The phytochemistry, toxicology, and food potential of velvetbean (*Mucuna* Adans. spp., Fabaceae)

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Abstract

This paper examines current knowledge of velvetbean, *Mucuna* spp. (Fabaceae), and provides new data on its phytochemistry, toxicology, and food potential. Small-scale farmers in the tropics have traditionally used *Mucuna* as a cover crop to suppress weeds. The genus *Mucuna* is large (>100 species) and includes 5 or more cultivated species, but the taxonomy is confused and has not been examined using modern molecular techniques or in relation to phytochemical markers. The most important cultivated species, *Mucuna pruriens* (L.) DC., produces the toxic principle L-Dopa and has been reported to contain the hallucinogenic compounds related to N,N-dimethyltryptamine. A new phytochemical assessment of seeds of 36 accessions of currently used cultivars shows the presence of L-Dopa, but tryptamines were not detected in any of the seeds examined. L-Dopa content in the accessions increases with proximity to the equator. An assessment of the risk of consumption of these seeds and processed material indicates that processed seeds can be safely consumed by humans. Implications for allelopathy and pest resistance if these toxic substances are removed are also considered.

Résumé

Dans le présent document, les auteurs examinent les connaissances actuelles sur le pois mascate, autrement appelé *Mucuna* spp. (Fabaceae), et présentent de nouvelles données sur sa phytochimie, sa toxicologie et son potentiel alimentaire. Les petits exploitants agricoles des régions tropicales utilisent depuis longtemps le *Mucuna* comme plante de couverture pour éliminer les mauvaises herbes. Le *Mucuna* est le nom générique d'une plante qui regroupe plus de 100 espèces, dont 5 au moins sont cultivées mais dont la taxonomie est confuse et n'a pas été étudiée au moyen de techniques moléculaires modernes ou avec des marqueurs phytochimiques. L'espèce cultivée la plus importante, le *Mucuna pruriens* (L.) DC., produit le principe toxique L-dopa, et elle contiendrait des composés hallucinogéniques apparentés au N,N-diméthyltryptamine. Une nouvelle évaluation phytochimique des semences de 36 obtentions de cultivars utilisés à l'heure actuelle montre la présence de L-dopa, mais on n'a décelé de tryptamine dans aucune des graines examinées. La teneur en L-dopa des obtentions augmente à mesure que l'on se rapproche de l'équateur. Une évaluation du risque que présente la consommation de ces semences et de matières traitées révèle que les graines traitées peuvent être consommées sans danger par l'être humain. Les auteurs examinent également les conséquences sur le plan de l'allélopathie et de la résistance aux ravageurs si l'on retire ces substances toxiques.

Introduction

Farmers practicing traditional shifting agriculture in the tropics often use fallows to manage natural succession processes. Although the fallow has a well-recognized role in restoration of soil nutrients, it also has an important role in weed control. Competition allows farmers to replace agronomically unmanageable weed species with more easily prepared secondary forest (Brubacher et al. 1989). Similarly, cover crops can be used to retard the succession to unmanageable tropical weed species, such as grasses, woody vines, and aggressive shrubs. In this case, the cover crop interferes with the weeds through allelopathy and competition for light. As scarcity of land has been forcing farmers to progressively shorten the fallow periods in recent years, the emphasis in weed management has been shifting from forest fallow toward beneficial cover crops.

Cover crops provide an added crop value in the agronomic system, but they compete with edible or cash crops. Many cover-crop species are too toxic because of high concentrations of phytochemicals, which are significant to allelopathy. Although these phytochemicals constrain the use of such cover crops for food or forage, they may provide farmers with a new opportunity: value-added phytochemical products.

Velvetbean (*Mucuna* spp.) is an example of a successful cover crop with several highly biologically active natural products. *Mucuna* Adans. spp. (syn. *Stizolobium*) have long been cultivated in humid tropical areas as soil-improving crops, as cover crops to control weeds, and as green manures and forage plants (Buckles 1995). Some species have also been used for human consumption; such foods are rich sources of minerals (especially K, Mg, Ca, and Fe), proteins, and amino acids (Duke 1981). Before the seeds are eaten, they are often cracked and removed from the seed coats, soaked for a period, and then boiled in water, roasted, or fermented to remove most of the toxic principle, which has been implicated in poisonings. Mature seed pods are regarded as less toxic than green pods and, along with leaves, have been boiled and eaten as vegetables (Bailey 1950; Duke 1981). A risk of toxicity may remain, however; thus, an assessment of the food potential of velvetbean is required.

Taxonomy

Perhaps as many as 100 species of wild or domesticated *Mucuna* can be found in the tropics and subtropics of both hemispheres; 13 have been documented in Indochina, the Malay Peninsula, and Thailand (Wilmot-Dear 1991a, b). No modern molecular studies have been performed on the genus, and as Duke (1981, p. 171) tellingly asserted, "the taxonomy of the cultivated species (of *Mucuna*) is confused." Duke recognized five species, namely, *Mucuna pruriens* (L.) DC., *Mucuna nivea* (syn. *Mucuna lyonii* Merr.) (Lyon velvetbean), *Mucuna hassjoo* (Yokohama velvetbean), *Mucuna aterrima* Holl. (Mauritius or Bourbon velvetbean), *Mucuna utilis* Wall. (Bengal velvetbean), and *Mucuna deeringiana* Merr. (Florida or Georgia velvetbean). The well-known taxonomist of Asian economic plants, Burkill (1966), recorded that *Mucuna cochinchinensis* is synonymous with *M. nivea* and *M. lyonii*; likewise *M. deeringiana*, with *M. pruriens* var. *utilis* auctt., but not *M. utilis* Wall. The United States Department of Agriculture, in a quest for plants suitable for use as cattle fodder, identified two additional species, namely, *M. cochinchinensis* A. Chev. and *Mucuna capitata*. Piper and Tracy (1910), using the generic designation *Stizolobium* instead of *Mucuna*, added the Indian species, *Stizolobium cinereum* and *Stizolobium pachylobium*; the former, identified as *S. cinerium* [sic], has been under cultivation in various countries, given a detailed nuritional assessment in Mexico, and judged to be a potentially valuable addition to human diets, especially when supplemented with wheat flour (De la Vega et al. 1981).

Some South Asian and Oceanic peoples consume the boiled seeds of the tribal pulse, *Mucuna gigantea* (Willd.) DC., which grows wild in Indian coastal areas, China, and in the region from Malaysia to Australia and Polynesia (Rajaram and Janardhanan 1991).

Mucuna pruriens (L.) DC. (syn. *Stizolobium pruriens* [L.] Medic.)

Mucuna pruriens is extensively cultivated worldwide and is the only species systematically investigated for its chemical and pharmacological properties (Ghosal et al. 1971). However, the taxonomic confusion alluded to by Duke (1981) extends to the identification of the species and its varieties. Indeed, the plant material used in a 1971 Indian study (Ghosal et al. 1971) appears not to have been subjected to a careful and thorough botanical characterization: their paper gives no indication that professional botanists were involved or that a voucher specimen was retained. Modern molecular studies would be extremely useful in defining the natural relationships between taxa.

The most commonly encountered varieties of *M. pruriens* are *M. pruriens* (L.) DC. var. *utilis* (Wall. *ex* Wight) Baker *ex* Burck. and *M. pruriens* var. *pruriens*. Velacourt (1979) listed *M. pruriens* ssp. *pruriens* and *M. pruriens* var. *utilis* (syn. *Stizolobium alterrimum* Piper & Tracy, *Stizolobium capitatum* [Roxb.] Kuntze, *Stizolobium cochinchinense* [Lour.] Burk., *Stizolobium niveum* [Roxb.] Kuntze). The *Kew Bulletin* recommends earlier publications by Wilmot-Dear (1984) for complete synonymy and detailed descriptions of both the species as a whole and its varieties.

The salient morphological differences appear to reside in the appearance of fruit and seeds of the varieties of the species. Velacourt (1979) described the fruits of *M. pruriens* as

> oblong, usually more or less S-shaped, 4–9 cm long, 1–1.5 (–2) cm wide, densely covered with brown or reddish-orange irritant bristly hairs, longitudinally ribbed under the hairs; in cultivated forms the fruits are glabrescent or velvet hairy but lack the bristles. Seeds pinkish brown, speckled black or almost entirely black (or white to black in cultivars), oblong-ellipsoid, compressed, 1–1.9 cm long, 0.8–1.3 cm wide, 4–6.5 mm thick, hilum oblong, about 4 mm long, with a cream rim-aril. Subsp. *pruriens*: Fruits with or without irritant bristles. ... Var. *utilis*: Fruits glabrescent or velvety hairy but lacking bristles ... seeds in New Guinea material seen, purple.

Wilmot-Dear (1984) recorded the following for *M. pruriens*:

> Fruit fleshy with 3–6 seeds, small, narrowly linear-oblong but swollen around seeds and sometimes misshapen usually with 1–2 longitudinal facial ridges. Seeds ellipsoid, small, 1–1.7 (–2) × 0.7–1.3 cm, 4–10 mm in thickness; hilum occupying ±1/8 circumference. ... Var. *pruriens*: Fruit narrowly linear-oblong, usually distinctly curved often in S-shape, 5–9 × 0.8–1 cm, somewhat laterally flattened ±5 mm in thickness; surface with dense covering of irritant deciduous bristles, red–gold or brownish (sometimes in longitudinal bands of alternating lighter and darker brown), completely concealing surface and ridges. Seeds fawnish brown, hilum ±6 mm long, marginal aril orange. ... *M. pruriens* worldwide ... almost always shows the details given above for var. *pruriens*. ... Var. *utilis*: Plants very similar to var. *pruriens* but with complete absence of irritant bristles, this most obvious in the fruit; differences from var. *pruriens* as follows. ... Fruit linear-oblong but often misshapen due to irregular sizes of swellings around seeds, sometimes up to 2 cm broad in places; surfaced with dense or sparse short appressed or spreading soft light-brown hairs, facial ridges usually clearly visible beneath. Seeds whitish, fawn,

pale orange or black, sometimes marbled in these colours or obliquely dark-marked; aril orange.

Phytochemical composition and toxicity

Cattle thrive on meal made from velvetbeans ground in the pod, but people have become sick from eating cooked green beans, and chickens have died from eating both raw and cooked beans (Bailey 1950). Duke (1981, p. 173) reported that "hogs, poultry and horses do not do well on velvetbeans or velvetbean meal" and that "when fed to pigs in excessive quantities, the seeds cause severe vomiting and diarrhea."

The toxic principle in *Mucuna* seed is held to be L-Dopa, 3-(3,4-dihydroxyphenyl) alanine (Figure 1), a compound chiefly used in treating the symptoms of Parkinson's disease. In addition to gastrointestinal disturbances — notably, nausea, vomiting, and anorexia — the most serious effects are reported to be (Reynolds 1989, annex)

> aggression, paranoid delusions, hallucinations, delirium, severe depression, with or without suicidal behaviour, and unmasking of dementia. Psychotic reactions are ... more likely in patients with postencephalitic Parkinsonism or a history of mental disorders.

In 1989, in Nampula, Mozambique, an outbreak of more than 200 cases of acute toxic psychosis was attributed to consumption of the seeds of *M. pruriens* (Infante et al. 1990). The seeds are usually detoxified by repeated boiling in water, which is discarded before further processing of the seed, but because of drought the people drank this water instead.

Mucuna spp. have also been reported to contain, in addition to L-Dopa, antinutritional factors, such as phenols and tannins, and to possess trypsin inhibiting and haemagglutonating activities (Rajaram and Janardhanan 1991). Duke (1981) also reported the presence of nicotine, physostigmine, and serotonin in *Mucuna* (see Figure 1). Ghosal et al. (1971) claimed that this last compound, the important neurotransmitter also known as 5-hydroxytryptamine (5-HT), is present in the golden-yellow trichomes of pods of *M. pruriens*. In addition, bufotenine, choline, N,N-dimethyltryptamine (DMT), DMT-Nb-oxide, 5-methoxy-DMT (see Figure 1), as well as two unidentified 5-oxy-indole-3-alkylamines, an unidentified indole-3-alkylamine, and an unidentified β-carboline, were isolated from a mixture of the pods, seeds, leaves, and roots of *M. pruriens* using thin-layer chromatography (Ghosal et al. 1971).

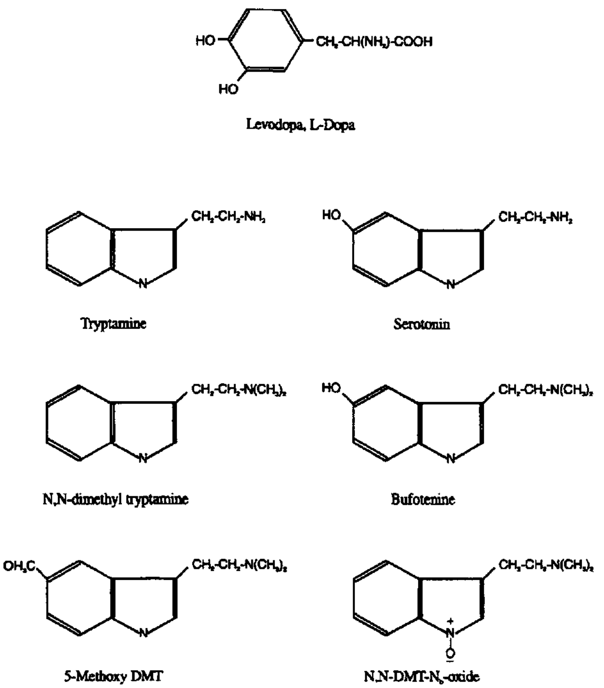

Figure 1. Phytochemical constituents of *Mucuna.*

The hallucinogenic properties of tryptamines, particularly DMT and its derivatives, are well documented, 5-methoxy-DMT being the main component of the intoxicating snuffs used by some South American Indians (Ahlborg et al. 1968). Ghosal et al. (1971, p. 283) suggested that the basis of the plant extracts used "by indigenous people as an uterine stimulant lies in the spasmolytic action of indole-3-alkylamines" and that the claimed "aphrodisiac action of *Mucuna* spp. is consistent with the presence of 5-methoxy-N,N-dimethyltryptamine." These researchers investigated the effect of *Mucuna* indole-3-alkylamines on the cardiovascular and central nervous systems, as well as on smooth and skeletal muscles, of experimental animals, but no one has so far undertaken a comparative phytochemical investigation of *Mucuna* species, subspecies, and varieties. Apart from the apparent universal incidence of L-Dopa (3-7%) in *Mucuna* spp. (Versteeg et al., this volume), one can expect variation in the alkaloid profile of plants of different genetic constitutions and species or varieties grown in different geographic locations under different climatic and environmental conditions. Burkill (1966) reported that seeds of *M. aterrima* (Mauritius or black velvetbean) grown in Nyasal and St. Vincent, West Indies, contained neither alkaloids nor glucosides; Burkill made no reference to L-Dopa content.

In short, the main concern about the utility of *Mucuna* is its toxic effects on humans, effects involving L-Dopa itself, on the one hand, and the indole-3-alkylamines, on the other. N,N-dimethyltryptamine and bufotenine are controlled substances in many countries, and they are psychoactive in humans at extremely low doses. Hence, they are unacceptable in food derived from these plants.

A phytochemical assessment of currently used *Mucuna* cultivars

Because the phytochemical literature is unclear about the taxonomic and tissue distribution of secondary substances in *Mucuna*, we undertook a survey of 36 accessions for tryptamine content of seed. These represent a selection of many common cultivars of *Mucuna* grown worldwide. We used a method of high-performance liquid chromatography (HPLC) sensitive enough to detect nanogram quantities (modified from Borner and Brenneisen [1987] and Meckes-Lozoya et al. [1990]) but detected no tryptamines in any of the seed extracts of the accessions. Although general literature reviews report these compounds in the genus, no primary journal article reports tryptamines specifically in the seed of *M. pruriens*; the Ghosal et al. (1971) report was based on an analysis of whole-plant material, including pods, seeds, leaves, and roots.

We also analyzed the seeds of the same accessions for L-Dopa content, using new rapid-extraction procedures and HPLC developed in our laboratory (Lorenzetti et al., unpublished), which gave results largely in agreement with those obtained with procedures routinely used elsewhere (Daxenbichler et al. 1971; R. Myhrman, unpublished data[1]). The L-Dopa content of the seeds of the 36 accessions available to us (summarized in Table 1) ranged from a low of 2.18% dry weight (DW) (*Mucuna* [Georgia velvetbean]) to a high of 6.17% DW (*M. pruriens* var. *deeringiana*), a range comparable to that normally found in cultivated *Mucuna*.

Because of the uncertainty underlying the identification of the cultivars (many accessions bore vernacular or locally used names), it was impossible to ascertain whether each accession effectively represent a unique genotype. However, cultivars producing seeds of the same appearance were likely to have been derived from the same parental stock. When the data were pooled by seed colour or appearance (stippled, black, speckled, or white), we found that the group containing stippled seeds, including the Georgia velvetbean, had significantly lower L-Dopa content than the other groups (Figure 2), suggesting that some genetic variation

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[1]R. Myhrman, Director, World Hunger Resource Center, Judson College, Elgin, IL, USA, personal communication, 1996.

Table 1. L-Dopa content of *Mucuna* seeds tested in this study.

Accession name [a]	Accession number [b]	Seed colour	Country of origin [c]	Country grown in	Locality [d]	Source	L-Dopa (% DW)
M. blanca	1	White	Mexico	Mexico	Santa Rosa, Ver.	R. Puentes	3.95
M. blanca	2	White	Mexico	Mexico	Soteapan, Ver.	R. Puentes	4.38
M. blanca	3	White	Mexico	Mexico	La Candelaria, Ver.	R. Puentes	4.53
M. pruriens (Veracruz)	4	White	Mexico	Benin	Cotonou (IITA)	A.E. Eteka	5.63
M. pruriens (Tlaltizapan)	5	White	Mexico	Honduras	Tegucigalpa (CIAT)	H.J. Barreto	4.55
M. pruriens (IITA–Benin)	6	White	Benin	Honduras	Tegucigalpa (CIAT)	H.J. Barreto	4.70
M. pruriens (Brazil)	7	White	Brazil	Honduras	Tegucigalpa (CIAT)	H.J. Barreto	4.95
M. cochinchinensis	8	White	NA	Benin	Cotonou (IITA)	A.E. Eteka	5.89
M. cochinchinensis	9	White	NA	Benin	Cotonou	D. Buckles	5.90
M. cochinchinensis (*jaspeada*)	10	White	NA	Brazil	Santa Catarina	D. Buckles	4.85
M. cochinchinensis (*jaspeada*)	11	White	NA	Benin	Cotonou (IITA)	A.E. Eteka	5.84
M. pinta	12	Speckled	Mexico	Mexico	Santa Rosa, Ver.	R. Puentes	4.06
M. pinta	13	Speckled	Mexico	Mexico	Soteapan, Ver.	R. Puentes	3.54
M. pinta	14	Speckled	Mexico	Mexico	La Candelaria, Ver.	R. Puentes	4.83
M. pruriens (Veracruz)	15	Speckled	Mexico	Benin	Cotonou (IITA)	A.E. Eteka	5.37
M. pruriens (Veracruz)	16	Speckled	Mexico	Mexico	Sierra de Santa Marta, Ver.	D. Buckles	4.82
M. deeringiana	17	Speckled	Brazil	Benin	Cotonou (IITA)	A.E. Eteka	6.17
M. pruriens (Atlantida)	18	Speckled	Honduras	Honduras	San Francisco de Saco	H.J. Barreto	4.99
M. negra	19	Black	Mexico	Mexico	Santa Rosa, Ver.	R. Puentes	4.60
M. negra	20	Black	Mexico	Mexico	La Candelaria, Ver.	R. Puentes	4.50

M. negra	20	Black	Mexico	Mexico	La Candelaria, Ver.	R. Puentes	4.50
M. negra	21	Black	Mexico	Mexico	Soteapan, Ver.	R. Puentes	3.59
M. pruriens	22	Black	Mexico	Mexico	Sierra de Santa Marta, Ver.	D. Buckles	3.76
M. pruriens	23	Black	Mexico	Benin	Cotonou (IITA)	A.E. Eteka	5.48
M. pruriens	24	Black	NA	Honduras	Tegucigalpa (CIAT)	H.J. Barreto	4.40
M. pruriens var. *utilis*	25	Black	NA	Benin	Cotonou (IITA)	A.E. Eteka	5.74
M. pruriens (*preta*)	26	Black	Brazil (?)	Benin	Cotonou (IITA)	A.E. Eteka	5.52
M. pruriens (*preta*)	27	Black	Brazil	Brazil	Santa Catarina	D. Buckles	4.32
M. pruriens (*preta*)	28	Black	Brazil	Brazil	Santa Catarina	D. Buckles	3.77
Georgia velvetbean	29	Stippled	United States	United States	Georgia	D. Buckles	2.53
Georgia velvetbean	30	Stippled	United States	Honduras	Tegucigalpa (CIAT)	H.J. Barreto	2.18
M. pruriens (*rajada*)	31	Stippled	Brazil (?)	Benin	Cotonou (IITA)	A.E. Eteka	4.22
M. pruriens (*rajada*)	32	Stippled	Brazil	Brazil	Santa Catarina	D. Buckles	3.69
Mucuna spp. (*rayada*)	33	Stippled	Brazil (?)	Honduras	Tegucigalpa (CIAT)	H.J. Barreto	2.62
Mucuna spp.	34	Black	India	India	Mokokchung, Nagaland	D. Buckles	3.56
Mucuna spp.	35	Yellow	Ghana	Mexico	Santa Rosa, Ver.	R. Puentes	4.06
M. pruriens	36	Mainly black	Ghana	Benin	Cotonou (IITA)	A.E. Eteka	4.77

Note: DW, dry weight; CIAT, Centro Internacional de Agricultura Tropical (international centre for tropical agriculture); IITA, International Institute of Tropical Agriculture; NA, not available; Ver., Veracruz.

[a] Accession names as indicated on the label of the package received at the University of Ottawa.

[b] Accession numbers given by the University of Ottawa.

[c] Country where the cultivar has been grown traditionally.

[d] Locality where the cultivar was grown.

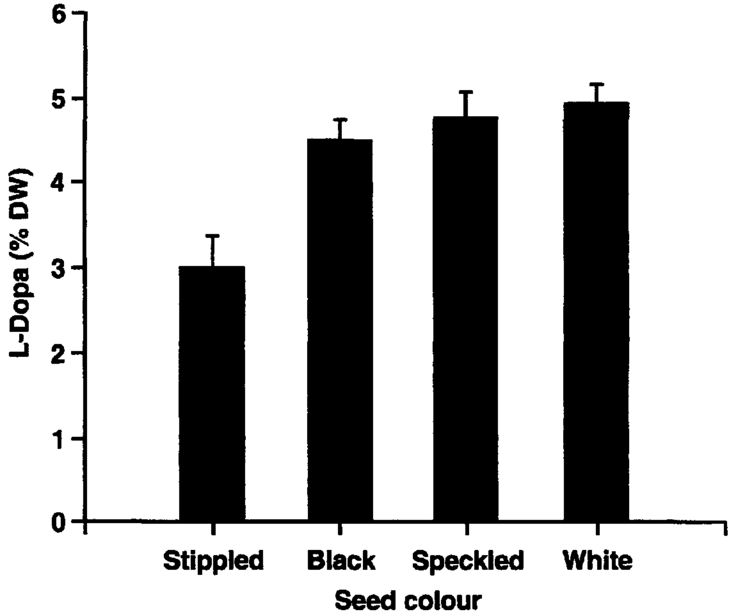

Figure 2. L-Dopa content of seeds of the *Mucuna* accessions tested in this study grouped on the basis of seed colour. Means and standard errors are shown. An analysis of variance indicated a significant variation in the L-Dopa content of seeds of different colour ($F_{3,29}$ = 7.828, P = 0.001). However, an *a posteriori* test for comparison among means (Tukey's test, P = 0.05) indicated that only stippled seeds have a significantly different L-Dopa content. Note: DW, dry weight.

occurs in the production of L-Dopa. Our study provides information not contained in previous reports on the variation in L-Dopa content in *Mucuna* spp. and cultivars (R. Myhrman, unpublished data[2]), as we observed the variation based on seed appearance pooled across different growing locations around the world.

A more detailed picture of the variation in L-Dopa content of seeds of different appearance is given in Figure 3, which shows data for each growing location. It is important to note, first, that the ranking of the types of seeds is the same when plotted by location (Figure 3) and pooled across all locations (see Figure 2). This is an encouraging observation, confirming that genetic variation is present. The second conclusion to be drawn from Figure 3 is that L-Dopa content

[2]R. Myhrman, Director, World Hunger Resource Center, Judson College, Elgin, IL, USA, personal communication, 1996.

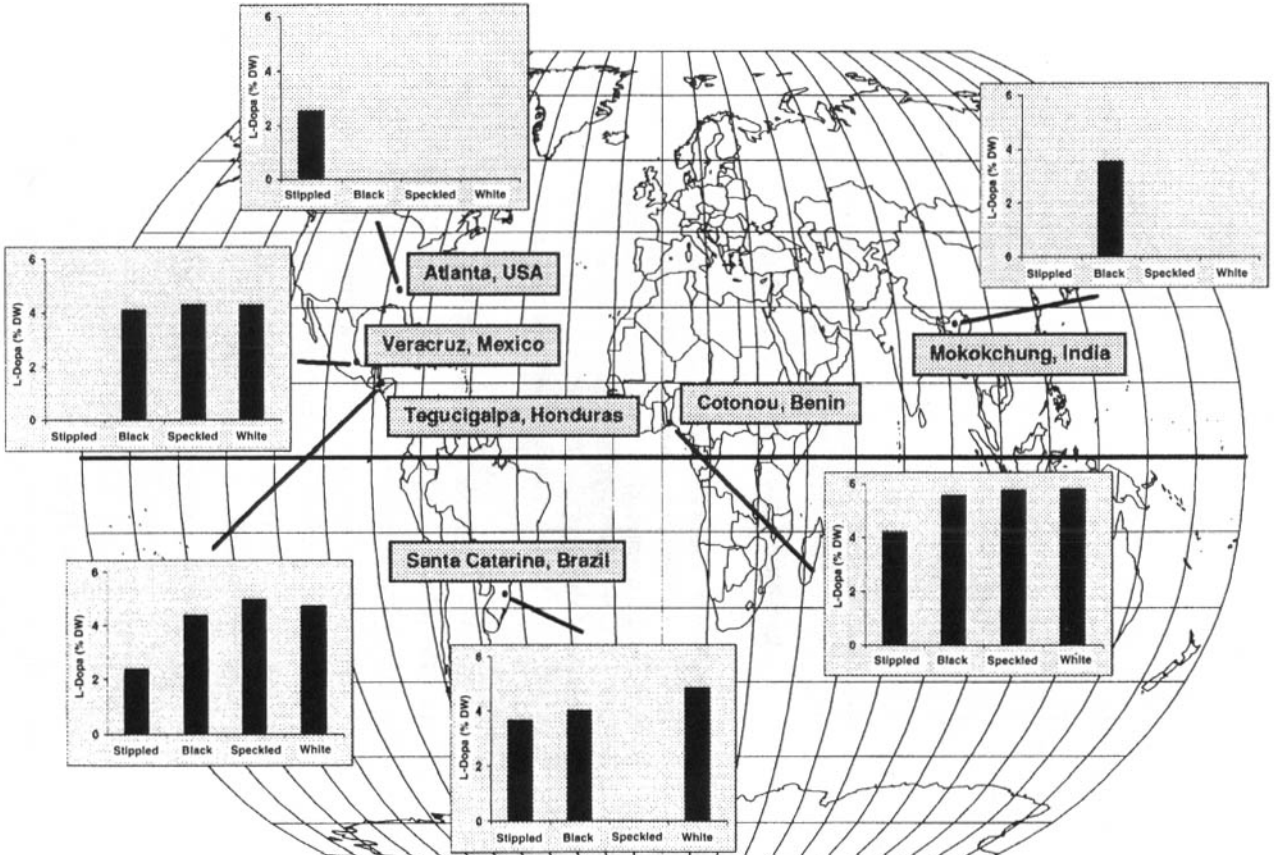

Figure 3. L-Dopa content of seeds of *Mucuna* accessions from plants grown in different locations around the world. Seeds of the same colour have not necessarily been collected from plants of the same cultivar when grown in a different location (see Table 1). Note: DW, dry weight.

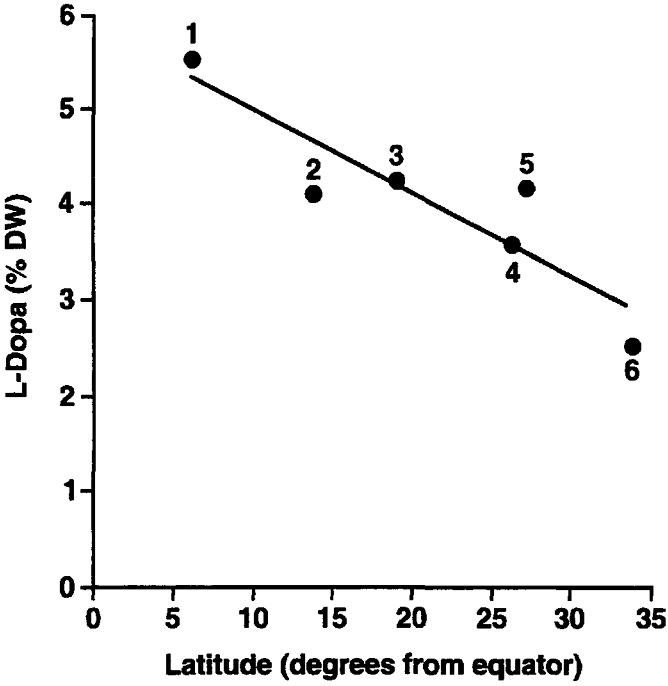

Figure 4. L-Dopa content of seeds of *Mucuna* accessions in relation to the latitude where the plants were grown. A linear regression analysis indicated that latitude significantly explained 78.2% of the variation observed in the mean L-Dopa content of the seeds ($y = -0.086x + 5.819$, $F_{1,4} = 14.386$, $P = 0.019$). Latitudes: (1) Cotonou, Benin, 6.24°N; (2) Tegucigalpa, Honduras, 14.05°N; (3) Veracruz, Mexico, 19.11°N; (4) Mokokchung, Nadaland, India, 26.20°N; (5) Santa Catarina, Brazil, 27.5°S; (6) Atlanta, Georgia, USA, 33.45°N (Collective 1968). Note: DW, dry weight.

varied between locations, with the seeds from Benin having the highest amount. A better indication of the relationship between location and L-Dopa content is given when the data are plotted in relation to latitude (Figure 4); seeds appear to contain significantly more L-Dopa in plants cultivated within 10° of the equator.

Variation in light intensity and in backscattered ultraviolet radiation, which increase toward the tropics, are potential factors underlying this relationship. In an experiment conducted by Pras et al. (1993) in which plant-cell suspension cultures of *M. pruriens* were grown under two intensities of light, more L-Dopa was produced under the lower light regime. Ultraviolet light induces the synthesis of phenylalanine-ammonia-lyase (Liu and McClure 1995), an enzyme involved in the deamination of phenylalanine, the precursor of several phenolic compounds of plants and L-Dopa. Whether ultraviolet light also increases the synthesis of the substrate phenylalanine, which in turn would stimulate the production of L-Dopa, is not known. Controlled experiments would be needed to precisely isolate the factors involved.

Table 2. Adverse reactions observed in 60 patients with Parkinson's disease treated for 12 weeks with *Mucuna* phytomedicine.

Reaction	Frequency (%)
Vomiting	1.7
Nausea	11.7
Abdominal distention	6.7
Dyskinesia	3.3
Insomnia	3.3

Source: Data from Manyam (1995).

A formally designed study of genotype × environment interaction would provide breeders with more information about the relative contribution of each source of variation in the yield of L-Dopa. At this early stage, however, our results suggest that a breeding program aiming to lower L-Dopa content in the seed should be conducted close to the equator.

Assessing and reducing the toxic risk of *Mucuna*

Fortunately, tryptamines represent no risk in any of the *Mucuna* seeds of common cultivars we have tested. Further research needs to be conducted on leaves, stems, and seedpods because these could be a hazard to farmers working with the crop and to animals consuming the foliage as fodder.

Although the acute oral LD_{50} of L-Dopa is very high in rats (4 g kg^{-1}), current European pharmacological literature gives 1 500 mg per patient as the maximum tolerable dose for the chronic treatment of Parkinson's disease, without bringing on serious physiological complications (OVP 1995). This figure could be used as an initial guideline for *Mucuna*-derived L-Dopa consumption, but other toxic interactions are always possible when *Mucuna* is consumed in foods produced from plant powder. Fortunately, some recent information is available on people's tolerance to *Mucuna* seed. In a 12-week clinical study of a standardized phytomedicine derived from *Mucuna* seed (3.33% L-Dopa) for treatment of Parkinson's disease, the mean daily dose was 45 g per individual at the end of treatment (Manyam 1995). This is the equivalent of 1 500 mg of L-Dopa per patient. The adverse reactions in 60 subjects afflicted with Parkinsonism were relatively mild (Table 2), and no significant effect on blood chemistry was observed. The reactions resembled those with refined L-Dopa. Even with chronic oral administration of the same phytomedicine to rats for up to 1 year at 10 g kg^{-1} d^{-1}, no serious abnormalities were observed.

Table 3. Consumption of *Mucuna* food products required to reach maximum daily tolerable dose of L-Dopa for adults.

Mucuna food product consumed	L-Dopa content (%)	Amount consumed to reach maximum [a] (g)
Unprocessed seed (maximum, this study)	6.170	24.3
Unprocessed seed (minimum, this study)	2.180	68.8
Pure *Mucuna* flour detoxified by boiling [b]	0.360	416.0
Pâte prepared from *Mucuna* flour–maize flour (1 : 2) [b]	0.095	1 579.0

[a] Maximum daily tolerable dose of L-Dopa = 1.5 g/individual.
[b] Data from R. Myhrman, cited in Versteeg et al. (this volume).

Although no information is available on the toxicological limit of *Mucuna* consumption specifically for children or pregnant women, for other adults at least it can be estimated from the toxicological study using the 1 500 mg L-Dopa per individual guideline (Table 3). Even a small meal (<100 g) prepared using unprocessed *Mucuna* seeds from any of the accessions exceeded safe L-Dopa limits. However, in some experiments the L-Dopa content was reduced by thoroughly cracking the seeds, soaking them overnight, boiling them for 20 min, and soaking them again overnight (Versteeg et al., this volume). When processed in this way, almost 0.5 kg of seed can be safely consumed. As reported by Versteeg et al. (this volume), a traditional West African *pâte* prepared with processed *Mucuna* flour and maize flour is safe to consume at any reasonable level.

Although processing is one option, there is still a risk of intoxication with high L-Dopa seeds, especially during times of crisis when it may be the only food readily available. Low L-Dopa genotypes are clearly desirable. Although the present study suggests a stronger environmental than genetic influence on L-Dopa content, enough variation occurs for breeders to consider a program of selection for low L-Dopa content. Reduction to a level of 1% would allow consumption of up to 150 g of seed d^{-1}, which would provide about 42 g of protein. Breeders will require a faster, less expensive analytical method than HPLC to process enough accessions for rapid selection. For this reason, we are investigating alternative techniques in our laboratory at the University of Ottawa. One attractive proposal entails cloning an enzyme for L-Dopa synthesis and using antisense technology to reduce L-Dopa levels.

Agroecological implications of altering secondary metabolism in velvetbean

Removal or reduction of velvetbean seed's secondary defences may seriously impair the plant's ability to protect itself against seed predators. Velvetbean seed is relatively free of insect problems, such as the bruchids that attack cowpea and *Phaseolus* beans. The reduction or removal of L-Dopa may make seeds more attractive to already established velvetbean pests or allow insects normally attracted to other hosts to switch to velvetbean. For example, we have found that the selection of alfalfa for lowered saponin concentration made it a suitable food substrate for European corn-borer larvae, whereas the high-saponin genotypes were inimical to insect development (Nozzolillo et al. 1997).

Conventional selection by breeders for lower expression of L-Dopa in seeds may have adverse effects on the beneficial role of *Mucuna* species as a cover crop if selection also alters the expression of secondary metabolism in vegetative parts. Suppression of weeds by cover crops is frequently related to the allelopathic and competitive abilities of the cover species. Allelopathic effects of cover crops on weeds have been clearly demonstrated in a number of studies. Rye has been used widely as a cover crop in temperate agriculture, and its ability to reduce weeds is related to the transformation of hydroxamic acid derivatives to phytotoxic azobenzenes in the soil (Chase et al. 1991).The traditionally used Mexican cover crop *Ipomea tricolor* reduces weeds in intercropped cornfields in Mexico. It produces the allelopathic resin trichlorin A, with potent inhibition of seedling growth, partly through its inhibition of plant H^{+}-ATPases, which are responsible for acidification and expansion of young plant-cell walls (Calera et al. 1995).

Postharvest processing

As sources of L-Dopa, *M. pruriens* and *M. cochinchinensis* have been extensively investigated (Lubis and Sastrapradha 1981; Parikh et al. 1990; Zhang et al. 1991; Su et al. 1992), as have a variety of treatment procedures for detoxification of the seeds and their food preparations (Osei-Bonsu et al. 1996; Versteeg et al., this volume). Chinese scientists have also examined *Mucuna macrocarpa* Wall. as a source of L-Dopa (Chen et al. 1993). The postharvest extraction of L-Dopa may lead to a commercially feasible chemical feedstock or fine chemical because L-Dopa is in demand in the pharmaceutical industry for treatment of Parkinson's disease. The cost–benefit of extraction would have to be evaluated. L-Dopa is prone to oxidation during extraction, and suitable procedures need to be developed to ensure good yields of pure material.

Conclusions

Tryptamines are not present in currently used cultivars of *Mucuna*, and simple processing techniques (Versteeg et al., this volume) reduce the L-Dopa content to levels safe for human consumption. Field testing of food-processing techniques and acceptability among smallholder households in West Africa should be continued, and promotional strategies for specific food products should be developed. Impacts on labour use by women and men, perceptions of taste, recipes, and nutritional composition of specific dishes are key considerations. A continuing chemotaxonomic study (phytochemical investigation, coupled with a modern molecular taxonomic assessment), is also proposed for the following species and varieties: *M. aterrima* Holl., *M. cochinchinensis* A. Chev., *M. macrocarpa* Wall., and *M. pruriens* (L.) DC. and its varieties. Selection or molecular manipulation of cultivars for lower L-Dopa content in seed should also be initiated, a step that would enhance the general utility of the crop.

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