

Induced Mutations for Accelerated Domestication-A Case Study of Winged Bean (*Psophocarpus tetragonolobus* (L.) DC)

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Abstract

Induced mutations have the ability to increase the rate of domestication of the many underexploited species of plants that may be potentially useful as source of food, forage and industrial raw materials. The process of domestication has been conditioned by single or major gene mutations. The role of mutagenesis in speeding up domestication, which is species dependent, is outlined in this paper. A case study of the role of induced mutations in the domestication of winged bean (*Psophocarpus tetragonolobus*) is also presented.

Key words: Genes, mutation, Psophocarpus tetragonolobus, winged bean

Introduction

Food production to meet the needs of the growing world population can be augmented by improving agronomic techniques and by growing genetically improved cultivars of a wide range of crops. This notwithstanding, there is the possibility to increase the range of crops either by aiming at new domesticates or by the existing cultigens (Smart, 1989). Underexploited and underutilized plants, which abound in the tropical ecosystem, may be useful in contributing to this objective. These are plants that may be potentially useful as source of food, forage or industrial raw material. Most of these plants have remained underexploited because they have received little or no research attention since emphasis has been on the cash crops for export.

It has been estimated that there are about 200,000 species of flowering plants worldwide of which about 3000 have been used by man for food, fibre, spices, etc. Out of this only 200 have been domesticated for commercial cultivation and barely 15-20 provide the bulk

of food for man (Anon, 1975). Although these plants are the vault of untapped genes, they remain underexploited.

In Ghana, there are over 35 plant species of about 16 families belonging to the group of neglected traditional food crops. Some of these crops include winged bean (*Psophocarpus tetragonolobus* (L.) DC), African yam bean (*Sphenostylis stenocarpa* Hochst ex A. Rich), Kersting's groundnut (*Macrotyloma geocarpum* Harms Marechal and Baudet) and Velvet bean (*Mucuna pruriens* DC var. *utilis*) (Adansi & Holloway, 1978).

In this paper the role of induced mutations in domestication of underexploited plants is highlighted.

The practice and acceleration of domestication

Plant domestication is a sympatric evolution (Zeven & de Wet, 1982). This implies that populations inhabiting the same geographic range become reproductively isolated. This process can be described as a process of

species formation (King & Stansfield, 1990; Reiger *et al.*, 1991). Domesticates (i.e. genetically adapted wild plants that are more or less regularly grown as crops) and their wild progenitors differ in phenotype and, in adaptation but remain sufficiently and genetically related to enable crossing that would yield fertile hybrids.

Domesticated plants may, among other things flower and fruit simultaneously, lack shattering of pods and loose dispersal mechanisms, change from perennial to annual plants and may acquire better palatability and better chemical composition. Changes in nodulation and elimination or reduction of undesirable constituents and changes in growth habit are also available (Anon, 1977; Zeven & de Wet, 1982).

The process of domestication has been conditioned by mutations and driven by selection (Röbbelen & von Witzke, 1989) and the major steps in the process have been linked to single major gene mutations or mutations of very few genes. These mutations are more often recessive and rarely dominant (de Wet, 1989) and the reproductive isolation among different groups of domesticated species has been caused by macromutations as well as micromutations (Gould, 1980; Stebbins & Ayala, 1981; de Wet, 1989). For example, chromosomal changes in the form of inversions have been recorded to be the source of differences between some cultivars of soybean (*Glycine max* L. Merr.) and *G. soja* Seb Zucc, the wild progenitor of soybean (Ahmed *et al.* 1979)

Additionally, the process of domestication is species dependent, i.e. some species are much better suited to domestication than others since there are differences in the ease of reproduction, response to the environment of cultivation and the genetic capacity to respond favourably to breeding methods

(Harlan, 1956).

Mutagenesis for increased genetic variation

Mutation induction and some other means of genetic modification, such as genetic transformation, are tools that can provide variation in some of the plant characters outlined, and hopefully lead to acceleration of domestication. The last 30 years have shown mutations to becoming a useful supplementary tool for the genetic improvement of cultivated plants (Novak & Micke, 1988); the FAO/IAEA Mutant Varieties Database contains over 1737 accessions (Maluszynski *et al.*, 1995). The majority of mutant varieties belong to the cereals, although successes have been recorded in the legumes, vegetatively propagated crops and ornamentals as well (Micke *et al.*, 1987; Maluszynski *et al.*, 1995). In the pulses some of these changes relate to plant architecture and include alteration of a winding plant structure to a nonwinding one, reduction or removal of tendrils (Blixt, 1972; Blixt & Gottschalk, 1975) and reduction of leafiness of legumes for production of grains (Rao *et al.*, 1975; Rennie, 1978).

Smartt (1989) has recorded that mutagenesis primarily compresses the time scale of domestication. In the genus *Cuphea* mutants for non-sticky hairiness, monocolm shoot and fasciated stem, which are inherited monogenically have been induced. These features have been induced in several *Cuphea* species, thereby adding to the genetic improvement of *Cuphea* (Röbbelen & Witzke, 1989).

Winged bean and its genetic improvement objectives

Recent phenetic analysis of herbarium collections has provided information on the

genus *Psophocarpus*. This genus includes two subgenera, *Psophocarpus* and *Lophostigma*. The former has two Sections (sect. *Psophocarpus* and *Vignopsis*), which include six species; *P. grandiflorus* Wilczek, *P. palustris*, *Desv. P. scandens* (Endl.) Verd P. (*P.*, *tetragonolobus* (L.) DC), *P. luka fuensis* (De Wild) Wilczek and *P. lancifolius*. The subgenus *Lophostigma* has three species, *P. obovalis*, *P. monophyllus* Harms and *P. lecomtei* (Maxted, 1990). All the nine species except the cultivated species, *Psophocarpus tetragonolobus*, have been found in the wild and appear to be indigenous to Africa, Madagascar and the Mascarene Islands in the Indian Ocean (Hymowitz & Boyd, 1977; Pickersgill, 1980; Smart, 1980; Maxted, 1990).

The winged bean (*Psophocarpus tetragonolobus*) plant is twining. Early and late flowering, day neutral, fungi resistant and non-shattering-pod types have been identified (Vietmeyer, 1978). Some cultivars develop root tubers under appropriate environmental conditions. This is a crop with considerable merit in that, apart from its stem and roots, all parts of the plant are edible and of high nutritional value since they are usually rich in protein, minerals and vitamins.

Research in Ghana (Cerny & Addy, 1973; Kordylas *et al.*, 1978; Plahar & Hoyle, 1987), Côte d' Ivoire (Ravelli *et al.*, 1978) and the former Czechoslovakia and Vietnam (Cerny *et al.* 1981) shows that the mature dry seeds have the potential of being processed into weaning foods for infants and toddlers, as well as high protein products and animal feed. The digestibility of the winged bean seed like some other pulses is adversely affected by the presence of several antinutritional factors. These include an antitrypsin and antichymotrypsin inhibitors (Anon, 1975; Poulter, 1982; Fernando & Bean, 1985, 1986)

and lectins in the seeds and tubers (Poulter, 1982). Various levels of tannin have been reported in whole seed meals and tuber of the winged bean (Anon, 1975).

Production of green pods with less stringiness is desired if the crop is to be used as a vegetable. However, if it is to be grown as a grain legume, and hence as a field crop, the ideal plant must be early maturing with compressed flowering period, a large number of relatively small pods, dwarf bush type with a few side branches and robust stem coupled with reduced internode length and/or reduction in the number of nodes (Stephenson, 1978; Eagleton *et al.*, 1985, Smartt, 1990). In line with these objectives the development of self-supporting determinate cultivars for single harvest, high yielding cultivars with high nutritional quality, cultivars with pods that have low pod wall fibre so that pods of large size remain edible and, consequently, useful as green vegetables, cultivars with good tuber development and cultivars that are disease resistant are desirable (Lazaroff, 1989). Intraspecific hybridization should be the normal way of breeding by combining existing genetic variation. However, these have not yielded the desired results. Interspecific hybridization could be an additional tool to be used but so far, no conspecific wild relatives have been identified and no cross-compatible wild species producing viable interspecific hybrids are known (Smartt, 1990). The use of mutation breeding and genetic engineering appear promising due to the low genetic variability resulting from the high level of self-pollination (Erskine, 1978).

Status of mutation breeding in winged bean

The use of induced mutagenesis has produced appreciable results in this crop. Gamma radiation doses up to 300 Gy on dry seeds

yielded mutants in M_2 and M_3 generations for earliness (Veeresh & Shivashankar, 1987), higher tuber yield (Armachuelo & Bernardo, 1981), dwarf and bush type mutants (Anon, 1982; Jugran *et al.*, 1986) and seed protein increases (Klu *et al.*, 1991).

Significantly, chlorophyll mutation frequency has led to the recovery of seed-coat-colour mutants as an indirect method of obtaining mutants with tannin content changes. The mutant 3/4-10-7 (light-brown) with a tannin content of 3.42 mg catechin equivalent (CE) per gram of testa has been obtained. This provides a reduction of about 75% from the parent cultivar, Kade 6/16 (brown) which had a tannin content of about 13.24 mg CE per gram of testa. This method has produced mutants with both increased and decreased tannin content (Klu *et al.*, 1997). These seed-coat-colour mutants also showed differences in nodulation. The mutants are earlier nodulators and they have increased numbers of nodules in some of them (Klu & Kumaga, 1999). These mutants are expected to be under the control of genes linked to the flavonoid biosynthetic pathway. Mutations on single or multiple enzymatic steps along the path could effect changes in the regulatory gene for nodulation and proanthocyanin expression.

Conclusion

Induced mutations have the potential to speed the domestication of the many underexploited but potentially useful plant species available. The advances so far made in the winged bean provide attestation to this.

References

Adansi, M. A. & Holloway, H. Q. (1978). Exploration for plant genetic resources in Ghana. Paper presented at a Symposium on Crop Improvement, University of Ghana, Legon. 15 December, 1978.
 Ahmad, Q. N., Britten, E. J., & Byth, D. E. (1979).

Inversion Heterozygosity in the hybrid soyabean-*Glycine soja* J. *Hered.* **70**: 358-364.
 Anon (1975). Underexploited Tropical Plants with Promising Economic Value. National Academy of Sciences, Washington D.C., 159 pp.
 Anon. (1977). Manual on Mutation Breeding, 2nd edition Joint FAO/IAEA Division of the Atomic Energy in Food and Agriculture IAEA. Vienna pp.288.
 Anon. (1982). Dr. Shivashankar develops bush type mutant in India. *The Winged Bean Flyer* **4**:32-33.
 Armachuelo, J. G., & Bernardo, F. A. (1981). Effects of ethyl methyl sulfonate and ^{60}Co gamma irradiation on winged bean. *Annals of Tropical Research* **3**: 241-249.
 Blixt, S. (1972). Mutation genetics in *Pisum*. *Agric. Hortique Gen.* **30**: 1-304
 Blixt, S., & Gottschalk, W. (1975). Mutation in the Leguminosae. *Agric. Hortique Gen.* **33**:33-85.
 Cerny, K., Duong Quynh Hoa, Nguyen Lan Dinh & Zelena, H. (1981). The winged bean seed as a major source of protein in infant nutrition. In the Study of Utilisation of Genetic Resources of Cultivated Plants of the Tropics and Sub-Tropics. Summaries of Papers Delivered at the COMECO Symp. 1981. Prague. 130 pp.
 Erskine, W. (1978). The genetics of winged bean. In: The Winged Bean. Paper presented in the 1st int. symp. On Development of the Potentials of the Winged Bean. PC ARR. Los Baños, Laguna. Philippines, pp 29-35.
 Fernando, T. & Bean G. (1985). Variation of the antinutritional behemic acid content among the cultivars of winged bean (*Psophocarpus tetragonolobus* (L.) DC). *Food Chemistry* **18**: 165-269.
 Fernando, T & Bean, G. (1986). The reduction of antinutritional behemic acid in winged bean (*Psophocarpus tetragonolobus* (L.) (DC) seeds. *Qual. Plant Foods. Hum. Nut.* **36**: 93-96
 Gould, S. J. (1980). Is a new and general theory of evolution emerging? *Paleobiology* **6**: 119-130.
 Harlan, J. R. (1956). Distribution and utilisation of natural variability in a cultivated plant. In Genetics in Plant Breeding. Brookhaven Symposia in Biology No. 9. Brookhaven National Laboratory. Upton N Y. 191-208 pp
 Hymowitz, T., & Boyd, J. (1977). Origin ethnobotany and agricultural potential of the winged bean (*Psophocarpus tetragonolobus*). *Econ. Bot* **31** : 180-188.
 Jugran, H. M., Nath, P., Banerji, B. K. & Datta S.K. (1986). Gamma ray induced dwarf mutant of winged

- bean, *Psophocarpus tetragonolobus*. (L.)(DC). *Nuclear Agric. Biol.* 15(3): 175-178.
- King, R. C. & Stansfield, W. D.** (1990). A dictionary of genetics. 4th Edition. Oxford University Press, New York. 405, pp.
- Klu, G. Y. P., Lamptey, T. V. O. & Awafo, V.** (1991). Radiation induced mutation for improved seed quality in winged bean (*Psophocarpus tetragonolobus* L. (DC)). In Plant Mutation Breeding for Crop Improvement. Vol 2, June, 1990. Vienna, IEAA. 179-181 pp.
- Klu, G. Y. P., Jacobsen, E. & van Harten, A. M.** (1997). Induced mutations in winged bean (*Psophocarpus tetragonolobus* L. DC) with low tannin content. *Euphytica* 98: 99-107.
- Klu, G. Y. P. & Kumaga, F. K.** (1999). Testing induced mutants of winged bean (*Psophocarpus tetragonolobus* (L.) DC) for nodulation and phenotypic performance. *Ghana Journal of Science* (In press).
- Kordylas, J. M., Duffie, Y. & Asibey Berko, E.** (1978). The processing and formulation for weaning foods based on the winged bean. In Winged Bean. Papers presented in the 1st Int. Symp. on Developing the Potentials of the Winged Bean. PCARR. Los Baños, Laguna, Philippines. 363-370 pp.
- Lazaroff, L.** (1989). Strategy for development of a new crop. In New Crops for Food and Industry. G.E. Wickens, N. Haq and P. Day Ed, pp. 108-109. Chapman and Hall, London.
- Maliga, P.** (1980). Isolation, characterization and utilization of mutant cell lines in higher plants. In Perspectives in Plant Cell and Tissue Culture. Vasil, I. K. (ed.) Rev. Cytol Suppl. IIA. 225-250.
- Maliga, P., Sidorov, V. A., Cséplö, A., & Menczel, L.** (1981). Induced mutations in advancing *in vitro* culture techniques. In: Induced Mutation a Tool in Plant Research, Vienna. IEAA. pp. 339-353.
- Maluszynski, M., Ahloowalia, B. S. & Sigurbjörnsson, B.** (1995). Application of *in vitro* and *in vivo* mutation techniques for crop improvement. *Euphytica* 85: 303-315.
- Maxted, N.** (1990). A phenetic investigation of the *Psophocarpus palustris*, *P. scandens* complex (Endl) (Leguminosae, Phaseolanae). *Kew Bull.* 44: 731-742.
- Micke, A., Donini, B & Maluszynski, M.** (1987). Induced mutations for crop improvement. A review. *Trop. Agric. Trinidad* 64: 259-278.
- Novak, F. J & Micke, A.** (1988). Induced mutations and *in vitro* techniques for plant breeding. In Plant Breeding and Genetic Engineering. Zakri (ed). pp. 63-85. SABRAO.
- Pickersgill, B.** (1980). Cytology of two species of Winged bean, *Psophocarpus tetragonolobus* (L.) DC and *P. scandens*. (Endl.) (Leguminosae). *Bot J. Linn Soc.* 80: 279-291.
- Plahar, W. A. & Hoyle, N. T.** (1987). Estimation of Protein quality in weaning foods prepared from local raw materials. Ghana Tech. Rept. No. WFI. Food Research Institute (CSIR).
- Poulter, N. H.** (1892). Some characteristics of the roots of the winged bean (*Psophocarpus tetragonolobus* (L.) DC) *J. Sci. Food Agric.* 33: 107 - 114.
- Rao, C. H. Tickoo, J. L., Hayat Ram & Jain, H. K.** (1975). Improvement of pulse crops through induced mutations: Reconstruction of plant type. In Breeding for Seed Protein. Improvement Using Nuclear Techniques. Proc. 2nd Research coordination Meeting Ibadan. 1973. IEAA Vienna. pp 125-131.
- Ravelli, G. P., N'zi, G. K., Diaby, L., N'dri, K. B., Mayer, C. G. & Sylla, B. S.** (1978). The winged bean as a new source of protein for rural populations in the Ivory Coast, West Africa. In The Winged Bean. Paper Presented in the 1st Int. Symp. On Developing the Potentials of the winged Bean pp. 313-321, Los Baños, Laguna, Philippines, PCARR.
- Rennie, R. J.** (1978). Potential use of induced mutation to improve symbiosis of crop plants with N₂-fixing bacteria. In Induced Mutations- A Tool in Plant Research. pp. 293-321. Vienna. IEAA.
- Rieger, R., Michaelis, A. & Green, M. M.** (1991). Glossary of Genetics. Classical and Molecular. 5th edition. Springer-Verlag. Berlin, Heidelberg, New York.
- Röbbelen, G. & von Witzke, S.** (1989). Mutagenesis for the domestication of *Cuphea*. In Plant Domestication by Induced Mutation. Proc. FAO/IEAA Advisory Group Meeting. 17-21. November 1986. pp 101-229. Vienna, IEAA.
- Smartt, J.** (1980). Some observations on the origin and evolution of the winged bean (*Psophocarpus tetragonolobus*). *Euphytica* 29: 121-123.
- Smartt, J.** (1989). The tribe Phaseoleae. A model system for accelerated domestication. In Plant Domestication by Induced Mutation. Proc. FAO/IEAA Advisory Group Meeting. 17-21 November 1986 Vienna, IEAA. pp. 135.
- Smartt, J.** (1990). *Grain Legumes: Evolution and genetic resources*. Cambridge University Press. Cambridge.
- Stebbins, G. L. & Ayala, F. J.** (1981). Is a new evolutionary synthesis necessary? *Science* 213: 967-971.

- Stephenson, R. A.** (1978). Field studies on winged bean growth and yield. In *The Winged Bean. Papers Presented in the 1st Int. symp. on Developing the Potentials of the Winged Bean.* Los Baños, Laguna, Philippines, PCARR. pp. 191-196.
- Veeresh L. C. & Shivashankar, G.** (1987). Early mutants in winged bean. *Indian J. Genet.* 4: 353.
- Vietmeyer, N. D.** (1978) Workshop notes. In *The Winged bean. Papers Presented in the 1st Int. Symp. On Developing the Potentials of the Winged Bean.* Los Baños, Laguna, Philippines PCARR. pp. xi-xiv.
- Zeven, A. C. & de Wet, J. M. J.** (1982). Dictionary for Cultivated Plants and Their Regions of Diversity. Excluding Most Ornamentals Forest Trees and Lower Plants. Center for Agricultural Publishing and Documentary. Wageningen, 227 pp.