Developing Australian acacia seeds as a human food for the Sahel

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Research results and methods aimed at developing a potentially important supplemental protein supply.

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Hunger, famine and malnutrition and their attendant diseases are major public health issues in the West African sub-Saharan semi-arid zone known as the Sahel. With mean rainfall below 600 mm per annum (FAO, 1995), rural food systems based on rainfed subsistence agriculture are characterized by annual "hungry seasons". This situation is compounded by recurrent droughts which cause serious failures of the main food crops, millet and sorghum. Southern parts of the Niger experienced famines in 1973-75, 1984, 1988, 1994 and 1996. During such lean times, the rural people have resorted to "famine foods" such as millet chaff and the bark and leaves of non-nutritious trees, but these are insufficient in quantity and quality to prevent malnutrition. This article reports on ongoing efforts to establish another food source, the edible seeds of Australian acacia trees (*Acacia colei*), that are likely to be beneficial in supplementing the main food crops.

At Maradi, the Niger, development has reached the point where people can reliably grow this little-known food and safely incorporate it into their diets. *A. colei* can easily be obtained locally because of prior introduction of the trees, and the trees themselves exhibit prolific seeding. The authors found that the only inputs required to develop this food source are basic plant nursery and tree-growing technologies, locally available methods of seed processing and cooking, and the knowledge of what to do. The research summarized in this article shows how, with appropriate silviculture involving wide spacing, weeding and repeated pruning, *A. colei* can yield about 2 kg of seed per tree for at least two to three harvests from age two years onwards, and its seed flour can be safely incorporated into millet- or sorghum-based human diets at rates of up to 25 percent by modifying traditional recipes. This food could be adopted across wide areas of semi-arid Africa and South Asia where climates are suitable for *A. colei* (Booth *et al.*, 1989) and food security is poor. The trees also yield valuable fuelwood and leaf mulch and can provide windbreak protection for food crops.

As well as briefly outlining the work done so far, this article considers the management of the multidisciplinary research and development effort aimed at benefiting the rural poor. The main participants in this work have been the Maradi Integrated Development Programme (MIDP) and villages associated with it, the Commonwealth Scientific and Industrial Research Organization (CSIRO) Australian Tree Seed Centre (ATSC) and a nutrition research group from Obafemi Awolowo University, Nigeria. The main lines of investigation over the past eight years of study have been taxonomic revision of the target species, field trials and silvicultural treatments to maximize seed production and a series of nutritional and toxicological studies involving chemical analysis, animal testing and, finally, human volunteer trials. Key factors contributing to the success of this work were the continuing enthusiasm and support of local people, the commitment of MIDP, a local organization with established infrastructure and good communication links, and the long-term, flexible funding of Australian researchers which enabled coordination and continuity of scientific advice.

In the 1970s and 1980s, trials of many Australian *Acacia* species were conducted by a number of research organizations in the semi-arid western African Sahel region to assess their potential to ease fuelwood shortages and serve as effective windbreaks (Cossalter, 1987). Because the Sahel and northwestern Australia have very similar climates, it was anticipated that the Australian trees would be well adapted. Halls Creek in northwestern Australia and Maradi in southern Niger, for example, both experience a severe eight-month dry season, with very hot conditions throughout most of the year. On sandy soils in the 400 to 700 mm rainfall zone *A. colei* (Maslin and Thomson, 1992) was found to be the best-adapted Australian species, showing excellent survival (over 90 percent of planted seedlings surviving at two years) and rapid early growth. Under these conditions, *A. colei* develops to the size of a large multistemmed shrub, with a dense crown up to 4 m high by 5 m across, within three years (Figure 1). Such characteristics were suitable for protecting food crops and providing a renewable source of fuelwood. Species classifications at the time were inadequate, and *A. colei* was included with two other species in the taxon *A. holosericea* A. Cunn. ex Don. "Holo", as it was known locally, was widely planted in southern Niger in the late 1980s, but its promotion by forestry agencies declined in the 1990s once it was found that the species was relatively short-lived, most trees dying after five to eight years when planted at conventional plantation spacings of 4 by 4 m.

Villagers around Maradi became aware of the food potential of Australian acacia seeds in 1989, when Australian forester Lex Thomson visited Maradi during a CSIRO technical advisory visit to West Africa. He observed the heavy seed crops on *A. colei* trees introduced to the region and suggested that the seeds be collected and tried as a food. Thompson knew that seeds of about 50 Australian dry-zone acacia species, including *A. colei*, were an important part of the traditional diet of Australia's Aboriginal people. Preliminary studies were therefore undertaken by MIDP to assess the possibility of incorporating acacia seeds into the local diet.

The results of these first trials were promising. Up to 10 kg of seed per tree was harvested from three-year-old trees in home compounds around Maradi. In addition, enthusiastic local villagers developed palatable foods that incorporated *A. colei* seed flour into their traditional millet- and sorghum-based recipes. They found that none of the phases of seed preparation – harvesting, threshing, cleaning, grinding seeds to flour (using manual methods or local mechanical grain mills) or cooking – required new or specialized skills or equipment. Moreover, in the Niger the acacia seed crop matures in March to April, two months before the end of the dry season, a time of low food availability and low labour requirement in the local farming system. The hard-coated seeds can be stored for a year or more before being ground, with no perceptible deterioration in flavour or food quality. Sifting with locally available, fine-meshed sieves removed many of the seed coat fragments, improving the palatability and appearance of the seed flour. Based on the initial response from local people and the positive technical assessment in 1990, intensive research and development efforts were mounted to develop *A. colei* seeds as a food source for the region.

An international workshop, organized in 1991 by ATSC, reviewed the "edible acacia seed" concept from several perspectives including traditional Aboriginal use, taxonomy and silviculture of candidate acacias, nutrition, toxicology and ethical and social considerations (House and Harwood, 1992). The ATSC workshop identified knowledge gaps and provided guidelines for future activities. Since then, the lines of investigation described below have proceeded in parallel.

FIGURE 1
Four-year-old stand of **Acacia colei** *planted at 4 x 4 m spacing, growing near Maradi, the Niger. This is about the maximum size attained by* **A. colei** *in semi-arid climates at this close spacing*

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FIGURE 2
R. Nangala with a harvest of Acacia coriacea *seed pods, Tanami Desert, Northern Territory of Australia. Nangala and another Aboriginal woman, K. Ross, visited the Niger in 1998 to share their knowledge of edible acacia seeds with African villagers*

SILVICULTURE AND SEED PRODUCTION AND HARVEST

On ATSC's advice, replicated species trials were planted by MIDP at two sites near Maradi in 1992. These trials confirmed *A. colei* and *A. elachantha* McDonald & Maslin (at that time known as *A. cowleana* Tate – see McDonald and Maslin, 1997a) as superior to the six other *Acacia* species planted, for growth, survival and seed production (Rinaudo, Burt and Harwood, 1995).

Extensive provenance collections of seed and botanical specimens of *A. colei*, *A. elachantha* and other promising edible-seeded acacia species were carried out in Australia over the period 1992-1995 to support species and provenance trials in the Niger and elsewhere overseas. Aboriginal people worked with ATSC to make these collections, and provided scientists with further insights into ongoing Aboriginal use of the seeds as food resources (Figure 2).

However, seed yields in the 1992 trials were not impressive. Many of the trees in the trial set no seed, mean yields per tree were low and yields tailed off after two seasons. After three and a half years, most trees were visibly under stress and dying back with no prospect of further seed production. There was also great year-to-year variability in rainfall and seed yield. Of the species in these trials, *Acacia colei* var. *ileocarpa* (McDonald and Maslin, 1997b) had the best characteristics for easy seed harvesting; seed ripening in this variety was found to be synchronous, so most of the seed can be collected in one or two harvests; and the seeds are retained in tightly coiled pod bunches (Figure 3), thus reducing seed loss resulting from the strong winds common during the March to April harvest time.

Excavation of root profiles showed that *A. colei* has a shallow, spreading root system. ATSC therefore recommended single-row plantings with wide spacing (8 to 10 m between trees) to reduce interplant competition for soil and water. By 1994, farmers around Maradi had planted thousands of wide-spaced *A. colei* trees, mostly under a food-for-work programme run by MIDP to provide famine relief. Several hundred of these trees were analysed.The yields of seed were much better than those in the 1992 tests, with an average of nearly 2 kg per tree from the first seed harvest at 20 months. Furthermore, it was found that three-year-old trees could be rejuvenated, and seed yields restored, by heavy pruning at the start of the rainy season (Table 1).

Based on the analysis, it can be concluded that, by carefully following recommended practices of wide spacing, weeding and pruning, farmers can obtain at least two seed harvests, each averaging around 2 kg of seed per planted tree, provided that the annual rainfall averages at least 350 mm over the sequence of harvesting years. Lower rainfall, as noted above, consistently reduces seed yield and planting of *A. colei* is not recommended where mean annual rainfall below 300 mm is anticipated. Further on-farm research is being conducted to determine the optimum pruning regime and the longevity of pruned trees, most of which remain healthy and vigorous at five years of age.

The acacia trees yield other useful products. Leaves from the prunings can be used as mulch either on the soil surface or in *zai* holes, and pruned twigs and branches make excellent fuelwood. At the end of their seed-bearing life, the trees can be harvested for fuelwood and small rough poles. The total sale price of the

FIGURE 3
Branches and seed pods of 20-month-old Acacia colei *var.* ileocarpa *growing near Maradi, the Niger*

pruned branches and final wood harvest is expected to be at least 1 000 CFA (US$2) per tree, based on yields of over 50 air-dried kg of wood per tree and the selling price of acacia wood from early plantings around Maradi.

Acacia colei grows well on cultivated farmland and on sites abandoned by agriculture, such as hardpans and eroded gullies, and can serve as a shade-tree in home compounds. A great advantage is that the foliage is unattractive to livestock, so protection from grazing is not required, except on stock routes. Farming systems around Maradi are extensive, with large areas in temporary fallow or abandoned because of low fertility or the development of surface hardpans, so ample land is available for large-scale planting of acacias. A suitable arrangement for the rehabilitation of degraded farmland is to establish rows of acacia trees planted at right angles to the prevailing winds so that they act as windbreaks for crops, such as millet, planted between the rows. The rows are spaced 30 m apart and trees within the rows are spaced at 6 m. The soil for 5 m on either side of the tree rows is not planted to crops, but regularly weeded to maximize water availability for the trees. This layout retains two-thirds of the field's area for crop production, while the tree rows act as windbreaks and provide edible seeds, fuelwood and organic matter (foliage residues) for soil improvement. Yields of acacia products and food crops from this type of system are now being measured on farms near Maradi.

Because water for village tree nurseries must be lifted by hand from deep wells – the water table is 70 m or more below the ground in many villages – and labour availability is a limiting factor during the growing season, raising large numbers of potted acacia seedlings is difficult for poor rural communities. It would be preferable to seed acacias directly and/or transplant bare-rooted seedlings, thus making establishment of *A. colei* cheaper and less labour-intensive, but these techniques have not yet been successfully developed.

As with other food crops, scientific research should enable us to increase seed yields. MIDP and ATSC have established on-farm trials to study the effect of fertilizer application and inoculation with selected rhizobium strains on growth and seed production, and to determine optimum pruning regimes. The breeding system of *A. colei* is not yet fully understood, but greenhouse trials by ATSC have shown that it is self-fertilizing. There may be genetically controlled variation in characteristics that affect seed production, such as the ratio of male to bisexual flowers. Selecting and planting the offspring of high-yielding individuals could lead to increased yields through genetic changes in the *A. colei* populations around Maradi.

The indigenous trees and shrubs of the Sahel provide many edible products used by the local people (Guinko and Pasgo, 1992) but, as yet, no local tree or shrub species has been identified that possesses the characteristics that make *A. colei* so attractive as a cultivated food crop. Planted *A. colei* seedlings establish easily

TABLE 1. **Seed yields from windbreaks of *Acacia colei* and *A. elachantha* at Dandja, near Maradi** (345 trees were planted in 1993. Heavy pruning was carried out at age 37 months)

Months after planting	22	34	46
Rainfall in preceding wet season (mm)	495	296	355
Total seed yield from trees (kg)	190	49	160
Number of trees contributing to harvest	> 100	68	50

in the Sahel, have excellent survival rates and produce heavy crops of nutritious, palatable seeds, as well as useful amounts of fuelwood, within two years of planting. One concern is that the establishment of exotic species such as Australian acacias in western Africa might upset the region's ecological balance. It should be borne in mind, however, that many of the useful trees and food plants around Maradi on which local people now depend, such as cassava, maize, mango, *Moringa oleifera*, neem, pigeon pea and sweet potato, were also exotic at one time. It may also be noted that the Australian acacias do not sucker, seldom regenerate naturally from seed under Sahelian conditions and have shown no ability to spread as weeds in the 20 years following their introduction to the Niger.

Farmers around Maradi working with MIDP have developed natural vegetation management practices, including the protection of coppice regrowth on farms and the use of conservative coppicing rotations. Such practices increase the cover of indigenous tree and shrub species on the farms, thus increasing supplies of fuelwood, livestock fodder, forest foods and other forest products. Growing Australian acacias, even if widely adopted, will only be one part of the ongoing efforts to diversify and strengthen farming systems and food production in the Niger.

NUTRITIONAL AND SAFETY EVALUATION

In parallel with the field research on survival, growth and seed productivity which commenced in 1992, ATSC coordinated a detailed nutritional and safety evaluation of the seeds of *A. colei*. Analysis of *A. colei* seed flour indicated that it has good nutritional value and that known toxic and antinutritional factors were absent or at levels below those that would cause any concern (Harwood, 1994; Adewusi, Falade and Harwood, 1998). *A. colei* seeds contained about 23 percent crude protein, 53 percent carbohydrate and 11 percent fat. Some of the nitrogen was non-protein and over half of the carbohydrate was dietary fibre. The protein digestibility-corrected amino acid scores (Adewusi, Falade and Harwood, 1998) indicated that tryptophan, methionine and cysteine are the limiting amino acids, while bioassay with rats indicated a positive response to methionine supplementation (Adewusi *et al.*, 1998a).

Acacia seed flour was used for dietary trials with laboratory rats at Obafemi Awolowo University in Nigeria. Nutritional and safety trials showed that 20 percent *A. colei* seed flour in millet-based diets improved growth rates and that rats remained in good health for trials lasting several months (Adewusi *et al.*, 1998b; Table 2). Some adverse health effects (hair loss, eye infections and occasional morbidity) were observed in some experiments when acacia seed flour comprised 40 percent or more of the diet, but supplementation of diets with the amino acid methionine improved the animals' health and boosted their growth (Adewusi *et al.*, 1998a). Three generations of rats were raised on sorghum-based diets incorporating 20 percent and 40 percent acacia without any mortality or evidence of birth defects (Adewusi *et al.*, 1998c). Animals on 40 percent acacia failed to reproduce when fed diets containing 12.6 percent crude protein, but reproduced successfully when the crude protein level was increased to 18 percent.

The animal feeding results and the insight from Australian Aboriginal diets suggested strongly that *A. colei* flour would be useful both as a famine food and as a supplement to regular human diets, if incorporated at not more than 25 percent of the total diet by weight. Several enthusiastic local people in the Maradi district had meanwhile, on their own

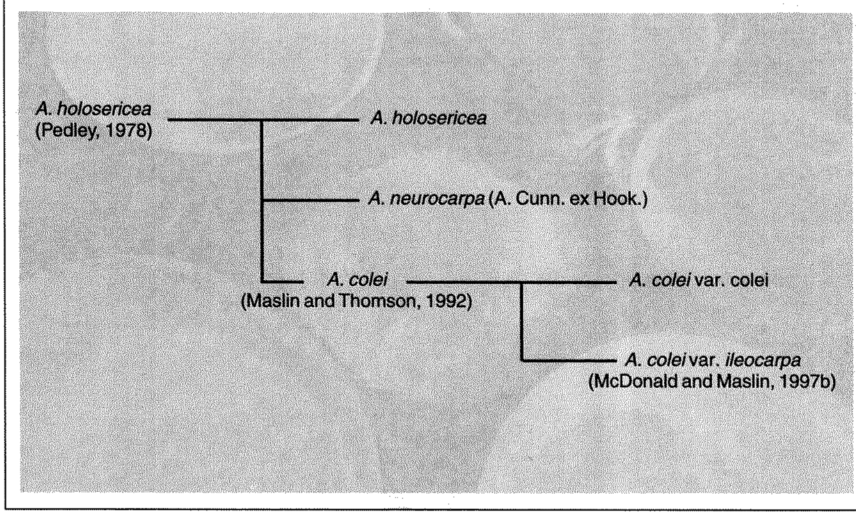

FIGURE 4
Taxonomic revision of* Acacia holosericea*, 1978 to 1997

initiative, eaten many meals incorporating *A. colei* seed flour over a period of up to five years and had not noticed any ill effects. Over 20 recipes using acacia flour had been developed by villagers, and roasted acacia seed flour had become popular around Maradi as a substitute for expensive imported coffee.

Of course, the nutritional value of foods, susceptibility to toxins and tolerance of particular diets vary between animals and humans and among human populations. A dietary trial was therefore conducted with volunteers from the Maradi district to check that a broad sample of adult people could safely incorporate known levels of acacia seed flour into their local diet (Adewusi *et al.*, 1998d). This trial followed the accepted ethical standards for research on human subjects set out in international guidelines (CIOMS, 1993). A protocol for the dietary trial was reviewed by the Australian National University's Ethics in Human Experimentation Committee, and permission to conduct the trial was provided by the Government of the Niger.

The dietary trial ran for three weeks during October 1995. Volunteers from five rural villages in the Maradi district assembled at the trial headquarters at Dandja. To participate, volunteers had to pass a medical examination, have the conditions of the trial explained to them and give their written consent. A medical doctor was on hand to attend closely to the health of the volunteers throughout the trial.

Cooks prepared a control diet (0 percent acacia) consisting of a range of traditional recipes with millet, sorghum and maize flours as the staple foodstuffs. *A. colei* seed flour, at 15 and 25 percent by weight, was then mixed with these staple flours (Figure 5) to serve as the two test diets (Adewusi *et al.*, 1998e). Nine male and nine female volunteers were assigned to each of the three experimental diets. The composition of *tuwo* and *fura*, two of the millet-based staple foods used in the trial, is shown in Table 3. The higher protein content of the acacia-incorporated foods is evident. The acacia foods were acceptable in taste, but a *tuwo*-sorghum recipe was rejected by most volunteers because of its unappetizing black colour. No health problems arising from the diets were encountered during the trial, or at a check-up 12 months after completion.

The weight of male and female volunteers who ate the control diet showed no change, while there was a slight but significant increase for those eating 15 and 25 percent acacia flour. Biochemical analysis of plasma and urine samples of the three groups of volunteers taken at the start and end of the trial indicated no adverse metabolic consequences of incorporating up to 25 percent *A. colei* seed flour. A supplementary study (L.-A. James, personal communication, 1998) compared the liver functions of ten people who had eaten acacia foods regularly for several years with those of a control group of ten, matched for age, sex and weight, who had never eaten acacia. There was no evidence of liver damage or malfunction in either group.

The positive results from the dietary trial and other nutritional studies indicate that incorporating acacia seed flour could extend food supplies by up to 25 percent without decreasing the quality of the local diet. However, caution must be observed and follow-up studies are required to check the effects of longer-term consumption of acacia flour at 25 percent of the diet in order to confirm that this new food is safe for children, pregnant women and other special groups. It would also be instructive to test whether higher proportions of acacia flour could safely be consumed and to identify favourable and unfavourable dietary combinations

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FIGURE 5
Preparation of acacia-millet flour mixtures at Maradi

of acacia with other foodstuffs. In this regard, laboratory rats fed a mix of *A. colei* seed flour and cassava have shown slow growth, poor health and mortality, suggesting that this diet would be deleterious for humans (Adewusi *et al.*, 1998f).

MANAGING MULTIDISCIPLINARY RESEARCH IN DEVELOPING COUNTRIES

Several factors have enabled this multidisciplinary research project to proceed successfully for the past eight years to the current stage:

- Crucially, Australian researchers' knowledge of the diets of Australian Aboriginal people introduced acacia seeds as a serious candidate food resource for western Africa.
- A receptive local community catalysed the initial testing of acacia seeds as a food source.
- MIDP, the organization that took responsibility for local management of the project, had already gained the confidence of village communities through its history of development activities prior to starting the project.
- Initial trials made by MIDP in 1990 indicated a good chance of success for the project. The local people found foods prepared with acacia flour to be palatable. Proven, locally available technologies could be used to produce and process the new food, which supplemented rather than replaced traditional recipes and diets.
- MIDP contacted agencies (ATSC and others) that could effectively assist with research, and eased the language barrier between scientists and villagers.
- Continued enthusiastic support by villagers encouraged MIDP, ATSC, Dr Adewusi and co-workers to continue their work. The local people came up with many improvements in silviculture, seed harvesting and processing methods and recipes.
- Long-term funding from AusAID and ACIAR enabled ATSC to provide ongoing scientific advice to MIDP.
- Additional funding grants enabled crucial research in taxonomy, silviculture, nutrition and toxicology.
- Specialists in silviculture, taxonomy, nutrition and toxicology were consulted for advice on particular aspects of the research.

TABLE 2. **Mean feed intake, weight gain, feed and protein consumed and protein efficiency ratio over 13 weeks ± standard errors** (for groups of 20 rats fed millet-based diets incorporating 0, 20 and 40 percent *Acacia colei* seed flour)

Level of *A. colei* seed flour in diet *(%)*	0	20	40
Weight gain *(g)*	143 ± 6.3	162 ± 6.3	113 ± 2.7
Feed consumed *(g)*	958 ± 13	1 032 ± 12	944 ± 11
Protein consumed *(g)*	144 ± 2.0	154 ± 1.8	141 ± 2.3
Protein efficiency ratio	1.0 ± 0.05	1.1 ± 0.05	0.8 ± 0.02

TABLE 3. **Composition of *tuwo*-millet and *fura*, principal foodstuffs in the experimental diets**

Food type and percentage acacia	Composition (percentage dry weight basis)				
	Crude protein	Fat	Ash	Dietary fibre	Carbohydrate
Tuwo (a type of porridge)					
0 %	9.3	5.1	5.4	9.5	70.7
15 %	10.7	5.5	4.7	12.5	66.6
25 %	12.7	4.1	4.3	14.4	64.5
Fura (boiled "dumplings" in milk)					
0 %	9.1	1.3	1.6	9.5	78.5
15 %	9.7	2.2	1.8	12.5	73.8
25 %	11.5	2.4	2.3	14.4	69.4

CONCLUSION

The authors believe that the concept of edible acacia seeds as a useful food for the semi-arid tropics should now be examined seriously by national agricultural research agencies (NARs), NGOs involved in rural development, FAO, the Consultative Group on International Agricultural Research (CGIAR) institutes, particularly the International Center for Research in Agroforestry (ICRAF) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and bilateral and multilateral donor agencies. Donor organizations could support the follow-up nutritional and silvicultural research needed and extend these studies to other countries in the Sahel region.

NARs and NGOs already working closely with local communities on agricultural development can play a vital extension role in testing and demonstrating the results already achieved, at low cost. ◆

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