Journal of Arid Environments (1994) 27: 27–35

Human food potential of the seeds of some Australian dry-zone *Acacia* species

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(*Received 25 October 1993, accepted 2 November 1993*)

The seeds of about 50 Australian dry-zone *Acacia* species are a traditional food of Australian Aboriginal people. Three species, *Acacia colei* (formerly included under *Acacia holosericea*), *A. cowleana* and *A. tumida* have grown rapidly in trials in semi-arid regions of sub-Saharan Africa. In the 450–700 mm annual rainfall zone of the Sahel, wide-spaced plants can produce heavy annual seed crops, whereas plants at the spacing of 4 × 4 m commonly used in the region experience moisture stress once they reach heights of 3–4 m and do not set seed. Nutritional and toxicological analysis of the seeds shows them to be quite high in protein, fat and carbohydrate, and to have low levels of known toxic and anti-nutritional factors. Trials conducted at Maradi, Niger have shown that seed of *A. colei* is easily processed using local technology and can be used to prepare palatable foods. Priorities for future research include feeding trials with laboratory animals, medically monitored dietary trials with human volunteers, and field experiments to determine appropriate silvicultural strategies for maximum seed yields.

Background

The seeds of some 50 Australian dry-zone *Acacia* species are known to have been a significant seasonal component of traditional Australian Aboriginal diets (Devitt, 1992). A number of these species have been widely tested in sub-Saharan Africa (Cossalter, 1987; Cazet & Sadio, 1988; Cazet, 1989; Kimondo, 1991; Chege & Stewart, 1991; Gwaze, 1992), and some have grown very well across a wide range of semi-arid environments. Thomson (1989) noted heavy seed production of Australian acacias in plantings in several Sahelian countries, and drew attention to their potential as a human food for famine-prone semi-arid regions in Africa. This prompted preliminary trials of the seeds as a food at Maradi, Niger, with encouraging results (Rinaudo, 1992). An international workshop held in 1991 (House & Harwood, 1992) reviewed the knowledge base for species with human food potential, including their Aboriginal use, ecology and botany, nutritional value, and performance in field trials.

Factors which favour the adoption of certain of these species as a food source in tropical semi-arid environments include the following: (1) The knowledge that their seeds were an important food item for Australian indigenous people. (2) Low levels or absence of toxic and anti-nutritional factors in the seeds, and high nutritional value as indicated by chemical analysis (Orr & Hiddens, 1987; Brand & Maggiore, 1992). (3) Easy establishment, rapid early growth, excellent survival, and heavy early seed production of

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some species compared with African *Acacia* species. (4) Phyllodenous foliage that is unpalatable to livestock, reducing the requirement for protection during establishment (Thomson, 1989). (5) Seeds that are easily collected, stored and processed to a flour with the local technologies used for staple grains (Rinaudo, 1992). (6) Extensive trials at Maradi, Niger indicating foods incorporating acacia seed flour that are palatable and acceptable to most people can be prepared by modifying local recipes (Rinaudo, 1992; Rinaudo, pers. comm.). (7) Some species have already become popular for planting in some areas of the Sahel for windbreaks, fuelwood and shade (Cossalter, 1987).

The seeds of at least one species of *Acacia* indigenous to Sahelian Africa, *A. macrostachya*, are consumed as a human food (Guinko & Pasgo, 1992). The related *Faidherbia albida* (Del.) A. Chev. is used as an emergency food source in some African countries such as Zimbabwe, where prolonged boiling with ash is carried out to reduce the levels of toxic factors in the seeds (Marunda, 1992).

Because of their easy cultivation and heavy yields of palatable seed that can be stored year-round, the Australian acacias have the potential to be a major component of diets. This makes issues such as nutritional imbalance and chronic toxicity effects more important than for minor items of diet. In the past, the introduction of new foods, even those which are now widely accepted staples such as corn, potatoes and soybeans, has led to problems of toxicity and nutritional imbalance (Liener, 1980). A scientific approach to the adoption of new foods, including analysis to detect known classes of toxic compounds, feeding trials using laboratory animals, and carefully monitored dietary trials by human volunteers, can now be used to avoid or at least minimize such problems. Scientific research can also speed up the process of identifying the species and provenances which are most productive of edible seed in particular environments, the silvicultural techniques to maximize plant survival, growth and seed production, and the best ways of processing and cooking the seeds to maximize nutritional benefit.

Growth, seed production and seed collection of priority species

Three phyllodenous species in the section Juliflorae, *Acacia colei* Maslin & Thomson, *A. cowleana* Tate and *A. tumida* F. Muell. ex Benth., have been identified as the most promising for human food production (Thomson, 1992, 1993; Harwood, 1993a). *Acacia holosericea* sens. lat. has now been shown to comprise at least thee taxa (Moran *et al.*, 1992; Maslin & Thomson, 1992) corresponding to three chromosome races: diploid (*A. neurocarpa* A. Cunn. ex Hook.), tetraploid [*A. holosericea* A. Cunn. ex Don (*sens. str.*)] and hexaploid (*A. colei* Maslin & Thomson). *Acacia colei* has shown better survival, growth and greater seed production than *A. holosericea* and *A. neurocarpa* in semi-arid Sahelian environments. *Acacia colei, A. cowleana* and *A. tumida* have been the best-performing Australian *Acacia* species in a number of species/provenance trials and demonstration plantings in Sahelian countries (Souvannavong & de Framond, 1992; Thomson, 1992).

Acacia colei reaches heights of 3–4 m within 2–3 years on infertile sandy soils with 450–700 mm rainfall and dry seasons of up to 9 months in Senegal, Burkina Faso and Niger (Cazet & Sadio, 1988; Souvannavong & de Framond, 1992). Surivival to this age is usually over 90% in monitored trials. Growth of *A. cowleana* and *A. tumida* in these environments is usually slightly slower, and survival somewhat lower. Major variation between provenances in growth rate and morphology has been demonstrated in provenance trials of all three species, although there is remarkably little within-provenance variation, particularly in *A. colei* and *A. cowleana*, which are polyploids and may be self-fertilizing (Moran *et al.*, 1992). Observations around trials and other planting sites (Harwood, 1993a) indicate that the priority species have not yet shown any propensity to spread as weeds in these Sahelian environments.

Acacia colei and *A. cowleana* are regarded by many researchers in the Sahel as short-lived. Stands planted at the close spacings (typically 4 × 4 m), commonly used in trials and block or multi-row operational plantings, commonly start to lose foliage and suffer shoot dieback after about 3–5 years. Observations made in 1992 at sites in southern Niger with mean annual rainfall of about 600 mm (Harwood, 1993a) suggest that once plants reach a height of about 4 m at 4 × 4 m planting density there is severe inter-plant competition for soil water well before the end of the 8-month dry season. In contrast, isolated single individuals, or those in single-row plantings, generally remain vigorous and healthy with dense crowns to ages of at least 5 years, and grow to much larger size: up to 6 m high × 8 m crown width (Fig. 1).

Excavations of root systems of four trees in a 6-year-old trial of *A. colei* on a sandy soil near Dosso, southern Niger, showed that the roots of this species had wide lateral extent but were largely confined to the uppermost 60 cm of the soil profile (P. Torrekens, pers. comm.). Cazet (1989) excavated the root systems of two 3-year-old *A. colei* trees growing in a line planting in sandy soil in north-central Senegal. He found that roots extended laterally at least 2·5 m from the trunk, and 97% of the root biomass was in the uppermost metre of the soil profile, although a few roots extended to a depth of 2 m. Assuming that plants obtain most of their water from the uppermost metre of the soil profile, isolated plants with root systems extending laterally several metres from their stems would have access to a much greater soil volume, and hence soil water resource, than the average available to plants at 4 × 4 m spacing.

In southern Niger, *A. colei* and *A. cowleana* flower in December, some 2–3 months after the end of the rainy season. Seed pods mature over the following 4 months and seeds are mature and pods ripe for seed collection the following April, well before the start of the next rainy season. The timing of flowering and seed production in *A. tumida* varies more between plants and is more extended for individual plants, but is basically similar. Clearly, flowering and seed production in these species depend on access to stored water in the soil during the dry season. Quantitative studies on seed production have commenced around Maradi, Niger (T. Rinaudo, 1992, pers. comm.). In 1992 it was observed that isolated trees and trees in single-line plantings often produced heavy seed crops, frequently in excess of 1 kg of seed per tree, and over 10 kg from one 3-year-old *A. colei* tree growing in a village compound. Plants at 4 × 4 m spacing may produce a little seed in the first dry season following planting, and substantial quantities of seed in the second dry season, but

Figure 1. 4·5-year-old *Acacia colei* near Maradi, Niger, growing well clear of nearby trees. 3·5 kg of seed was collected from this tree at age 3·8 years.

then seed yields fall away to negligible levels in 4-year-old stands, as competition for soil moisture sets in. Numerous flower spikes are initiated in these older close-spaced stands, but they wither and fall.

Seed collection is best undertaken when the fully ripe pods are beginning to open and shed their seeds. The branches are beaten so that seeds fall onto a sheet placed beneath the tree. Alternatively, pod clusters may be picked, or pod-bearing branches may be cut, and then placed on a sheet and beaten; the seeds fall from the pods and the other material is easily removed. Using these methods, a kilogram or more of seeds can be collected in a few minutes from a tree with a heavy crop. Seeds are then cleaned by sieving and winnowing.

Nutritional value and toxic factors

Tables 1–4 summarize the results of nutritional and toxicological testing carried out on the seeds of the three priority species identified above.

The seeds appear to have good nutritional value (Table 1). The protein levels of 18–25% calculated by multiplying nitrogen content by a factor of 6·25 (Brand & Maggiore, 1992) are overestimates, as nitrogen is also present in non-protein amino acids and other non-protein nitrogenous compounds (Murray & McGee, 1986). However, non-protein nitrogen is likely to be of dietary value (J. Brand-Miller, pers. comm.). *Acacia tumida* has substantially lower protein and fat levels than the other two species, a consequence of its very thick seed coat and associated high level of dietary fibre, which 'dilutes' the nutrient levels contained in the seed (Table 1). The aril (the fleshy external tissue connecting the seed to the seed pod) is rich in fat. Hence, retention or removal of arils during processing will affect the oil content and composition. The seed oils of edible Australian *Acacia* species generally exhibit a high proportion of linoleic, oleic and palmitic acids, and have a high ratio of polyunsaturated to saturated fatty acids, greater than 1 : 1 in most cases (Brand & Maggiore, 1992).

Table 1. *Macronutrient composition of seeds of three Australian dry-zone* Acacia *species with human food potential, per 100 g of seed (summarized from Brand & Maggiore, 1992)*

	*A. cowleana**	*A. holosericea†*	*A. tumida‡*
Energy (kJ)	1246	1398	703
Water (g)	5·6	6·6	7·4
Protein (g)			
—estimated§	23·8	24·6	17·9
Extractable protein (g)			
—measured¶	10·4	9·3	
Fat (g)	11·0	7·7	6·4
Carbohydrate			
—total (g)	57·1	57·1	n.d.
—available (g)	13·1	22·8	9·2
Dietary fibre (g)	44·9	34·5	56·0
Ash (g)	3·5	3·8	2·7

n.d., Not determined.
* Mean of three different Australian seedlots.
† *Acacia holosericea* sens. lat.—mean of three Australian seedlots. Uncertain whether seed of *A. colei*, *A. holosericea* sens. str. or *A. neurocarpa* tested.
‡ One seedlot (CSIRO 17046), except for fat, which is mean of Australian seedlots 17406 and 15745.
§ Estimated by multiplying nitrogen content by a factor of 6·25.
¶ Measured by Biuret method on a different seed sample (Murray & McGee, 1986).

Table 2. *Concentrations of the three principal non-protein amino acids in the seeds of five dry-zone acacia seedlots (C. Perera & P. B. Nunn, pers. comm.)*

CSIRO seedlot	Species	Djenkolic acid	S-carboxyethyl cysteine	Albizzine
		Dry seed, mg g^{-1} (μmol g^{-1})		
14561	*A. colei*	1·36 (5·35)	4·45 (23·0)	7·81 (53·1)
17502	*A. cowleana*	1·38 (5·43)	3·79 (19·6)	10·40 (70·7)
17046	*A. tumida*	2·23 (8·77)	n.d.	0·12 (0·8)
17069	*A. neuracarpa*	2·37 (9·32)	7·23 (37·4)	6·47 (43·9)
17706	*A. holosericea*	1·72 (6·76)	3·62 (18·7)	6·60 (44·9)

n.d., Not detectable.

Toxic amino acids have caused serious health problems when certain legume seeds are used as human foods (Liener, 1980). For example, djenkolic acid produces kidney failure when Djenkol beans (which commonly contain 1–2% djenkolic acid by weight) are eaten in large quantities. Lathyrogenic amino acids cause permanent paralysis when the seeds of *Lathyrus* species are consumed in moderate amounts. Qualitative studies (Evans *et al.*, 1977) indicated low levels of djenkolic acid and absence of lathyrogens in *A. holosericea* and *A. tumida*. Quantitative analysis (Table 2) confirms that the three principal non-protein amino acids djenkolic acid, S-carboxyethyl cysteine, and albizzine are present in low, non-dangerous concentrations in the priority species, and that lathyrogenic amino acids are not detectable.

Protease inhibitors, which interfere with the digestion of proteins by inhibiting their breakdown into peptides, are present in acacia seeds (Table 3). The levels in *A. cowleana*, *A. holosericea* sens. lat. and *A. tumida* are sufficiently high to interfere seriously with human protein metabolism if raw seed flour is used as the main source of dietary protein (J. Weder, pers. comm.). A simulated cooking treatment (soaking in water for 15 min, followed by boiling at 100°C for 15 min) completely denatured the inhibitors of the human and bovine proteases, trypsin and chymotrypsin, in *A. colei* and *A tumida* seed meal.

There is a possibility that *Acacia* seeds might accumulate toxic concentrations of metal elements, particularly on certain soil types such as serpentine soils where high levels of these elements may be present. Analysis of seeds of *A. colei* collected in Maradi, Niger, and Australia (Table 4) shows that this is unlikely to be a problem. The concentrations of the

Table 3. *Influence of heat treatment on protease inhibitors of seeds of* Acacia colei *and* Acacia tumida *(J. Weder, pers. comm.)*

Species and CSIRO seedlot No.		Inhibition* of HT	BT	HCT	BCT
A. colei	Untreated	9·90	5·82	1·34	0·78
14651	Cooked†	n.d.‡	n.d.	n.d.	n.d.
A. tumida	Untreated	7·31	4·18	1·50	1·20
17046	Cooked	n.d.	n.d.	n.d.	n.d.

HT, Human trypsin; BT, bovine trypsin; HCT, human chymotrypsin; BCT, bovine chymotrypsin

* Inhibitor activities in mg enzyme 100% inhibited by extracts from 1·0 g seed material.

† 5 g seed meal + 25 g distilled water, 15 min at room temperature, 15 min boiled.

‡ Not detectable, less than 0·05 mg active enzyme inhibited per g seed meal.

Table 4. *Concentrations of six metallic elements* in seeds of* Acacia colei *(A. Johnston, pers. comm.), compared with Australian standards*

Species and seedlot	Metallic element concentrations (p.p.m.) Cadmium	Manganese	Nickel	Copper	Zinc	Lead
A. colei from Maradi, Niger	0·43	135	4·5	7·2	29	0·73
A. colei CSIRO seedlot No. 14651	0·22	35	3·3	6·6	20	0·19
Standard†	0·2‡					
Standard†	0·05§	—¶	—¶	10§	150§	1·5§

* Determined on a nitric acid digest by inductively coupled plasma mass spectroscopy.
† Australian standard (maximum permitted concentration, National Food Authority, 1992).
‡ Bran and wheat germ.
§ Most other foods.
¶ No current standard.

metal elements analysed are well below Australian standards for their presence in foodstuffs, with the exception of cadmium which is slightly above the Australian standard. Further study of metal element concentrations, particularly cadmium, should be carried out for the target species, using seed from trees growing in environments where use as a food is anticipated. Partial or complete removal of the seed coat will alter the concentrations of metals in the fraction of the seed which is retained and eaten.

Tests for cyanogenic glucosides and haemagglutinins were carried out on seed meal of *A. holosericea* sens. lat. from Maradi, Niger (J. Ahokas, pers. comm.). Seed meal was dry-heated to 115°C for 15 min to simulate a cooking treatment. The measured cyanide value of 0·62 $\mu g\ g^{-1}$ of seed flour was within the range found for cereal grains and much lower than that commonly found in cassava. No haemagglutinating activity was detected.

Discussion

Differences in soil water holding capacity and rainfall will obviously affect growth of the acacias and their seed yields. Better growth and seed production may be expected on sites which accumulate water runoff from adjacent land, and soils with good water-holding characteristics (fine sand, loams or loams). Conversely, growth and seed yields should be poorer on coarse sands, hilltop sites, and where competition with other vegetation occurs. The best growth and seed production is often observed on single *A. colei* trees planted around village compounds, or on single-line plantings along roadsides. Careful choice of planting positions and wide spacing so that each plant can realise its maximum growth potential will minimize the number of plants required to meet a given objective (windbreak, shade, fuelwood production, seed production, etc.) and therefore minimize the resources and effort required.

Systematic observations are required on seed production at different planting densities across a range of soil types and rainfalls to obtain a better picture of seed yields. It is important to know whether acacias can produce seed in drought years when other crops fail. Seed crops of *A. colei*, *A. cowleana* and *A. tumida* in the Kimberley region of north-western Australia were light or non-existent in 1992, which was a severe drought year with rainfalls some 50% below average. Heavy seed crops were produced by these species in 1993, a year of above-average rainfall (unpublished Australian Tree Seed Centre collection records). This demonstrates that individual trees which survive a severe drought year can resume seed production the following year. *Acacia colei* has failed in trials at Tanout, Niger, where annual rainfall is about 200 mm (P. Beckmann, Eden Foundation, pers.

comm.). An annual rainfall of around 300–400 mm may be the minimum required for substantial seed crops, even when other factors such as soil type, siting and spacing are optimized. However, acacias should be better able than annual grain crops, such as sorghum, millet and maize, to produce seed crops in years with intermittent or unseasonal rainfall, as they are perennial plants which produce their seed crops by 'integrating' the rainfall through use of stored soil water during the subsequent dry season.

Because of the presence of protease inhibitors, foods incorporating *Acacia* seed should not be eaten raw. A simple cooking treatment such as steaming the green seeds, or boiling or baking foods made with seed flour, will eliminate this potential problem. Other toxic factors known to be present in certain other legume seeds, such as toxic amino acids, cyanogens, haemagglutinins and toxic heavy metals do not appear to pose health risks in the three *Acacia* species reviewed in this paper. However, it will be necessary to check other candidate species. Certain Australian *Acacia* species are known to be toxic: *A. georginae* F. M. Bail., for example, contains poisonous levels of the toxin mono fluoroacetate in its leaves and seeds (Everist, 1981).

Tannins (plant polyphenols) can bind proteins, making their nitrogen unavailable to the digestive tract (Griffith, 1991). It is known that the seeds of acacias contain tannins, so studies of tannin content and effects on nutrition are required. The level of dietary fibre in the seeds, over 30% when the seed coats are retained, is substantially higher than that in staple food grains (Duffus & Duffus, 1991). High fibre levels may interfere with the absorption of mineral elements, which bind to phytates and similar compounds associated with the fibre. It is known that Australian Aboriginal people often removed a large proportion of the seed coat during the preparation, which involved parching with hot coals, grinding and winnowing (Devitt, 1992). Preparation of some foods for taste trials of *A. colei* seed in Niger involved removing the aril, and also the seed coat by soaking and then rubbing the seeds (T. Rinaudo, pers. comm.). Removal of part or all of the seed coat with modern processing techniques such as mechanical milling followed by winnowing may be possible.

The extent to which the amino acid profiles of acacia seeds complement those of staple foods such as millet, sorghum and maize will be important in the assessment of their dietary value.

Laboratory animal feeding trials using cooked seed flour of *A. colei* and *A. tumida* are being conducted at Obafemi Awolowo University, Nigeria (S. Adewusi, pers. comm.). Weight gain in laboratory animals will give an indication of the overall nutritional value of the seeds, and subsequent histopathological observation of vital organs will provide a further check for the presence of toxic compounds. Favourable results from such trials, together with the chemical testing summarized here, will provide a sound basis of knowledge for interested communities to incorporate acacia seeds into their diets. Assuming positive results of chemical testing and animal feeding trials, a staged process of short, medium and long-term testing by volunteer subjects, carefully advised and monitored by competent medical and nutritional personnel, is recommended.

Adoption of the seeds of Australian *Acacia* species as a new food rests ultimately with the communities involved. Apart from silvicultural and nutritional considerations, more subjective criteria such as palatability, perceptions of the status of the new food, and compatibility with existing agricultural and food-processing systems will be critically important. However, the general concept that food-bearing tree and shrub species can diversify and stabilize food production in semi-arid tropical environments appears sound. Australian acacias should be evaluated together with indigenous and other exotic tree and shrub species with human food potential (Booth & Wickens, 1988).

This paper revises and updates work presented at an IUFRO conference in 1992 (Harwood 1993b). I am most grateful to those who carried out the following analyses: amino acids — Dr C. Perera and Dr P. B. Nunn, Molecular Biology and Biophysics Group, King's College London (their amino acid analyser was supported by a grant from the University of London, Central Research Fund);

cyanogens and haemagglutinins — Prof. J. Ahokas, Key Centre for Applied and Nutritional Toxicology, Royal Melbourne Institute of Technology; macronutrient analysis of *A. tumida* — Dr J. Brand Miller, University of Sydney; metal elements — Mr A. Johnston, CSIRO Division of Tropical Crops and Pastures; protease inhibitors — Prof. J. Weder, Munich Technical University Mr. T. Rinaudo provided seed samples of *Acacia colei* from Maradi, Niger. The assistance and hospitality of government and NGO organizations in Niger during my visit there in 1992 is gratefully acknowledged. Drs J. C. Brand Miller, M. P. Hegarty, P. K. Kreidemann and L. A. J. Thomson provided helpful comments on earlier drafts of this paper.

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