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Yield component analysis of cowpea varieties in competition with weeds[1]

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ABSTRACT - There is great interest in varieties with greater competitive ability against weeds. This can be facilitated by path analysis, which involves the statistical evaluation and interpretation of the relationship between yield and its components. In this analysis, the occurrence of multicollinearity results in inconsistent estimates of the coefficients, and overestimates of the direct effects of the explanatory variables on the response variable. The aim of this study was to identify the characteristics with the greatest direct effect on pod yield and green and dry bean yields in traditional cowpea varieties, evaluated in competition with weeds in two experiments. In addition, the presence of multicollinearity was investigated in the analyses. In Experiment-1, twelve varieties with the highest bean yields in a preliminary evaluation were assessed in a randomized block design with five replications. In Experiment-2, six varieties, selected in the preliminary evaluation, were assessed using two methods of weed management: three of the most productive and three of the least productive. Randomized blocks and split plots were used, with five replications. Multicollinearity, indicated by the number of conditions and the variance inflation values, was greater in Experiment-2. In the six cases under study (three yields x two experiments), the number of pods per plant had the greatest direct effect on yield.

Key words: *Vigna unguiculata*. Path analysis. Green beans. Dry beans. Multicollinearity.

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INTRODUCTION

Biological yield is the total weight of the dry matter of a plant. Economic yield is the economically useful part of the biological yield. In the cowpea [*Vigna unguiculata* (L.) Walp.], although in most regions the economic yield is the dry bean, in other regions interest lies in the pod and green bean yields.

The various plant characteristics can be considered as yield components (Meena; Krishna; Sing, 2015; Udensi *et al*., 2012). However, in the cowpea, the main components to be considered are the number of pods per plant, the number of beans per pod and the average weight of the beans. The product of these characteristics is expected to reflect bean yield. This multiplicative model (Kozak; Madry, 2006) is popular because it is simple, mathematically correct, and because the components are easily measured. Nevertheless, additive models are used for some crops (Kozak; Madry, 2006). Various aspects of the relationship between yield and its main components have been studied (Patrick; Colyvas, 2014; Smith; Hamel, 1998 Umaharan; Ariyanayagam; Haque, 1997), especially from the point of view of breeding (Diwaker *et al*., 2018).

There is interest in varieties with greater competitive ability against weeds due to the environmental degradation caused by herbicides and weed resistance to these herbicides. In plant breeding, the correlation between characteristics can be of interest when a desirable characteristic (A) has low heritability but is correlated with another characteristic (B), which has higher heritability than A. In this case, it is possible to select for B while aiming for A. In other situations, the desirable characteristic might be difficult to measure but is correlated with another trait whose measurement is easier.

Yield component analysis involves the statistical evaluation and interpretation of the relationship between the economic yield of a crop and the so-called yield components (Kozak; Madry, 2006). There are various methods for this analysis (Olgun; Aygün, 2011), but the use of correlations is the most common. In breeding, three types of correlation can be estimated between any two characteristics: genotypic, environmental, and phenotypic. The most important of these is genotypic (Falconer; Mackay, 1996). If no genotypic correlations can be estimated, path coefficients derived from the phenotypic correlations are sufficient (Vencovsky; Barriga, 1992). Path analysis, developed by Wright (1921), is one of the most useful methods (Ogunbodede, 1989).

In the context of the present study, the main interest is to identify the characteristics having the greatest effect on bean yield. The information obtained can then be used in breeding programs. Path analyses carried out with the cowpea have shown that the number of pods per plant is the characteristic with the greatest direct effect on dry bean yield (Diwaker *et al*., 2018; Freitas *et al*., 2019), although bean yield can also be affected by other characteristics (Meena *et al*., 2015; Patel *et al*., 2016).

The aim of this study was to identify the characteristics with the greatest direct effect on pod yield and green and dry bean yields in traditional cowpea varieties, evaluated in two weed competition experiments.

MATERIAL AND METHODS

The experiments were carried out at the Rafael Fernandes Experimental Farm of the Federal Rural University of the Semi-Arid Region (UFERSA), located 20 kilometers from the city of Mossoró, in Rio Grande do Norte (RN) (5º11’ S, 37º20’ W, and altitude of 18 m). The soil in the experimental area is classified as a Red Yellow Argisol (PVA) (Santos *et al*. (2018). According to the Köppen classification (1948), the climate in the region is of type BSwh’, i.e. a very dry climate, with an average annual rainfall of 825 mm, with the greatest rainfall during the summer. According to Carmo Filho and Oliveira (1989), the region has an average maximum air temperature that varies between 32.1 ºC and 34.5 ºC, and average annual rainfall of approximately 825 mm. The path analysis was carried out using the data from two experiments that were irrigated by sprinkler (identified as Experiments 1 and 2).

Experiment-1

In Experiment-1, twelve varieties with the highest bean yields in a preliminary evaluation (carried out with 48 varieties) were evaluated for competitiveness with weeds (Umarizal, Itaú, Upanema, Lagoa de Pedra, José da Penha, São Tomé, Baraúna, Campo Grande, Luiz Gomes, Angicos, Jaçanã and Macaíba) in a randomized block design with five replications. These varieties were subjected to moderate weed stress and cultivated with a single weeding 30 days after sowing.

Experiment-2

In Experiment-2, six traditional cowpea varieties were evaluated that were selected based on the results of a preliminary selection for competitiveness with weeds: three that proved to be the most productive (Umarizal, Itaú and Upanema), and three that presented low yields (Mossoró, Santa Cruz and São Miguel). These varieties were subjected to two types of weed control (one or two weedings). A randomized block design was used, with five replications and split plots. Weed management was applied to the plots, with the varieties applied to the subplots. Weeding was carried out 30 days after sowing (DAS) in the case of the single weeding, and at 20 and 40 DAS in the case of the double weeding.

Methodology common to both experiments

The experiments were set up on October 29, 2018. Each experimental unit comprised four rows, 6.0 meters in length. The working area was taken to be the two center rows disregarding the plants from one hole at either end of the rows in all the evaluations. One of the rows in the working area was used to assess the green bean yield and the other to assess the dry bean yield. A spacing of 1.0 m x 1.0 m was used, with two plants per hole.

The green bean yield was determined as the weight of the pods and beans harvested from 53 to 82 days after sowing. The green bean yield was corrected for a moisture content of 65 percent. The following were also assessed: the number of pods plant^{-1}, the number of beans pod^{-1} (in 10 pods), the 100-bean weight (in five samples), and the length, width, and thickness of 10 pods and 10 beans.

Dry bean yield was determined as the weight of the dry beans harvested from 70 to 82 days after sowing. In addition to yield (moisture content of 15.5 percent), the following were assessed: the number of pods plant^{-1}, the number of beans pod^{-1} (in 10 pods), the 100-bean weight (in five samples), and the length, width, and thickness of 10 beans. After the final dry bean harvest, the plants from one hole, selected at random, were cut close to the ground, weighed, and crushed. A sample of the crushed material, weighing approximately 100 g, was placed in a forced-air oven at 70 ºC to constant weight. This allowed the dry weight of the cowpea shoots to be estimated.

In both experiments, multicollinearity diagnostics and path analysis were carried out with the aid of the Genes software – Computer Application in Genetics and Statistics (Cruz, 2001). For the path analysis, the main characteristics considered were the total green pod weight, and the green and dry bean yields.

For the path analysis, the degree of multicollinearity of the X’X correlation matrix was established based on its condition number (CN, ratio between the highest and lowest eigenvalues of the correlation matrix) and on the test of the value for the determinant of the correlation matrix between the characteristics under study. Multicollinearity causes no serious problems for path analysis when CN is less than 100 (Toebe; Cargnelutti Filho, 2013), while determinant values close to zero indicate a strong association between the characteristics under study, which is likely to introduce bias into the estimates. Preliminary analyses were carried out to check for multicollinearity for the path analysis. This method uses a procedure similar to ridge regression analysis (Carvalho; Cruz, 1996). In contrast to conventional path analysis, path analysis under multicollinearity is carried out by introducing a constant (*k*) into the X’X correlation matrix to reduce the variance associated with the least squares estimator in the path analysis (Carvalho; Cruz, 1996). As such, the normal system of equations $X'X\beta = X'Y$ becomes $(X'X + kI)\,\beta = X'Y$.

RESULTS AND DISCUSSION

The values of the coefficients of determination, *k*, number of conditions, residual effects, and the determinant of the X’X matrix from the path analyses of the two experiments are shown in Table 1. The coefficients of determination were high, indicating that a large part of the variation in the main characteristics (pod yield, and green and dry bean yields) was determined by the explanatory characteristics.

In practical terms, when the number of conditions is less than 100, multicollinearity is weak; between 100 and 1000, multicollinearity is moderate to strong; when greater than 1000, multicollinearity is severe (Montgomery; Peck, 1981). Only when the degree of multicollinearity is considered weak does it constitute no serious problem for the analysis (Carvalho *et al*., 1999). Multicollinearity is present when there is some level of interrelationship between the variables under study (independent variables). The effects of high multicollinearity include inconsistent estimates of the regression coefficients and overestimates of the direct effects of the explanatory variables on the response variable, which can result in incorrect interpretations (Coimbra *et al*., 2005; Cruz; Carneiro, 2003). Applying path analysis to a severe degree of multicollinearity produces results of no biological importance to plant breeders (Coimbra *et al*., 2005). The number of conditions in the present study ranged from 38.13 (green pods in Experiment-1) to 117.42 (green beans in Experiment-2) and was greater in Experiment-2 than in Experiment-1 (Table 1). In other words, according to the above criteria, multicollinearity was weak for the three characteristics of Experiment-1 and the dry bean yield of Experiment-2, and moderate to strong in Experiment-2 for the pod and green bean yields. This indicates that multicollinearity may depend on the treatments being evaluated, and on what is considered an economic yield.

The estimates of the variance inflation values and of the direct and indirect effects of some of the components of the green pod and bean yields in the path analysis of Experiment-1 are shown in Tables 2 and 3. The corresponding values for Experiment-2 are shown in Tables 4 and 5. Tables 6 and 7 show the estimates of the direct and indirect effects of various components of dry bean yield and the variance inflation values in the path analysis of both experiments.

The variance inflation value (VIV) quantifies the degree of multicollinearity, and as an index, measures how much of the variance of an estimated coefficient increases due to collinearity. Multicollinearity is considered a problem when VIV ≥ 10 (Gwelo, 2019). In Experiment-1, there were no VIV values greater than 10 (Tables 2, 3, 6 and 7). In Experiment-2 however, 27 of the VIV values in the path analysis for green bean yield (Tables 4 and 5) and three VIV values in the path analysis for dry bean yield were greater than 10 (Tables 6 and 7). The VIV data support the data for the number of conditions, showing that multicollinearity was greater in Experiment-1 than in Experiment-2, and that in Experiment-2, multicollinearity was greater when evaluating the green bean data than when evaluating the dry bean data.

Table 1 - Statistics obtained with the estimates of the direct and indirect effects on three economic yields (main characteristics), and of various yield components (independent explanatory characteristics) in two experiments. Mossoró, RN. UFERSA. 2020

Statistic	Experiment-1		
	Economic yield		
	Green pods	Green beans	Dry beans
Coefficient of determination	0.87	0.85	0.91
Value for k used in the analysis	0.115	0.108	5.64×10^{-2}
Number of conditions	38.13	40.25	55.70
Residual effect	0.355	0.389	0.292
Determinant of the X’X matrix	4.18×10^{-3}	3.41×10^{-3}	5.58×10^{-3}
Statistic	Experiment-2		
	Economic yield		
	Green pods	Green pods	Green pods
Coefficient of determination	0.94	0.96	0.96
Value for k used in the analysis	5.45×10^{-2}	5.26×10^{-2}	5.26×10^{-2}
Number of conditions	113.11	117.42	74.88
Residual effect	0.253	0.194	0.193
Determinant of the X’X matrix	1.30×10^{-6}	1.09×10^{-6}	6.23×10^{-4}

Table 2 - Estimates of the direct and indirect effects of various components of the green pod and green bean yields and variance inflation values (VIV) in the path analysis of Experiment-1. Mossoró, RN. UFERSA. 2020

Characteristic	Association effect	Green pods		Green beans	
		Estimate	VIV	Estimate	VIV
100-bean weight	Direct	0.326	4.309	0.253	4.414
	Indirect, via:				
	Number of beans pod^{-1}	-0.022	0.057	-0.021	0.058
	Number of pods plant^{-1}	-0.352	0.320	-0.382	0.327
	Pod length	1.112	1.273	0.108	1.311
	Pod width	-0.005	1.792	0.017	1.860
	Pod thickness	0.250	2.023	0.221	2.106
	Bean length	-0.031	1.131	-0.116	1.170
	Bean width	0.025	2.516	0.047	2.634
	Bean thickness	0.041	2.763	0.029	2.872
	Total	0.382		0.182	

Continuation Table 2

Number of beans pod^{-1}	Direct	0.113	1.837	0.109	1.858
			Indirect, via:		
	100-bean weight	-0.064	0.133	-0.050	0.138
	Number of pods plant^{-1}	0.216	0.121	0.234	0.123
	Pod length	-0.048	0.239	-0.047	0.246
	Pod width	0.001	0.124	-0.004	0.129
	Pod thickness	-0.135	0.590	-0.119	0.615
	Bean length	0.011	0.133	0.040	0.138
	Bean width	0.001	0.007	0.002	0.007
	Bean thickness	-0.004	0.026	-0.003	0.027
	Total	0.104		0.174	
Number of pods plant^{-1}	Direct	0.767	1.896	0.834	1.913
			Indirect, via:		
	100-bean weight	-0.149	0.727	-0.116	0.755
	Number of beans pod^{-1}	0.032	0.117	0.031	0.120
	Pod length	-0.039	0.156	-0.038	0.161
	Pod width	0.004	0.958	-0.012	0.994
	Pod thickness	-0.071	0.164	-0.063	0.170
	Bean length	0.016	0.296	0.059	0.307
	Bean width	0.014	0.795	-0.026	0.832
	Bean thickness	-0.014	0.333	-0.010	0.346
	Total	0.619		0.748	
Pod length	Direct	0.151	2.908	0.146	2.953
			Indirect, via:		
	100-bean weight	0.241	1.887	0.187	1.960
	Number of beans pod^{-1}	-0.036	0.151	-0.035	0.155
	Number of pods plant^{-1}	-0.198	0.102	-0.216	0.104
	Pod width	-0.004	0.925	0.012	0.960
	Pod thickness	0.249	2.011	0.220	2.095
	Bean length	-0.022	0.594	-0.084	0.615
	Bean width	0.012	0.601	0.023	0.629
	Bean thickness	0.034	1.937	0.024	2.014
	Total	0.445		0.294	

Table 3 - Estimates of the direct and indirect effects of various components of the green pod and green bean yields and variance inflation values (VIV) in the path analysis of Experiment-1. Mossoró, RN. UFERSA. 2020

Characteristic	Association effect	Green pods		Green beans	
		Estimate	VIV	Estimate	VIV
Pod width	Direct	- 0.007	4.105	0.023	4.202
	Indirect, via:				
	100-bean weight	0.240	1.881	0.187	1.954
	Number of beans pod^{-1}	-0.022	0.056	-0.021	0.057
	Number of pods plant^{-1}	-0.414	0.443	-0.449	0.453
	Pod length	0.080	0.655	0.077	0.675
	Pod thickness	0.260	2.190	0.230	2.281
	Bean length	-0.034	1.382	-0.128	1.431
	Bean width	0.027	2.750	0.049	2.879
	Bean thickness	0.034	1.959	0.024	2.037
	Total	0.164		- 0.007	
Pod thickness	Direct	0.331	4.418	0.293	4.539
	Indirect, via:				
	100-bean weight	0.246	1.973	0.191	2.049
	Number of beans pod^{-1}	-0.046	0.245	-0.044	0.252
	Number of pods plant^{-1}	-0.165	0.070	-0.179	0.072
	Pod length	0.114	1.324	0.110	1.363
	Pod width	-0.006	2.034	0.018	2.111
	Bean length	-0.030	1.064	-0.112	1.101
	Bean width	0.020	1.477	0.036	1.547
	Bean thickness	0.037	2.276	0.026	2.366
	Total	0.54		0.369	
Bean length	Direct	- 0.047	3.391	- 0.180	3.462
	Indirect, via:				
	100-bean weight	0.210	1.437	0.163	1.492
	Number of beans pod^{-1}	-0.025	0.072	-0.024	0.074
	Number of pods plant^{-1}	-0.253	0.166	-0.275	0.170
	Pod length	0.071	0.510	0.068	0.525
	Pod width	-0.005	1.673	0.016	1.737
	Pod thickness	0.207	1.386	0.183	1.444
	Bean length	0.027	2.760	0.049	2.890
	Bean thickness	0.038	2.397	0.027	2.492
	Total	0.216		0.007	

Continuation Table 3

Bean width	Direct	0.032	5.086	0.059	5.253
	Indirect, via:				
	100-bean weight	0.256	2.131	0.199	2.214
	Number of beans pod^{-1}	0.005	0.003	0.005	0.003
	Number of pods plant^{-1}	-0.338	0.296	-0.368	0.303
	Pod length	0.058	0.343	0.056	0.354
	Pod width	-0.006	2.219	0.019	2.303
	Pod thickness	0.199	1.283	0.176	1.337
	Bean length	-0.039	1.840	-0.148	1.905
	Bean thickness	0.038	2.368	0.026	2.462
	Total	0.208		0.031	
Bean thickness	Direct	0.047	4.720	0.033	4.840
	Indirect, via:				
	100-bean weight	0.278	2.522	0.216	2.620
	Number of beans pod^{-1}	-0.009	0.010	-0.009	0.010
	Number of pods plant^{-1}	-0.227	0.134	-0.247	0.137
	Pod length	0.108	1.193	0.105	1.229
	Pod width	-0.005	1.704	0.016	1.768
	Pod thickness	0.257	2.130	-0.227	2.219
	Bean length	-0.038	1.722	-0.143	1.783
	Bean width	0.026	2.552	0.047	2.672
	Total	0.442		0.249	

Table 4 - Estimates (under multicollinearity) of the direct and indirect effects of various components of the green pod and green bean yields and variance inflation values (VIV) in the path analysis of Experiment-2. Mossoró, RN. UFERSA. 2020

Characteristic	Association effect	Green pods		Green beans	
		Estimate	VIV	Estimate	VIV
100-bean weight	Direct	0.233	14.069	0.256	14.512
	Indirect, via:				
	Number of beans pod^{-1}	0.054	7.684	0.167	7.922
	Number of pods plant^{-1}	0.144	0.245	0.127	0.252
	Pod length	-0.041	0.303	0.007	0.311
	Pod width	-0.105	6.131	-0.171	6.351
	Pod thickness	0.250	4.842	0.006	4.940
	Bean length	0.179	7.007	0.121	7.228
	Bean width	0.089	12.978	0.029	13.427
	Bean thickness	-0.210	10.868	-0.151	11.222
	Total	0.607		0.406	

Continuation Table 4

Number of beans pod^{-1}	Direct	0.568	9.395	0.175	9.651
			Indirect, via:		
	100-bean weight	0.222	11.507	0.245	11.912
	Number of pods plant^{-1}	0.069	0.056	0.060	0.058
	Pod length	-0.004	0.002	0.001	0.002
	Pod width	-0.100	5.566	-0.163	5.766
	Pod thickness	0.214	3.564	0.006	3.637
	Bean length	0.135	4.003	0.092	4.129
	Bean width	0.082	11.053	0.027	11.435
	Bean thickness	-0.195	9.381	-0.141	9.686
	Total	0.485		0.311	
Number of pods plant^{-1}	Direct	0.748	7.313	0.657	7.497
	Indirect, via:				
	100-bean weight	0.045	0.471	0.049	0.487
	Number of beans pod^{-1}	0.005	0.072	0.016	0.074
	Pod length	-0.122	2.726	0.021	2.792
	Pod width	0.081	3.703	0.133	3.836
	Pod thickness	-0.021	0.034	-0.001	0.035
	Bean length	0.062	0.854	0.042	0.880
	Bean width	-0.010	0.168	-0.003	0.174
	Bean thickness	0.033	0.265	0.024	0.274
	Total	0.862		0.972	
Pod length	Direct	- 0.168	5.805	0.029	5.924
	Indirect, via:				
	100-bean weight	0.056	0.735	0.062	0.761
	Number of beans pod^{-1}	0.001	0.003	0.004	0.003
	Number of pods plant^{-1}	0.540	3.435	0.475	3.534
	Pod width	0.027	0.421	0.045	0.436
	Pod thickness	0.081	0.509	0.002	0.520
	Bean length	0.136	4.076	0.093	4.204
	Bean width	0.014	0.322	0.005	0.333
	Bean thickness	-0.042	0.444	-0.031	0.459
	Total			0.684	

Table 5 - Estimates of the direct and indirect effects of various components of the green pod and green bean yields in the path analysis of Experiment-2. Mossoró, RN. UFERSA. 2020

Characteristic	Association effect	Green pods		Green beans	
		Estimate	VIV	Estimate	VIV
Pod width	Direct	- 0.153	14.487	- 0.249	14.952
	Indirect, via:				
	100-bean weight	0.160	5.955	0.176	6.164
	Number of beans pod^{-1}	0.037	3.610	0.115	3.721
	Number of pods plant^{-1}	-0.399	1.869	-0.350	1.923
	Pod length	0.030	0.169	-0.005	0.173
	Pod thickness	0.259	5.215	0.007	5.320
	Bean length	0.132	3.802	0.089	3.922
	Bean width	0.086	12.009	0.028	12.424
	Bean thickness	-0.208	10.709	-0.150	11.057
	Total	- 0.063		- 0.352	
Pod thickness	Direct	0.305	8.020	0.008	8.152
	Indirect, via:				
	100-bean weight	0.191	8.494	0.210	8.793
	Number of beans pod^{-1}	0.040	4.176	0.123	4.305
	Number of pods plant^{-1}	-0.051	0.031	-0.045	0.032
	Pod length	-0.045	0.369	0.008	0.378
	Pod width	-0.130	9.420	-0.212	9.758
	Bean length	0.189	7.843	0.128	8.090
	Bean width	0.090	13.327	0.030	13.788
	Bean thickness	-0.218	11.754	-0.157	12.136
	Total	0.389		0.093	
Bean length	Direct	0.217	11.517	0.148	11.837
	Indirect, via:				
	100-bean weight	0.192	8.560	0.211	8.861
	Number of beans pod^{-1}	0.035	3.266	0.109	3.367
	Number of pods plant^{-1}	0.215	0.542	0.188	0.558
	Pod length	-0.106	2.054	0.018	2.104
	Pod width	-0.092	4.783	-0.151	4.954
	Bean length	0.265	5.461	0.007	5.572
	Bean width	0.081	10.715	0.027	11.086
	Bean thickness	-0.194	9.321	-0.140	9.624
	Total	0.626		0.424	
Bean width	Direct	0.096	16.710	0.031	17.225
	Indirect, via:				
	100-bean weight	0.217	10.927	0.238	11.312
	Number of beans pod^{-1}	0.049	6.214	0.151	6.407
	Number of pods plant^{-1}	-0.079	0.074	-0.070	0.076
	Pod length	-0.025	0.112	0.004	0.114
	Pod width	-0.136	10.411	-0.223	10.785
	Bean length	0.287	6.396	0.007	6.525
	Bean width	0.183	7.385	0.125	7.618
	Bean thickness	-0.230	13.053	-0.166	13.477
	Total	0.367		0.100	

Continuation Table 5

Bean thickness	Direct	- 0.232	14.882	- 0.168	15.311
	Indirect, via:				
	100-bean weight	0.210	10.274	0.231	10.636
	Number of beans pod^{-1}	0.048	5.922	0.147	6.106
	Number of pods plant^{-1}	-0.105	0.130	-0.092	0.134
	Pod length	-0.031	0.173	0.005	0.178
	Pod width	-0.136	10.424	-0.223	10.798
	Bean length	0.286	6.334	0.007	6.462
	Bean width	0.181	7.213	0.123	7.440
	Bean thickness	0.095	14.656	0.031	15.162
	Total	0.301		0.053	

Table 6 - Estimates of the direct and indirect effects (under multicollinearity) of the main components of dry bean yield on bean yield in the path analysis of both experiments. Mossoró, RN. UFERSA. 2020

Characteristic	Association effect	Experiment-1		Experiment-2	
		Estimate	VIV	Estimate	VIV
100-bean weight	Direct	0.447	7.919	0.312	3.926
	Indirect, via:				
	Number of beans pod^{-1}	-0.007	0.001	-0.117	2.711
	Number of pods plant^{-1}	-0.338	0.242	0.156	0.427
	Bean length	0.007	5.127	0.139	4.101
	Bean width	0.136	6.607	-0.057	7.961
	Bean thickness	0.111	3.237	0.022	3.009
	Plant dry matter	0.031	0.191	0.007	0.015
	Total	0.413		0.478	
Number of beans pod^{-1}	Direct	0.278	1.573	- 0.252	13.830
	Indirect, via:				
	100-bean weight	-0.011	0.004	0.146	0.770
	Number of pods plant^{-1}	0.184	0.072	-0.385	2.611
	Bean length	0.000	0.001	0.077	1.260
	Bean width	0.026	0.237	-0.056	7.581
	Bean thickness	0.032	0.264	0.035	7.757
	Plant dry matter	-0.016	0.049	0.004	0.006
	Total	0.509		- 0.443	
Number of pods plant^{-1}	Direct	0.788	1.469	0.622	7.589
	Indirect, via:				
	100-bean weight	-0.192	1.305	0.078	0.221
	Number of beans pod^{-1}	0.065	0.077	0.155	4.757
	Bean length	-0.002	0.663	0.077	1.254
	Bean width	-0.040	0.566	0.005	0.073
	Bean thickness	-0.047	0.593	-0.012	0.949
	Plant dry matter	-0.039	0.291	0.008	0.020
	Total	0 577		0.968	

Table 7 - Estimates of the direct and indirect effects of bean size and shoot dry matter on dry bean yield in the path analysis of both experiments. Mossoró, RN. UFERSA. 2020

Characteristic	Association effect	Experiment-1		Experiment-2	
		Estimate	VIV	Estimate	VIV
Bean length	Direct	0.008	7.561	0.206	9.982
	Indirect, via:				
	100-bean weight	0.389	5.370	0.211	1.613
	Number of beans pod^{-1}	-0.003	0.000	-0.094	1.746
	Number of pods $plant^{-1}$	-0.246	0.129	0.233	0.954
	Bean width	0.146	7.661	-0.055	7.550
	Bean thickness	0.083	1.796	0.023	3.438
	Plant dry matter	0.024	0.081	-0.030	0.286
	Total	0.397		0.504	
Bean width	Direct	0.155	9.571	- 0.069	12.999
	Indirect, via:				
	100-bean weight	0.392	5.467	0.257	2.404
	Number of beans pod^{-1}	0.046	0.039	-0.202	8.065
	Number of pods $plant^{-1}$	-0.202	0.087	-0.049	0.042
	Bean length	0.007	6.052	0.166	5.798
	Bean thickness	0.095	2.400	0.034	7.188
	Plant dry matter	0.006	0.007	-0.004	0.006
	Total	0.508		0.128	
Bean thickness	Direct	0.128	4.829	0.037	9.848
	Indirect, via:				
	100-bean weight	0.387	5.309	0.182	1.200
	Number of beans pod^{-1}	0.069	0.086	-0.235	10.894
	Number of pods $plant^{-1}$	-0.292	0.181	-0.204	0.732
	Bean length	0.005	2.812	0.128	3.485
	Bean width	0.115	4.757	-0.062	9.488
	Plant dry matter	0.034	0.228	0.004	0.005
	Total	0.454		- 0.147	
Plant shoot dry weight	Direct on bean yield	- 0.090	1.775	0.086	2.593
	Indirect, via:				
	100-bean weight	-0.155	0.854	0.025	0.023
	Number of beans pod^{-1}	0.049	0.043	-0.013	0.032
	Number of pods $plant^{-1}$	0.337	0.241	0.058	0.060
	Bean length	-0.002	0.345	-0.072	1.101
	Bean width	-0.010	0.038	0.003	0.029
	Bean thickness	-0.049	0.621	0.002	0.019
	Total	0.074		0.094	

Table 8 shows the classification of the characteristics under evaluation based on the strength of the direct effect on pod and bean yields in the two experiments. In the six cases under evaluation (3 types of yield x 2 experiments), the characteristic with the greatest direct effect on yield was the number of pods per plant. The main reason for the large role played by the number of pods per plant in determining yield may be the fact that each pod includes the other two components: number of beans per pod and bean weight. As such, any variation in the number of pods per plant, however small, will correlate with yield (Duarte; Adams, 1972).

Aryeetey and Laing (1973) found that, in the cowpea, the number of pods per plant was correlated with bean yield. However, they suggested that due to the low heritability of this characteristic (around 20%), it could only be used as a preliminary selection criterion; whereas other authors have observed relatively high values for the heritability of the number of pods per plant (Aliyu; Makinde, 2016; Khan *et al*., 2015). It is well known that heritability depends on the population being considered, as has been demonstrated in the cowpea by Gupta and Patel (2017). Several authors have suggested that the number of pods per plant could be used as a criterion in breeding for bean yield (Aliyu; Makinde, 2016; Khan *et al*., 2015).

Yield components are not widely used by breeders as selection criteria to improve yield. There are reasons for this lack of interest (Frey, 1971): 1) the relationship between yield and its components is generally non-linear, 2) the environment can affect the relationship between yield and its components, and 3) collecting yield-component data can be more expensive than collecting yield data. However, selection for yield components can be effective when developing strains. If these strains have greater combining ability for yield, the yield components would be useful selection criteria (Kuhn; Stucker, 1976). Furthermore, there is an important negative aspect to analyzing yield components to identify simpler characteristics that are directly related to yield: the components consistently show a negative correlation. This disadvantage makes the yield-component approach undesirable from a physiological point of view, at least for predicting the effect on crop yield of manipulating a component (Slafer, 2007). Negative correlations between components occur in many crops, particularly under conditions of environmental stress. The correlations are believed to be developmental, rather than genetic per se. It is suggested that they are caused by genetically independent components that develop in a sequential pattern and which can vary in response to either the constant or oscillating limitation of metabolites, so that the metabolites become limiting at critical stages during the development sequence (Adams, 1967).

As seen in the present study, the number of pods per plant is not always the characteristic with the greatest direct effect on bean yield in the cowpea (Table 8). Lopes *et al*. (2017) found that the number of beans per pod was the most important characteristic in determining cowpea yield. In another study, bean weight had the greatest direct effect on bean yield (Bezerra *et al*., 2001). Yield components

Table 8 - Classification of the characteristics of traditional cowpea varieties based on the strength of the direct effect on pod and bean yields in both experiments. Mossoró, RN. UFERSA. 2020

Characteristic	Experiment-1			Experiment-2		
	Yield			Yield		
	Green pods	Green beans	Dry beans	Green pods	Green beans	Dry beans
	Classification of characteristics based on the strength of the direct effect (1 = greatest direct effect)					
Number of pods per plant	1	1	1	1	1	1
Pod thickness	2	2	-	3	7	-
100-bean weight	3	3	2	4	2	2
Pod length	4	4	-	8	6	-
Number of beans per pod	5	5	3	2	3	7
Bean thickness	6	7	5	9	8	5
Bean width	7	6	4	6	5	6
Pod width	8	8	-	7	9	-
Bean length	9	9	6	5	4	3
Shoot dry matter	-	-	7	-	-	4

are developed during a series of events involving various metabolic changes and developmental activities. The effect of stress due to environmental factors on the final yield can therefore vary depending on the growth stage at which it occurs (Saeed *et al*., 1986). The reproductive phase in the cowpea begins with the appearance of buds, the opening of flowers, the start of pod formation, and the development of pods in terms of length, width, diameter and volume. The pod is a protective wrapping for the developing seeds; they act as receptors, transport ‘channels’ and temporary reservoirs for solutes mobilized from the vegetative parts to the seeds and, if green and illuminated, they play a part in the photosynthetic fixation of CO_2. Thus, grain formation takes place at the same stage as initial pod development, followed by seed filling (Deshmukh *et al*., 2011).

CONCLUSIONS

1. Multicollinearity, indicated by the condition number and the variance inflation values, was greater in Experiment-2;
2. In the six cases under study (three yields x two experiments), the number of pods per plant was the characteristic with the greatest direct effect on yield;

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