic recurrent selection (PRS). However, in recurrent selection, selected female plants are randomly crossed only with selected male plants. This modification doubles the genetic gain compared to mass selection due to the control of both male and female parents (Sing et al., 2021). The difference between genotypic recurrent selection (GRS) and phenotypic recurrent selection (PRS) lies in the selection basis; GRS is based on progeny performance, while PRS is based on individual phenotype without including progeny testing.

Hallauer et al. (2010) divide recurrent selection procedures into two main categories: a) intra-population improvement, where selection occurs within the population, with methods such as half-sib and full-sib family selection; and b) inter-population improvement, where selection occurs between two populations, including reciprocal recurrent selection methods that maximize the use of general and specific combining abilities of the populations.

This study aimed to review the application of recurrent selection for the development and recommendation of onion cultivars for the Northeast region of Brazil by the Pernambuco Agricultural Research Corporation (IPA) and Embrapa Semiárido.

3 METHODOLOGY

Cultivars of two onion breeding programs for the Brazil Northeast region were analyzed to evaluate the efficiency of phenotypic recurrent selection:

1) Cultivars Valeouro IPA 11 and Franciscana IPA 10 from the IPA breeding program. These IPA cultivars were developed at the Belém do São Francisco station (latitude 08°45'14"S, longitude 38°57'57"W, altitude 310m) over nearly 30 years (Costa et al., 1999).

'Valeouro IPA-11' resulted from the cross of Roxa IPA-3 × Belém IPA-9. 'Roxa IPA-3' was obtained through cycles of mass selection from the Roxa do Barreiro population, originating from ESALQ, University of São Paulo, Piracicaba, SP. 'Belém IPA-9' was developed through several cycles of mass selection (phenotypic recurrent selection) from a population resulting from polycrosses of Baia Periforme type onions from Piracicaba, São Paulo. 'Franciscana IPA-10' resulted from the cross of Roxa IPA-3 × Red Creole, the latter being an American cultivar (Costa et al, 1999).

2) Cultivar BRS Alfa São Francisco from the Embrapa Semiárido breeding program. BRS Alfa São Francisco was developed through five cycles of phenotypic recurrent selection for various traits within the Alfa Tropical population, under the conditions of Petrolina, PE (latitude 09º09’00’’S, longitude 40º22’00’’W, altitude 360m). The base population of Alfa Tropical originated from the polycross of 10 Baia Periforme type cultivars, having undergone 11 cycles of phenotypic recurrent selection under the conditions of Brasília, DF (latitude 15º56’00’’S, longitude 48º08’00’’W, elevation of 997m above sea level).

In the sixth cycle of phenotypic recurrent selection (PRS), resistance to *Thrips tabaci* was emphasized in BRS Alfa São Francisco. No insecticides were applied to control the pest, neither during the bulb production phase nor the seed production phase after vernalization in cold chambers. The number of selected bulbs per cycle ranged from 600 to 1200.

The genetic gain for commercial bulb yield over six cycles in 'BRS Alfa São Francisco' for resistance to *T. tabaci* was estimated through experiments conducted using a randomized block design with three replications in two environments. The degree of nymph and adult insect infestation on the plants was assessed five times after transplanting (Ferreira et al. 2021).

3) Cultivars BRS Riovale and BRS Carrancas, from the Embrapa Semiárido breeding program. 'Valenciano' type populations were selected from cycle IV of the CNPH 6400 population, which resulted from the cross between 'Baia' × 'Valcatorce INTA' onions, developed in Brasília, DF. Two populations were selected from the control population CNPH 6400 after ten cycles of phenotypic recurrent selection (PRS) under conditions in Petrolina, PE. The main selection criteria were adherence and thickness of cataphylls, round bulbs, and brownish or purplish skin. 'Valcatorce INTA,' selected from 'Valenciana Synthetic 14,' requires photoperiods longer than 14 hours to produce bulbs and has medium-sized, globular bulbs with two to three dark brown scales (Galmarini 2000).

Genetic gains in onion bulb yield over five and six cycles for the 25CA10 (yellow) and T811CR13 (purple) populations of the 'Valenciano' type, respectively, were estimated in experiments conducted in a randomized block design with three replications in two environments. The control population CNPH 6400 served as the basis for comparison and estimation of genetic gains (Oliveira et al. 2017).

4 RESULTS AND DISCUSSION

1. Recurrent Selection for the Development of Onion Cultivars in the IPA Series for the Northeast Region

In the São Francisco Valley, historically the primary onion-producing region in the Northeast, the dominance of cultivars can be divided into four phases: From 1940 to 1980, the variety Amarela Chata das Canarias, originating from the Canary Islands, Portugal, was predominant. This variety exhibited high susceptibility to diseases and limited post-harvest preservation. From 1980 to 1992, Texas Early 502, developed for the conditions in Texas, USA, became predominant. It offered good yield and seed quality but was also susceptible to major diseases and had post-harvest preservation issues. From 1992 to 2012, IPA cultivars Vale Ouro IPA-11, with yellow bulbs, and Franciscana IPA-10, with purple bulbs, dominated cultivation in the region. These cultivars demonstrated yields around 30 $ton.ha^{-1}$, good post-harvest preservation, and resistance to major diseases (Costa et al., 1999). From 2012 to the present, foreign onion hybrids have increased in the cultivated area, becoming dominant in the Irecê region, BA, the main onion-producing hub in the Northeast.

The varieties developed by IPA are successful examples of onion breeding, capable of replacing up to 70% of imported cultivars with regionally developed ones. These cultivars, created through successive cycles of phenotypic recurrent selection, have enjoyed widespread acceptance among growers for over 10 years.

2. Phenotypic Recurrent Selection for High Temperatures and Resistance to *Thrips tabaci* at Embrapa Semiárido

The genotype BRS Alfa São Francisco showed a selection response or gain of 25.3% or 10.9 $ton.ha^{-1}$ of commercial bulbs in the first three cycles of phenotypic recurrent selection (PRS) in Alfa Tropical (Santos et al., 2003). BRS Alfa São Francisco was selected and recommended for the late second half of the year, when temperatures are higher and the rainy season occurs in the São Francisco Valley region. The base population of Alfa Tropical, when evaluated in Petrolina, PE, produced bulbs of low commercial quality and reduced productive potential.

In the IX selection cycle of BRS Alfa São Francisco for *T. tabaci*, the commercial yield of bulbs was 32.1 $ton.ha^{-1}$, while the base population 'Alfa Tropical' and the control cultivar 'IPA 10' yielded 15.9 and 14.0 $ton.ha^{-1}$, respectively ($p<0.01$). Broad-sense heritability values ranged from 0.65 to 0.74 for bulb yield, with an estimated average genetic gain of 1.0 $ton.ha^{-1}$ or 6% per selection cycle for thrips resistance (Ferreira et al., 2021).

Table 1

Total and commercial bulb production, mean squares (MS), coefficient of variation (CV) in six cycles of recurrent selection for resistance to T. tabaci in the 'BRS Alfa São Francisco' and two control cultivars (Alfa Tropical and IPA 10) of onion evaluated in the municipalities of Petrolina, PE, and Juazeiro, BA (polled data).

Population	Bulb yield $t.ha^{-1}$		
	Commercial (C)	Total (T)	C/T
Alfa SF TT C-IV	26.94	34.30	0.82
Alfa SF TT C-V	23.78	31.28	0.76
Alfa SF TT C-VI	24.18	32.16	0.81
Alfa SF TT C-VII	26.99	35.50	0.79
Alfa SF TT C-VIII	28.90	35.55	0.85
Alfa SF TT C-IX	32.07	38.40	0.86
Alfa Tropical	15.87	24.20	0.64
IPA 10	13.99	15.93	0.86
Trat MS	228.6**	303.1**	-
Local MS	20.23	8.43	-
Trat*Local MS	32.84	36.23	-

CV (%)	20.69	16.73	-
Cycles mean	27.14	34.54	
Overall Mean	23.86	30.18	-

**: significant at 1% probability, by F test. Adapted from (Ferreira et al. 2021).

T. tabaci is the primary pest in the Northeast region of Brazil, thriving in high temperatures. Onion producers apply insecticides up to three times a week to minimize losses from insect attacks. This practice incurs additional costs and poses potential environmental and consumer health risks (Ferreira et al. 2021). Onion thrips are a global concern due to their increasing pesticide resistance and ability to transmit other pathogens, such as the Iris yellow spot virus (IYSV), which can result in more than a 50% reduction in bulb yield and total loss when combined with IYSV (Diaz-Montano et al. 2011).

In the XI cycle of phenotypic recurrent selection (PRS) for thrips in the BRS Alfa São Francisco population (Fig. 1), direct-seeded with a population density of ~830,000 plants.ha^{-1}, yielded 60 ton.ha^{-1}. This was 10% higher than a commercial hybrid in the same area during the late second half of the year in Canudos, BA. During this planting, insecticide sprays were applied for thrips control.

Figure 1

BRS Alfa São Francisco in direct seeding in an area in Canudos, BA.

These results indicate the efficiency of the PRS method in increasing the frequency of favorable alleles in `BRS Alfa São Francisco` for resistance to *T. tabaci*. Additionally, they suggest the possibility of cultivation with no or reduced insecticide applications to control the primary onion pest.

3. Phenotypic Recurrent Selection for Brown and Thicker Outer Scales at Embrapa Semiárido

Heritability values in the broad sense ranged from 0.47 to 0.85 for commercial bulb yield. The genetic gain per cycle for 25CA10 was 6.83% and 11.54% in Juazeiro and Petrolina, respectively. For T811CR13, the gains were 7.84% and 10.92% in these two environments, respectively (Oliveira et al., 2017). These results attest to the efficiency of PRS for accumulating favorable alleles in 'Valenciano' type onion populations.

The outer scale, also known as the tunic or skin, is the layer that surrounds the onion bulb. It can vary in color, thickness, and transparency. Onions cultivated in the Northeast region of Brazil are typically yellow with a thin tunic, while the 'Valenciana' variety from Argentina features a darker yellow color and a thicker tunic. The 'Valenciano' type is widely imported from Argentina to supply the Brazilian market, especially from April to June, when it fetches the highest prices (Oliveira et al., 2017).

Populations 25CA10 (Fig. 2A) and T811CR13 (Fig. 2B) were registered with the Ministry of Agriculture, Livestock, and Supply as BRS Riovale and BRS Carrancas, respectively. These are the first 'Valenciano' type onion cultivars available for the Northeast region.

Figure 2

'Valenciano' type onion cultivars: BRS Riovale with yellow scales and brown tunic (A) and BRS Carrancas with purple scales and purplish tunic.

High heterozygosity and outcrossing favored wide adaptation

Onion is an herbaceous species with hermaphroditic flowers, exhibiting protandrous dichogamy, where the androecium becomes viable before the gynoecium (Currah, 2002). This floral system promotes cross-pollination (OP), despite the plant being perfectly capable of self-pollination. Cross-pollination enhances high heterozygosity, recombination, and selection of favorable alleles, generating new potential genotypes adapted to different conditions and increasing hybrid vigor in a species (Allard, 1999).

Alves and Santos (2022) estimated heterozygosity rates ranging from 0.82 to 1.00 in eight populations of tropical onion. High heterozygosity, a measure of genetic variation within a population, favors plant vigor and the yield of onion populations. Onion's high heterozygosity, coupled with its outcrossing mating system, resulted in extensive variability, facilitating adaptation to distinct edaphoclimatic conditions from its domestication region.

Inbreeding depression, the opposite of heterosis vigor exploited in hybrids, is the decline in quantitative trait expression caused by high homozygosity, resulting in less vigorous plants and lower seed yield (Hallauer et al., 2010). Onion's strong inbreeding depression reduces the viability to two or three successive self-fertilization cycles (Currah, 2002), further promoting heterozygosity in this crop.

Ttheoretical simulation demonstrated the superiority of PRS over mass selection (MS).

Let us estimate the probability of obtaining the AABBCC genotype, which has favorable alleles for a specific trait. First, consider the initial frequency of p=q=0.5, yielding $(1/4)^3 = 1/64$. Next, with allele frequencies of A=0.1, B=0.2, and C=0.3, a population of 63,960 plants (95%) ($p=3.6\times10^{-5}$) would be required to achieve the AABBCC genotype in one cycle of mass selection.

However, applying PRS increases allele frequency with each selection cycle. This process could raise the initial allele frequencies to A=0.6, B=0.7, and C=0.8, resulting in a population of 19 plants (95%) (p=0.112) needed to obtain the AABBCC genotype.

Consequently, this makes it 3,136 times more likely to achieve the AABBCC genotype with multiple PRS cycles compared to one mass selection cycle.

An experiment on oil and protein content in maize, initiated in 1886 at the University of Illinois, USA, confirms the superiority of repetitive selection or PRS. After 100 generations of selections, variability had not been eliminated, and genetic progress continued for 'Illinois High Oil' and 'Switchback High Oil' (Dudley & Lambert, 2004). According to these authors, the initial aim was to determine if maize grain composition was altered by selection.

The breeding programs for onion in Northeast Brazil, conducted by IPA (08°45'S, 38°57'W) and Embrapa (09°09'S, 40°22'W), operate in areas with high temperatures. Minimum temperatures rarely drop to 17°C from July to August, while maximum temperatures reach ~40°C from October to December. These conditions differ significantly from the climate of onion domestication in Central Asia, between latitudes 35°N and 50°N. In practice, initial onion farmers' application of PRS (Ochar & Kim, 2023) and breeding programs in different cultivation zones led to the wide global adaptation of onion.

5 CONCLUSION

The analyses of cultivar development in Northeast Brazil emphasize the efficiency of recurrent selection for accumulating favorable alleles in both IPA and Embrapa Semiárido breeding programs, allowing the recommendation of onion cultivars in areas with high temperatures, different from the domestication region.

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