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Phenotypic, genotypic, and environmental correlations between characters in onion segregate populations obtained under different generations

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ABSTRACT. Onion (Allium cepa L.) is the third most valuable vegetable crop worldwide and the third most produced in Brazil. The knowledge of the nature and the value of the relationship between the traits of interest is very important, since it is possible to select a main trait, with low heritability or difficult measurement, obtaining higher genetic gain faster than with direct selection. The aim of this work was to estimate the genotypic, phenotypic and environmental correlations between the characteristics of the plant, the bulb and seed production in onion segregating populations obtained from different breeding methods. Most of the estimations of the genetic correlations (rg) were higher than the phenotypic (rp) and the environmental (re) ones. The genotypic, phenotypic and environmental correlation coefficients for plant and bulb characteristics were low, except for plant vigour and its components (plant height, neck diameter and plant architecture). The phenotypic and genotypic correlations revealed an association between the traits related to the plant vigour in onion, nevertheless, it was not reflected in the bulb and seed production, in the two years evaluated. The traits “Seed setting” and “Resistance in Alternaria” can be useful in the indirect selection for “Seed mass per umbel.

KEY WORDS: Onion Segregating Populations; Genetic

Correlations; Intercross Between Plants; Breeding Methods.

INTRODUCTION

Onion (*Allium cepa* L.) was originated in Central Asia and it has been cultivated since ancient times (3000 BC) because of its unique flavour and medicinal properties (Galmarini et al., 2001; Shigyo and Kik, 2008). The onion bulb is not only edible, but it is also well-known for its medicinal and functional properties, since ancient time; Pliny the Elder, for example, in his Naturalis Historia, describes 30 ailments that can be alleviated by onions and pointed out that any onion containing dishes are, to a certain extent, curative as well as more nourishing and tasty (Lisanti et al, 2015). Consumption of onions and related Alliums, including garlic (*Allium sativum* L.) and leek (*A. ampeloprasum* L.), is associated with reductions in blood lipids, cholesterol, and platelet activity, contributing to decreased risk of cardiovascular disease (Sainani et al., 1976; Kendler, 1987; Augusti, 1990). Vegetables are the most important source of phenolic compounds in the Mediterranean diet, among which flavonoids in particular are thought to be essential bioactive species that provide health benefits (Ninfali et al., 2005; Panico et al., 2005). Bulb onion has been recognized as an important reservoir of valuable phytonutrients such as flavonoids, fructo-oligosaccharides, thiosulfinates, and other sulfur containing compounds (Slimestad et al., 2007).

Onion is the third most valuable vegetable crop worldwide and the third most produced in Brazil. In 2015, the total production of onion was about 1,42 million tons in 56,4 thousand hectares harvested (IBGE, 2016), with an average productivity of 25, 2 ton. ha^{-1}. It is estimated that about 40% of this volume is hybrid onion, it is expected to continue growing in the next years. In countries such as Brazil, the use of hybrids is recent, and takes up about 20% of the planted area, being this percentage lower than in countries like US and Japan, where the planted area with hybrid onion reaches 81% and 83% respectively (Almeida, 2015). Although huge genetic diversity is available in bulb onion, crop improvement progress is not at the pace of other monocot taxa, such as grasses (McCallum 2007, Varshney et al. 2012).

Systematic breeding started with mass selection in various countries during the 19th century, and the discovery of cytoplasmic male sterility paved the way for development of F1 hybrids in the middle of 20th century (Brewster 2008, McCallum et al. 2008). Nowadays, F1 hybrids predominate in regions where long-day onions are grown and open-pollinated varieties (OP) predominate in the short-day growing regions of Asia and Africa (Currah and Proctor 1990, Brewster 2008). Due to this Brazilian’s potential market several onion’s breeding programs are being developed to produce hybrids. In these programs, the selection of the populations is done in first place via mass selection (before flowering), where several traits of the plant and the bulb are evaluated. Then, the inbred lines are obtained from the selected populations. Because these programs begins with a large number of genetic materials, the process is arduous, and the seed’s production cost is high. Bulb onion is an outcrossing, biennial diploid (2n=2x=16), which is highly susceptible to inbreeding (Brewster, 2008). Production of onion inbreds is a time-consuming task because of the biennial and open-pollinated nature of the plant. Up to five generations of selfing (~10 years) are required to stabilize agronomically important traits (Alan et al, 2004). The knowledge of the nature and the value of the relationship between the traits of interest is very important, since it is possible to select a main trait, with low heritability or difficult measurement, obtaining higher genetic gain faster than with direct selection (Cruz et al., 2004). In addition, it is possible to identify the inheritable proportion of the phenotypic correlation, that is due to genetic causes (genotypic correlation), and to evaluate the interaction between them and the environment.

There are a few investigations about correlations between traits evaluated in onion. Loges et al. (2004) evaluated 62 progenies of half-sibs of the Vale Ouro IPA-11 onion cultivar, and founded that the marketable bulb production can be increased through the selection for high weight and percentage of marketable bulbs. Mallor et al. (2009) evaluated 15 grower’s open-pollinated lines of the cultivar “Fuentes de Ebro” for the traits bulb weight, size, soluble solids content and pungency. They found higher levels of genetic variation for bulb size and pungency than for soluble solids content, and significant phenotypic correlations indicated that milder onion tends to show larger size and lower soluble solids content. Porta et al. (2014) worked with S_1 creole lines obtained from one cycle of self-pollination. The authors found positive correlations between plant’s vigour, measured 80 days after sowing, and bulb weight, number of leafs and neck diameter. There were no researches in the literature where plant, bulb and production traits were correlated in segregating onion lines, obtained from populations of two or three plants.

The aim of this work was to estimate the genotypic, phenotypic and environmental correlations between the characteristics of the plant, the bulb and seed production in onion segregating populations obtained from different breeding methods.

MATERIALS AND METHODS

Place of study

The experiment consisted in 33 populations of onion (*Allium cepa* L.), in different generations of genetic segregation (F_2S_1, F_2S_2, S_4 and S_3), obtained from generations which had low or moderate inbreeding level. Agronomic traits were evaluated for two years (2014 and 2015), in the vegetative and reproductive stage of the crop. The experiments were carried out at the Bayer Vegetable Seeds' experimental field (Latitude: 18º 55' South and Longitude: 48º 16' West, Altitude of 873m) and the populations used belong to the breeding program of the company in Brazil, in Uberlândia, Minas Gerais state.

Experimental design, field layout and crop management

The experiment was laid out in a randomized block design with three replications. Each plot consisted in five rows of one-meter length x 0, 9 meters width. The distance between plants was 5 cm and the distance between rows was 20 cm, with 100 plants per plot. The observations were recorded per plot and for the non-measurable traits were used a scale from 1 to 9, where 1 represents the worst value for the trait and 9 represent the best value of the trait.

The plants were sown on 19th March 2014 and were transplanted on 27th April 2014. The field was fertilized according to the recommendations for the onion crop. The traits evaluated in the vegetative phase were: Plant Vigor at 90 and 120 DAS (days after sowing): through the measure of the leaf diameter, plant height and number of leaves; Plant Height at 150 DAS, in centimeters; 'neck' Diameter: using a rating of 1 (thick) to 9 (thin); Plant architecture: being 1: prostrated, 9: erect; Cycle, in days from sowing to 'top down' (more than 50% of the plants fall or in tops down); Severity of *Botrytis spp*., evaluated according with the severity of the pathogen *Botrytis cinerea* in the plot.

After the bulb's harvest, the following evaluations of the bulb were done: skin colour, where the higher rating was to the bulbs with dark brown colour; Bulb Firmness; Number of Bulbs per plot; Commercial Bulbs: percentage of marketable bulbs, belonging to the classes II, III and IV of bulb diameter and Total Production, in kg/plot. When the evaluations were finalized, the bulbs were stored and vernalized for about three months until the sowing in the field for the evaluation of traits related to seed production. The bulb's transplant for the formation of these second field (reproductive phase) was on 30/04/2015.

The traits evaluated related to the seed production were: General characteristics of the plant at 30, 60 and 90 DAT (days after transplant), evaluating the number, the diameter and the stem's height, the umbel's size in average in the plot, where the higher value got the higher mark; Stem's vigour: using a rating of 1 (low) to 9 (high); Umbel's vigour: 1 (low) to 9 (high); Number of umbels: number of umbels per plot before the seed's harvest; Flowering uniformity, it was counted the number of umbels with open flowers per plot weekly using a rating of 1 (less uniform) to 9 (more uniform); Seed setting, using a rating of 1 (low seed setting) to 9 (high seed setting); Resistance in Alternaria: it was evaluated according to the severity of *Alternaria solani* in the plot, where 1: low severity and 9: high severity; Seed mass per umbel: average mass (in grams) of seed per umbel in the plot.

Data analysis

The estimation of the correlation coefficients genotypic (r_g), phenotypic (r_p) and environmental (r_e) were obtained through analysis of covariance, combining the pairs, in the first place of the vegetative characteristics and then of the reproductive ones, in all of the possible combinations in each phase (Cruz & Regazzi, 2004). The t test was used to calculate the statistical significance of the estimates at 1% and 5% level. The program GENES (Cruz, 2013) was used to do the statistical analysis.

RESULTS AND DISCUSSION

Most of the estimations of the genetic correlations (r_g) were higher than the phenotypic (r_p) and the environmental (r_e) ones (Tables 1 and 2), showing a greater influence of the genetic component in relation with the others. According to these results, Mohanty (2001) observed in his study of genetic variability, interrelationship and path coefficient in 12 onion varieties that the genotypic correlations were of a higher magnitude than the corresponding phenotypic ones for all the character combinations. Gashua et al. (2013) obtained similar results in their inheritance studies for quantitative traits in onion. Haydar et. al. (2007) also reported that the genotypic correlation coefficients were higher than the phenotypic ones between traits of the bulb yield components in their experiment with 10 onion varieties. They suggested that there was an inherent association among the traits, but the environment minimized the phenotypic association.

High genetic correlation was found between the traits plant vigour at 120 DAT and neck diameter (1,00), plant height and plant architecture (0,92), general appearance at 60 days and umbel's vigour (0,89), seed setting and number of seeds per umbel (0,89). These results revealed a direct relationship between these traits, making possible the indirect selection from only one of them. In a study with soybean, Machado et al. (2017) confirmed that indirect selection through the number of pods per plant is efficient to select more productive plants.

Negative genetic correlations were observed between plant height and total number of bulbs per plot (-0,95) and between neck diameter and total number of bulbs per plot (-0,53). A higher number of bulbs per plot is desirable in a breeding program, since it enables the multiplication, the bulb selection and the evaluation of a new genotype's cycle. The larger plant vigour, showed by the higher height and neck diameter, did not represent a higher number of bulbs per plot (Table 1).

The genotypic, phenotypic and environmental correlation coefficients for plant and bulb characteristics were low, under 0,50, for most of the traits (Table 1), except for plant vigour and its components (plant height, neck diameter and plant architecture). The greater r_p and r_g coefficients were observed between the traits plant vigour at 120 DAT and neck diameter (0,71 and 1 respectively), plant height and plant architecture (-0,39 and -0,92) and cycle and Botrytis severity (-0,81 and -0,86). The r_g had the same sign, and in most of the correlations, higher values than the r_g related (Table 1). Torres et al. (2016), found identical results in their experiments with *Urochloa brizantha*, revealing the reduction of the phenotypic expression in front of the environment influence.

The bulb's traits presented a low but significant r_g between total number of bulbs and bulb's production (0,43). Despite this, it is not possible to do indirect selection of the trait, because the genetic gain is low and there is not a time gain comparing with direct selection.

Table 1: Phenotypic (r_p), genotypic (r_g) and environmental (r_e) correlations between fourteen vegetative and bulb production traits, evaluated in different genetic generations, Uberlândia-MG.

		PV120	HP	ND	PA	CYCLE	SB	SC	BF	TB	PC	BP
	r_p	0,75**	-0,14	0,63**	0,63**	-0,12	0,06	-0,15	0,24	-0,01	0,07	0,17
PV90	r_g	0,98	-0,39	1,00	0,97	-0,14	0,08	-0,22	0,35	-0,14	0,10	0,19
	r_e	0,50	-0,05	0,05	-0,12	-0,14	0,01	0,05	0,03	0,21	0,16	-0,04
	r_p		-0,21	0,71**	0,60**	-0,15	0,16	-0,08	0,01	-0,15	0,32	0,14
PV120	r_g		-0,64	1,00++	0,88++	-0,18	0,25	-0,11	-0,08	-0,31	-0,40	0,10
	r_e		-0,04	0,18	-0,10	-0,12	-0,04	-0,03	0,30	0,12	0,21	0,24
	r_p			0,10	-0,39*	-0,16	0,36*	0,35*	-0,03	-0,30	-0,03	0,05
HP	r_g			-0,05	-0,92++	-0,41	0,93+	0,95++	-0,19	-0,95++	-0,34	0,13
	r_e			0,23	-0,05	-0,06	0,12	-0,08	0,09	0,03	0,15	0,03
	r_p				0,28	-0,21	0,25	-0,09	-0,26	-0,46**	0,35*	0,05
ND	r_g				0,37	-0,24	0,30	-0,11	-0,35+	-0,53+	0,36	0,08
	r_e				-0,09	-0,05	0,07	0,09	0,09	-0,27	0,32	-0,07
	r_p					0,08	-0,23	-0,42*	0,21	0,11	0,18	0,13
PA	r_g					0,07	-0,22	-0,44++	0,24	0,18	0,28	0,18
	r_e					0,21	-0,28	-0,13	-0,04	-0,23	-0,26	-0,22
	r_p						-0,81**	-0,39*	-0,30	-0,03	-0,05	-0,27
CYCLE	r_g						-0,86++	-0,41+	-0,34	-0,04	-0,05	-0,31
	r_e						-0,46**	0,05	0,07	-0,01	-0,02	0,09
	r_p							0,40*	0,11	-0,05	0,16	0,22
SB	r_g							0,43+	0,11	-0,04	0,18	0,26
	r_e							-0,10	0,11	-0,12	0,10	-0,04
	r_p								0,17	0,13	-0,24	0,13
SC	r_g								0,18	0,15	-0,30	0,15
	r_e								0,09	0,05	0,10	0,03
	r_p									0,44**	-0,27	0,22
BF	r_g									0,57++	-0,40+	0,23
	r_e									-0,02	0,18	0,12
	r_p										-0,20	0,44**
TB	r_g										-0,17	0,43+
	r_e										-0,27	0,51**
	r_p											0,27

PC	r_g	0,33
	r_e	0,11

PV60: Plant vigor at 60 days PV120: Plant vigor at 120 days PH: Plant height ND: Neck diameter PA: Plant architecture CYCLE: Duration of the cycle SB: Severity at Botrytis SC: Skin color BF: Bulb firmness TB: Total bulbs PC: Percentage of commercial bulbs BP: Bulb production
**,* : Significant at 1% and 5% probability respectively, by Student's t-test.
++,+ : Significant at 1% and 5% probability respectively, by Bootstrap method with 5000 simulations.

Despite the high r_p founded between some traits, mainly those associated with the vegetative phase, it is important to clarify that the r_f can induce false interpretations. Galmarini et al. (2001) reported significant phenotypic correlations among soluble solids content, total dry matter, pungency, and onion-induced in vitro antiplatelet activity in their work with onion F_3M families derived from a cross between two inbred populations. The strong phenotypic and genetic correlations revealed by this study may be the result of linkage among genes that independently control these traits or to pleiotropic effects of the same gene(s).

The r_e between traits with differences in magnitude and sign, related to the respective r_g correlations, showed that the environment benefited a trait putting other at a disadvantage. Also demonstrated that the causes of the genetic and environmental variations present different physiological mechanisms, what can make difficult indirect selection (Cruz et al., 2004).

The r_p estimations for the seed production traits were higher than the ones related to the plant and the bulb. The traits general characteristics of the plant at 30 DAT, general look at 60 DAT, stem vigour, number of umbels and flowering uniformity, presented high correlations between them (Table 2), what would allow the selection of one or two of these traits in a breeding program at a lower cost.

Positive and high r_p coefficients were observed between "flowering uniformity" and the traits general characteristics of the plant at 30, 60 and 90 DAT, demonstrating that a higher plant vigour causes lower flowering outbreaks, and therefore, higher uniformity. On the other hand, the r_p between flowering uniformity and number of umbels was negative (-0,46), similar results were obtained by Sunil et al., (2014) in their work with 23 inbred lines in India.

A considerable reduction in the correlations magnitudes was observed in the traits seed setting, Alternaria resistance and seed mass per umbel. It elucidates that the higher umbels vigour did not reflect in a higher seed setting. The r_p and r_g between umbel vigour and seed setting were 0,25 and 0,27 respectively. These results suggest that it is not possible to select populations with high seed production potential through traits related to plant vigour, because other factors such as pollinator attraction, genetic compatibility, maturation, and plant physiology at the end of the cycle are involved. Onion is an allogamous plant, so pollinators are essential for seed production. According to Nascimento et al. (2012), a poor pollination is one of the causes of a low seed production. The absence of natural pollinators on onion seed plantations poses a serious problem for breeders all over the world. Widespread use of the honeybee as the pollinator does not always bring about the expected results because the onion nectar is not particularly attractive for it and the appearance of different sources of nourishment can easily pull away this bee from plantations of flowering onion (Wilkaniec et al. 2004).

Despite this, significant re was observed between general plant look at 90 days and seed mass per umbel (0,53), supporting the hypothesis that these results could be influenced by the sowing date, considering that several populations were evaluated, so the different adaptation ability could influence the r_p and r_g founded. According to this, Mondal et al. (1986) in their experiment with spring- and autumn-sown onions planted in two dates observed that for each cultivar the maturity date increased linearly with decreases in the percentage radiation intercepted by the leaf canopy. the productivity of onion crops is strongly influenced by the time of the onset of bulbing and the duration of bulb growth. Bulb formation in onion is a process consisting of both growth and apical development (Brewster, 1990).

High and positive r_p and r_g were observed between the traits seed setting and seed mass per umbel (0,87 and 0,92 respectively). The traits Resistance in Alternaria and seed mass per plot were positive correlated, (r_p: 0,72 and r_g: 0,82). Similar results were obtained by others authors, like Mamgain et al. (2013) in their work with mustard (*Brassica juncea*) in India. They observed great damages in the plant tissues and in the seed production caused by the necrotic nature and the high potential of the specie toxins. The yield losses can reach up to 50%, if the climate conditions were propitious for the fungus infection.

Despite the low magnitude, it was observed positive phenotypic correlation between general aspect of the plant at 90 DAT and seed setting (0,37) and Resistance in Alternaria (0,47). The correlations between the traits related to seed production (stem vigour, number of umbels, umbel vigour) were not significant and presented low magnitude, supporting the fact that the physiological processes at the end of the plant cycle are decisive to define the seed mass per umbel produced. Correlation coefficients around zero were founded between traits associated with seed production (Table 2), revealing the absence of a linear relation between them (Cruz et al., 2004).

Table 2: Phenotypic (r_p), genotypic (r_g) and environmental (r_e) correlations between twelve characters of seed production, evaluated in different genetic generations, Uberlândia-MG.

Caráter		GA60	GA90	VS	VU	NU	NP	FU	SS	RA	SMU
	r_p	0,93**	0,86**	0,78**	0,81**	-0,56**	-0,33	0,90**	0,15	0,27	0,04
GA30	r_g	0,96	0,91	0,82	0,88	-0,60	-0,36	0,94	0,15	0,28	0,04
	r_e	0,65**	0,27	0,31	0,25	0,08	0,10	0,27	0,22	0,11	0,10
	r_p		0,92**	0,91**	0,89**	-0,51**	-0,26	0,85**	0,15	0,29	-0,01
GA60	r_g		0,96	0,95	0,96	-0,55	-0,29	0,89	0,12	0,30	-0,04
	r_e		0,52**	0,49**	0,34*	0,06	0,15	0,36*	0,30	0,07	0,19
	r_p			0,84**	0,88**	-0,37*	-0,10	0,80**	0,37*	0,47**	0,16
GA90	r_g			0,89	0,95	-0,41	-0,11	0,84	0,39	0,49	0,17
	r_e			0,37*	0,18	0,16	0,45**	0,29	0,21	0,20	0,53**
	r_p				0,89**	-0,52**	-0,33	0,65**	0,09	0,21	-0,08
VS	r_g				0,94	-0,57	-0,36	0,68	0,07	0,23	-0,11
	r_e				0,53**	0,16	0,10	0,31	0,22	0,07	0,13
	r_p					-0,44**	-0,20	0,75**	0,25	0,32	0,09
VU	r_g					-0,50	-0,23	0,81	0,27	0,36	0,09
	r_e					0,12	0,14	0,29	0,18	-0,04	0,12
	r_p						0,85**	-0,46**	0,05	-0,10	-0,09
NU	r_g						0,86	-0,51	0,07	-0,11	-0,08
	r_e						0,63**	0,21	-0,11	0,05	-0,21
	r_p							-0,27	0,18	0,04	0,02
NP	r_g							-0,29	0,21	0,04	0,03
	r_e							0,09	-0,04	0,07	-0,12
	r_p								0,14	0,24	0,03
FU	r_g								0,13	0,25	0,03
	r_e								0,18	0,02	0,01
	r_p									0,84**	0,87**
SS	r_g									0,95+	0,92+
	r_e									0,22	0,72**
	r_p										0,72**
RA	r_g										0,82+
	r_e										0,19

GA30: General appearance at 30 days GA60: General appearance at 60 days GA90: General appearance at 90 days VS: Vigor of stem VU: Vigor of umbel NU: Number of umbels NP: Number of plants FU: Flowering uniformity SS: Seed setting RA: Resistance to Alternária SMU: Seed mass per umbel.
**,* : Significant at 1% and 5% probability respectively, by Student's t-test.
++,+ : Significant at 1% and 5% probability respectively, by Bootstrap method with 5000 simulations.

CONCLUSIONS

The phenotypic and genotypic correlations revealed an association between the traits related to the plant vigour in onion, nevertheless, it was not reflected in the bulb and seed production, in the two years evaluated. The traits “seed setting” and “Resistance in Alternaria” can be useful in the indirect selection for “Seed mass per umbel”.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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