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NOTE

Correlations and path analysis of morphological and yield traits of cactus pear accessions

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Abstract – *The objectives of this study were to evaluate the relationships between morphological characteristics and fresh matter yield of cactus pear and identify their direct and indirect effects. Nineteen accessions were evaluated for the following traits: number (NCl), thickness (ThCl), length (LCl) and width (WCl) of cladodes, plant height (PH) and plant width (PW), and green matter yield (GMY), dry matter yield (DMY) and dry matter percentage (DM). The correlations were estimated, and path analysis was performed by the method proposed by Wright. GMY was strongly correlated with DMY, allowing indirect selection for this trait. NCl and ThCl had a direct effect on GMY and can be used for indirect selection or as secondary traits in the selection process. Given the lack of significant correlations between MS and DMY, it is possible to select a palm variety with high DMY and DM.*

Key words: *Genetic variability, selection, semiarid,* Opuntia ficus indica*.*

INTRODUCTION

The family of cactaceae includes approximately 130 genera and 1500 species, among which the genera *Opuntia* and *Nopalea* stand out, known as cactus pear and sweet palm, respectively, as the most important for human use (Flores-Valdez and Osorio 1996). Cacti are specifically adapted to conditions of water deficit, opening their stomata to capture CO_2 only at night, when temperatures are lower and humidity higher than during the day, resulting in less water loss (Nobel 1995). This makes it possible to produce large quantities of biomass feed (Felker et al. 2006), a valuable forage resource in arid and semiarid regions, especially in the dry period when the availability of herbaceous plants is reduced. Moreover, they produce tasty and nutritious fruits, used as human food in many countries, while the cladodes can also be directly used as vegetable (Scheinvar 1995, Le Houérou 2000, Juárez and Passera 2002).

Although cactus pear is native to Mexican, the conditions for its development in the Brazilian semiarid region are suitable, which has led to its expansion. According to Santos et al. (2006), the area used for cactus pear in the northeastern region of Brazil, was 500,000 ha in 2006, with yields of up to 40 tons of dry matter ha^{-1}. In the sub-humid woodland (agreste), three cactus pear varieties are grown: 'Palma Gigante', 'Palma Redonda' (both *Opuntia ficus indica*) and 'Palma Doce' (*Nopalea cochenillifera* Salm-Dyck), while in the semi-arid woodland (sertão), only *O. ficus indica* is able to adapt to the poor soil conditions, with high temperatures (above 20.5 °C) and rainfall in the warmer months of the year.

One breeding target of cactus pear is to obtain genotypes that produce higher amounts of biomass with higher quality for use in animal feed. However, yield is a complex trait resulting from the expression and association of different components (Carvalho et al. 2002). Thus, knowledge of the degree of this association through correlation studies can identify traits that could be used as indirect selection criteria for yield or as secondary traits, improving the efficiency of the selection process. Knowledge of the correlations between forage traits can measure the magnitude of the relationship between various plant traits and identify on which traits selection could be based for gains in biomass yield.

For a better understanding of the factors involved in the associations of traits, Wright (1921) proposed a method of

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partitioning correlations, estimating the direct and indirect effects of variables on a main variable, which is called path analysis. The direct influence of one variable on another is measured independently of the others (Gonçalves et al. 2003, Gomes and Lopes 2005, Bárbaro et al. 2006). Path analysis can therefore be made from genetic or environmental correlations (Cruz 2001). Despite the potential of this methodology for the determination of selection strategies in breeding programs and knowledge of direct and indirect relations between the traits, which may provide a basis for understanding the genetic control of a given trait, no reports were found in the literature about its application to cactus pear.

This study evaluated the relationship between morphological characteristics and dry matter yield of cactus pear and identified their direct and indirect effects by path analysis, with a view to contribute to the selection process.

MATERIAL AND METHODS

Nineteen accessions of *Opuntia ficus indica* introduced from Mexico by the Agronomic Institute of Pernambuco (IPA) and transferred to the National Institute for the Semi-Arid Region (INSA), were evaluated in the field, on the Fazenda Miguel Arraes of INSA in Campina Grande, Pernambuco (lat 07° 13' 50'' S, long 35° 52' 52'' W and alt 551 m asl), where the minimum temperature is on average 20 °C, maximum 30 °C, and the relative humidity between 75% to 82%.

These accessions were evaluated in a completely randomized design with three replications and one plant per plot, spaced 2.0 m x 1.0 m. Thirty months after planting, we analyzed the number of cladodes (NC), thickness of cladodes (ThCl), length of cladodes (LCl), width of cladodes (WCl), plant height (PH), plant width (PW), green matter yield (GMY), dry matter yield (DMP), and dry matter percentage (DM).

Initially, analysis of variance was performed for each trait. The estimates of genotypic (r_g), phenotypic (r_{ph}) and environmental correlation (r_e) between the traits were obtained as described by Mode and Robinson (1959), tested at 1 and 5% probability by the t test, at n-2 degrees of freedom, and by the Mantel test with 10,000 iterations for each trait combination, to obtain information about their nature and intensity.

Later, the phenotypic correlations were partitioned in direct and indirect effects of morphological characteristics (independent variable) on dry matter yield (dependent variable) by path analysis (Wright 1921). The software Genes (Cruz 2001) was used for all analyses.

RESULTS AND DISCUSSION

The summary of the analyses of variance (Table 1) showed significant differences between the nine traits, revealing genetic variability among cultivars. The ratio between the coefficients of genetic variation and environmental (CVg/CVe) was above 1 for seven of the nine characteristics, except for DM and NC, suggesting a high genetic control in the expression of these traits. The high heritability detected in all traits also corroborated this fact.

The estimates of phenotypic (r_{ph}), genetic (r_g) and environmental correlations (r_e) are listed in Table 2. Most environmental correlations were not significant and there was virtually no signal difference between genotypic and environmental correlations. In general, the genotypic were higher than the phenotypic and environmental correlation estimates, but not significant. This fact may have been a result of the modifying effects of the environment on the association of genetic traits (Gonçalves et al. 1996).

Kang et al. (1983) stated that when the correlations are not similar, the genotypic correlations are inherently more useful than the phenotypic to decide on selection strategies.

Table 1. Summary of the analysis of variance for the traits green matter yield (GMY), dry matter yield (DMY), dry matter percentage (DM), number of cladodes (NC), thickness of cladodes (ThCl), length of cladodes (LCl), width of cladodes (WCl), plant height (PH) e plant width (PW)

SV	df	MS								
		GMY	**DMY**	**DM**	**NC**	**ThCl**	**LCl**	**WCl**	**PH**	**PW**
Accessions	18	3568160.09**	130518.46**	18.33**	83.52**	75.34**	83.75**	26.01**	490.56**	1493.32**
Error	38	454941.23	22825.64	5.69	21.90	12.51	8.91	5.64	75.00	307.52
Mean		1500.17	291.16	19.81	6.53	13.29	19.24	12.12	50.25	47.95
CVe (%)		44.96	51.89	12.04	71.71	26.61	15.51	19.60	17.24	36.57
CVg (%)		67.90	65.07	10.36	69.44	34.43	25.95	21.50	23.42	41.46
CVg/CVe		1.51	1.25	0.86	0.97	1.30	1.67	1.10	1.36	1.13
Heritability (%)		87.25	82.51	68.98	73.77	83.39	89.37	78.31	84.71	79.41

* and **significant at 5 and 1% probability, respectively, by the F test

However, phenotypically uncorrelated genotypic traits may be unpractical for selection, which is usually based on the phenotype (Shukla et al. 1998). We therefore chose to use phenotypic correlation path analysis, since phenotypes are the focus of breeding.

The traits with significant correlations of DMY (Table 2) were GMY (0.99), NCl (0.76), PW (0.74), and LCl (0.53). Although, a priori, DMY should be preferred for selection of higher-yielding genotypes, due to genotypic variations in DM, the high association between DMY and GMY indicates that selection based on GMY, with proportional gains in DMY, would be perfectly possible, without requiring determination of the plant dry weight. Interestingly, the correlation between DM and DMY was not significant, suggesting that the genetic control of these traits occurs independently and that selection of genotypes with high GMY and DM is possible.

The estimates of the direct and indirect effects of path analysis (Table 3) of the trait NCl were high and positively correlated (0.77) and had a high direct effect (0.76), indicating that truncated selection with this trait can provide satisfactory gain in DMY.

For trait PW, the correlation coefficient was positive and high (0.74), but the direct effect proved low (0.18). The indirect effect via NCl (0.45) and LCl (0.25) contributed most to the high correlation between PW and DMY. In this case the best strategy, according to Cruz and Carneiro (2003), could be the simultaneous selection of traits, focusing on those with significant indirect effects.

Table 2. Estimates of the coefficients of phenotypic (r_{ph}), genotypic (r_g) and environmental correlations (r_e) for the traits green matter yield (GMY), dry matter yield (DMY), percentage of dry matter (DM), number of cladodes (NC), thickness of cladodes (ThCl), length of cladodes (LCl), width of cladodes (WCl), plant height (PH) and plant width (PW), in cactus pear accessions

Trait	Correlation	DM	DMY	NC	ThCl	LCl	WCl	PH	PW
GMY	r_{ph}	-0.26	0.99^{**++}	0.77^{**+}	0.19	0.56^{*}	0.40	0.43	0.77^{**++}
	r_g	-0.35	0.99^{+}	0.85	0.18	0.65	0.50	0.47	0.89
	r_e	0.06	0.97^{++}	0.50	0.27	-0.09	-0.10	0.19	0.19
DM	r_{ph}		-0.14	-0.16	-0.43^{*}	-0.36	-0.03	-0.21	-0.34
	r_g		-0.26	-0.27	-0.49	-0.42	0.04	-0.22	-0.49
	r_e		0.23	0.12	-0.24	-0.18	-0.23	-0.18	0.08
DMY	r_{ph}			0.76^{**+}	0.12	0.53^{*}	0.42	0.40	0.74^{**+}
	r_g			0.82	0.10	0.63	0.56	0.44	0.86
	r_e			0.58	0.21	-0.10	-0.14	0.20	0.22
NC	r_{ph}				-0.15	0.25	-0.06	0.25	0.59
	r_g				-0.20	0.23	-0.11	0.19	0.61
	r_e				0.01	0.34	0.09	0.48	0.51^{++}
ThCl	r_{ph}					0.31	0.34	0.38	0.15
	r_g					0.32	0.38	0.43	0.16
	r_e					0.25	0.19	0.15	0.10
LCl	r_{ph}						0.78^{**++}	0.73^{**+}	0.75^{**++}
	r_g						0.82	0.76	0.81
	r_e						0.67^{++}	0.48^{++}	0.45^{+}
WCl	r_{ph}							0.53^{*}	0.52^{*}
	r_g							0.49	0.55
	r_e							0.71^{++}	0.38
PH	r_{ph}								0.34
	r_g								0.33
	r_e								0.37

* and **significant at 5 and 1% probability, respectively, by the T test.

+ and ++ significant at 5 and 1% probability, respectively, by the test of Mantel.

Table 3. Estimates of the direct and indirect effects that involve the main variable (dry matter yield - DMY) and the explanatory variables dry matter percentage (DM), number of cladodes (NC), thickness of cladodes (ThCl), length of cladodes (LCl), width of cladodes (WCl), plant height (PH), and plant width (PW)

Trait	Effect of association	Estimate
DM	Direct effect on DMY	0.04
	Indirect by NC	-0.12
	Indirect by ThCl	-0.05
	Indirect by LCl	0.07
	Indirect by WCl	-0.01
	Indirect by PH	0.00
	Indirect by PW	-0.06
	Total	-0.14
NC	Direct effect on DMY	0.76
	Indirect by DM	-0.01
	Indirect by ThCl	-0.02
	Indirect by LCl	-0.05
	Indirect by WCl	-0.03
	Indirect by PH	0.00
	Indirect by PW	0.11
	Total	0.76
ThCl	Direct effect on DMY	0.12
	Indirect by DM	-0.02
	Indirect by NC	-0.11
	Indirect by LCl	-0.06
	Indirect by WCl	0.17
	Indirect by PH	0.00
	Indirect by PW	0.03
	Total	0.12
LCl	direct effect on DMY	-0.20
	Indirect by DM	-0.01
	Indirect by NC	0.19
	Indirect by ThCl	0.04
	Indirect by WCl	0.39
	Indirect by PH	0.00
	Indirect by PW	0.14
	Total	0.53
WCl	Direct effect on DMY	0.49
	Indirect by DM	0.00
	Indirect by NC	-0.04
	Indirect by ThCl	0.04
	Indirect by LCl	-0.16
	Indirect by PH	0.00
	Indirect by PW	0.09
	Total	0.42
PH	Direct effect on DMY	0.00
	Indirect by DM	-0.01
	Indirect by NC	0.19
	Indirect by ThCl	0.04
	Indirect by LCl	-0.15
	Indirect by WCl	0.26
	Indirect by PW	0.06
	Total	0.40
PW	Direct effect on DMY	0.18
	Indirect by DM	-0.01
	Indirect by NC	0.45
	Indirect by ThCl	0.02
	Indirect by LCl	-0.15
	Indirect by WCl	0.25
	Indirect by PH	0.00
	Total	0.74
Coefficient of determination		0.82
Effect of residual variable		0.42

Trait LCl, with a positive and significant correlation in relation to DMY (0.53), had a direct negative effect (-0.20). The explanation for this is due to its positive effect on other traits related to DMY as NC, favoring his expression. Therefore, direct selection would be more promising on NCl than on LCl, which would disqualify this trait for selection. On the other hand, the correlation coefficient of LCl with DMY was nonsignificant (0.42), but the direct effect was high (0.49), indicating the use as secondary variable in the selection for DMY.

Among the traits, NCl had the greatest positive effect, indicating the presence of cause and effect. This trait is related to gains in DMY. On the other hand, the trait LCl can be considered secondary in terms of effect on DMY. For PW however, despite a high correlation coefficient, the effects on the said traits were weak.

Low direct and indirect effects were observed for the other traits, indicating possible indirect selection for DMY through selection for NCl, with or without LCl in the selection, as well as the use of these as secondary traits, to increase the efficiency of the selection process.

The results showed: i) a strong association of trait GMY with DMY, allowing indirect selection for this trait, ii) the traits number and width of cladodes have a direct effect on DMY and can be used for indirect selection or as secondary traits in the selection process, emphasizing, however, the low correlation of the latter, iii) the percentage of dry matter was not significantly correlated with DMY, indicating an independent genetic control and the possibility of selecting palm varieties with high green and dry matter production.

Correlações e análise de trilha de caracteres morfoagronômicos e de produção em acessos de palma forrageira

Resumo – *Os objetivos deste trabalho foram avaliar as relações entre caracteres morfoagronômicos e a produção de matéria verde de palma forrageira e identificar seus efeitos diretos e indiretos. Dezenove acessos foram avaliados para os seguintes caracteres: número (NC), espessura (EC), comprimento (CC) e largura (LC) de cladódios, altura (AP) e largura (LP) de planta, produção de matéria verde (PMV) e seca (PMS) e porcentagem de matéria seca (MS). Estimaram-se as correlações, e fez-se a análise de trilha pelo método proposto por Wright. O caráter PMV apresentou elevada associação com PMS, permitindo a seleção indireta para este caráter. Os caracteres NC e EC apresentaram efeito direto sobre a PMV, podendo ser empregados na seleção indireta ou como auxiliares no processo seletivo. Tendo em vista, a não existência de correlações significativas entre MS e PMS, é possível a seleção de variedade de palma com elevada PMS e MS.*

Palavras-chave: *Variabilidade genética, seleção, semiárido,* Opuntia ficus indica.

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