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Inter-relationships among potato traits and their significance in determining tuber yield

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Abstract

Research aimed at selecting potato varieties from Standard International Field Trials (SIFT) with high tuber was carried out at five locations during three seasons of 2001 - 2002 in Uganda. Data were collected on number of leaves, number of stems, plant height, percentage tuber dry matter, number of tubers, mean tuber weight and yield. Results from the simple phenotypic correlation and multiple regressions indicated that mean tuber weight ($r = 0.61$, $P<0.001$) and number of tubers per plant ($r = 0.47$, $P<0.001$) had the highest correlation values and were also retained in the regression equation across all locations, suggesting that these are the most important components of tuber yield. Path analysis was used to estimate the magnitude, significance and directions of causal relationships between these variables and yield; and thereafter an output path diagram developed. Path analysis identified number of leaves, number of stems, percentage tuber dry matter, number of tubers and mean tuber weight as the main yield components, with mean tuber weight ($P = 0.62$) and number of tubers per plant ($P = 0.46$), having the highest direct path coefficients. Although the direct effect of plant height on tuber yield was negative, plant height and number of stems per plant were important components of mean tuber weight. Path coefficient analysis also showed that direct and indirect effects of plant traits on yield explained only 47% of the total variation in fresh tuber yield probably due to environmental influence.

Key words: Multiple regression, path coefficient analysis, phenotypic correlation, *Solanum tuberosum*, yield, Uganda

Introduction

The potato (*Solanum tuberosum* L.) is the world's fourth most important food crop (Fehr, 1997). It is considered the number one cash crop in the eastern and western highlands of Uganda (Adipala *et al.*, 2000b). in Uganda, potato is grown on about 56,000 ha with an output of about 392,000 tonnes, giving an average yield of about 7 t ha^{-1} and production per capita of 13.3 kg (FAO, 1995; Adipala *et al.*, 2000a). According to a report by FAO (2002), although the area under potato production has been steadily increasing from 1990 to 2002, the yield per unit area has not been increasing at the same rate. This could be due to subsistence level production on small farm holdings, averaging less than 0.5 ha (Adipala, 1999; Adipala *et al.*, 2000b).

The main goal of any potato breeding programme and potato grower is high tuber yield. Nevertheless, potato yield is a complex quantitatively inherited trait that is difficult to improve directly. According to Kang (1994), improvement of such a complex trait may be achieved through selection for a component trait or traits that cumulatively contribute to the final phenotype. Potato tuber development is a product of three distinct physiological processes; stem emergence from the eyes, tuber initiation from the stolons and tuber bulking. It therefore appears that tuber yield is determined during these three processes. Although some studies on tuber yield have been conducted, there is paucity of information on appropriate yield indicators for selection of elite potato clones (Berga Lemaga and Caesar, 1990; Ebwongu *et al.*, 2001).

Some of the common analyses used to study inter-relationships among variables include correlation, regression and path coefficient analyses. More recently, Allen and Wurr (1992) reported that the number of main stems produced per potato plant is dependent on tuber size or variety. Earlier studies also showed that an increase in stem numbers markedly favoured haulm production (Sevenson and Naglicka, 1975), stem elongation, plant height (Harris, 1972), increased tuber numbers (Hammes, 1985) and total tuber yield per plant or per unit area of land (Irritani *et al.*, 1972). These past studies suggest that potato tuber yield is determined mostly by number of stems, tubers per plant, and tuber size or weight.

Multiple regression is one of the most commonly used method to elucide relationships between sets of variables contributing to a final outcome. Path coefficient analysis is an extension of multiple regression that aims at providing estimates of the magnitude and significance of hypothesised causal connections between sets of variables and gives an in-depth understanding of these relationships. Path-coefficient analysis has been considered more informative and uséful than simple correlation coefficients and multiple regressions (Li,1975; Gravois and McNew, 1993; Kang 1994). This is due to the fact that a path coefficient measures the direct influence of one trait upon another trait and permits separation of correlation coefficients into components of direct and indirect effects. Path-coefficient analysis also simultaneously captures the effects of intricate relationships among various traits under study. Several studies have used path-coefficient analysis to investigate direct and indirect effects from a set of causal effects in many crop species (Gravois and Helmes, 1992; Gravois and McNew, 1993; Board *et al.*, 1997; Ntawuruhunga *et al.*, 2001). In the present investigation, path coefficient analysis was used to elucidate critical components of potato yield that could be used to indirectly select for high yield.

Materials and methods

Field experiments were initiated during the second rains (September – December) of 2001 (2001B) and repeated for two consecutive seasons in 2002 (2002A and 2002B). The study was conducted at five different elevations; Kalengyere (2450 m.a.s.l.), Kachwekano Agricultural Research Technology Development Centre (ARDC) (2200 m.a.s.l.), Katukuru-Mbarara (1500 m.a.s.l.) in southwestern Uganda, Buginyanya ARDC (1980 m.a.s.l.) and Wanale (1900 m.a.s.l.) in eastern Uganda, selected to represent the major potato growing areas of the country, except the west Nile region (Sikka *et al.*, 1991). The potato genotypes used in this study were; 389746.2, 384866.5, TORRIDON, 386040.9, 381381.20, ROBIJN, 381390.30, 720118, 386056.7, 381381.13 and 386209.10 plus two widely adopted varieties *Victoria* (moderately resistant to late blight) and *Kisoro* (susceptible). A randomised complete block design (RCBD) using a spacing of 70 cm x 30 cm in 4 row plots with three replications was used for each genotype at each experimental site. Basal NPK fertiliser was applied at planting, at a rate of 60 g m^{-1}, each plot received 3 to 6 sprays (depending on the site, season and rainfall amounts) of a contact fungicide, Dithane M 45 (Mancozeb 80% WP) to control late blight disease. Weeding and hilling were carried out whenever necessary. Dehaulming was done at 90 days after planting, while harvesting was done 10 – 14 days after dehaulming.

Data collection

Assessment of late blight severity commenced upon first symptom (lesion) development and continued weekly up to physiological maturity. A 1 – 9 CIP scale as described by Henflings (1987) was used in disease assessment. Data on growth parameters (number of leaves per plant, number of main stems per plant and plant height) were collected at 50% flowering. Plant height was obtained by measuring the heights from the collar region right up to the shoot tip using a metre rule. Tuber number

and fresh weights were measured at harvest and were used to compute tuber multiplication rate/ number of tubers per plant, mean tuber weight and yield per hectare. A sample of tubers weighing 100 g from each plot was oven-dried at 80°C up to constant weight so as to determine dry matter content.

Data analyses

Linear relationships among the different plant traits were studied by performing a simple phenotypic correlation analysis. A stepwise multiple regression analysis was performed for each location and for the combined locations to determine which variables adequately and consistently explained the observed variations in potato tuber yields. Correlation and regression coefficients were estimated using the Genstat computer package (Genstat, 1995). A path analysis was also performed to determine the direct and indirect effects of the causal-effects using Genstat and an output path diagram generated following the procedures described by Li (1975).

Results and discussion

Correlation analysis

Tuber yield was positively correlated (P<0.01) with all the plant traits measured in this study (Table 1). Mean tuber weight (r = 0.61, P<0.001) was most strongly correlated to yield, followed by number of tubers per plant (r = 0.47, P<0.001), number of stems per plant (r = 0.42, P<0.001), plant height (r = 0.36, P = 0.02), percentage tuber dry matter (r = 0.31, P<0.001) and number of leaves per plant (r = 0.26, P<0.001). The significant positive correlation coefficients between yield and all the plant traits measured in this study suggest that these traits contributed to variation in tuber yield. In addition, the high correlation coefficients obtained for mean tuber weight and number of tubers per plant implies that they were the most important traits in increasing tuber yield as earlier suggested by Abalo *et al.* (2001). Therefore, a high mean tuber weight and tuber multiplication rate could be a good indication of high yield. The low correlation coefficients between these plant traits and tuber yield of some of the materials used in this study may be attributed to the significant G x E interactions (El-Bedewy *et al.*, 2001). This is because when the G x E interactions are large and apparent, progress from selection and the correlation between phenotypic and genotypic values are reduced (Kang,1990). Plant height was positively correlated with number of leaves per plant (r = 0.29, P<0.01), number of stems per plant (r = 0.20, P<0.01), number of tubers per plant (r = 0.23, P<0.01), mean tuber weight (r = 0.25, P<0.01) and percentage tuber dry matter (r = 0.17, P<0.05). The number of stems per plant was also positively correlated with number of tubers per plant (r = 0.30, P<0.001) and mean tuber weight (r = 0.25, P<0.01). The significant and positive correlation between number of stems and number of tubers per plant and mean tuber weight may be an indication that a high number of stems enhances these two traits. Earlier studies have also shown that an increase in stem numbers favours plant height (Harris, 1972), increased tuber numbers (Hammes, 1985) and total tuber yield per plant or per unit area of land (Iritani *et al.*, 1972). These results are however, contrary to those of Allen (1992), who reported that an increase in stem numbers decreases average tuber weight. The contradiction may be due to the fact that different genotypes were used in these studies, yet the genotypic effect on these plant traits was highly significant (Nakitandwe, 2003). Mean tuber weight had a negative but weak correlation with number of tubers per plant (r= -0.09), suggesting that a high tuber multiplication rate reduces the weight per tuber but the reduction is not significant (P<0.05). In addition to plant height, percentage tuber dry matter was also positively correlated with mean tuber weight (r=0.17, P<0.05). The lack of significant correlation between percentage tuber dry matter and most plant traits has been reported in other correlation studies in root and tuber crops (Mahungu *et al.*, 1994; Ntawuruhunga *et al.*, 2001), where it was concluded that dry matter of storage roots and tubers is of least importance when compared to other plant traits studied in yield variation. Nevertheless, the positive and significant and fresh weights were measured at harvest and were used to compute tuber multiplication rate/ number of tubers per plant, mean tuber weight and yield per hectare. A sample of tubers weighing 100 g from each plot was oven-dried at 80°C up to constant weight so as to determine dry matter content.

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Table 2. Regression equations relating tuber yield with several potato plant traits at different locations in Uganda.

Location	Variable	Parameter estimated	SE	Probability
Kalengyere	Intercept	-29.230	3.490	<0.001
	Mean tuber weight	0.113	0.019	<0.001
	Number of tubers per plant	0.746	0.222	0.002
	Number of leaves per plant	1.366	0.109	<0.001
	Plant height	0.147	0.043	<0.001
	Percentage tuber dry matter	0.405	0.140	0.004
	R^2 (adjusted)	0.80		
Kachwekano	Intercept	-8.120	1.390	<0.001
	Mean tuber weight	0.169	0.011	<0.001
	Number of tubers per plant	1.780	0.153	<0.001
	Number of stems per plant	0.703	0.229	0.003
	R^2 (adjusted)	0.81		
Buginyanya	Intercept	-12.790	1.340	<0.001
	Mean tuber weight	0.300	0.013	<0.001
	Number of tubers per plant	1.747	0.118	<0.001
	Number of stems per plant	0.622	0.179	<0.001
	R^2 (adjusted)	0.77		
Wanale	Intercept	-9.240	1.620	<0.001
	Mean tuber weight	0.150	0.015	<0.001
	Number of tubers per plant	2.335	0.193	<0.001
	R^2 (adjusted)	0.56		
Mbarara	Intercept	-6.394	0.553	<0.001
	Mean tuber weight	0.221	0.010	<0.001
	Number of tubers per plant	1.927	0.104	<0.001
	Number of stems per plant	-1.086	0.310	<0.001
	R^2 (adjusted)	0.97		
Combined	Intercept	-22.120	1.900	<0.001
	Mean tuber weight	0.198	0.009	<0.001
	Number of tubers per plant	1.543	0.094	<0.001
	Number of leaves per plant	0.329	0.048	<0.001
	Number of stems per plant	0.694	0.147	<0.001
	Plant height	-0.035	0.015	0.019
	Percentage tuber dry matter	0.442	0.077	<0.001
	R^2 (adjusted)	0.71		

R^2 = Coefficient of determination.
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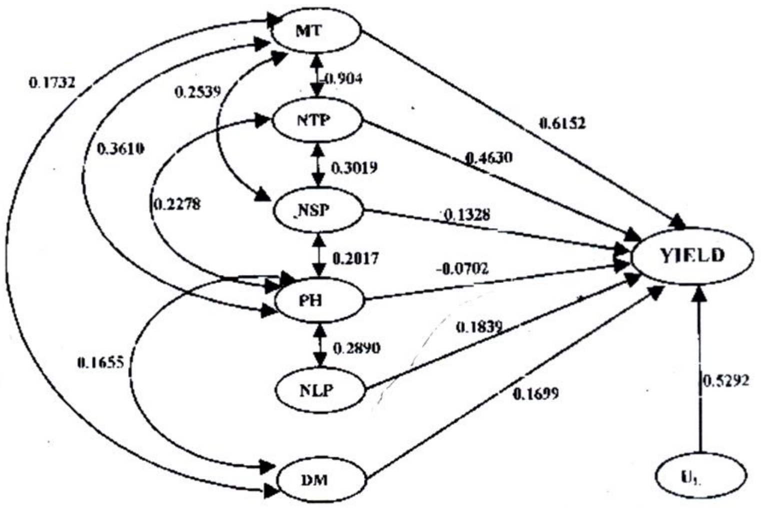
of (1 - R^2), giving an estimate of 0.53. This implies that only 47% of the total variation in fresh tuber yields was explained by the direct and indirect effects of the plant traits on yield. This could be attributed to the interdependency among the variables and other unpredictable factors.

Conclusion

This study has shown that fresh tuber yield is mainly influenced by mean tuber weight and tuber multiplication rate. Although the relationship between these two traits was negative it did not affect overall tuber weight. The data also suggest that plant height and stem number are important components of mean tuber weight. Consequently, mean tuber weight and number of tubers per plant may be used for indirectly selecting for high potential potato tuber yield. Furthermore, these two traits should be improved together with plant height and number of stems per plant due to the strong relationships among these traits. However, the parameters used accounted for only 47% of the variation in fresh tuber yield. Therefore, other parameters should be included so as to attain better R^2 values of equations that can explain >75% of the variation in yield.



Where: MTW is mean tuber weight; NTP is number of tubers per plant; NSP is number of stems per plant; PH is plant height; NLP is number of stems per plant; DM is percentage tuber dry matter and UL is the residual (unknown source of variation in yield.

Figure 1. Causation diagram indicating relationships between fresh tuber yield and other plant traits.

Table 3. Calculated direct and indirect effects of plant traits on yield of potato genotypes in SIFT.

Mean tuber weight Vs. fresh tuber yield	Direct and indirect effects
Direct effect of mean tuber weight on yield	0.6152
Indirect effect of mean tuber weight via plant height	-0.0253
Indirect effect of mean tuber weight via number of stems per plant	0.0337
Indirect effect of mean tuber weight via percentage tuber dry matter	0.0294
Indirect effect of mean tuber weight via number of tubers per plant	-0.0419
Indirect effect of mean tuber weight via number of leaves per plant	0.0072
Total indirect effects	-0.0031
Total (Direct + Indirect) effect	0.6121
Number of tubers per plant Vs. fresh tuber yield	
Direct effect of number of tubers per plant on yield	0.4630
Indirect effect of number of tubers per plant via plant height	-0.0160
Indirect effect of number of tubers per plant via number of stems per plant	0.0401
Indirect effect of number of tubers per plant via percentage tuber dry matter	0.0193
Indirect effect of number of tubers per plant via mean tuber weight	-0.0556
Indirect effect of number of tubers per plant via number of leaves per plant	0.0219
Total indirect effects	0.0097
Total (Direct + Indirect) effect	0.4727
Number of leaves per plant Vs. fresh tuber yield	
Direct effect of number of leaves per plant on yield	0.1839
Indirect effect of number of leaves per plant via plant height	-0.0203
Indirect effect of number of leaves per plant via number of stems plant	0.0019
Indirect effect of number of leaves per plant via percentage tuber dry matter	0.0193
Indirect effect of number of leaves per plant via mean tuber weight	0.0240
Indirect effect of number of leaves per plant via number of tubers per plant	0.0551
Total indirect effects	0.0800
Total (Direct + Indirect) effect	0.2639
Number of stems per plant Vs. fresh tuber yield	
Direct effect of number of stems per plant on yield	0.1328
Indirect effect of number of stems per plant via plant height	-0.0142
Indirect effect of number of stems per plant via percentage tuber dry matter	0.0089
Indirect effect of number of stems per plant via mean tuber weight	0.1562
Indirect effect of number of stems per plant via number of tubers per plant	0.1398
Indirect effect of number of stems per plant via number of leaves per plant	0.0026
Total indirect effects	0.2933
Total (Direct + Indirect) effect	0.4261
Plant height Vs. fresh tuber yield	
Direct effect of plant height on yield	-0.0702
Indirect effect of plant height via number of stems per plant	0.0268
Indirect effect of plant height via percentage tuber dry matter	0.0281
Indirect effect of plant height via mean tuber weight	0.2221
Indirect effect of plant height via number of tubers per plant	0.1055
Indirect effect of plant height via number of leaves per plant	0.0531
Total indirect effects	0.4356
Total (Direct + Indirect) effect	0.3654
Percentage tuber dry matter vs. fresh tuber yield	
Direct effect of percentage tuber dry matter on yield	0.1699
Indirect effect of percentage tuber dry matter via plant height	-0.0116
Indirect effect of percentage tuber dry matter via number of stems per plant	0.0069
Indirect effect of percentage tuber dry matter via mean tuber weight	0.1066
Indirect effect of percentage tuber dry matter via number of tubers per plant	0.0382
Indirect effect of percentage tuber dry matter via number of leaves per plant	0.0209
Total indirect effects	0.1610
Total (Direct + Indirect) effect	0.3309
R^2	0.72
Residual (U_L)	0.53

SIFT = Standard international field trials.

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References

Abalo, G., Hakiza, J.J., Kakuhenzire, R.M., El-Bedewy, R. and Adipala, E. 2001. Agronomic performance of twelve elite potato genotypes in southwestern Uganda. African Crop Science Journal 9:17-23.

Adipala, E. 1999. Potato Production in Uganda. A Survey Perspective. Makerere University, Kampala.

Adipala, E., Namanda, S., Mukalazi, J., Kimoone, G. and Hakiza, J. 2000a. Understanding farmer's perception of potato production constraints and response to yield decline in Uganda. African Potato Association Conference Proceedings 5:429-437.

Adipala, E., Namanda, S., Mukalazi, J., Kimoone, G. and Hakiza, J. 2000b. Farmer potato varietal selection criteria in Uganda. African Potato Association Conference Proceedings 5:439-443.

Allen, E. J. and Wurr, D. C. E. 1992. Plant density. In: *The Potato Crop*. P. Harris (ed.). 2nd ed. Chapman and Hall, London Institute of Agricultural Botany, Cambridge, U.K. pp. 292-330.

Berga Lemaga and Caesar, K. 1990. Relationships between numbers of main stems and yield components of potato (*Solanum tuberosum* L. cv. Erntestolz) as influenced by different day lengths. Potato Research 33:257-267.

Board, J.E., Kang, M.S. and Harville, B.G. 1997. Path analyses identify indirect selection criteria for yield of late planted soybean. Crop Science 37:879-884.

Ebwongu, M., Adipala, E., Ssekabembe, C.K., Kyamanywa, S. and Bhagsari, A.S. 2001. Effect of intercropping maize and *Solanum* potato on yield of the component crops in central Uganda. African Crop Science Journal 9:83-96.

El-Bedewy, R., Olanya, M., Adipala, E., Ewell, P., Kabira, J., Walingo, A., Lung'aho, C., Hakiza, J.J., Wagoire, W., Kakuhenzire, R., Anginyah, P.S., Ojiambo, P.S. and Nakitandwe, J. 2001. Performance of potato genotypes and resistance to *Phytophthora infestans* in Standard International Field Trials in selected locations of East Africa. African Crop Science Conference Proceedings 5:461-468.

Ewell, P.T. 1991. Potatoes and sweetpotatoes in the food systems of eastern and southern Africa. In: CIP-NARS Collaboration on Potato and Sweetpotato Research and Development in Eastern, Central and Southern Africa. CIP, Lima, Peru. pp. 15-27.

FAO (Food and Agriculture Organisation), 1995. Potato in 1990s'. Situation and Prospects of World Potato Economy. International Potato Center (CIP), Food and Agriculture Organisation, Rome. 39pp.

Fehr, W.R. 1997. Principles of Cultivar Development. Crop Species, Vol 2. MacMillan Publishing Company, New York. 672 pp.

Genstat, 1995. Genstat 5 Release 3.2 (PC/Windows NT), 1995. Lawes Agricultural Trust (Rothamsted Experimental Station).

Gravois, K.A. and Helms, R.S. 1992. Path analysis of rice yield and yield components as affected by seeding rate. Agronomy 84:1-4.

Gravois, K.A. and McNew, R.W. 1993. Genetic relationship among and selection for rice yield and yield components. Crop Science 33:249-252.

Hammes, P.S. 1985. The effect of stem population on tuber yield in a trial with single stem seed pieces. Potato Research Journal 28:119-121.

Harris, P.M. 1972. The effect of plant population density and irrigation on sugar beat. Journal of Agricultural Sciences 79:289-302.

Harris, P. 1992. The Potato Crop. The Scientific Basis for Improvement. 2nd edition. Chapman and Hall, London. 909 pp.

Henflings, J.W. 1987. Late blight of potato, *Phytophthora infestans*. Technical Information Bulletin, 4. CIP, Lima, Peru. 25pp.

Irritani, W.M., Thornton, R., Weller, L. and O'learly, G. 1972. Relationships of seed size, spacing and stem numbers to yield of Russet Burbank potatoes. American Potato Journal 49:463-469.

Kang, M.S. 1990. Genotype-by-Environment Interaction and Plant Breeding. Louisiana State University, Baton Rouge, LA.

Kang, M.S. 1994. Applied Quantitative Genetics. Department of Agronomy, Louisana State University, Baton Rouge, LA 70803-2110, USA.

Li, C.C. 1975. Path Analysis. A Primer. Boxwood Press, Pacific Grove, CA.

Mahungu, N.M., Chelda, H.R., Aken'Ova, M.E. and Hahn, S.K. 1994. Correlation response and use of selecton index in cassava. Pages 114-117. In: Proceedings of the 9th ISTRC Symposium, 20-26, Accra, Ghana.

Nakitandwe, J. 2003. Resistance to late blight and Yield stability of SIFT and Population B3 potato selections in Uganda. MSc. Thesis, Makerere University. 146pp.

Ntawuruhunga, P.H., Rubaihayo, P.R., Whyte, J.B.A., Dixon, A.G.O. and Osiru, D.S.O. 2001. Additive main effects and multiplicative interaction analysis for storage root yield of cassava genotypes evaluated in Uganda. African Crop Science Journal 9:591-598.

Sevenson, B. and Naglicka, I. 1975. Development of potato stands in relation to stand density. Potato Research Journal 18:105-108.

Sikka. L., Bhagsari, A.S., Ssebuliba, J.M. and Kanzikwera, R. 1991. Potato production from true potato seed. Proceedings of the 9th symposium of the international society for tropical root crops, 20-26 October 1991. Accra, Ghana. pp. 484-489.

Varma, S.P. and Marthura, R. 1993. Genetic variability and inter-relation in cassava (*Manihot esculenta* Crantz) under rained conditions of Tripura. Journal of Root Crops 19:77-80.