

Australian Acacias for food security in semi-arid Africa: A multidisciplinary assessment

A dissertation presented

By

Peter Allan Yates

To

The Research Institute for Environment and Livelihoods

in partial fulfillment of the requirements for the degree of

Doctor of Tropical Environmental Management

Charles Darwin University

Casuarina, Australia February 2014

I hereby declare that the work herein, now submitted as a thesis for the degree of Doctor of Tropical Environmental Management of the Charles Darwin University, is the result of my own investigations, and all references to ideas and work of other researchers have been specifically acknowledged. I hereby certify that the work embodied in this thesis has not already been accepted in substance for any degree, and is not being currently submitted in candidature for any other degree.

Signed:_____. Date:_____.

Abstract

Many countries in semi-arid regions of Africa face serious challenges to food security due to a combination of population growth, resource degradation and climate change. In Niger, traditional agricultural systems, based primarily on pearl millet, are failing to produce to expectation as often as two years in three, with near total crop failures that lead to famine occurring approximately every five years.

Some Australian Acacias (*A. colei*, *A. torulosa*, *A. tumida*) are well adapted to the harsh and variable climate of southern Niger, and have been shown to support rural livelihoods through the production of edible seed, wood and environmental services. The nutritional value of many species of acacia seed is well documented, with the main lacunae concerning the potentially anti-nutritional and toxic effects of non-protein amino acids. This thesis shows that acacia seed has strong potential for use as a human food so long as the seed is appropriately processed. Acacia seed can fit into local diets in Niger from a cultural and nutritional viewpoint. The seed of the Australian acacias is high in protein and is an excellent nutritional complement to millet. The author was able to incorporate acacia seed into a local staple recipe to produce a nutritious food that is well accepted by Hausa people.

The potential of a complementary food based on acacia seed is assessed in this thesis. The proposition is feasible in terms of acacia production systems, cost, nutritional content and cultural acceptability. Acacia seed is likely to be suitable for use as an ingredient in a locally produced food aid product aimed primarily at reducing child malnutrition. Further work will be required to determine the significance of djenkolic acid which is found in acacia seed. The research shows that djenkolic acid content can be reduced by more than 90% through appropriate processing.

Table of contents

Abstract	iii
Table of contents	v
Table of Figures	vi
List of Tables.....	vi
Acknowledgements.....	vii
List of Abbreviations.....	ix
1. Introduction.....	1
2. Food Security	13
3. Malnutrition	37
4. Niger – An Environmental and Social Overview	49
5. Australian Acacias in the Agricultural System	59
6. Research Methods.....	77
7. A Hausa Initiative.....	91
8. The Potential for Weediness	99
9. Acacia Seed as Food	111
10. Acacia Seed – Food Safety.....	121
11. Potential modes of production for an Acacia <i>kunu</i>	139
12. The <i>Kunu</i> recipe	153
13. Implementation: Issues and the potential for scale-up, scale-out.....	169
14. Conclusion	189
15. References	195
Appendix 1: The Weed Risk Assessment System (Australia 2013) applied to <i>Acacia colei</i> in Niger and <i>A. saligna</i> in Tigray, Ethiopia	217

Table of Figures

Figure 2-1 The Sustainable Livelihoods Framework.....	19
Figure 6-1. Location of the Study Site	81
Figure 6-2. Location of Study Villages	84
Figure 13-1. Acacia intervention strategies: Pathways to impact.....	176
Figure 13-2. Estimated household acacia seed needs and land required for production.....	182

List of Tables

Table 5-1 Average annual economic benefits from a 1 ha FMAFS at Maza Tsaye (2007-2009)	69
Table 5-2. Average annual economic benefits from a 1/2 ha FMAFS vs. control farm at Magajin Kware (2007-2009).....	69
Table 6-1. Villages where community meetings were conducted	83
Table 9-1. Proximate analysis of seed of four acacia species (raw, whole seed)	119
Table 9-2. Amino acid analysis of seed of three acacia species (raw, whole seed)	119
Table 9-3 Micronutrients present in <i>Acacia colei</i> seed (raw, whole seed)	120
Table 10-1. Cyanide content of seed of selected acacia species. Surface and Chemical Analysis Network, University of Melbourne, commissioned by the author.	127
Table 10-2. Summary of acacia seed studies prior to 2008.	133
Table 10-3. Acacia nutrition and toxicology research since 2009: <i>excluding</i> work commissioned by the author as part of this study.	134
Table 10-4. Research commissioned by the author as part of this study	135
Table 10-5. Anti-nutritrients and toxins in seed of selected acacia species	136
Table 11-1. Ingredient preference chart for improved child feeding at the village level.	142
Table 11-2. Production cost estimate per tonne acacia <i>kunu</i> (dry weight) in Niger	152
Table 12-1. Nutritional content of potential ingredients for a complementary food	161
Table 12-2. Three acacia <i>kunu</i> recipes	162
Table 12-3 Nutritional analysis of first iteration <i>kunu</i> mix.....	164
Table 12-4. Comparison of selected nutrients in initial Acacia/Moringa <i>kunu</i> against international standards and millet <i>kunu</i>	165
Table 13-1. Institutional Levels Relevant to the Research	173
Table 13-2. Key Actions in Implementation of Acacia Interventions	174
Table 13-3. Risks in Implementation of Acacia Interventions.....	177

Acknowledgements

Andre Gidé wrote in 1925 that "One doesn't discover new lands without consenting to lose sight of the shore for a very long time" (Gidé, 1925). So it is with most research, I imagine. It was certainly the case for me, though I was not without friends and guides in that wilderness, and one rarely sails alone.

The journey began several years ago, with a phone conversation between myself and Penny Wurm who was coordinator of the Doctorate in Tropical Environmental Management course at Charles Darwin University. Penny was in her office in Darwin. I was walking on red sand, amongst mulga, mobile phone in one hand, a rope in the other, moving tethered camels between scant patches of feed. As usual, the sky was a riotous blue. Penny told me that I should enrol in the DTEM rather than a Masters. A few days later, sitting by a winking fire of mulga wood, surrounded by the rhythmic sound of cud-chewing camels, Tony Cunningham persuaded me to take on the Doctorate, and offered to supervise.

That night a decision was made, though the direction of the research had not yet been discovered. Evidently the trees that surrounded us in that encampment of beasts rhythmically chewing their cud made their influence felt, for the focus of my work soon fell upon acacia. This drew together my long history of interest in community and international development, bushfoods and deserts.

Tony Rinaudo has been incredibly supportive from the very beginning, and it has to be said that without Tony's vision and determination, the idea of acacias for human food would have withered long ago. Neither was Tony alone in those early days, and one must acknowledge the contribution of Chris Harwood, Lex Thompson, Steve Adewusi, Tougiani Abasse, Jock Morse and Peter Cunningham, all of whom took an unlikely idea and helped to coax it into the tenuous being I build upon with this thesis.

From the earliest I was supported, encouraged and nourished by Anna Szava, as we talked on numerous long walks in the hills north of Alice Springs, and later when Anna joined me in Niger, on long walks in the mysterious fedama that sits below the town of Maradi.

In Niger, the support of Peter and Sally Cunningham, Ruth Perkins and the entire SIM team was crucial. Ibrahim Jaho leant a note of humour and passion, always kept the way open,

and ensured safe travels on sandy roads sandwiched between great green walls of millet plants. Hadiza Daniel, Mariama Mahaman and Baro Mahamman made the work a lot of fun, and shared much skill and knowledge with me.

My supervisors in this endeavour were Stephen Garnett, Jocelyn Davies, Tony Rinaudo, Tony Cunningham and Rolf Gerritsen. Without these people on board (to return to the nautical metaphor), one's boat is likely to go around in circles, or plunge right off the edge of the world. I thank them all for their various contributions. Jocelyn in particular showed me where the thesis lay in what was otherwise just a good story, and gave wind to my becalmed sails more than once.

I also need to thank World Vision Australia for essential financial support, and World Vision Niger for logistical support in the field. I also need to thank the many people whose names I do not know, who gave freely of their time and knowledge. I sincerely hope that this work comes back to you in better livelihoods and better health.

Finally I need to thank Suzanne McLeod, for unwavering support for the dream, for letting me go for so long.

Ethics Approval was granted by the Charles Darwin University Human Research Ethics Committee (HREC Approval No: H13028.)

List of Abbreviations

CDM Clean Development Mechanism

CSB++ Corn-Soy Blend with nutritional fortifications (a product widely used in emergency food distributions).

CSIRO Commonwealth Scientific and Industrial Research Organisation

FAO Food and Agriculture Organization of the United Nations

FEWSNET Famine Early Warning System (a service of USAID)

FMAFS Farmer Managed Agroforestry System (developed by SIM)

FMNR Farmer Managed Natural Regeneration

ICRAF International Centre for Research in Agroforestry, now called World Agroforestry Centre.

ICRISAT International Crops Research Institute for the Semi-Arid Tropics

INRAN Institut Nationale de Recherche Agronomique du Niger

IRIN Integrated Regional Information Networks: Humanitarian news and analysis service from the UN Office for the Coordination of Humanitarian Affairs

MSF Médecins Sans Frontières

OCHA Office for the Coordination of Humanitarian Affairs

PAM/WFP Programme Alimentaire Mondial/World Food Program

RDI Recommended Daily Intake

SIM Serving in Mission (formerly the Sudan Interior Mission)

UNDP United Nations Development Programme

WFP World Food Programme, United Nations

WHO World Health Organization

WVA World Vision Australia

WVE World Vision Ethiopia

WVN World Vision Niger

1. Introduction

This thesis examines the proposition that a suite of edible-seeded acacia trees from the semi-arid tropics of Australia could improve food security and household nutrition in Niger, one of the poorest, and most famine-prone countries in the world. The utility of perennials in dryland agriculture has been well described by Sanchez and Leakey (1997), who point to the ability of trees to access deeper soil layers, reduce wind erosion and effectively utilise scattered and occasional rainfall events (see also Sholto-Douglas et al., 1984, Garrity, 1994). Australian acacias share these attributes and have been shown to be particularly useful, through the combination of rapid growth under harsh conditions and the range of valuable products and services the trees provide (Rinaudo et al., 2002). As such these species may prove to be an important element in the transition of Sahelian agriculture from a highly vulnerable annual system to a more resilient system dominated by perennials.

The viability of rural livelihoods is a critical underpinning for local and regional food security in Africa. Around 80% of Niger's population is rural, and virtually all of this population is dependent upon either farming or pastoralism for their livelihoods. Where these modes of production falter, as they often do, food security is compromised. The persistent poverty, growing population, land degradation and increasingly erratic climate combine to create a negative spiral that further erodes the potential for stable and sufficient livelihoods in rural areas. The first step in halting this negative spiral is to shift agriculture and environmental management more generally onto a more productive, sustainable and resilient footing. I show in this thesis that an increase in trees, including Australian acacias in appropriate settings, will contribute much towards this goal.

The current cycle of production shock and livelihood collapse, followed by the provision of food aid, does nothing to engender structural changes, either to societies or to agricultural systems that might enable an escape from poverty and vulnerability. Indeed, it could be argued that when an economic system becomes unable to support a population reliably, the provision of food aid amounts to a “moral hazard”, that actually works against change, and entrenches the failing system further (Rinaudo, 2002, Bar-Yam, 2004). I do not suggest that food aid can or should be denied to the hungry: the food aid safety-net is a “necessary evil” that is likely to be a permanent and growing feature of rural livelihoods for many regions of the world for the foreseeable future. What I argue in this thesis is that there are strategies that could harness the economics of food aid to serve the livelihoods of the vulnerable at a fundamental level - by building more resilient agricultural systems and by building a more resilient population by making better nutrition available at every stage of life. One such strategy involves the use of exotic Australian acacia species to improve farm productivity and nutrition.

The potential of Australian acacias in the Sahel has been demonstrated by several researchers over the past two decades (Rinaudo et al., 2002, Thompson et al., 1996, Cunningham and Abasse, 2005b, Rinaudo and Cunningham, 2007, Midgley and Turnbull, 2003, Harwood et al., 1999, Harwood, 1994, Cunningham et al., 2008), and good arguments can be made, particularly with respect to environmental services, for the wider adoption of acacias in the Sahel. While there is much work yet to be done in the refinement of agronomic systems, in species and provenance selection, in trialling species and provenances for more arid conditions and in fully understanding nutritional chemistry of acacia seed, the need for further work does not diminish the value of what can be achieved with the knowledge that is currently held. As one researcher has pointed out, the greatest current limitation on the expansion of acacia plantings is not technical, but relates to the

lack of a functioning market for the seed (Rowlands, 2009). If such a market were to be created, either endogenously or through external intervention, farmers would need little convincing that acacias can play a major role in the *bricolage* of their livelihoods.

This research arose through my enrolment at Charles Darwin University in a Professional Practice Degree called the Doctorate in Tropical Environmental Management. In this I was required to partner with 'industry' to identify and conduct a research project. I negotiated a professional placement with World Vision Australia (WVA), and the research direction was decided in consultation with WVA as a feasibility study looking into the potential of Australian acacias to improve food security in semi-arid Africa, with a particular emphasis on the potential for the production of an emergency food utilising acacia seed as a protein and carbohydrate source. The potential food security improvements from using acacia seed as a food are important, but they are second to the benefits expected from the general amelioration of environmental and livelihood conditions that I expect would follow plantings of acacia.

The field research was conducted in the Maradi region of Niger in the latter half of 2009. A report was provided to WVA in 2010 (Yates, 2010). Whilst I undertook my research in Niger, acacias are relevant to most of the Sahel, the semi-arid tropical region which stretches across Africa from Senegal in the West, to Eritrea in the East. Acacias will grow well and yield significant environmental services and livelihood values anywhere where rainfall is between 250-600mm/annum. In the Sahel this is a zone that is highly vulnerable to livelihood shocks caused by the vagaries of climate, and yet it supports up to 100 million people, albeit poorly and with periodic recourse to emergency assistance. Acacia species¹

¹ Principally *Acacia saligna*.

originating in temperate areas of Australia are growing very well and yielding substantial benefits in the equally famine-prone highlands of Tigray, northern Ethiopia.

1.1 The research brief

My research was determined in negotiation with my sponsor, WVA. Based on previous research and field experience, my project had three equally weighted intentions. The first was to show that nutrition in rural villages could be greatly improved using foods that can be grown on family farms, thus empowering families to better feed themselves. The second intention was to create a market for acacia seed that could provide a stimulus to further plantings, and thus provide a 'pull' toward the increased resilience and agricultural sustainability that many researchers believe acacia can confer. The third objective of my research was to investigate the wider environmental benefits of Australian acacias since these include many livelihood benefits beyond human nutrition.

My brief was summarised as follows:

To explore the feasibility of using acacia seed as the protein and carbohydrate basis of an emergency food product.

The design criteria were:

- That the product contain a significant proportion of acacia seed;
- That the product be able to be made using, as far as possible, local ingredients.

Specific nutritional components were to be sought in whole food products that are available locally in Niger, rather than in imported supplement form;

- That the product be as nutritionally complete as possible, to cover as wide a spectrum

of a target population as possible;

- That the product fit well into West African cuisine(s);
- That the product be cost effective compared to other forms of nutritional support; and
- That the product have a long shelf life.

The WVA brief very clearly asked me to consider the feasibility of developing a product that could be produced at scale, stored, and distributed as food aid in times of need. My research has addressed this objective and gone further, to consider strategies for the use of acacia seed within the household as an everyday food.

To meet the WVA aims, I consider production issues, compatibility with overall agricultural systems, price and price fluctuations, farmer acceptance of Acacia as a crop, potential weediness, taste acceptability and 'fit' with local cuisine. The quality, food safety and nutritional requirements that an emergency food product would have to meet were also considered, including toxicity and anti-nutritional aspects of some acacia seed, as well as the institutional context in which an acacia-based food enterprise would ultimately need to be located. This raised many questions.

1.1.1 Productive/environmental feasibility.

I needed to look at the suitability of the acacias for the task we are setting them. Is there an environmental fit between acacias and the target environments? Which species have been used, what is known about their performance? What other species could or should be trialled? What environmental benefits have been observed or could be expected from acacias? What products (seed, mulch, fuelwood, building materials) and what environmental services (wind speed reduction, erosion reduction, nutrient cycling,

replacement of native timber for fuelwood) have been observed, or can be expected from acacias? What values can be attributed to these products and services?

Acacias have significant potential for weediness. What indices of weediness potential might be appropriate to apply in relation to the species in question? How do these species rate under such measures? What particular environmental/social factors might mitigate weed risk? What factors might increase risk? What weedy behaviour can be observed on the ground in Niger? How could the risks of weediness be managed when new tree species are introduced?

1.1.2 Cultural feasibility.

I needed to understand the “fit” between what I proposed and the customs and usages of the local people. The nature of agriculture is constrained by factors such as soil and climate, but within these constraints, crop selection will be determined by cultural ideas of food, or by market opportunities. What are the food preferences? What are the market opportunities? I needed to look at the likelihood of a species such as acacia being adopted for one or more of its potential uses. What might be the constraints to adoption? How can a society that has been strongly fixated on annual cereal agriculture be encouraged to increase their use of perennials in the farming system? What impediments may be encountered to new crops/foods/technologies?

1.1.3 Economic feasibility.

Can the various attributes of Australian acacias be shown to be economically beneficial?

When the expected or observed benefits are combined, does this comprise a compelling

case for widespread adoption of acacias? Can a food aid product be made cheaply enough to compete with established products, such as Corn-Soy Blend (CSB) and similar products? What is the market potential for a nutritional support product?

1.1.4 Nutritional feasibility.

I was investigating the nutritional possibilities of acacia. This involved knowing what was the nutritional status of the study community? How is food insecurity/malnutrition distributed within the community? What specific factors have been identified as causes of food insecurity/malnutrition? What foods are produced in the semi-arid farming system? What nutritional potential do these represent? How can the available foods be combined to maximise nutritional benefits for target sectors of the population? What are the nutritional profiles of various species of acacia seed? What anti-nutritional and toxic factors need to be taken into account?

1.1.5 Legislative environment.

Here I needed to understand the regulatory environment. What are the relevant national and international systems and protocols for approval of foods? What issues may arise in Niger or other countries if the concept is further expanded? What national policies and laws may impact on the development or use of acacia as a food?

1.1.6 Other factors to be considered.

What additional livelihood contributions could arise from the widespread planting of acacias? Could local energy markets and/or global carbon markets offer a significant income stream for farmers?

Each facet of the research required specific data, and this needed to be collected in a range of ways. Much of the data, especially that concerning the silviculture and productivity of acacias is the work of others, but needed to be drawn together from numerous research papers and unpublished sources. I have listed above a large number of questions, and certainly I was not able to answer all of them. On one hand, the timeframe available for fieldwork was too short, and on the other, there were many questions that could not be answered in advance. My research was rooted in a participatory action methodology, and thus was *defacto* a first step in an unfolding process of adoption. Many answers, indeed, many questions will not take shape until later phases of implementation.

1.2 How the research was done

The use of Acacia seed is not new: a small group of local innovators made and distributed baby foods comprising a pearl millet/acacia blend in a Hausa village from 1998 to the time of the research. This group accepted my offer to help them to refine their product and maximise its nutritional content. The group brought with them a detailed knowledge of crops and agricultural systems, as well as a nuanced, first-hand understanding of the local child-rearing practices and food preferences. I brought my knowledge of how best to use Acacia seed, a nutritional database and basic linear programming capacity that enabled me to assess various recipes for their nutritional content. In a collaborative process, we reformulated a local millet porridge, known as '*kunu*', to maximise nutrition whilst

maintaining the sensory qualities of taste, colour and texture that are culturally essential to a food's acceptability. The mix, we hoped, would greatly improve the nutrition of children in the 6-12 months age group during and following weaning.

Our *kunu* could be produced in remote villages from readily available ingredients – so long as acacia seed is available, of course. This led to the next set of important considerations: How available is acacia seed? How can it be made more available? How can the overall production of acacia seed be boosted to a level that can make a meaningful contribution to food security?

I also needed to look at the much larger scale concept of an emergency or supplementary food product, based on acacia seed and other common Sahelian food crops, which could be distributed to support vulnerable families *in extremis*. With a small amount of supplementation on certain micro-nutrients, the porridge mix my team developed could be adapted into a product that would meet international standards. The main challenge, again, was how to build up acacia seed production to the level required to achieve the necessary production efficiencies within a reasonable timeframe.

1.2.1 Nutritional and toxic evaluation of acacia seed.

Evaluation of the nutritional and toxicological status of acacia seed was also important. Consequently I commissioned detailed laboratory analyses of several species. When a sub-acute toxicity trial conducted by the Ethiopian Ministry of Health in 2012 (unpublished) returned unfavourable results for *Acacia saligna* as a food, it became necessary to identify the source of the apparent toxicity, to determine whether it could be reduced through processing and to discover whether it occurred in the species of acacia that are being used

in Niger – particularly *A. colei* and *A. torulosa*. I subsequently ruled out both cyanide and fluoroacetate as the problem, but found djenkolic acid to be present in all species tested.

1.3 Organisation of the Thesis

As described above, this research was developed and undertaken in collaboration with World Vision Australia. It takes the form of a feasibility study, and as such needed to encompass a range of issues covering several disciplinary areas. Chapters 2-5 comprise a review of the relevant literature. **Chapter 2** considers the concept of food security and the policy approaches that have been employed to address the on-going issue of hunger and malnutrition in the developing world. **Chapter 3** details medical understandings of malnutrition and describes in detail the nutritional situation in Niger. In **Chapter 4** I provide an environmental and social overview of Niger, considering some important factors that are impacting on rural livelihoods and agricultural sustainability in Niger. In **Chapter 5** I draw together the current knowledge and experiences of integrating Australian acacias as multi-use species, both as an element in agroforestry systems and as tools for the rehabilitation of severely degraded land in West Africa, the potential for using an acacia based food to improve child nutrition in Niger and describe multiple scales at which acacia *kunu* could be promoted.

Chapters 6 and 7 are concerned with methodology. In **Chapter 6** I describe my field research methods. In **Chapter 7** I expand further on my research methods, in particular to describe a collaborative partnership around which the development and refinement of an acacia-based product evolved.

In **Chapter 8** I consider the risk that Australian acacias could become invasive, and suggest some social and environmental factors that minimise this risk.

In **Chapter 9** I describe how some Australian acacias have been used as food in the past in Australia and in the present, in both Australia and Niger. I also detail the state of knowledge of the nutritional content of some species of acacia, and add the details of analyses of acacia seed commissioned by myself. In **Chapter 10** I consider the anti-nutritional and toxic factors present in some species of acacia seed. I summarise current knowledge and detail new data from several laboratory studies commissioned by myself as part of the study.

In **Chapter 11** I describe three different but potentially complementary approaches to the promotion of an acacia-based complementary food in Niger. In **Chapter 12** I describe the various iterations of the *kunu* formula as it was developed and refined. In **Chapter 13: Implementation: Issues and the potential for scale-up, scale-out** I describe how acacia production can be scaled out to smallholder farmers, or scaled up to address land degradation. Chapter 13 also considers pathways to impact, key actions for implementation and a project risk assessment.

I conclude in **Chapter 14** that some Australian acacias have significant potential as multi-use trees in semi-arid Africa. The potential of improving nutrition by using acacia seed as a food is strong, provided that outstanding toxicological issues can be adequately answered.

2. Food Security

Food security is one of the major developmental challenges for the semi-arid regions of Africa. In densely populated regions such as the Sahel (Watts, 1983, Tenenbaum, 1986), Sudan (Keen, 1994), and the Horn of Africa (de Waal, 1991, Webb et al., 1992), food insecurity, including major famine events have been a major recurring theme throughout history. Agricultural and development policy in Africa throughout the past four decades has evolved partly in response to changing conceptualisations of food security, with a gradual shift from a focus on catastrophic famine events to issues of on-going under-nutrition, and a concomitant shift in emphasis from national level production, to a concern for household economy and livelihoods.

Malthus (1999), writing in the early part of the nineteenth century, first pointed out the impossibility of (forever) matching the food production increase of an arithmetically growing agriculture with the food needs of an exponentially growing human population. Famine, according to Malthus was both inevitable and natural. Though famine occurred periodically in the centuries following Malthus, and many commentators sought to explain these events in Malthusian terms (see Keneally, 2011 with reference to the Irish famine), food production has for the most part kept pace with human needs (see also Grigg, 1979). Though Malthus has not yet been proven correct, the ultimate truth of his thesis: that the human population cannot grow forever unchecked in a finite world still looms powerfully, both for those who are concerned for human welfare, for those who are concerned for our ecosystems and the life-forms with which we share the planet and upon which humans also ultimately depend (Ehrlich and Ehrlich, 2009, Gilland, 1988, Shepard, 1978).

Boserup (1981, 2005) explained the ability of growing human populations to expand their food needs through the idea of 'agricultural intensification'. According to Boserup, population growth in itself is the main driver for the technological and social innovations that have enabled a steadily increasing food supply (see also Matson et al., 1997, Sakara et al., 2007, Phillips-Howard and Lyon, 1994, Braun et al., 1991). The Malthusian argument is not necessarily in conflict with Boserup's theory, and Evans (1998) argues that the both propositions can operate - that population must needs be restricted by food supply, but also that increasing population pressure (together with new technologies) can stimulate increased food production within certain limits.

Contemporary examples of agricultural intensification in West Africa have been described by several authors (Reardon et al., 1997, Reardon, 1999, Mortimore, 1989, Aune and Bationo, 2008, Matson et al., 1997, Adams and Mortimore, 1997, Mortimore, 2005). More generally, the ecological implications of agricultural intensification have been a major concern, as human needs increasingly threaten natural ecosystem values (Butler et al., 2007, Braun et al., 1991, Evans, 1998, FAO, 2009, Sanchez and Leakey, 1997, Ehrlich et al., 1993). Garrity (2010) points out that the most food insecure regions of the world, such as parts of eastern and western Africa, and the Indian subcontinent, are generally also the most densely populated, with the most vulnerable also tending to be more arid. Such regions suffer a shortage of farm land, with limited prospects for intensification due to low and erratic water availability. The situation is exacerbated by endemic poverty and climatic change (see Chapter 4 below).

2.1 Food Security: understandings and policy

Prior to the 1980's food security policy was centred on food availability and was mainly concerned with food production and stocks at the national level, usually labelled 'aggregate food security' (Stryker, 1978, Staatz and Eicher, 1990). Thompson defines this as: "...ensuring adequate food supplies to feed the country's population at reasonable prices, regardless of how crop yields fluctuate from year to year" (1983). The United Nations definition of food security, formulated at the 1974 World Food Conference, reflected this as : " availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in supply and prices" (United Nations, 1975). This national level approach focussed mainly on famine, and was largely blind to the hunger that was part of everyday life in many developing countries. Under this understanding, hunger was the result of food availability decline and the answer was to grow, or import, more food (Myhrvold-Hanssen, 2003, Adebayo, 1989).

Major advances were made in aggregate food security, through the 'green revolution' (Frankel, 1971, Griffin, 1974, Evenson and Gollin, 2003), which boosted cereal production through a combination of improved genotypes, utilisation of fertilisers and pesticides, and mechanisation. The green revolution was particularly effective in monsoonal Asia, but contributed little to improving the productivity of agriculture in Africa, where the widespread policy bias against agriculture (Anderson and Masters, 2009, Thiele, 2002, Koning and Smaling, 2005), the persistence of traditional land tenure systems, poor soils and relatively low population densities, rendered the model ineffective (Glaeser, 1987, Evenson and Gollin, 2003). A belated African Green Revolution has been described by Sanchez et al. (2009) in Malawi, based on policy changes that supported farmers with improved seed and fertiliser.

2.1.1 The legacy of Amartya Sen

In a seminal essay in 1981, Amartya Sen showed that food security is not only about production and availability but that people's rights to access food are determined by their economic status. Thus, hunger and famine can exist even when there is sufficient food available (Sen, 1982). Though Sen focussed on catastrophic famines, and the ways in which entitlement collapse was implicated in such events, his analysis made it clear that hunger was always a function of the economy and, as such, could exist anywhere there was poverty. Sen's entitlement theory transformed the policy approach to food security by emphasising the importance of the household in understanding and preventing serious hunger.

The decade of the 1980's was a productive time in the development of food security theory. In 1980, the World Bank had defined food security in a relatively unsophisticated phrase thus: "...the assurance of a minimally adequate level of food consumption..." (World Bank, 1980). In light of Sen's ideas, aggregate food security came to be seen as a necessary, though insufficient, condition for household food security (World Bank, 1990). The focus fell onto the household and individual vulnerabilities (Maxwell and Smith, 1992). Thus Pinstrip-Andersen proposed that food security involved four components: that food be physically available; that food be affordable; that there be a will to purchase food (as opposed to choosing to preserve assets); and that food is adequately distributed within the household (Pinstrip-Andersen, 1983). In an argument well ahead of it's time, Oshaug (1985) suggested that:

"A society which can be said to enjoy food security is not only one which has reached the Food Norm (... "a basket of food, nutritionally adequate, culturally acceptable, and procured

in keeping with human dignity”), but which has also developed the internal structures that will sustain the Norm in the face of crises threatening to lower the achieved level of food consumption. The internal structures form the basis of the capacity to endure” (Oshaug, 1985).

Oshaug uses the term “internal structures” to describe what more recently have come to be known as ‘institutions’ in the ‘sustainable livelihoods’ discourse, as described below. That is, the civil structures operating at various levels of society that serve to mitigate risk.

Through much of the 1980’s UNICEF adopted an approach that focused on household food security, with the intent that “ All households should be able to assure adequate food for all family members throughout the year” (Toole, 1989). There was a further realisation that food security differentials exist even within households, and thus there developed an awareness of the potential importance of gender (Kabeer, 1990). The economic dynamics that created vulnerability also became important and livelihood analysis emerged with scholars such as Swift (1989) describing the way progressive asset depletion created by repeated shocks caused the rural poor to be increasingly vulnerable to food insecurity and famine.

2.2 Livelihoods

The 'sustainable livelihoods' approach originated with the work of Chambers (Chambers, 1989, Chambers, 1983), and drew together many of the ideas current to the development and food security debates, with the exception that sustainable livelihoods were as much about the assets and the potential of the rural poor as they were about their vulnerabilities and deprivations. The approach was further developed by the UK's Department for International Development (DFID) (Scoones, 1998, Ashley and Carney, 1999, Carney, 2003, Conroy and Litvinoff, 1988, Solesbury, 2003, Chambers, 1987), and by other rural development practitioners such as (Bebbington, 1999) and Mukherjee (2004).

The sustainable livelihoods approach has shown great longevity, with a plethora of studies employing the approach published every year. Sustainable livelihoods has become an important analytical methodology as well as a best-practice approach for participatory action in poor environments, whether rural or urban. The real strength of the approach is that it requires a local-centred situational analysis as the starting point and thus is able to capture strengths, vulnerabilities and opportunities at many levels.

In a review of the sustainable livelihoods framework, Turrall (2011) shows that the concept has been used in applications where it is used to help analyse vulnerability, disaster risk reduction and adaptation to climate change; to explore ways in which markets can be employed to better support the poor; and to build food security and resilience in rural communities threatened by climate change. Areas identified by Turrall as needing further attention related to ensuring accountability to people and not just donors, and to reforming unjust power relationships; willingness to engage with policy makers to effect institutional

change; a greater focus on cultural factors impacting on development; and an improved awareness of opportunities across multiple scales (2011).

A typical diagrammatic representation of the Sustainable Livelihoods Framework is reproduced in Figure 2-1.

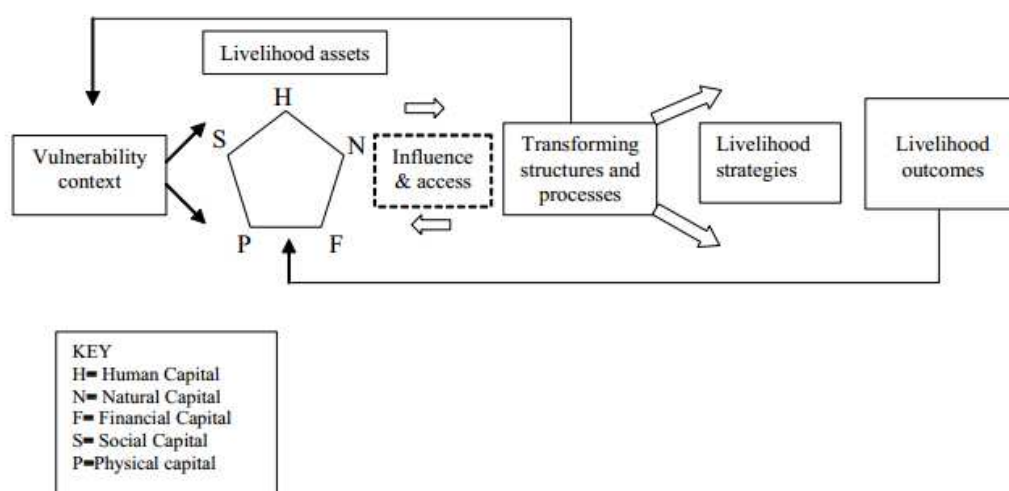


Figure 2-1 The Sustainable Livelihoods Framework. Source: (Carney, 1998).

2.2.1 Key concepts in Sustainable Livelihoods

Capitals.

The sustainable livelihoods framework is based around the idea that everyone has access, to varying degree, to a set of capitals with which they are able to build their livelihood. Typically the capitals are human, financial, natural, social and physical, though Scoones (1998) notes that there are others.

Vulnerability Context.

Capitals are employed in imperfect situations. The vulnerability context describes the range of environmental (drought, flood, fire, pests), political (strife, corruption, neglect), health

(disease, malnutrition) or other factors that may impact on a person's ability to build a secure and sustainable livelihood.

Institutions (also called 'transforming structures/processes in some of the literature).

In the sustainable livelihoods framework, 'institutions' are the means by which vulnerability is managed (and in reality it is how people are managed). For the rural poor, the capacity to manage vulnerability is low, due to lack of economic power, lack of education and lack of influence. Thus external agencies have moved to create, as best they can, the institutions of social security, resource management and development (Ostrom, 1990, Bromley and Cernea, 1989). However, institutions built by organisations tend to take on the character of 'things' with a fixed, managerial character, whereas in reality, institutions as they are known and experienced by people are cultural constructions and often highly negotiable: 'what people do' (Lund, 2001, Lund, 2006). Cleaver and Franks (2005) argue that for this reason, exogenous institutions tend to 'elude' their intended design and function, being built according to one logic, but (mis)used according to another.

An 'institution' can include cultural or societal 'rules' that operate to direct or moderate behaviours through moral or normative pressures, through to large-scale, even global, structures such as markets. Institutions operate at different levels, with different 'rules' of access and influence and different scales of operation and impact (Dorward et al., 2002). Bingen (2000) lists five categories of institution. These are the familial (kin or descent based); communal (trust and reciprocity based); social (societal interest based); collective (contractual interest based); and policy/governance (legislative or regulatory based). In the context of this study, the multi-level structure of institutions (and their sometimes conflicting objectives) are important, since it is policy - whether of a local NGO or of multilateral agencies with a global remit - which has powerful, though often invisible,

impacts on what is possible (Thompson, 2000). Market institutions have attracted particular attention, and it has been strongly argued that the failure of markets is a major factor in continuing poverty and food insecurity (Dorward et al., 2002, Fafchamps, 2004).

Vulnerability

Ericksen et al. (2010) describe social vulnerabilities such as poverty, marginalisation and lack of choice, and environmental vulnerabilities such as a tendency to flood or drought. Environmental vulnerabilities may well be worsened by anthropogenic environmental changes such as changed climate or desertification. Vulnerabilities can often operate in a vicious cycle. For example, deep poverty leads people to discount their future in order to live today, risking productive assets and vital ecosystem services by overharvesting finite reserves (Dasgupta, 2001, Markandya and Pearce, 1991). Ben Yahmed and Kawaguchi (1996) argued that vulnerability to disasters can best be conceptualised as a continuum between emergency response and preventative diplomacy. Vulnerability is seen as having two sides: exposure to external hazards; and a limited capacity to cope with those shocks, attributed to social, political, and economic factors. Reducing vulnerability to famine and food insecurity, they argue, is best addressed as an issue of human development (c.f. Sen, 1999).

Resilience

Resilience refers to the ability of a system to absorb disturbance whilst retaining the same functional characteristics. The erosion of function beyond a certain point can cause that system to change state and display a very different set of functions that may well be detrimental to human wellbeing (Ericksen et al., 2010).

In this thesis, as is common in the development literature, 'resilience' refers either to the ability of the household to manage livelihood shocks (Adams et al., 1998), or to the ability

of the environment (usually) to absorb (usually) anthropogenic changes without losing its functional characteristics (Swanstrom, 2008, Perrings, 1994). The two are, of course, closely linked and a decline in one is almost certain to result, before long, in the decline of the other (Adger, 2000, Fernandez et al., 2002, Berkes et al., 2000, Peterson, 2000).

Resilience in environmental systems refers to their ability to withstand the impacts of human production systems or adverse natural events without reaching a state of fundamental change or collapse. If, for example, too many trees are removed or wood harvested to make way for cropping, soil erosion may accelerate to a point that cannot be reversed and both the nature and the productivity of the system may be irreversibly changed (Sanchez and Leakey, 1997).

In the social-ecological systems literature, 'resilience' is more broadly conceived and is value-neutral. Resilience is not necessarily beneficial to humans. Maru (2010) and Maru et al. (2012) show that chronic poverty can be the result of societal 'resilience', with the social-ecological system resisting multiple forces of change, to maintain a (dys)functional state; a 'poverty trap.'

In development thinking, the resilience of people, households and communities is built by good nutrition and health, education, social inclusion, the opportunity for dignified and gainful employment; many of these factors are mediated and reinforced through institutions, though the social-ecological systems approach reminds us that institutions may in fact hinder 'progress' in human social development.

2.2.2 Food Sovereignty

The concept and language of food security has been co-opted and splintered by agribusiness and government interests in recent years, to justify dubious strategies such as food stockpiling or the buying up of land and water resources in hunger-prone developing countries across Africa (Siegenbeek Van Heukelom, 2011). Such practices mask corporate 'business as usual' and value the 'food security' of people who are able to pay over those who cannot (Shepherd, 2012).

The co-option of food security has led to the emergence of the concept of food sovereignty, with its emphasis on the local and rejection of the failed global food system. Food sovereignty is about local production and control, emphasising regionality, diversity and self-reliance (Schanbacher, 2010). For Schanbacher, 'food security' is concept with an indisputable neo-liberal provenance, concerned with global economics and relying on markets to redistribute food from regions of oversupply to regions of shortage. In practice the international food distribution system is very different from the neo-liberal ideal, as Keane (2013) points out: "Only 10% of the world's grain is traded internationally, and of that, only 1% is traded to poor countries". The reality for the world's poor is that they cannot afford to buy expensive imported food, and the vast majority of food is, and will continue to be eaten where it is grown (Keane, 2013). On Keane's figures, faith in global markets as a redistributive force capable of feeding a growing population seems misplaced unless dramatic (and unlikely) reductions in severe poverty occur.

2.3 The Human Right to Food

That the international food system is failing a great many people does not seem to be in dispute. Shaw (2007) argues that even the major international organisations charged with delivering food security have been implicated in the persistence of hunger, whilst Schanbacher (2010) comments that “the current food system constitutes a massive violation of human rights”. The persistence of hunger has been seen (along with other on-going injustices) as a structural feature of world political and economic systems (Galtung, 1990). The importance of governance, both in protecting rights and ensuring access to food led to the emergence of rights-based approaches to food security. For Edkins (2000), famine is a deeply political matter. Famine does not just happen due to an unfortunate set of circumstances; it is *allowed* to happen, and acts of mass starvation, according to Edkins, need to be dealt with under international criminal law (Edkins, 2002).

In 1986, the World Bank changed its definition of food security to “access by all people at all times to enough food for an active, healthy life” (World Bank, 1986). Taking a rights-based approach, Shepherd (2012) comments that such a definition, whilst very noble, fails to identify actors, actions or responsibilities. We are left with no idea whether the food needs of ‘all people at all times’ should be secured by themselves, by their government, or by the international community. Put another way, the World Bank is silent on exactly which institutions should be responsible for people’s food needs.

Shepherd argues that hunger is one of the most basic oppressions against which people must be secured. In this light, food security can be framed in terms of “*securing vulnerable populations from the structural violence of hunger*”. (Shepherd, 2012). Structural violence is a concept that responds to the twin facts of severe material inequality across the globe and

similarly distributed disparities in rights and the enforcement of those rights. Structural violence describes the gap between the rights of a person and the avoidable failure to ensure that those rights are met (Ho, 2007). Whilst most commentators cited above are principally concerned with wide-scale famine events, the salience of the approach to the adequacy of everyday nutrition for children in the developing world is obvious, as I will show in Chapter 3.

2.4 Non-Governmental Organisations

One response to the repeated failure of governments to provide food security to their people has been the rise of the NGO. NGOs have proven to be nimble in responding to need, and much more able to avoid corruption than most developing world governments. NGOs also offer important alternative approaches to development, and the plethora of philosophies and operational foci add significantly to the diversity of development activity (Escobar, 1995). It has been argued that NGOs are often not accountable, and in many ways are a continuation of the colonial paradigm (Manji and O'Coill, 2005, Escobar, 1995). Shivji (2007) describes how NGO's were used by donor governments to cover the worst social effects of the structural adjustment policies imposed throughout the developing world in the 1980's and 90's and in so doing helped protect the hegemony of neo-liberal policies. He argues that many NGOs continue to erode democracy by allowing social policy to be determined by donors rather than the people themselves (cf. Mosse, 2005). With the rise of 'participation' in development ideology and practice, NGOs came to be seen as small and sensitive enough to avoid the problems common to large bureaucracies, yet they all too often simply delivered projects designed and financed by those same bureaucracies. Whilst the rise of the NGO may be important in respect of the rapid dissemination of western values, it raises some serious issues as to whether the *need* for good governance by the

government is being evaded, and the capacity for a country to develop the skills and culture of good governance is being furthered (Fisher, 1997, Salamon, 1994).

2.5 Food Security Interventions

Interventions to ameliorate famine and malnutrition have been driven by a complex of political and humanitarian concerns since the 1940s, much of which crystallised around the concept of 'development'. The hegemony of 'development' ideology was built on the concept of 'underdevelopment' (Esteva, 1992), there being no greater symbol of underdevelopment than that of famine and persistent hunger. Hunger is seen as symptomatic of inadequacy across governance, production systems, education and markets. As such, the alleviation of hunger has been the motivation and justification for almost any development intervention. The problem could also be viewed from the other side, as Lofchie and Commins (1982; 1) comment: "Hunger is the most immediate, visible, and compelling symptom of a continent-wide agricultural breakdown in tropical Africa". The failure of agriculture, they argue, places in serious doubt the potential for any real development on that continent. Lofchie (1986) argued that the failure of African agriculture can be attributed to three factors: The commitment of African governments to a rapid expansion of public services, particularly in urban areas; the pursuit of industrialisation, and the need to satisfy a powerful urban elite (Lipton, 1977).

Practical interventions to improve food security and nutritional status have tended to be singular in focus, taking little account of potential synergies across disciplines (Hoddinott, 2012, Pinstруп-Andersen, 2012, Action Contra la Faim and FAO, 2011). This is despite calls for an integrated approach from many scholars for more than two decades (Swallow and Ochola, 2006, Scoones et al., 1992, Ogden, 1990, Grivetti and Ogle, 2000, Tontisirin et al., 2002, Frison et al., 2006).

2.5.1 Food Aid

Food aid has taken a number of forms over the past several decades, with a range of reported effects, both positive and negative. Food aid was never simply practice or ideology. Rather than evolving as a whole in response to new knowledge or approaches to food security, it has tended to splinter and proliferate, with some aspects of food aid provision unchanged since the 1950's, whilst other aspects have become highly technical and medicalised. Other streams have changed focus from aid provision to development and enabling (Barrett and Maxwell, 2005). In a review of the literature, Rogers (1995) concluded that no approach could be considered as superior to the others, and that each intervention needed to be designed and assessed within its unique situational context.

2.5.2 Food Aid Debates

In the 1950's, the United States government developed a strategy that could dispose of excess domestic cereal production, provide a channel for US statesmanship, reduce poverty and hunger and thus defuse the attraction of communism in the so called 'third world'. Summarising this evolution, Reutlinger (1999) comments that:

“While the earliest food aid had been provided in response to humanitarian concerns for victims of disasters, food aid blossomed into the very large programs of the 1950s and 1960s in response to mounting stockpiles of commodities, the by-product of governments fixing farm prices. A strong coalition of political constituencies — farm commodity groups, shippers and handlers, and relief agencies — provided political support for a program, which, in order to hold together, had to embrace non-compatible and sometimes conflicting objectives” (1999; 9).

Schultz (1960) first alerted the world to the very unclear intentions behind US food aid, and the potential for disruption of underdeveloped economies (see also Barrett, 1998, Marchione, 2002). There followed a debate as to the effects, positive and negative, of food aid which continues five decades later. Positive effects (other than the relief of suffering) were seen to include increased political stability and stimulus to the economy, whilst negative effects were the distortion of markets, the disincentivisation of agriculture, propping up of incompetent governments and changes to eating habits that could be either unhealthy or could lead to preferences for imported foodstuffs over locally produced traditional fare (Barrett, 2006, Barrett and Maxwell, 2005, Fryer, 1981, Jackson and Eade, 1982, Hancock, 1994).

Most studies of the effects of food aid have taken a solely economic approach, and of these the majority concluded that the effects of food aid were overwhelmingly positive, or at worst that any negative effects were small and restricted to particular commodities. A vast body of work exists in this vein and includes scholars such as Seevers (1968), Schubert (1981), Lentz et al. (1995), Abdulai et al. (2005), Tadesse and Shively (2009), Lavy (1990), del Ninno et al. (2007) and Mabuza et al. (2009).

The economics-biased approach taken by so many scholars was based on the idea of underdeveloped nations being largely passive recipients of largesse from the developed world, with little regard for the importance of local structures and systems. Bar-Yam argued that, though food aid might improve the immediate nutritional status of communities, it simultaneously erodes the need for robust food production and distribution systems:

“...food aid has a subtle, but disastrous effect: it disrupts local mechanisms of food production, gathering and distribution. These local social and economic systems are bypassed entirely by the distribution of food relief, which weakens and sometimes destroys them – leaving the region even more vulnerable to food shortages...In societies with healthy food distribution systems, food passes through production, processing, packaging, handling, distribution, storage, and sale, with each step managed through relationships and transactions between different kinds of workers. Conversely, in a community receiving direct food aid, most of this process is carried out by outsiders...thus there is no environmental pressure requiring social organisations to provide food. Therefore...no internal system of food distribution will develop – and any existing vestiges of that system will atrophy” (Bar-Yam, 2004; 203).

By the end of the 1990's, the focus of food security interventions was moving from provision of food to providing the means to purchase food, (though other approaches remained according to situation or the ideology of donors or recipient governments (Reutlinger, 1999, Stewart, 1986)). The movement gained further impetus with a World Food Programme (WFP) policy change that committed to buying food supplies 'locally' as far as practicable (WFP, 2012). Since 2001 WFP has sought to stimulate agriculture in low and middle income countries through the significant purchasing power of the organisation. The P4P (Purchase for Progress) pilot program, which began in 2008, removes many of the institutional barriers that hitherto had structurally excluded small farmers and restricted participation to large commercial farmers/cereal traders (WFP, 2012).

A further, perhaps decisive, impetus in the shift to financial support and away from in-kind food transfers was the diminishing volume of food donations available. Most important was

the U.S. mandate requiring that petrol contain 10% ethanol by 2011 (Tenenbaum, 2008). In 2005, 14% of the U.S. maize crop was used to make ethanol; by 2011, the figure had risen to 38% (Carter et al., 2012, McPhail and Babcock, 2012). In 2005, with a stroke of the proverbial pen, legislators wiped out the maize excess that had driven U.S food aid policy since 1954.

The argument as to the effects of food aid has been somewhat myopically concerned with the direct effects in recipient countries. Watkins and von Braun (2003) point to a more complex situation than just food aid, citing the continued subsidisation of agriculture in the developed world, with subsidy levels six times that contributed as development assistance. Thus at best the developed world is giving with one hand and taking with the other, since agricultural subsidies prevent market entry by poorer agricultural trading nations.

The continued flow of food aid, either in kind or as cash, seems to be highly contingent on domestic politics in donor countries. Changes to agricultural policy, as in the US diversion of corn to ethanol, or the onset of 'donor fatigue' in western democracies, can impact suddenly on the availability or price of basic food stuffs in the developing world. This can lead to civil conflict, as occurred in Mexico in 2007 with the 'tortilla riots' (Watts, 2007) and in Egypt in 2008 (Adam, 2008) , which ultimately spawned the "Arab Spring". Such vulnerabilities underline the importance of developing countries, and indeed households, striving for a high level of food self-sufficiency.

2.6 Types of Food Aid Intervention

2.6.1 Targeted Interventions

There is a point where food aid and medical/emergency interventions begin to overlap.

Even in non-emergency situations, children can be affected by malnutrition at several times the rate of the broader population (Bryce et al.). This is reflected in high rates of hospitalisation and death for children between the ages of 6 months and 5 years (Prudhon et al., 2006, Briend and Prinzo, 2009, Young et al., 2004). Pregnant and lactating women are another group commonly recognised as being particularly vulnerable to malnutrition, with a near inevitability that their nutrition issues will be passed on to their children (Young and Jaspars, 1995).

Food aid has often been distributed as a single commodity, or a more-or-less complementary group of foods, maize, beans and oil for example. Such combinations of foods are not necessarily nutritionally complete, and thus may be ineffective in reducing malnutrition amongst the most vulnerable groups, and so a range of blended and fortified foods have been developed to improve the effectiveness of food aid.

Targeted interventions began as early as the 1960's, when Australia's CSIRO developed a fortified milk biscuit for distribution in emergency settings (Buchanan, 1969). During the 1970's WHO developed and recommended a fortified milk product called F100, to treat child malnutrition. F100 and its lower energy counterpart F75 remain in use. However, these products are not without problems as they need to be mixed with water, which can be a vector for disease (WHO, 1999).

Cereals and legumes have been combined in various ways to maximise nutrition. Initially the WFP and USAID used a dry flour blend of wheat and soy, or maize and soy, these being

the commodities in gross oversupply in the United States due to that country's domestic agriculture policies. Later such blends became standardised as UNIMIX or corn-soy blend (CSB). More recent refinements were CSB+ and CSB++ (LaGrone et al., 2012), both of which are fortified with micronutrients to maximise nutritional content. Variations on such products are, in most African countries, routinely distributed freely or at a small cost through government and NGO-run clinics to families assessed as 'vulnerable'. Other adaptations have included the provision of CSB type products precooked through a high pressure extrusion process. Products that have emerged specifically to deal with micronutrient deficiencies include micronutrient 'sprinkles' or 'nutritabs', that can be used to improve the nutritional content of any normal family food (Adu-Afarwuah et al., 2008). A new generation of Ready to Use Therapeutic Foods (RUTF's) provide a relatively expensive, but very effective means of treating severe-acute malnutrition in a community setting. (See Chapter 3).

2.6.2 Access-based Interventions

Access based interventions seek to restore entitlement to food to people who have been rendered vulnerable through a production shock, price spikes, disability or other reasons. Access based interventions are typically either in the form of cash payments or actual food products, 'in-kind'. Both cash and in-kind transfers can be gratis, or in exchange for specified work, the latter being known as 'cash-for-work', or 'food for work'. The question of whether it is better to provide income support as cash or in-kind has been around since at least 1974, when Thurow (1974) stated that in a perfect world, income support objectives were best met with cash since this gave the best result both for 'consumer sovereignty' and competitive markets, but qualified this by saying that in many instances in-kind support served government objectives better (c.f. Farrington and Slater, 2006).

Cash transfers are increasingly the mode by which African governments choose to provide income support. Reasons include the reduced availability of in-kind food aid, ideological preferences for aid solutions that nurture local production and distribution systems and the need to harmonise income support schemes with national labour laws. Khogali and Takhar (2001) describe cash transfers as a very effective, and rapidly implemented way of empowering women to escape deep poverty in the Congo, and argue that in-kind donations of food aid are often late arriving and are not necessarily appropriate to the recipient culture (see also Mascie-Taylor et al., 2010). Mattinen and Ogden (2006) make the point that cash-for-work has the particular advantage that it can be implemented more easily in insecure environments, though this assumes that the private sector is functioning to a reasonable degree.

Cereal Banks

Cereal banks are an access based intervention through which proponents seek to stabilise the prices of staple cereals across the agricultural cycle. The intense seasonality of agricultural production, coupled with poverty and poorly developed transport, storage and market infrastructure in the semi-arid tropics, leaves farmers and the rural poor vulnerable to deep price fluctuations. Many farmers are forced to sell a large proportion of their crop at harvest, resulting in a market awash with cereal, and correspondingly low prices. Cereal banks allow farmers to purchase at controlled prices later in the year, thus avoiding inflated prices and usurious loan arrangements (Berg and Kent, 1991). Cereal banks operate at both national and local scales, and are financed by a wide range of donors with a concomitant range of operational policies (Coppola, 1991, Beer, 1990). The success of cereal banks in 40 Millenium villages across Africa has been described by Sanchez et al. (2007). Cereal banks are also documented to fulfil other roles. Tollens (2006) found that in Kenya community owned cereal banks have assumed the function of *de facto* grain wholesalers in the

absence of adequate private-sector market structures. Community management minimises the opportunity of exploitative behaviours that can limit food entitlements for the poor. In this sense cereal banks are an expression of social capital and an extension of the moral economy that has traditionally functioned to redistribute food in much of Africa (Adams, 1993).

2.6.3 Production-focussed interventions

With the world population predicted to stabilise at around nine billion by the end of the 21st century, the pressure on food supply can be expected to increase significantly. According to some authors there is a need to double food supply over the next 30-50 years, in order to keep pace with population growth (Alexandratos and de Haen, 1995). Other opinions hold that food supply is not a problem, and that a population of nine billion could be fed adequately today if markets and distribution systems were equal to the task (Leathers and Foster, 2004).

Three cereal species - rice, maize and wheat - contribute around 70% of human food supply though in excess of 80,000 species are believed to be edible (Frison et al., 2006). It is these three species that have dominated the research landscape over the past century at least and there is a veritable mountain of literature – most of which is beyond the scope of this thesis - concerned with increasing world food supply by increasing the production of cereals. Extensive research has been concerned with breeding varieties that are variously high yielding, drought evading, easy to harvest, disease and pest resistant, palatable and, more recently, with a program of bio-fortification, high in micronutrients (Bouis and Islam, 2012).

2.7 A New Green Revolution?

It has been observed that the green revolution of the 20th century laid the foundations for rapid economic growth and poverty reduction in much of Asia. Similar hopes persist that a renaissance of agriculture in Africa can lead the way in poverty reduction in that region (Diao et al., 2008), especially if supported by region-wide policy reform (Mosley, 2002). The challenges to such an achievement are manifold, and include climate change (Hanjra and Qureshi, 2010, Schmidhuber and Tubiello, 2007), depleted soils (Stocking, 2003, Sanchez and Leakey, 1997), relentless population growth, weak rural infrastructure (Mosley, 2002), and diminishing returns on the improvement of crops crucial to semi-arid regions (Matlon, 1990). Poverty in the farming community of Africa is also of key importance, and limits both the human potential through malnutrition, and the ability of that community to make the investments that could improve productivity (Dorward et al., 2004, Aune and Bationo, 2008).

Nevertheless, Pretty (1999) is sanguine about the potential for significant increases in African agricultural production, citing several examples where simple sustainable interventions have more than doubled output. Pretty et al. (2003) also found similar results in a meta-study of over two thousand projects in 52 countries. The key variables in such improvements in agricultural yields seem to be a matter of scale and targeting. Aune and Bationo (2008) propose a 'ladder approach' to agricultural intensification, arguing that agricultural investments need to be conceptualised as a scale. At the lower levels, small, low cost investments relying only on the families' labour inputs can make small but significant differences to productivity. Such investments might include a homestead garden (Chadha and Oluoch, 2003, Kumar and Nair, 2004, Bernholt et al., 2009), small scale water harvesting works to support valuable trees (Boers and Ben-Asher, 1982), or farmer managed natural regeneration activities (Rinaudo, 2001b, Tougiani et al., 2009, Haglund et

al., 2011). Higher up the scale, progressively larger investments can yield correspondingly larger productivity returns. The vast majority of African farmers are initially unable to afford to invest beyond the lowest levels, thus the targeting of interventions to an appropriate scale of capacity may be crucial to successful implementation.

The appropriateness of intervention in African agriculture is not confined to getting the scale right, and it has been argued by Rinaudo et al. (2002) that an appropriate green revolution for the semi-arid tropics would need to look beyond incremental improvements to traditional agricultural crops such as maize, sorghum and millet, to food producing plants that are fundamentally adapted to be able to thrive and produce under harsh and variable conditions. This new 'revolution' needs to be based on entirely new crops that are more fundamentally adapted to the limitations and variability of the semi-arid environment: "If there is to be a 'green revolution' for the arid and semi-arid tropics, it will have to be through plants that thrive under such conditions, yield well and require minimal inputs. Millions of third-world farmers have no access to the usual green revolution inputs. Increasingly they are farming on exhausted, marginal lands under adverse climatic conditions that are unsuitable for conventional crops. For them, a biological revolution is needed, in which plants are selected and bred to suit the prevailing environmental conditions..." (Rinaudo et al., 2002; 167).

Australian acacias have enormous potential to extend the range of livelihood options whilst lessening the risks pertaining to a drying climate. Predictions of worsening desiccation in the Sahel as the effects of climate change deepen suggest that the development and promotion of alternative crops such as acacias is a matter of urgency. Australian acacias are offered as trees that display qualities that can be integrated into existing annual cereal agricultural systems to demonstrable nutritional (Adewusi et al., 2003, Falade et al., 2005, Ee and Yates, 2013), economic and environmental benefit (Cunningham et al., 2008, Cunningham, 2009).

3. Malnutrition

3.1 Malnutrition: medical understandings and interventions

Malnutrition is the single greatest cause of ill health and premature death in the world today. Over one third of global infant mortality is attributable to malnutrition (Walton and Allen, 2011, WHO and FAO, 2006). Malnutrition is generally thought of as under-nutrition – where a person does not have access to enough food. In addition, it can also manifest as over-nutrition, where the issue may be an excess of food or *lack of food of a sufficient quality*, as is increasingly the case as wealth levels increase in sectors of the developing world, in what has been described as the ‘nutritional transition’ (Kapoor and Anand, 2002). Under-nutrition occurs due to a lack of food or a lack of food quality so that essential nutrients are in chronic undersupply. In virtually all cases, the underlying cause of under-nutrition is the collapse of entitlement – access to food – either through poverty or conflict. Under-nutrition can involve a deficit of a range of essential nutrients, and in most cases will involve multiple deficiencies.

3.1.1 Protein-Energy Malnutrition (PEM)

Perhaps the most visible diseases of malnutrition involve Protein-Energy Malnutrition (PEM). At one extreme of PEM, is the disease known as kwashiorkor. Kwashiorkor is caused by a lack of protein in the diet, and typically occurs when a child is weaned suddenly onto a cereal based diet with insufficient protein. Symptoms include oedema of the feet and lower legs, a distended abdomen, loss of hair and teeth, skin problems including depigmentation, irritability and anorexia (Brock and Autret, 1952, Trowell et al., 1954). At the other end of the spectrum of PEM is marasmus, which is caused by a lack of energy in the diet. Symptoms involve severe weight loss, wasting and general ill-health. In a moderate case of marasmus, the victim’s body is so deficient in energy that all protein in the diet is diverted

for use as energy. As the disease becomes more severe, the proteins that make up the body are consumed, leading firstly to muscle wastage and organ damage, and ultimately to loss of all ability to synthesise or metabolise proteins (Gopalan, 1968). Walton and Allen (2011) note that more recent understandings of kwashiorkor and marasmus stress the interlinked nature of the conditions, given the overwhelming likelihood that a child deficient in energy would also be deficient in protein, and vice versa.

3.1.2 Micronutrients

Micronutrient malnutrition lacks the headline-grabbing qualities of acute PEM.

Nevertheless, it is a silent epidemic that is far more deadly (Shetty, 2011, Ramakrishnan, 2002). WHO and FAO (2006) and WHO (2004b) report that over two billion people worldwide suffer from micronutrient malnutrition, with the worst problems centred on iron, vitamin A, iodine and zinc (Micronutrient Initiative, 2008).

Micronutrient Intervention Strategies

Shetty (2011) calls for a range of strategies in addressing micronutrient malnutrition, including supplementation and fortification as well as food and agriculture based approaches. Huffman and Steel (1995) point out that health strategies designed to improve child survival, such as the promotion of oral rehydration salts and immunisation, have done nothing to reduce child malnutrition. They argue that specific interventions are required that pay attention to child feeding and especially the use of appropriate complementary foods.

The World Health Organisation, takes a medical approach and promotes the use of micronutrient supplements (WHO, 2011) and the fortification of certain foods (WHO and FAO, 2006). Agriculture and food-based approaches are also important, through programs such as the promotion of the orange-fleshed sweet potato (Faber and Laurie, 2011, Hagenimana et al., 1999, Low et al., 1997, Woolfe, 1992, Low et al., 2007) and the promotion of homestead gardens to increase dietary diversity (Talukder et al., 2000). Tree resources and wild foods on common property lands have also been flagged as potentially important in improving micronutrient status of poor rural communities. Scoones et al. (1992), Frison et al. (2006), Oniang'o et al. (2005), Grivetti (1981), Grivetti and Ogle (2000) and many more authors all point to the loss of access to wild foods and the shrinkage of the range of plants eaten for food as contributing to a lowering of nutrition status. These arguments are supported by the increasing acceptance of dietary diversity as a proxy for nutrition status in many communities (Hoddinott and Yohannes, 2002, Arimond and Ruel, 2004, Steyn et al., 2006, Becquey et al., 2010). The way food is prepared is also very important, both in terms of the micronutrients retained through the cooking process as well as the bioavailability of those nutrients, which can be increased markedly through simple processes such as fermentation (Gibson et al., 2006, Hotz and McClafferty, 2007, Svanberg and Lorri, 1997).

Biofortification is a high-tech approach that seeks to breed, or genetically engineer, micronutrients back into staple crops. The micronutrients in many foods tend to be associated with colour. The long term consumer preference in Africa and elsewhere for lighter/whiter foods has led to a diminution of food value as older, coloured landraces are abandoned in favour of new less-coloured varieties (Bouis and Islam, 2012, Hotz and McClafferty, 2007, Frossard et al., 2000, Nestel et al., 2006).

3.1.3 Lipid-based Treatments

The release of Plumpy'Nut, a lipid based Ready to Use Therapeutic Food (RUTF) developed by Andre Briend (Briend, 2001, Briend, 2002), heralded a major breakthrough in the provision of food aid and the treatment of child malnutrition. This was because it enabled treatment of malnourished children in the home rather than in the highly problematic clinical setting. (Collins, 2001, Defourny et al., 1994). Hospitals are unhealthy places for sick children, and a malnourished child may be admitted for several weeks, requiring a mother to be away from the rest of the family for extended times. Plumpy'nut is a nutrient-dense milk and peanut-based paste, distributed in individual serve sachets. The product is ready to use, stable and requires no mixing with water. Plumpy'Nut has been replicated in many analogous products that have arisen with the development of community-based treatment of severe-acute malnutrition (WHO and FAO, 2006, WHO et al., 2007, Dibari et al., 2012, Nackers et al., 2010). Related products include supplements such as Plumpy'doz, which is a micronutrient concoction designed to supplement the mainly cereal diet eaten by most poor rural children.

Cooper hails Plumpy'nut as a development that: "...gave [women] a means of agency they seized upon because they could afford it and because it did not imperil their ability to meet their other obligations in the home" (2009; 22). Certainly it has proven very effective in the treatment of malnourished individuals (Amthor et al., 2009). The limitations of RUTF's like Plumpy'Nut is that they "...do not encourage any community ownership in the food systems that underpin community wellbeing, build any resilience into agricultural systems...or deliver any long-lasting understanding of how malnutrition might be avoided in the future" (Yates, 2010).

Palmer observes that:

“...[There is] a sad state of affairs in the 21st century where under-nutrition in poor countries has come to be viewed as a matter of medical prescription through healthcare systems rather than an issue of food security...the use of a ready-made food designed for emergencies should not become the norm just because public authorities neglect their basic duty to provide water and support locally sustainable food systems. The other danger of the use of such foods is that this crushes a central value of human relationships and cultures which is a family’s skill to feed itself and include its youngest members in food sharing” (Palmer, 2009; 8).

3.2 Malnutrition in Niger

Malnutrition in Niger is the result of many factors: climate, poverty, lack of access to health services, low levels of literacy, unremitting population growth, lack of nutritional knowledge, lack of food or limited food options, the powerlessness of women, plus a range of weaning and feeding practices. A person’s nutritional status in Niger is strongly linked to their power in the society. Thus men tend to be somewhat better fed than women and children with (relatively) regular access to meat and sufficient cereals. Women are relatively more restricted to a cereal based diet and have a particular vulnerability to malnutrition during pregnancy or whilst breastfeeding, whilst children between the ages of six months and five years are highly vulnerable to malnutrition (Cooper, 2009).

According to the World Health Organization, the infant mortality rate (0-12 months) in Niger in 2011 was 66 per 1000 live births, whilst the under-five mortality rate for the same

year was 125 per 1000 live births. Both measures show a slightly higher mortality rate for boys than for girls (WHO, 2013). Household income levels have a lesser impact than might have been expected; in 2006, in the lowest wealth quintile of the Nigerien population, under-five mortality was 206/1000, whereas for the highest quintile, the rate was 157/1000, giving a ratio of 1:1.3. Much more important than household wealth was the education levels of mothers: the difference between highest and lowest education levels produced a ratio of 1: 2.4 (WHO, 2009). The apparent discrepancy in these figures relating to wealth and education can be explained in large part by the low status of women in Niger and the fact that wealth is gendered in that country. A man may be wealthy and still fail to pass adequate resources to his wives (Cooper, 2009). Besides the lack of education, women are typically very limited in their opportunities to earn income, to move about in public (even to take a sick child to a clinic), have little ability to control their own fertility and may be summarily divorced leaving them with little or no support and few assets (Cooper, 2009).

Hampshire et al., (2009) and Cooper (2009) describe a number of weaning practices that contribute to the serious levels of child malnutrition in Niger. In the first hours and days of an infant's life, there is a tendency to withhold colostrum, thus weakening both the mother/child feeding relationship, and the child's immune system. Breastfeeding is further undermined by supplementary feeding. Hampshire et al. found that:

“...observations and dietary recall indicate[d] that it is common practice to give water-based infusions of medicinal plants... [to very young infants], and also that early supplementation with pearl millet-based foods is widespread” (2009; 140).

Another serious issue is the practice of precipitous weaning if and when a mother becomes pregnant. Though a child will be breastfed for up to two years as an ideal, it is widely believed that when pregnant, a mother's milk will harm a feeding infant (Hampshire et al., 2009). As a result, as soon as pregnancy is known, the feeding is stopped, often overnight, by removing the child to the home of a grandmother. Writing on their study in the Tahoua and Illéla regions of Niger, Hampshire et al. comment that: "Many mothers recounted a pattern of early [breastmilk] supplementation, early subsequent pregnancy, and early and abrupt cessation of breastfeeding" (2009; 141). The weaned child is then fed a diet of pearl millet porridge '*kunu*', which does not provide sufficient in energy, protein, fat or micro-nutrients for normal growth and activity:

"Eating millet porridge every day is the equivalent of living off bread and water. With luck, toddlers... [in Niger] might have milk once or twice a week. Young children are so susceptible to malnutrition because what they eat lacks essential vitamins and minerals to help them grow, remain strong and fight off infections" (Shepherd, cited in Medecins Sans Frontieres, 2007).

The cereal diet delivers neither sufficient micro-nutrients nor sufficient energy to children for normal growth and development. To make matters worse, children under two years of age have a limited ability to produce the enzyme amylase, and so are limited in their ability to digest and benefit from the cereal diet (Palmer, 2009; 21).

Even children who are breastfed up to and beyond 24 months often suffer from deficiency in some micro-nutrients, most commonly Vitamin A, iron and zinc, but it may also involve a shortage of iodine (Adelekan, 2003, Palmer, 2009, Tielsch and Sommer, 1984). Blum (1997) found very high levels of vitamin A deficiency amongst women in the Filingué region, a

condition that could deteriorate to night-blindness during pregnancy, and which resulted in babies being born with lower than optimal vitamin A reserves and thereby at high risk of subsequent vision loss.

Hampshire points out that quality and quantity of the foods available to children are not the only issues impacting on the diets of children:

“...*Boule [kunu]* is left in a calabash for all the family to consume at will. Because it rarely runs out... most mothers conclude that all the children have had enough to eat... foods of higher quality are distributed more formally. Men are served first, and typically get the best portions (such as meat). Children over the age of one eat from a common plate, separately from adults, who thus have little control over what, or how much each child actually eats” (Hampshire et al., 2009; 141).

If a child is unwell, weak or socially withdrawn, there is a very real likelihood that she will not get a fair share of the meal: “Sick children are not usually given special foods (high quality or easy to digest); indeed cultural practices of food distribution make it very difficult for parents to single out a child for special treatment” (Hampshire et al., 2009; 142).

The impacts of malnutrition are normally expressed quite gradually but the end results are dramatic; in June 2010, WFP and UNICEF reported that Niger had acute malnutrition rates for children under five of 16.7%, whilst severe acute malnutrition, with high risk of mortality, was reported to be 3.2% (IRIN, 2010b). With base levels of nutrition so poor, even in reasonably good years, it takes only a small livelihood shock – a drought or food price rises – to plunge the country into a full scale nutritional emergency such as occurred in 2005. During the 2005 famine, the incidence of acute malnutrition (described as ‘severe

wasting') in children under five was reported to have peaked at 33% (Gross and Webb, 2006).

3.3 A rationale for an acacia-based complementary food.

Complementary or 'weaning' foods are the solids given to infants to supplement a mother's breast milk as a growing infant's nutritional needs develop. Complementary foods are ideally introduced to the diet at around six months of age, and provide the growing child with additional energy and key micronutrients such as iron. They also begin to acculturate a child toward a family diet that will be 'normal' throughout her life.

In the developing world, infants who have been healthy and have grown well whilst receiving a diet comprised mostly or solely of breastmilk often begin to fall behind ideal growth curves at the time complementary foods are introduced (Young and Jaspars, 1995). There are a number of possible reasons, including lack of access to food, inappropriate foods and lack of access to safe water (leading to diarrhoea and dehydration). Poverty is an important risk factor, as are the education levels and status of women. Another serious issue described in the previous Chapter, is the practice of precipitous weaning if and when a mother becomes pregnant. Though a child will be breastfed for up to two years as an ideal, it is widely believed in rural Niger that, when she is pregnant, a mother's milk will harm a feeding infant (Hampshire et al., 2009). These child feeding practices mean that the diets of many children are well below the optimal even in 'normal' times. In times of food shortage, such children (who are almost certainly suffering shortages of micronutrients) fall very rapidly into a state of clinical malnutrition.

Products such as Plumpy’Nut have been very successful in the treatment of clinical malnutrition, particularly by enabling treatment to take place in the home through Community Based Therapeutic Care (Cooper, 2009, Valid International, 2008). It does not follow, however, as is claimed by MSF, that the next ‘logical’ step is a blanket feeding program using a nutrient-dense product, and it has been argued that here is a risk that products such as Plumpy’Nut and Plumpy’Doz carry a subtle and incapacitating message to mothers that they cannot feed their children adequately with everyday foods and that the answer lies outside their world (Palmer, 2009).

The nutrition of infants and young children has become medicalised beyond emergency settings. The success of nutrient-dense lipid based products to treat malnourished children in emergencies has led proponents to argue that provision of such foods should be extended to the broader population of countries such as Niger, even outside of emergency settings. In 2007 in Niger, MSF trialled the use of Plumpy’Doz, a nutrient dense food supplement in the Guidan Roundji region of Niger, and concluded that the supplement was effective in ameliorating seasonal spikes in malnutrition morbidity (Isanaka et al., 2010). In 2009, UNICEF rolled out supplies of Plumpy’Doz to over 100,000 vulnerable children in Somalia. In an IRIN News report related to the intervention, Fitsum Assefa, a nutrition specialist with UNICEF is quoted:

“We are not saying that we can cull malnutrition, which is a complex problem, with Plumpy’Doz, but we hope to make a difference to thousands of children in Somalia, where access to quality complementary food for young children remains difficult due to drought, extreme poverty and in addition high food prices” (IRIN, 2009).

The sustainability of large scale interventions such as was undertaken in Somalia using Plumpy'Doz is questionable. Cost alone is prohibitive, (IRIN reports that the recommended preventative treatment cost US\$0.17 per day for each child in Somalia (IRIN, 2009)), and the supplement provides only the micronutrient elements of the child's diet. Palmer raises deeper, philosophical issues, arguing that the issue does not begin and end with anthropometric standards; the longer term problem is as much about the ability of local food systems to adequately feed local people, including infants and young children. For Palmer, sustainability is about farming, food production, livelihoods, access to food and about the ways food and food systems articulate large swathes of human identity and culture. To undermine or replace the ability of people to provide for themselves and their children with expensive, imported industrially produced foods is anathema to sustainability (Palmer, 2009).

“[Whilst] such products as ready-to-use therapeutic foods, designed to treat severe malnutrition in the context of emergencies, are useful tools among a range of life-saving strategies; promoting their use for normal life must be challenged.

Addressing nutrition problems through the mass provision of pills and products is to treat humans like farm animals. Most humans are poor and by 2050, eight out of nine billion will live in developing countries. If such emergency provision is ‘brought up to scale’ it will lead to a world where most small humans are fed with an industrialised mass-produced food in the same way that battery chickens are fed with pellets. Someone will be profiting from this degradation” (Palmer, 2009; 8).

Palmer sees the medicalised approach to ‘treating’ child malnutrition as myopic in that it elides the possibility that food aid may actually be undermining the links between human health, population and productive potential. There is a ‘moral hazard’ implicit in divorcing

people from their culture and environment. If the foods that sustain and grow a community are imported, there is no *need* for anything to change. There is a resonance here with complex-systems theory, and Bar-Yam (2004) makes the point that many development interventions prove unsustainable because project designers try to impose external models and standards, rather than building on existing social infrastructure and ways of doing things.

It is impossible to argue, of course, that the food system of a country like Niger is in anything approaching a healthy condition. The predominance of cereals, especially pearl millet, and the susceptibility of farmers to market fluctuations around that commodity; the lack of vegetables in the diet; the diminution of available wild resources and the loss of soil fertility, all conspire to create severe vulnerability to food shortage and famine. One answer is to import food aid from elsewhere, but this is an open-ended proposition.

The introduction of a tree crop such as acacia offers another approach that may enable some of the endemic vulnerabilities to be lessened. Acacia is a new crop, but it has been shown to fit into the agricultural system easily and to confer significant benefits in terms of productivity and resilience (see Chapter 4 below). Acacia does not require dramatically new farming systems, new modes of distribution or storage. It does not even require significantly different ways of cooking. Acacia simply adds value and stability, effectively filling some gaps in ecological function that are the legacy of decades of poverty, land degradation and climate change.

4. Niger – An Environmental and Social Overview

Niger is a desperately poor country, ranked at 186 out of 186 in the United Nations Development Programme Human Development Index (UNDP, 2013). It is also a country where the limits of human population expansion and environmental degradation are becoming starkly evident. Mortimore comments on life in the African drylands that: "...poor people manage their livelihoods and natural resources in conditions of great difficulty... [where] nature's greatest constraints (low productivity and high variability) have to be managed" (2003; 505). Despite there being considerable optimism amongst many scholars (Adams and Mortimore, 1997, Mortimore et al., 2008, Mortimore, 2005, Mortimore, 2003) concerning increases in agricultural production and apparently improving soil and range condition, these promising developments have yet to manifest significantly in human wellbeing. For many Nigeriens, the margins have diminished to the point that the balance seems to have shifted between what is normal and what is an emergency (Baro and Deubel, 2006).

In Niger the majority Hausa are a rapidly growing population, determinedly persisting with an annual agriculture that has been stranded by a gradually drying and increasingly variable climate. Staple crops are failing for two years in each three, due to drought and dwindling soil fertility. In some areas, around half of the 'arable' land is so degraded it cannot provide more than the most rudimentary rainy season grazing (Tougiani et al., 2009). Whilst any single drought may be negotiated through the sale of assets, calls upon social networks, switching of livelihoods to wild resources or labour migration (see Mamouda and Diop, 2010), the impact of successive droughts is progressively more debilitating. Capital is

exhausted, soil lost and natural resource safety nets depleted, often beyond repair (Leisinger et al., 1995).

The heavy reliance on annual agriculture has led to a catastrophic loss of tree cover. Trees were initially lost to make way for agriculture, especially during the peanut boom of the 1950's. Since then they have been progressively whittled away for sale as building materials and fuel by the growing population, as they sought to bridge the gap between agricultural productivity and family income needs. The result in many places is a catastrophic level of environmental destruction that further erodes food security and biodiversity. The Farmer Managed Natural Regeneration (FMNR) movement is a dramatic and positive reversal of this trend over the past decade (see Sendzimir et al., 2011, Haglund et al., 2011, Rinaudo, 2001b).

Rinaudo (2011) described the scene in Maradi when he first arrived in the early 1980's:

"What I saw shocked me. Almost total deforestation followed by desertification, strong winds of up to 70kph causing massive soil erosion on the treeless farms, soil surface temperatures of 50°C plus, a battalion of different insect and disease problems attacking crops, severe fodder shortages, and very little firewood for the average household (most used manure and/or straw). Consequently crop yields were low in any year and totally inadequate in bad years, poverty was severe and hunger common".

Challenges to sustainable development in the Maradi region (FAO, 2003) are reasonably typical of much of densely populated southern Niger: irregular and poor rainfall distribution in time and space; pressure on land; sharp deterioration of dune soils due to

wind and water erosion; a lack of agricultural extension workers (1 extension worker per 31,112 agricultural workers); conversion of pastoral land to agriculture with resulting very tense relations between herders and farmers; rangeland degradation; depletion or outright disappearance of some tree and pasture species; the spread of unpalatable species in grazing lands; silting of water bodies; rapid population growth; and rapid urbanisation (FAO, 2003). These challenges are well illustrated by the fact that less than one percent of farming households are sustained by their own farm's harvest for 12 months of the year (Mamouda and Diop, 2010). As a result acute child malnutrition rates are 'normal' even as they approach, and periodically exceed, the World Health Organization's threshold for intervention (10-14%) (WHO/UNHCR, 2009).

4.1 The Sahel: A Changing Climate

The Sahelian climate has probably always been challenging, and livelihoods in the Sahel have always been threatened by periodic drought. In an excellent ethnography of the Hausa in northern Nigeria, Watts (1983) showed how the inevitable hard times are etched into Hausa consciousness through their linguistic and cultural 'knowledge' of hunger. There have been 18 'severe droughts'² that would have caused widespread crop failure in Maradi Department during the 68 year period 1932 – 2000, meaning that severe livelihood stress has occurred on average every 3.7 years (Mortimore et al., 2001). This high frequency has arisen because the Sahel suffered a drop in rainfall of 20-40% between the middle and the latter part of the twentieth century, "representing the largest and most sustained rainfall shift of any contemporary region on Earth" (Mahe and Paturel, 2009).

² 'Severe drought' is defined as < -1.28 in the Standard Precipitation Index . AGNEW, C. & CHAPPELL, A. 2000. Drought in the Sahel. *GeoJournal*, 48, 299-311.

Over the past two decades, another very disturbing trend has been reported to the author by farmers as far apart as Maradi in Niger and Tigray in Ethiopia (Meze-Hausken, 2004, Mamouda and Diop, 2010). Whereas in the past the rainy season has been relatively predictable in timing and precipitation patterns, there is now a sense of unpredictability, with the season often beginning late and ending early or following a stop-start pattern, with long dry spells between rains that cause annual crops to dry out and fail (c.f. Hulme et al., 2001). Mamouda and Diop (2010) comment:

“The adverse effects of climate change on lives and livelihoods of the poor no longer need to be demonstrated. In many Sahelian countries, perturbations on normal seasonal cycles are observed over time and space; the rain begins either too early or too late; total annual, monthly and daily rainfall very often reach unexpected higher or lower thresholds and the global trends are generally in decrease. Global trends of maximum and minimum temperatures are unexpectedly increasing because of global warming...Even if grassroots communities are not able to understand the causes of global warming, they are however aware of the fact that something unusual, abnormal and negative is happening because the impacts of these changes are felt on local livelihoods” (Mamouda and Diop, 2010; 2).

These reports are borne out in a review of climate data by Ali and Lebel (2008) who found that, following a period of prolonged drought from 1970-1994, the Sahel has entered a new state characterized by large and unpredictable fluctuations in rainfall (Ali and Lebel, 2008). Reduced rainfall has also resulted in a shortening of the vegetation growing season, with serious consequences for cereal production given that even the earliest maturing millet varieties require 60+ days to mature (ICRISAT, 2012). Variation is not only temporal but also

occurs spatially; the statistical averages drawn over large areas are tending to mask wildly varying rainfall conditions, with, for example, the majority of the Sahel experiencing dry conditions whilst a few areas suffer flooding (Jalloh et al., 2011, Ali and Lebel, 2008). Reduced rainfall has been exacerbated by an increase in temperature averaging 0.6° Celsius since 1975 (FEWSnet, 2012, Mamouda and Diop, 2010). Modelling reported by Jalloh et al. (2011) indicates that a temperature rise of this magnitude will cause a yield reduction in tropical cereal crops of 5%. A temperature increase of 2° Celsius is expected to result in the loss of six growing days (due to temperatures over 30°), and reduce the harvest by 15%. More alarmingly, the FAO predicts that climate change will cause a cereal harvest reduction in Niger of more than 50% on 1961 levels by 2050 (FAO, 2008).

4.2 Population Growth

Climatic vulnerability has been exacerbated by population growth. Niger has a population estimated at 16.5 million, and a growth rate of 3.6%, giving a doubling time of around 19.5 years (FEWSnet, 2012). More than 80% of the population are engaged in either agriculture or livestock production, and thus are highly dependent on the climate for their livelihoods (Mortimore et al., 2008).

Rapid population growth has driven an expansion of agriculture into marginal lands that have traditionally been considered pastoral, and where risk of crop failure is heightened (Mortimore et al., 2001). The 'agricultural horizon' (Boserup, 2005) in Niger is flexible. Compared to more humid and densely populated regions of Africa, land is plentiful, but the new land is invariably in the drier north, and exposes farmers to higher climatic risk. Less than 17% of households in the Maradi region can rely on their agricultural production for sustenance for more than nine months of a year, whilst less than one percent of

households report that the harvest stretches an entire twelve months (Mamouda and Diop, 2010).

4.3 Other Factors contributing to poverty in Niger

4.3.1 Markets and the need for cash

Shortfalls in farm food production must be filled through the markets, and along with the many other pressing needs (such as clinic visits, livestock vaccinations, school fees, religious obligations, loan repayments, etc.), the need for cash is overwhelming. Yet farmers have few means by which to obtain cash. Local wage labour opportunities are very limited, and many farmers are forced to sell a significant portion of their staple crop at harvest (when prices are lowest) in order to meet these basic cash needs, even in the knowledge that this will assuredly lead to a grain shortage later in the season. One of the most pressing needs for cash can be to pay back loans incurred in the pre-harvest period when it is not uncommon for cereal prices to double. In extreme years (such as 2005 and 2011), prices have trebled, with serious consequences for food entitlements (RESIMAO and WAMIS-Net, 2013). Faced with an inability to pay for cereal, the poor are often forced to choose between hunger and usurious credit arrangements which can subsequently undermine the household economy for many years (Berg and Kent, 1991).

In a good season, cash cropping of peanut, tigernut (*Cyperus esculentus*), roselle (*Hibiscus sabdariffa*) and cowpea can alleviate the cash shortage somewhat. Nonetheless, the most widespread solution has become 'the exodus': labour migration to the farms, mines and factories of Nigeria, Burkina Faso, Benin, Libya and Cote d'Ivoire (Rain, 1998). I was told

clearly and repeatedly in village interviews with farmers that most of the men who make this migration would rather avoid the dangers and privations of the 'exode' and stay home.

4.3.1 Crops and Dietary Diversity

When severe drought led to famine in the past, most people had the option of hunting and foraging for items of food or for sale in the bush (Belcher et al., 2005, Etkin and Ross, 1982). Humphrey et al. (1993) recorded at least 80 species that were harvested from the wild by members of a Hausa village during a dry year. Today, the opportunities for such supplementation are highly limited, and such areas as may superficially appear to be reserves of 'famine food' are more than likely crucial to someone's everyday livelihood. Years of pressure to fill human needs in successive crises – compounded by population growth – means that many plant species that have been useful in the past are now rare or have disappeared altogether (Tougiani et al., 2009, Mortimore, 2003, see Maranz, 2009 for an alternative view). Thus, the range of species that can make up the Hausa diet has diminished, with a concomitant loss of nutritional potential and resilience (c.f. Grivetti and Ogle, 2000).

An assumption underlying this research is that the nutritional strengths and weaknesses of a cash poor rural society are strongly co-related to the range and appropriateness of species employed in local agriculture (or that are otherwise harvested and used) (c.f. Apodaca, 2008, Frison et al., 2006, Keatinge and Easdown, 2009). A lack of crop diversity creates vulnerability to external factors such as drought, pests or disease, that can reduce or destroy an entire community's annual production (Thrupp, 2000). A limited crop repertoire also limits the food options that are available to poor people, making it harder (though not necessarily impossible) to aggregate all the nutrients necessary to a healthy life, a fact that is reflected in the use of 'Dietary Diversity Scores' as a quick and efficient

means of estimating the likely incidence of micro-nutrient malnutrition (Steyn et al., 2006, Allen, 2003, Arimond and Ruel, 2004, Becquey et al., 2010).

Amongst the Hausa in Niger, food and crop diversity is secondary to the ubiquitous pearl millet that dominates cultural space almost as much as it dominates cropland (Bivins, 2007; 53). Pearl millet production is very marginal in the Maradi district, though it has been a major grain producing area for Niger in the past. There is evidence that production conditions are deteriorating: according a former Regional Director of Agriculture in Maradi (Illiassou, M. 2009 pers. comm.), cereal production is failing to deliver to expectations two years out of three, with catastrophic failure in one in five years. FEWSnet (2012) reports a less dramatic situation but “poor food security conditions” are still experienced in one in three years. It should be noted that whilst this may be the majority view, scholars such as Mortimore et al. (2008) argue that indigenous agricultural intensification processes, supported by international investment in agriculture and pro-farmer policy changes, have enabled food production in countries like Niger to keep pace with population growth and for the agricultural sector to thrive despite the severe/challenging? physical constraints.

Pearl millet is a rain-fed crop that is grown virtually everywhere in the country where the average rainfall exceeds 400mm/annum. Water supplies to ... “Pearl millet fields are subject to severe ecological constraints, notably strong annual, inter-annual and geographical variations in rainfall. Over the past fifty years, the cultivated area of... pearl millet has increased five-fold, but the yield per hectare has decreased” (2008;168).

Mortimore et al. (2001) show, between 1979 and 1998, significant geographical variation in both millet plantings and yield per hectare between higher and lower rainfall zones within the Maradi Department. In the drier Dakoro *arrondissement*, millet plantings increased almost fourfold, whilst yield per hectare remained steady. In the more southerly

Madarounfa *arrondissement*, during the same time period, planting area increased only marginally, whilst yield per hectare increased by 20%. In 2012 Niger produced 3,200,00 tonnes of pearl millet from 5,200,00 hectares of land. As a further measure of the importance of cereal crops, in the period 1987-89, cereal sources (principally pearl millet) contributed 93.7% of energy, and 83.1% of protein to the Nigerien diet (FAO, 1995).

Efforts directed towards crop variety improvements are on-going and an important strategy for dry-land Africa has been to increase the drought tolerance of crops. New shorter season pearl millets that require less rainfall have greatly increased reliability. Pearl millet varieties have been developed that mature in 60-80 days, compared to the 90-120 days typical of traditional varieties (INRAN, 2009, Mortimore, 2003; 513), yet crop failure remains frequent. Genetic improvements aimed at increasing productivity seem unlikely to bridge this moisture-needs gap reliably and so the crop's long term potential may be limited to regions with rainfall in excess of 600mm/annum (Matlon, 1990). On average, no part of Niger receives this amount of rain.

5. Australian Acacias in the Agricultural System

There are conservatively 1380 species within the genus *Acacia*, with 993 of these endemic to Australia (World Wide Wattle, 2004). Acacias have adapted to all ecological zones in Australia, including regions that have much in common with the extremely harsh semi-arid tropics of Niger and the Sahel more generally. Many of these Australian species of *Acacia* produce large crops of seed, and have a very long history of consumption by Aboriginal Australians (Devitt, 1992, Rinaudo et al., 2002). Over the past 25 years several species of Australian *Acacia* have been trialled in Niger (Harwood, 1994, Cossalter, 1986, Rinaudo et al., 2002, Midgley and Turnbull, 2003, Cunningham et al., 2008). Initial experiences were mixed, and many thousands of trees planted in the 1980s died after only 2-3 years, mainly due to inadequate spacing. Since that time, through the work of Ibrahim Jaho and Peter Cunningham, knowledge of how best to cultivate Australian Acacias in the Sahel has increased greatly, whilst elite provenances have been identified for the production of seed and wood (Cunningham et al., 2008).

The species of *Acacia* thus far adopted in Niger (*A. colei*, *A. torulosa*, *A. tumida*) share many general characteristics of successful crops. In particular, they are species that are fast-growing pioneers (Wilson et al., 2011, Kull and Tassin, 2012). In their native environment, these Acacias grow quickly to colonise an area following a disturbance – in the Australian context this is generally fire – they seed quickly and prolifically and die off after a few years, thus first giving protection to, and then making way for, the next succession of species (Latz and Green, 1995). Field trials in a 450mm rainfall zone in Niger have shown that with good management, and especially with appropriate pruning, *A. colei* can live up to 10 years; whilst *A. torulosa* and *A. tumida* will live in excess of 10 years (Cunningham et al., 2008).

5.1 The products and benefits of growing Australian acacias

Many of the products and functions attributed to Australian acacias are common to all trees. Trees, for example greatly increase agricultural resilience by supporting a range of ecological processes and ameliorating extremes of climate. Where the Australian acacias excel is in the rapidity of their growth, their tolerance of harsh conditions, their versatility and the range (and value) of products they make available. Australian acacias cannot, and should not replace indigenous trees, rather they should be seen as valuable additions to the agricultural landscape with the potential, firstly, to deflect harvest pressure from indigenous species and even to create microclimates amenable to the regeneration of indigenous flora.

5.1.1 Seed production

The first crops of seed are generally harvested 18 months after planting. Yield is influenced by species, provenance, rainfall and to some extent other climatic factors such as wind. The early introductions made to Maradi region were collected from northern and coastal districts of Western Australia where the average rainfall matched the long term average for Maradi, at around 500mm/annum (Climate Data, 2013). The steep precipitation gradient from south to north in the Sahel means that a difference of only a few kilometres can have a huge effect on rainfall and therefore the viability of agriculture, including the success of 'drought tolerant' trees such as acacias. Amongst the species/provenances currently used in Niger, rainfall below around 300mm/annum is likely to seriously reduce seed production. Under such conditions all other crops could also be expected to fail.

Selections and trials of species and provenances better adapted to arid conditions are currently being undertaken by World Vision Australia and it is hoped that these will increase both the reliability of seed yield in dry years, and the potential range of Acacia production in the Sahel. New collections have been made in the drier regions of the Northern Territory and Western Australia, where the rainfall average is below 300mm/annum. Parallel research (by the author through his role in World Vision Australia) is screening the nutritional and toxicological status of all new species that are aimed at food production.

Agronomic practice is an important determinant of seed yield, particularly factors such as tree spacing, weed control and pruning. Trials of a branching³ provenance of *A. torulosa* in the Maradi district by Peter Cunningham, of the NGO Serving In Mission (SIM), produced an average of around 4.5kg of seed per tree from 64 trees. It is a 'rule-of-thumb' across the developing world that on-farm production is around 30% lower than is achieved on research facilities (Alam, 2006, Mondal, 2011), so that a farmed average of closer to 3kg per tree may be a realistic expectation. With future plantings based on the best provenance selections, good silvicultural practice and taking into account years of poor rainfall, a yield of >1kg per tree is a fair but conservative annual expectation (Cunningham and Abasse, 2005b).

³ *A. torulosa* tend to be either branching types that produce good crops of seed, or tall growing, with little seed.

5.1.2 Wood production

The Australian acacias are very rapid wood producers, anecdotally four times faster than *Acacia senegal*, the best of the African acacias. Nigerien farmers reported to the author that acacia wood is hard and strong, it can be pruned to encourage long, straight poles and the trees are thornless and easy to handle. The short life-span of Acacias was at first thought to be a potential limiting factor for their use in agricultural settings, but agronomic work in Niger has demonstrated that the life span of the trees⁴ can be greatly increased through pruning every two years.

Fuelwood

All rural cooking and most urban cooking in Niger is done with wood. The strong market for fuelwood in Niger places heavy pressure on remnant native woodlands, especially around the larger towns and cities. In the early 1990s, the Nigerien government developed the Household Energy Strategy (HES) in an attempt to secure fuelwood supplies in the face of rapidly increasing demand and the challenges of recurring drought. The HES devolved management of forests to rural populations, and established a network of rural firewood markets to link producers with consumers (Fanny et al., 2012). The governance changes embodied in the HES have enabled the rapid spread of Farmer Managed Natural Regeneration across much of southern Niger, since farmers came to feel that they had secure ownership of the trees they tended on their land (Sendzimir et al., 2011). The widespread adoption of Australian acacias would fit well into this model, since wood would

⁴ Particularly *A. colei*. SIM now have a trial with trees 10x10 m spacing at Danja with 10 yr old *A. colei* trees (4 provenances) that have been pruned every 2nd yr- 4 times since 2001. The 1/2 ha area has 95% tree survival with good strong trees. This would imply that we may be able to significantly extend tree longevity with good silvicultural practices (P. Cunningham, pers. comm.)

be produced on individual farms where tenure is clear, a fact that is well recognised by the Niger Forestry Department who have exempted all (Australian) acacia wood from forest taxes.

Energy

Though the wood market is large and robust, it is conceivable that a future scale-up of *Acacia* production could generate volumes of wood in excess of the market's capacity. Should this situation eventuate (and it would take several years), wood could be burned, depending on market conditions and infrastructure availability, to produce electricity and bio-char. Subject to infrastructure availability, electricity could be fed into the national grid, used to supply remote towns or specific facilities such as hospitals, and bio-char can be interred on farmland to claim a carbon sequestration price on international markets whilst realising significant fertility enhancing benefits (Lehmann and Joseph, 2009). No study has yet considered the feasibility of biochar electricity production systems in the Sahel; however Shackley et al. (2011) show that with the right scale of technology and feedstocks, such a system could be profitable in the UK. The potential of Australian acacias for energy, biochar and carbon trading is explored further below.

Building materials

Some innovative farmers in Niger have seized on the opportunity offered by Australian acacias and have started producing tall, straight building poles. An analysis by the forester Jon Lambert has suggested that growing Australian acacias for poles alone could exceed the profitability of agroforestry by around four times, and annual pearl millet crops by over seven times (J. Lambert, pers. comm., 2010). Though growing for poles does not preclude

some seed harvest, tree management and provenance selection tends to favour either seed production or wood production. In the future, provenances specifically selected for pole production are expected to be available. Smaller branches are regularly used in building also, principally as roof battens. Even the seed pods have a role in building, being pounded and added to mud-mortars to increase their resistance to rain.

5.1.3 Bee forage

Honey production is an important livelihood activity for some people in Niger. Acacias flower profusely, and though not renowned for their nectar, offer a useful seasonal supplement to the very limited bee forage that is available in many areas.

5.1.4 Mulch

Pruning yields not just wood but a large amount of leaf material. Leaves can be left on the soil surface as mulch, to slow drying and to be slowly interred and recycled through termite activity; or they can be buried in 'zai' holes for a more rapid recycling of nutrients.

5.1.5 Windbreaks

Wind can be a very destructive force in Sahelian agriculture, and Rinaudo has observed farmers having to replant pearl millet crops up to five times as each successive crop emerges, only to be buried or sand-blasted (Rinaudo et al., 2002). Plantings of trees on field boundaries and within fields helps reduce wind speeds, slows desiccation and causes suspended organic matter, silt and sand to fall from the air – the reverse of soil erosion, in fact adding nutrients to the soil. Australian acacias are particularly useful in this regard due to their rapid growth and dense foliage compared to indigenous species.

5.1.6 Nitrogen fixation

All Acacias in Australia are regarded as having nitrogen fixing potential (Turnbull, 1987).

Remigi et al. (2008) found strong evidence of nitrogen fixing rhizobial associations in *Acacia holosericea* (a species closely related to *A. colei*), in dry land regions of Senegal.

Cunningham comments that:

“We have identified nodulation on all Acacia species, especially *A. colei* in the Maradi tree nursery. *A. colei* is very promiscuous for nodulation with root nodule bacteria. 75-100% of all strains tested were able to form nodules. This is significant and born out in our observations. Native Rhizobium from *A. nilotica*, *Faidherbia albida* and *A. senegal* can nodulate *A. colei*” (P. Cunningham, Pers. Comm.).

5.1.7 Livestock forage

If appropriate management structures that take into account the rights and needs of both transhumant and settled livestock owners can be devised, plantings of palatable acacia could help reclaim degraded lands and support dry season feed supplies. Use of Australian acacias garners many of the same benefits mentioned above: speed of growth relative to indigenous species, deep root systems, drought tolerance, reduced wind speeds, soil accumulation and so on. Australian acacias are particularly suitable to use as livestock feed compared to indigenous species since they are thornless. For both transhumant pastoralists and settled livestock owners, grazing resources are under increasing pressure, and by the end of the dry season feed levels can become critically low. Feed shortage is caused not only by the sheer numbers of grazing animals, but also by the way penned animals are fed during the cropping season. Grasses flourish under the warm, moist conditions, and are collected from farms and common property reserves and carried to the

penned animals. In order to make the handling of the grasses easier, (huge bundles are often to be seen carried on the head or on the rack of a bicycle), the grasses are pulled up by the roots so that the strands hold together, and the whole can be securely tied together with a cord. The result is a selective removal of the vigorous and palatable grasses, in favour of unpalatable and inedible plants, so that by the end of the growing season, all that is left is a carpet of '*bunzen gari*', useless plants, more often than not a near pure carpet of the noxious weed *Sida cordifolia*. Palatable species of Australian acacia could be grown on degraded land that is currently of minimal productivity, and used within a cut-and-carry system. The feed provided by these acacias would initially be additional to the grasses, and would over time help to increase the grass supply by building soil and fertility. Acacia foliage would be of particular value if the bulk of the feed could be reserved for the late dry season.

The species thus far being used extensively in Niger have been successful in part due to their lack of palatability to livestock. More tasty species are very promptly destroyed by goats, sheep, cattle, donkeys or camels. Provided that management systems can afford trees adequate protection from livestock grazing at critical times, the Australian acacias offer the opportunity to bring broader benefits to the community in semi-arid regions. The rapid growth and lack of thorns of Australian acacias commend them over any indigenous species. The author has personal knowledge of the importance of species such as *Acacia victoriae* as a livestock feed in arid regions of Australia. Of particular note are *A. victoriae* and *A. saligna*, the latter of which has been planted extensively in Tigray, Ethiopia, and which has been shown by Gebru (2012) to be very effective in fattening sheep in a cut-and-carry system.

In Niger, the green Acacia pods are often fed to livestock to encourage fattening, and seed is often given to nanny goats following parturition to encourage the milk. The seed coatings sieved out of the Acacia flour are usually given to sheep or goats, which devour it with relish. Whereas livestock tend to ignore green leaves of *A. colei*, the leaves can be made palatable to livestock by drying and pounding, though they are of low nutritional value.

5.2 Australian Acacias in an agroforestry system

Peter Cunningham and SIM in Maradi have developed an agroforestry system based on Acacias, which they call the Farmer Managed Agroforestry System, or FMAFS (Cunningham, 2009). FMAFS integrates crop rotations, crop residue mulching, crop diversification and encouragement of native trees with acacias to create a system that is robust, productive and regenerative. The system is highly flexible to farmer preference, but broadly involves Acacias (usually at least two species), planted in rows on or near the field boundaries, and in other rows within the field. Alley crops such as pearl millet, sorghum, peanuts, hibiscus or cowpeas are grown between the rows of acacia on a rotating basis (Cunningham et al., 2008). Additional tree species are encouraged, including any remnant native species, but also useful and high value specimens such as *Zizyphus mauritania*, *Moringa stenopetala*, *Sclerocarya birrea*, *Adansonia digitata* and others.

FMAFS spreads the risk of farming across several crops, freeing farmers to some degree from vulnerability to the plunge in cereal prices that typically comes at harvest time. Acacias offer a particular benefit since the seed and wood harvests come in the late dry season when household resources are at their lowest ebb. FMAFS is a departure from

traditional farming not just in the diversity that is encouraged, but also in terms of the degree of market orientation.

Trees in general contribute to the stability and fertility of the agricultural system. Trees reduce damage and drying due to wind, contribute biomass, and (over multiple seasons) draw nutrients from deep in the soil and make these available to shallow rooted crops (Sanchez et al., 1997). Leguminous trees also contribute to soil nitrogen. In addition to these more general benefits of trees, acacias are rapid producers of wood and some species produce edible seed.

Cunningham minimises the tendency of the trees to compete with annual crops for soil moisture by limiting the number of trees to be planted per area, by restricting trees to particular areas of the field (mostly the boundary), and by restricting the size of the trees. The latter is achieved through heavy pruning every two years just prior to the onset of the rains, which reduces leaf bulk, and causes substantial root die-off. With the rains, the dead roots rot away and contribute nutrients to the surrounding soil, whilst the trees resume their growth cycle with minimal resource needs. Nevertheless, there is typically a radius of 2-3 metres around the larger trees where annual crop growth is somewhat impaired (Cunningham, 2009, Pasternak et al., 2005).

In field trials, the wood produced through pruning has made a major contribution to farm and household incomes. Field trials by Peter Cunningham measured wood production from well-spaced mature *A. colei*. Cunningham estimated that each tree can generate 500 cfa (AUD\$ 1.08) from prunings, every second year. In an agroforestry system of the type promoted by Cunningham and SIM, with 107 *A. colei* trees planted on one hectare, the result is approx 30,000 cfa (AUD\$64.70) of wood value per year. This would be additional

to the normal expected pearl millet crop value of 50,000 cfa (AUD\$107.93) per annum (P. Cunningham, Pers. Comm.). The economics of the FMAFS system are still under investigation by Peter Cunningham and SIM, but early results (Tables 5-1 and 5-2) show a dramatic improvement in farm income when the FMAFS is compared to a traditional monoculture of pearl millet:

Table 5-1 Average annual economic benefits from a 1 ha FMAFS at Maza Tsaye (2007-2009). (Cunningham, 2009)

FMAFS component	Product yield (Kg/ha)	Value (cfa) ⁵
Pearl millet	640	24,000
Sorghum	475	21,400
Cowpeas	390	36,560
Hibiscus	270	13,500
Peanuts	25	2,300
Wood (Acacia)	120	3,000
<i>Andropogon</i> grass		6,000
Total		106,760

Control comparison. Traditional monoculture pearl millet farm.
Niger: Average annual pearl millet & Sorghum production 445
and 335 kg/ha (2003-2007).

Table 5-2. Average annual economic benefits from a 1/2 ha FMAFS vs. control farm at Magajin Kware (2007-2009) (Cunningham, 2009).

FMAFS Component	FMAFS (cfa)	Control (cfa)	% Increase
Annual crops	34,630	11,460	202
FMNR wood	6,500		
Acacia wood	5,660		
Acacia seed	10,750		
Total	57,540	11,460	502

⁵ 1000cfa = \$AUD2.16 11th October 2010

5.3 Australian Acacias and Farmer Managed Natural Regeneration

Farmer Managed Natural Regeneration (FMNR) was initiated in Niger, based on the insights of Tony Rinaudo⁶, and has led to the reforestation of over five million hectares in Niger (Haglund et al., 2011, Rinaudo, 2001b, Tougiani et al., 2009, Cunningham and Abasse, 2005a, Sendzimir et al., 2011, Reij et al., 2009). Averaging forty trees per hectare, this amounts to around two hundred million trees (World Resources Institute, 2008). FMNR utilises the below-ground stumps of trees to encourage regrowth of forest cover. Farmers choose which species and how many trees they want to retain on their land (though some less resilient species will have been lost after decades of repeated clearing).

FMNR has been reported to have yielded significant improvements in household income and food security, both in Niger and other Sahelian countries. Leyland, cited in Haglund et al. (2011), estimated an increase in household income of \$200/year, whilst more broadly, Reij et al. (2009) attribute an increase in cereal harvest across Niger and Burkina Faso of 500,000 tonnes to the improved fertility and growing conditions produced under FMNR systems. In 2004, the then Director of World Vision Senegal wrote that: “despite severe famine in Niger, farmers practicing FMNR in the Aguié region did not need food assistance because they were able to meet their own needs through selling firewood and non-timber forest products” (Toumieux, 2004).

⁶ Serving in Mission and (currently) World Vision Australia.

Australian acacias can integrate very effectively with FMNR. The rapid growth of the acacias enables a greater wood harvest than natives alone, or enables the wood harvest to be deflected from the regenerating native trees for longer. This can result in larger poles that are more valuable in the marketplace. One very effective arrangement is described by Cunningham, who planted the standard FMAFS arrangement of acacias and annual crops beneath the cover of regenerating *Faidherbia albida*. This created a diverse multi-layered and highly productive system (P.Cunningham, *Pers. Comm.*).

There are some regions in Niger, such as Tahoua and Filinguie, where FMNR is not a viable means of land regeneration as there are few stumps surviving in the sand. In such regions, Australian acacias offer a rapid and cost effective means of producing biomass and stabilising the soil.

5.4 Further potentials for Australian acacias in semi-arid regions

Though there is currently a buoyant market for building materials and fuelwood in Niger, it is possible that this could be saturated if acacia production were to take hold at a large scale. It is worthwhile, therefore, to consider how an excess of fuelwood could be absorbed and turned to economic benefit. I suggest that a system could be developed that produces income streams from seed, fuelwood and charcoal, energy and the sequestration of carbon. Such a system could, furthermore, attract expansion funding as an 'adaptation to climate change' activity. See Joseph (2009) for a detailed framework and methodology by which small scale biochar systems could benefit communities in the developing world (Whitman and Lehmann, 2009).

The technology is now well developed by which wood and other biomass can be efficiently burned to yield electricity, with biochar as a major by-product (Lehmann and Joseph, 2009, Pacific Pyrolysis, 2012, Ahrenfeldt et al., 2013, de Miranda et al., 2013). The value of electricity is clear enough in a rapidly growing country where the supply is expensive and unreliable. The value of biochar requires some elucidation.

Biochar is charcoal that comes from sustainable, natural sources. According to Lehmann and Joseph, "...biochar is the carbon-rich product obtained when biomass such as wood, manure or leaves, is heated in a closed container with little or no available air" (2009; 1). Biochar can be made from crop wastes, manure or from purpose-grown woody material. The value of biochar is twofold: firstly, it has highly beneficial effects when added to soil, and secondly, it is a substance that stores carbon in a relatively stable way (Sohi et al., 2010). The process by which biochar is made can, furthermore, yield carbon-neutral or even carbon-negative energy (Gaunt and Lehmann, 2008, Shackley et al., 2011).

Added to soil, biochar helps to improve moisture retention, reduces nutrient leaching (Major et al., 2009), reduces the release of non-CO₂ greenhouse gases (van Zwieten et al., 2009), increases bioavailability of many nutrients including nitrogen and phosphorus (De Luka et al., 2009, Chan et al., 2007, Clough and Condon, 2010), and provides habitat for many beneficial soil micro-organisms (Thies and Rillig, 2009). The carbon stored in biochar breaks down very slowly, even when added to soil where other material of biological origin would rot. Actual residence times of the carbon in biochar are dependent on soil type and climate, and are subject to ongoing investigation. However, charcoal particles (essentially the same as biochar) have been found in many old forests that date to several thousand years old (Lehmann and Joseph, 2009). This long residence time means that biochar has the potential to be a significant and effective way of sequestering carbon dioxide (CO₂), and this

opens the possibility of African farmers participating in the carbon trade. Whereas the storage of carbon in living trees is difficult to measure and verify and is of highly tenuous security (forests can be cut and burned), biochar stored in soil is stable, secure and should be easily and reliably measured once appropriate protocols have been approved (Manning and Lopez-Capel, 2009).

5.4.1 Components of an energy/biochar system for the Sahel

The implementation of a viable energy/biochar system in the Sahel would need to be based on significant new plantings of Australian acacias but could also draw on existing trees managed through FMNR or stands of problematic species such as *Prosopis*. Acacias can be grown in an agroforestry system, either on existing farms or on degraded land, with a positive benefit to cereal production. Crop wastes are significant across the region, but these should not be used for biochar as they are in heavy demand for dry season stock feed and building, and what is not thus consumed has an invaluable role to play as mulch, protecting the soil from sun and wind.

Funding

Funding to cover the cost of implementation should be readily available from international sources, since the outlined project strongly meets the objective of ‘adaptation the climate change’, that was endorsed by the 2010 Copenhagen Agreement. However it is worth noting that as at the time of writing, biochar is not approved under the Clean Development Mechanism of the Kyoto Protocol (Whitman and Lehmann, 2009).

An acacia/biochar project aid could contribute to climate change adaptation in the following ways:

- by diversifying agricultural systems toward drought tolerant perennial plants;
- by improving livelihoods and food security at both farm and regional levels;
- by reclaiming degraded lands for food and income production;
- by increasing tree cover, potentially across wide areas;
- by improving soil health including water and nutrient holding capacity; and
- by targeting vulnerable groups for interventions.

An acacia/biochar project could also contribute strongly to mitigation of climate change by:

- increasing the supply of renewable energy; and
- sequestering a durable form of carbon in soils, and thus offsetting atmospheric CO₂.

Technology

The technology to convert woody feedstock to electricity and biochar is well developed. It is relatively simple, cheap and can be scaled from a small village level unit (such as might serve the needs of a small hospital) up to very large automated systems (Ahrenfeldt et al., 2013). The main governing factors are the size of the supply of feedstock, the efficiency of the distribution of the biochar and the availability of an end-user for the electricity.

The commencement of a project would not be dependent on an immediate investment in biochar technology. Multiple benefits will be realised just by planting trees – without a single leaf being converted to biochar. This allows for the economics of the proposal to become clear in a ‘real-world’ trial prior to any decision being made.

Management

Acacias can be grown on family farms as part of an agroforestry system, or they can be grown very successfully on degraded lands as part of a larger community mobilisation program. A trading company or association would need to be established to manage the purchase of feedstock, to operate the electricity/biochar producing equipment and to manage sales of electricity. Further possible functions would be to manage the return of biochar to wood producers, to measure and verify soil carbon increases, and to channel carbon funds between the global carbon markets and the people on whose land the carbon is being sequestered. It would be highly desirable that the feedstock producers – the small farmers – have a stake in the ownership and management of this trading entity.

Carbon markets

International carbon markets are expected to grow substantially in the coming years as emissions trading becomes established on a global basis (World Bank, 2012). Prices have varied widely through time and across jurisdictions, indicating both the infancy of the market itself and its nature as an ‘artificial’ market that is strongly influenced by national legislative and regulatory frameworks (World Bank, 2012).

The World Bank’s Clean Development Mechanism (CDM) has taken a leading role in researching and verifying methodologies by which carbon capture can be measured under various conditions. The capture or preservation of carbon through forestry and land use change has been a major area of interest, but the lack of security inherent in carbon stored in trees and forests (especially in poor developing country environments) makes such investments risky, resulting in lower carbon prices and higher verification costs, factors that

impact on the viability of projects on the ground. Biochar, on the other hand, offers a much more secure and (theoretically) easily measurable store of carbon in the soil.

In order to link small farmers in the Sahel with International carbon markets, the following would be required:

1. An efficient and approved protocol for the measurement of changes in soil carbon content;
2. A carbon broker. This could be the World Bank CDM or a commercial trading entity (probably in Europe);
3. An organisation capable of monitoring changes in soil carbon content on individual farms to the satisfaction of verification authorities and market actors; and
4. A means by which carbon funds can be reliably and efficiently dispersed to participating farmers.

6. Research Methods

6.1 The research approach

To meet the needs of World Vision Australia, who required me to assess the potential of Australian acacias to build livelihoods in the semi-arid tropics, I adopted a 'real-world iterative process' (Stepien and Gallagher, 1993), based in a participatory action-research methodology (Whyte, 1991, Pernecky, 1963, Stringer, 2007, McNiff and Whitehead, 2002). The process was thus to begin with what was known, and to work with people in the field (farmers and/or practitioners) to determine their understandings and to ascertain what factors might influence the viability of an acacia based product, and to find ways to augment the process of adoption that had been on-going since the mid-1980s. The reality for me, as with most other researchers, was that time limitations made the full employment of such an approach impossible (Waters-Adams, 2006).

The other dimension of the research involved commissioning a series of laboratory analyses – to determine the nutritional content of acacia seed and the product that was developed. When toxicity issues emerged, I commissioned a further set of tests to identify the toxic factor(s) involved, and to discover how best the risk could be minimised. The research thus evolved to be multidisciplinary; it was simply not possible to assess feasibility of such a complex proposal from within the confines of a single disciplinary approach.

In order to maximise sustainability and relevance to the Hausa community, I aimed to engage local capacities and resources wherever possible. To this end, it was important to consider how any proposed intervention could build on existing local knowledge, and how

local resources and institutions could serve to sustain it over the longer term (c.f. Mortimore, 2005, Ostrom, 1990). It was important that I worked with people who were familiar with Australian acacias, both as elements in the agricultural system and as food. This was relatively easy since World Vision Niger and SIM have been actively promoting acacias in the district for several years, and maintain excellent working relationships with many villages in the district.

There was also the question of just who was the 'community'? I intended to involve farmers/local people as participants. However I found that placing rural communities centrally was difficult because so many of the institutions that gave some form of governance and security to rural communities actually lay outside the control, or even knowledge, of the communities themselves. As noted by Ihonvbere, the modern state (and by extension international organisations) is existentially irrelevant to many African communities who focus their identity, loyalties and survival strategies predominantly at the local level (Ihonvbere, 1994). Yet for many researchers in the field of development e.g. (Ostrom, 2009), higher order institutional change is an essential precondition for sustainable change 'on the ground'.

Though my ideal was that solutions to food insecurity and child malnutrition should first be sought within local, rural communities, the reality was that the NGO's, government workers and international organisations that work against poverty, famine and malnutrition in the developing world were as much a part of the 'community' as the rural poor themselves, though the lines of communication within that community were usually tenuous and one-way. This reality bears out Ostrom's (1990, 2009) observations that the sustainability of an intervention is dependent on institutional change at multiple levels. In the case of my project, any potential food product would have to gain the acceptance and support of the

government agricultural authorities, and the broader NGO community as much as it would need to be accepted by the local villagers.

The international and NGO community needed to be engaged, with concerns including policy 'fit', nutritional appropriateness, cost effectiveness, targeting, regulatory approval, weediness risk assessments, toxicological assays, safety trials and so on. Thus I needed to engage as much as possible with this disparate and fractured group of organisations and individuals that constituted the "gatekeepers of the poor". Participation - if it can be called such - became a multi-stakeholder exercise (c.f. the work of Shivji (2007) and Edwards and Hulme (1996) and many others concerning the power of NGO's in the development encounter).

6.2 'Institutions'

Institutions exist at several levels and since they are the creations of potentially competing actors, it is by no means certain that any one level is consistent with another, or even within itself. In this study, I found that institutions at five levels were of particular importance: the local/village, the regional, national government, national and international NGOs, and international/multilateral organisations. The higher the layer, the less the institution looked like a 'means of managing vulnerability', and the more it looked like a constraint on the possible, or sometimes (more cynically perhaps), principally a means of managing risk to the organisation in question. In this study, I address the different layers of institutions with different types of data. Institutions and institutional change are discussed further in Chapter 13.

6.3 The field research location

I chose Maradi in Niger as the field research location because the NGO Serving in Mission (SIM) has been working to domesticate and promote Australian acacias in that district for over twenty-five years, whilst World Vision Niger (WVN) has been working there with acacias sporadically for more than ten years. In 2009, Acacias were being grown for food production on over 480 farms in some 33 villages in Maradi *Department*, Niger (World Vision Australia, unpublished data). I was thus able to work with people who had, for the most part, a long term familiarity with Australian acacias, who had eaten the seed regularly, and who had discovered many ways of integrating acacias into their livelihoods.

Maradi is the administrative centre of a region that covers 38,500km² of central, southern Niger, see Figure 6-1. The population of the Maradi region was estimated at the 2011 census to be 3,117,810 people of whom upwards of 80% were rural dwellers and dependent on agriculture or pastoralism for their livelihoods (Geohive, 2013).

In Maradi I interviewed rural people in villages, mostly within a 30km radius of the city (See Figures 6-1 and 6-2.) Within the city of Maradi I worked with a group of urban people, all of whom retained strong links to their rural origins. In Maradi and the capital Niamey I interviewed staff of international agencies, NGOs and government research institutes.



Figure 6-1. Location of the Study Site

6.4 Talking to Government and NGOs

In Niger, I interviewed staff from the Office for the Coordination of Humanitarian Affairs (OCHA), the World Food Program (WFP/PAM), International Centre for Crop Research in the Semi-Arid Tropics (ICRISAT), Institute Nationale Recherche Agricole du Niger (INRAN), Action Contra Faim (ACF), the Red Cross, Institute Nationale Recherche (INRAN), the Ministry of Health and the Forestry Department. Through these interviews I was seeking to gain a broad understanding of the issues addressed by each institution, plus the constraints under which they operated. I tried repeatedly to meet with Medecins Sans Frontieres (MSF), they being a major actor in food aid and nutrition interventions in Niger, but was repeatedly ignored. Although little of this institution-related interview material finds its way directly into this thesis, the interviews did greatly aid my understanding of how things work (or don't work) in Niger.

6.5 Village meetings and interviews

I had the opportunity to visit many villages in the Maradi region of Niger along with Tony Rinaudo and Chris Rowlands, both of whom worked for World Vision Australia, and with Ibrahim Jaho, who was a project worker with SIM. Chris Rowlands was conducting research into the nature, extent and potential of the acacia seed market in the Maradi region, and this gave me a good opportunity to listen and observe in many meetings in rural villages, and some urban settings. I took the opportunity to begin shaping my own research during these meetings, either waiting for Chris to finish, or interspersing my questions with his to the villagers. Tony Rinaudo, a fluent Hausa speaker, took the role of interpreter so that these meetings were dynamic and engaging.

After Tony and Chris departed Niger, I travelled again to these and other villages with Jaho as he made his scheduled visits. For these visits, I seconded an interpreter named Nuhu from the International Women's Development and Relief Organisation. The content of villagers' responses to questions that I gathered with the help of Nuhu did not differ greatly from those interpreted earlier by Tony Rinaudo, but the engagements were less florid and the responses perhaps more matter-of-fact. On some occasions I travelled to the villages with staff of World Vision Niger. Whenever possible I had Nuhu come along to interpret. Sometimes I travelled without him and relied for interpretation on a WVN staff member who spoke Hausa and some English.

I asked a range of questions, mostly concerning people's attitudes to acacia as a multi-purpose crop, and in particular as a food. In each village I asked how many trees had been planted in recent years, how many had survived, how much seed had been harvested, and what had become of this seed - whether it was collected, eaten in the household or sold.

On one round of visits I discussed the potential for growing acacias on degraded lands near the villages, asking who would have to be consulted, what resources would be needed and what might be the appropriate elements of a consultation process. On another set of visits I consulted with village cereal bank committees to ask their opinion of making acacia seed available in the bank as a supplement to millet. I inquired as to any constitutional constraints, an appropriate price to buy and sell acacia seed and the willingness of the committee to trial acacia seed for a season.

In all I visited thirteen different villages between once and three times each (Table 6-1 and Figure 6-2). The villages were all within a 40km radius of the regional centre of Maradi, except for Dan Saga, which was 70km to the east. Villages were selected on the basis that they had been involved in the growing of acacia, which in practice meant that they had been receiving assistance from either SIM or World Vision Niger.

Table 6-1. Villages where community meetings were conducted

Name	Dominant ethnicity	Location (Decimal Degrees)	Times visited
Dogon Baushe	Hausa	13.8236, 7.0217	4
Kibiya I & II	Hausa	13.8480, 7.0028 13.8490, 7.0055	1
Garin Sarki	Hausa	13.8271, 7.0166	2
Magajin Kware	Hausa	13.7960, 7.0833	3
Zodaye	Hausa	13.7177, 6.8338	3
Botsi	Hausa	13.7267, 6.8960	2
Dadoe	Hausa	13.7123, 6.8400	2
Alfari	Hausa	13.7672, 6.8612	1
Koudoumus	Hausa	13.7834, 6.8031	1
Garin Djido	Hausa	13.3100, 7.0579	2
Rugga Tsaune	Fulbe	13.3091, 7.0286	3
Dan Saga	Hausa	13.7001, 7.7331	2

Selection of villages for meetings and discussions was ad-hoc. Systematic or randomised sampling was not possible because I was dependent for my travel on other organisations or projects, so that my capacity for autonomous activity was limited.

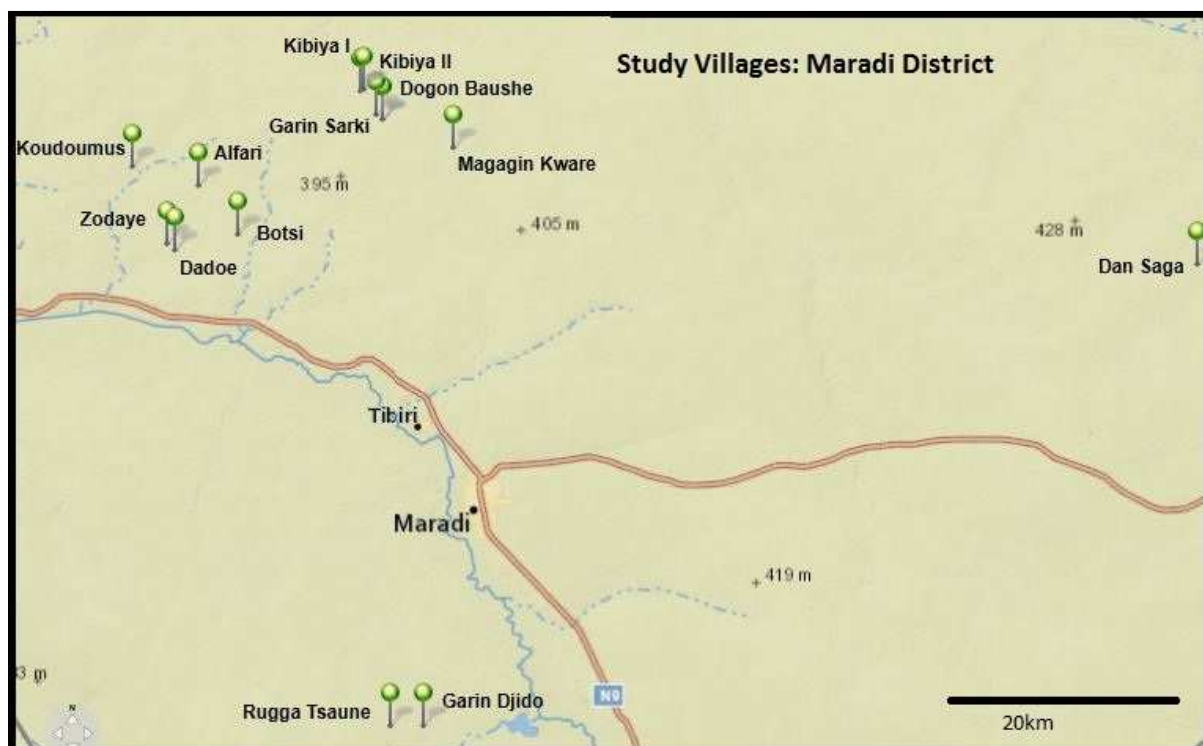


Figure 6-2. Location of Study Villages

My colleagues or assistants tried to contact each village some days prior to our arrival, and in most cases our visit was expected by the time we arrived. Nevertheless we could never know how many people would be present, or who they would be. The interviewees were self-selecting in that even though the headman would call a meeting, some potential attendees chose to remain in the fields, or were away from home on other business. Since it would be known that the meeting concerned acacias, people who were not farmers, had no interest or who held a negative opinion, were unlikely to have attended. In the case of meetings with Cereal Bank Management Committees, most of the members were present at each meeting, but a large number of ‘non-participating’ men also attended, many contributing their opinions.

Village meetings were always held away from the sun, under a rickety shade structure made of acacia wood poles topped with millet stalks. Steel framed chairs with seats woven from brightly coloured plastic thread were brought for the visitors, whilst the men - for it was only men - sat or reclined on garishly coloured plastic prayer mats. Children, mostly boys would hang about on the outskirts, listening and trying to get a look at the strangers.

There was a fair range of ages amongst the assembled men, although it was often stated that a large number of the village men were absent, most of them '*en exode*', working in Nigeria and Cote D'Ivoire to support the family. The village headman was almost always present, and a large part of the discussion seemed to be channelled through him. It was very rare that I had an opportunity to interview a village woman, and sometimes this was only possible with her husband speaking for her.

In all cases I interviewed groups of people rather than individuals. These meetings were usually fairly fluid, with participants constantly coming and going. Contributions to the discussion were usually restricted to a few, or even only one or two people. The others listened, and periodically nodded or murmured their agreement.

The field work period extended for 12 weeks, with village visits comprising about three weeks of the total. It helped me to understand village people's way of life and attitudes to acacias. However these meetings yielded very little specific data of use to the project beyond a general affirmation that acacias are a useful – indeed valued – addition to the agricultural system, and the seed a valued addition to the diet.

6.6 Ethics approval and informed consent

Ethics Approval was granted by the Charles Darwin University Human Research Ethics Committee (HREC Approval No: H13028.)

I was unable to obtain an answer from either the Nigerien Embassy or the Nigerien Ministry of Health as to whether I was required to follow any particular procedures for ethics approval within Niger. I was advised by senior Nigerien social researchers that ethics approval was not required in that country. Thus the default ethical standards applied were those required in Australia.

Given the extremely low levels of literacy in the villages where I worked, the use of written consent materials was inappropriate. Informed consent was therefore obtained by means of witnessed consent. An information sheet was translated into Hausa and was read to the assembled group at the beginning of each meeting. A physical copy was also made available, though few were taken.

The information sheet covered the following matters:

- a. the aims, methods and risks of the research;
- b. that participants are free to choose whether they participate or not;
- c. that if they do choose to participate, they may withdraw their participation at any time and any information obtained will be returned or destroyed on request; and
- d. that aggregated results may be used in a report for World Vision, and/or in a thesis for the purpose of the researcher's studies and/or in scientific journals.

Participants were asked to affirm that they understood the project and had agreed to be interviewed. A record of the agreement was then entered into the field notes and witnessed by the interpreter, village headman or World Vision staff member.

6.7 Acacia based food development

Because of the logistical difficulties in getting to villages, and the problems with accessing women in the villages, even when I was able to get there, I was failing to engage Hausa people adequately with regard to issues of child nutrition, cuisine and food preference. I was fortunate enough to encounter a group of people who had been connected to SIM for many years, and who had used acacia seed in children's food for some years. Through discussions with nutrition experts in World Vision International I had already come to the conclusion that the best return for effort would lie in addressing the nutrition of infants between the ages of 6 months and 5 years (C. Emary, Pers. Comm.). I focused on improving the availability and quality of complementary foods; that is, foods that are brought into an infant's diet alongside breast milk, from around six month of age (Gibson et al., 1998). This priority for impact is well supported in the literature (Hampshire et al., 2009, Young and Jaspars, 1995, Gross and Webb, 2006), although whether feeding children with a ready to eat food is the best way forward remains a matter of contention (Palmer, 2009).

Working with this group of people was important to my research because I needed a quick and reliable way to access local knowledge, in particular the local cuisine, tastes and attitudes to food. This aspect of the research is described in more detail in Chapter 7.

6.8 Acacia Nutritional Evaluation

On the basis of my prior knowledge of acacias and literature review, I had concluded that the key issues in evaluating acacia as a food revolved around nutritional content and the processing methods that could best reduce the impacts of a few common anti-nutritional factors. Thus I searched for published analyses of acacia seed and supplemented these by commissioning further analyses of raw seed of certain species where I felt there were serious gaps in the knowledge. My early focus was on *A. colei* and *A. torulosa*, building on the work of Adewusi et al. (2003) who analysed *A. colei* and *A. tumida* more than a decade before. In 2011 I was asked to arrange nutritional analysis of another acacia species, *A. saligna*, that has been widely planted in Tigray region of Ethiopia for soil conservation, fuelwood production and livestock fodder.

A further consideration was how the nutritional profile of acacia seed could best be combined with other foods common to the semi-arid tropics to meet people's nutritional needs. Thus I sought published analyses of several food items such as pearl millet, sorghum, moringa leaf (*Moringa oleifera*), sesame and peanut, and used this information along with the acacia nutrition data to optimise nutritional potential in the recipes that were developed with the Hausa group (Chapter 7 below). The nutritional aspects of acacia seed are further discussed in Chapter 9.

6.9 Safety Tests

When I began the research, I was happy to take at face value the belief, well supported in the literature (Adewusi et al., 2006a, Adewusi et al., 2003, Harwood et al., 1999, Brand and Chirikoff, 1985) and in practice, that many acacia seeds are edible and nutritious. Having

worked for many years with Aboriginal people in central Australia, I was personally familiar with several species having been used as foods within living memory.

Testing initially focussed on finding effective ways of removing anti nutritional factors that are found in legume seeds and many other common foods. In particular I was interested in protease inhibitors, phytate and oxalate. Tests were commissioned with the Graham Centre for Agricultural Innovation and School of Agricultural and Wine Sciences, Charles Sturt University to determine the best method for denaturing these anti-nutrients. (See Chapter 10).

Further concerns involving anti-nutrients emerged with the publication of a study that showed a possible blocking of methionine availability by a non-protein amino acid, carboxyethyl-cysteine (Falade et al., 2012). In response, I commissioned measurements of amines, including all known toxic amino acids present in several species of acacia seed from Metabolomics Australia. (See Chapter 10).

7. A Hausa Initiative

This chapter reports on the engagement I had with a group of Hausa people – a man and three women—to develop a way of using acacia seed that can fit comfortably with Hausa cuisine and contribute positively to nutrition. The focus of the work was on creating a complementary, or weaning, food that could help to reduce the incidence of malnutrition for children aged between six months and five years.

During village fieldwork in Maradi, Niger, I was reacquainted with a farmer called Baro who I had first met on my two earlier visits to Maradi, in 2004 and 2006. After telling Baro the reason for my visit – to develop a complementary food based on acacia seed – I was extremely surprised to hear that he had in fact been making and distributing just such a food for several years.

Baro is a farmer who has a long history of working with acacias. He is a member of the small Christian community in the Maradi region, and this perhaps both gave him easier access to the agricultural teaching of the SIM staff and made him more receptive to the new ideas he would receive. Baro was very quick to see the benefits of using acacia on his farm and became a key innovator, developing himself many of the silvicultural practices that have become standard in the management of acacia trees.

With very many acacia trees on his farm, Baro is a significant producer of acacia seed, and held a large stock of seed. With the unfolding famine in 1988, he saw many children in his village developing signs of malnutrition, and was moved to take such action as he could. He began producing a simple *kunu* mix, containing pearl millet and around 20% acacia flour,

and giving this to mothers whose children were failing. The food was well received, and Baro was kept busy (and stretched financially) providing acacia/pearl millet *kunu* to the many women who approached him from his own and neighbouring villages. As the famine conditions eased, women continued to approach Baro, asking for the acacia/pearl millet *kunu*. Understandably, he was unable to afford to keep giving the mix away, and offered to sell it instead.

Baro has been involved in a small but regular trade since that time, and the value of his acacia/pearl millet *kunu* in childrearing is well-recognised in and around his village. Baro's *kunu* formulation was very simple, being just acacia seed and pearl millet. As such it was definitely an improvement on the pure pearl millet *kunus* that most village children were fed. The acacia seed was particularly important in boosting protein intake, both in overall terms and by providing a better balance of amino acids, since acacia seed is high in lysine, in which pearl millet is very low (see Chapter 9). The mix was still seriously lacking in energy, fat and several micro-nutrients so I offered to work with Baro to see if we could improve the nutritional profile of the *kunu*.

We also approached three women; Hadiza, Mariama and Rahilla, who had worked with SIM for many years (since 1984 in the case of Rahilla) conducting acacia food demonstrations in the villages around Maradi. The three women were all experts in the preparation of acacia and other grains, in Hausa cuisine, and were mothers with a total of 18 children between them! Hadiza was especially important, acting as an interpreter between English and Hausa.

7.1 Refining the *Kunu*

That *kunu* – a thin pearl millet or sorghum based porridge – was an appropriate product on which to focus my research seemed clear enough, based on Baro’s earlier success. This was readily affirmed by the new team members, and so we began a process of sharing knowledge, and surveying the potential ingredients that could be used in a *kunu*. With the exception of iodised salt and sugar, we tried to look only at ingredients that were produced locally. This was based on a desire to maximise the market opportunities for local farmers should mass production of the product for distribution as a nutritional supplement ensue, as well as ensuring that the product was comprised entirely of ingredients that lay within the experience and knowledge of rural people. Were this not the case, the likelihood of widespread adoption would be greatly diminished. If foods are not available in local markets, if they are expensive, or are simply unfamiliar, the team felt that people would be unable, or reluctant to use them.

A survey of markets in Maradi and Sabon Marche yielded the same basic list: pearl millet, sorghum, cowpea, sesame, peanut, roselle and moringa leaf. Soybean was added to the list as it is also widely available and well known as a good food, though it is grown well to the south, in Nigeria. Another Nigerian import was added at the suggestion of Hadiza: *garin kuka* - the pulp of the baobab fruit, which is very high in vitamin C. The other ingredient, and the *raison d’être* of the study, was of course, acacia seed.

The team discussed the relative nutritional benefits of the various ingredients, and then launched into a series of cooking experiments. The objective was to use a selection of ingredients – always including acacia seed – to produce a *kunu* with a good taste and appearance. Each recipe was assessed for nutritional content using NutriSurvey, a linear

programming application and nutritional database, and the results were fed back into subsequent recipes.

Some important design constraints emerged quite early in the process:

- Cowpea was not considered a suitable food for babies. I was unable to ascertain any particular reason for this – it was simply a baldly stated fact: that people will not feed cowpea to their young children.
- Colour was regarded as important. The inclusion of higher amounts of moringa leaf would add considerably to levels of micro-nutrients, in particular iron and vitamin A. Nutritionally optimal moringa levels led to a distinct green colour, which was felt to be unacceptable by the design team. I was told the green colour would lead mothers to fear that the food contained ‘medicine’, ie dangerous and possibly magical herbs.
- Despite the reluctance to use cowpea, soybean was believed to be a good food for children, and the group were keen to include at least some in the mix.

After several versions of *kunu* had been mixed, cooked, tasted, nutritionally assessed and discussed, the group set about taking the best recipes in terms of taste and nutrition, and trying to capture the best elements of each in a single recipe. This was an interesting and contested process, as some members of the group strongly favoured the sweeter mixes (and would add large amounts of sugar to any batch they were tasting), with rather less concern for nutrition. At the other extreme, in the interest of high vitamin A and iron levels, I was pressing for Moringa to be included at 8%, then 5%, and was finally able to reach agreement at a mere 3%, at which point the resulting colour was deemed acceptable ‘to the village women’.

Another point of contention was the levels of soybean flour to be included. Soybean is a non-local crop and is too expensive for many rural people to afford, though it is available in most rural markets. Soybean has been promoted widely as a good element in food for children, through nutritional programs such as those run through Government clinics and through a SIM child and maternal health education program. I argued that acacia seed was a reasonable and (importantly) local substitute for soybean. A compromise reduced the soybean content to a low 5%, whilst boosting acacia seed to 15%.

7.2 Too much ownership? Losing control of the process.

I had planned that this recipe should be refined and checked nutritionally in the lab, then produced in quantity for distribution to vulnerable families, thus replacing an imported aid product with a local one. Taking a completely different approach, I had also planned that the recipe would be taught to village women as part of an extension package that included instruction on how to grow acacias, and how to integrate them into annual farming systems. One day, the *kunu* design team called me to meet with them, and told me that the recipe belonged to them, and that they did not want to proceed with any teaching of the recipe to village women. Instead, they said they wanted to produce the *kunu* mix as their own business, and sell the mix into the villages. My arguments that the recipe was not completely ready, that the rural poor could not afford to buy a prepared food, or that we had undertaken this work - and the team had been paid - with the needs of the poor clearly in mind, fell on deaf ears.

When consensus was reached on the 'final' recipe, the group were keen to take samples home for taste testing on their own and neighbour's children. It was at this point that I began to feel that the project was spiralling out of my control. Or, to put it another way,

that I had achieved just the sort of community engagement and ownership of which every researcher dreams. Despite the obvious ethical dilemma, I felt very confident in allowing taste testing to proceed - indeed, how was I to stop it? The food was simply a new recipe comprising foods that were already regularly eaten by many people and which I was eating myself on a daily basis. The only food that could be considered at all novel was the acacia seed, and this had been eaten in the district for more than fifteen years. It seemed that the development of the product had become a major community talking point around the homes of each of the group, and a great clamour had arisen for a taste of this new *kunu*.

Fifty packets of 400g each were duly produced and taken home. The *kunu* mix was fed to husbands, children and babies. I asked the *kunu* development group to follow up all tasters (or their mothers) with a set of questions that included:

- Did the taster like the flavour/appearance/texture of the *kunu*?
- Were there any ill-effects from eating the *kunu* (eg. diarrhoea, stomach discomfort, etc)?
- Were the tasters satisfied after eating the *kunu*?

I had little control over which questions were asked, or how they were asked, and so no useful analysis is possible from this small and informal taste test, except to say that the reception seems to have been close to 100% enthusiastically positive. The one exception was an Australian SIM missionary who thought the mix 'too gritty'. Husbands asked for more, enjoying the 'strength' the *kunu* gave them, whilst mothers reported that their babies 'slept through the night', instead of waking up hungry.

Perhaps the best measure of the endorsement that the *kunu* received was that the group decided to begin commercial production of the *kunu* as a micro-enterprise immediately. One member of the group, Hadiza, was already running a successful small food producing business (cakes) and so was quick to see the market potential of the *kunu*.

After discussing the idea, (and realising that I had no chance of bringing the process back under my control), I agreed to loan 40,000 cfa (around AUD\$100) to allow the purchase of ingredients and equipment, and the first batch was being sold a few days later at a SIM acacia promotion event. SIM has made a suitable shed space available, and a SIM worker agreed to support the enterprise with small business training.

The *kunu* enterprise remains small, with most sales being from the 'compound door' or, with the assistance of SIM, to people in rural villages. with the assistance of SIM. In several villages agents have been engaged holding a small amount of stock for sale. Since 2010 sales of *kunu* have increased dramatically, mainly to NGOs that are engaged in promoting acacias, but other outlets include the maternal and child nutrition program at the Danja Leprosy Hospital and retail outlets across Maradi. Larger sales are made to other NGOs such as Samaritan's Purse and the Adventist Development and Relief Agency, who have started to promote the use of acacias, and use the *kunu* for distribution to vulnerable families and to demonstrate the types of culturally appropriate and nutritious foods can be made with acacia seed.

The initial pack size was 400g (enough for a child for 4-5 days), and sold for 400 cfa (just under AUD\$1). Discussions conducted by the author with the women involved in the *kunu* enterprise in 2010 and 2012 indicated a continued high level of taste acceptability, and a great keenness to buy amongst the rural population.

I was surprised to find that the producer women regarded the rural population as a key part of their market. I had envisaged that difficulties with transportation and the shortage of cash would preclude these regions. Indeed I felt that teaching rural women to make the *kunu* for themselves was a better and more sustainable option. Rural interest has persisted however, and the producers have tried to make the product more affordable by reducing the pack size (and therefore outlay price) to reflect the very limited cash available to rural women.

8. The Potential for Weediness

The potential for exotic plants to become invasive is a perennial concern in parts of Africa. For example, 180 exotic species, including Acacias from Australia, have been classified by the South African Government as ‘invasive alien plants’ (Turpie, 2004, Yelenik et al., 2004, Richardson and Van Wilgen, 2004, Le Maitre et al., 2004). Invasive alien plants, it is argued by le Maitre et al. (2004), globally cost as much as US\$314 billion per year, and cost “South Africans tens of billions of rand annually in lost agricultural productivity and resources spent on weed control” (2004; 103). The case for great caution in the introduction of an alien plant with the potential for invasiveness is thus very clear (cf. Keller et al., 2007). Nevertheless, it is also true that the forces that bear on the introduction and dispersal of alien species are complex. Human agency plays a big part, and ‘invasive alien plants’ have been found to be extremely useful by some sectors of the population even as they are hated by others (Kull and Rangan, 2008, Kull et al., 2011).

The risk, and reality, of weediness is clear for many species. However in many cases, their economic benefit is also clear. For example, the ‘invasive’ tree, *Acacia mearnsii* was crucial to a large tannin production industry in South Africa until the advent of chemical tanning processes rendered the species largely obsolete (Carruthers and Robin, 2010, Dunlop et al., 2003). Unfortunately the debate on potentially useful introductions has rather unhelpfully polarised between environmental purists and those seeking economic or social outcomes. Low (2012) argues that the international development community has redefined ‘sustainability’ to favour social, over ecological values, and that a benefit in the present will in all likelihood become a significant cost in the future, if (when) exotic species escape human control. He argues that, at the very least, robust risk assessment processes should

precede the introduction of exotic species such as acacias. Proponents of agroforestry argue that the greatest threat to the environment is human poverty itself and that many exotic species have made, and will continue to make, valuable contributions to poverty alleviation (Griffin et al., 2011, Rinaudo, 2001a). The economic benefits of Australian acacias have historically crossed several sectors of society in southern Africa, particularly through the tannin industry. Although this industry is now in decline, the benefits of acacias to the poorest and most marginal people continue to be significant (Kull et al., 2011). Furthermore it could be argued that many African environments (especially those in semi-arid regions) are already anthropogenic disasters where the concept of weed-induced degradation is redundant.

One problem for people such as myself, who are grappling with the risk/benefit analysis of using Australian acacias outside of their native range, is that many of the attributes that made a tree species useful in agroforestry are also the very attributes that confer greatest weediness risk (Witt, 2010, Wilson et al., 2011). Attributes such as ability to grow on poor soils, to fix nitrogen, to produce plentiful seed and to grow rapidly score highly in weediness assessment tools (see next section). Still they are precisely the factors that make some species of acacia an attractive addition to the agricultural systems of many highly degraded, semi-arid and hunger-prone regions of Africa.

8.1 Weediness risk assessment

Using assessments that are primarily ecologically oriented, trees such as acacias can appear to be an unacceptable weed risk. The Australian Government's quarantine protocols for weed risk assessment offer just such an assessment (see Appendix 1.) Such assessments are

based solely on a set of physical characteristics and likelihoods, whilst taking little account of any social factors that modify risk.

The Australian process is conceived in three tiers. The first considers a species' current status in Australia; whether it is present in the country, whether it is listed as a threat or whether it is permitted for import. The second tier uses a question-based tool designed to assess the risk of a given species becoming a weed, whilst the third tier involves post-entry evaluation (Australian Government, 2013).

Tier two of the weed risk assessment system (Australian Government, 2013, Pheloung et al., 1999) employs a tool listing 49 questions that contribute to a score that is intended to describe a plant's weediness potential. An aggregate score of <1 makes a plant an acceptable risk. A score of 1-6 requires further evaluation. A plant scoring >6 should be rejected. As an exercise (and with some necessary minor adaptations), I applied the Australian Weed Risk Assessment System to *Acacia colei* in Niger and *A. saligna* in Tigray. *Acacia colei* scored 10 overall. The same test applied to *A. saligna* in Ethiopia resulted in a score of 16, reflecting that species' history of invasions in southern Africa, the Mediterranean and Australia (O'Sullivan and George, 2007). I list in Appendix 1 responses to questions in the Weed Risk Assessment Tool (Australian Government, 2013), along with the score I arrived at for each species and some comments concerning the relevance of some species' attributes to agroforestry species selection.

Ecological risk versus social benefit

Based on the weediness risk assessment scores produced by the Australian Weed Risk Assessment System (Australian Government, 2013), (see Appendix 1), both *Acacia colei* and

Acacia saligna would seem to be patently unsuited for introduction to new regions. Yet after 25 years in Niger, *A. colei* shows little sign of invasive tendencies, with little recruitment from seed and no vegetative reproduction (Rinaudo et al., 2002, Thomson et al., 1997). Similarly, after 40 years in Tigray, *A. saligna* is not weedy, and moreover is regarded by farmers and many Ethiopian ecologists alike as a highly valuable addition to the landscape (Hagazi, 2011). The discrepancy arises because an ecologically focussed risk assessment offers no insight into the social conditions of the area where a species might be introduced. Yet the *social ecology* of any site is crucial. Ecology does not exist in a vacuum free of human action and aspiration. The concept of a pristine environment that lies at the heart of the ecological approach is fanciful – the more so in densely populated regions of Africa, where the human struggle to survive has already changed the environment irreversibly. Social, economic and environmental conditions provide the rationale for new species importation as well as the context of the introduction. These conditions may also be important modifiers of risk.

In an overgrazed region that is being over-run by shifting sand, can a drought tolerant woody ‘weed’ really be seen as an ecological disaster? In a region where remnant native forests are remorselessly being cut down for fuelwood, can a woody ‘weed’ with excellent burn characteristics really be construed as a threat? In a region where up to 17% of children under five suffer acute malnutrition (IRIN, 2010a), can a ‘weed’ that produces nutritious food really be called a ‘weed’? These conditions describe the vast majority of agricultural and pastoral land in countries like Niger (Leisinger et al., 1995). According to Shackleton et al.:

“While the negative impacts of [alien invasive species] on ecosystem structure and function are undisputed, understanding of their potential impacts on rural

livelihoods and well-being is less developed, especially since it is [rural people's] land and waters that are most affected by [alien invasive species]. It is tacitly assumed that the harmful impacts on ecosystem goods and services automatically translate into negative effects on human wellbeing. Yet, [alien invasive species] are frequently integrated into local livelihoods, both as managed species, as well as exploitation of wild invasive populations" (2007; 113).

De Neergaard et al. (2005) are very clear about the importance of exotic acacias, such as *Acacia mearnsii* and *Acacia saligna*, in South Africa for rural livelihoods:

"For local rural communities the wattle serves as a valuable resource providing firewood, building materials and in some instances... cash income... Although the species may encroach on grazing land, the problems related to the spread of the wattle such as reduced stream flow, competition with indigenous species, etc., are often not a particularly pertinent issue to rural communities who seek to use this resource as a part of their livelihood strategy. There is a potential conflict between the perceived interests of society (control of the wattle) and local communities (a continued resource of woody species)" (de Neergaard et al., 2005; 218).

There is, furthermore, a strong likelihood that the existence of a wood resource comprised of alien species can actually help to protect ecosystems by deflecting some of the fuelwood harvest from native vegetation.

Some of the major risk modifiers present in semi-arid Africa are discussed in their social context below.

8.1.1 Livestock Pressure

In both Niger and Tigray, livestock are a crucial part of many households' livelihood strategies. Some ethnic groups rely almost completely on livestock for their livelihoods, but across the rural areas, almost all families either keep or aspire to keep some livestock. Livestock provide a quick and flexible means of increasing capital in good years. In addition, they can also provide sustenance directly in the form of milk and meat. Livestock are often kept and fattened in order to meet a family's religious obligations.

High levels of grazing reduce the weed risk of acacias because young seedlings are vulnerable to trampling and browsing. There is almost no place in the landscape that is not subject to grazing by cattle, sheep, goats, donkeys and/or camels at some stage of the year. Acacia seedlings are palatable to livestock for the first year and any volunteers are likely to be destroyed.

In Tigray, livestock grazing has been implicated in the failure of forest regeneration over many years. This has resulted in certain areas being designated as 'closed' to grazing, with a resulting increase in tree cover (Hagazi, 2011). *A. saligna* has increased along with native species and is being used as a 'cut and carry resource for livestock feed (Gebru, 2012).

8.1.2 The Absence of Fire

Most of the land that is not designated as 'pastoral' in both Niger and Tigray is generally under agriculture, and is cleared of all grass and herbage. Livestock grazing removes virtually all grass from pastoral land in the agricultural districts (where *A. colei* is grown in Niger), well before the end of the dry season, so that fire, which is the single most

important driver of acacia regeneration, is virtually absent from the system (Lex Thompson⁷ pers. Comm.).

8.1.3 Demand for Fuelwood

Virtually all households in rural Africa, and most in urban areas, use biomass for cooking (Anderson and Fishwick, 1984). In tree-poor regions this can mean that crop residues are all that is available for fuel, with a resulting increased risk of soil erosion, accelerated soil fertility decline and animal feed shortages. Acacia wood is regarded as excellent fuelwood in both Niger and Tigray, and it is a valuable commodity both in homes and in local and regional markets. Acacia has also been shown to produce biomass at around four times the rate of any indigenous tree (Cunningham, 2009). The spread of Farmer Managed Natural Regeneration has resulted in significant increases in the availability of native wood in some areas (Tougiani et al., 2009, Sendzimir et al., 2011). This is greatly supported by the availability of acacia wood, the reduced pressure allowing regenerating native trees longer growth periods between harvests (Cunningham and Abasse, 2005b).

When fuelwood is in very short supply, as it is perennially in both Niger and Tigray, the concept of a 'woody weed' is a nonsense. Such *de facto* common pool resources are quickly harvested and sold for cash. Indeed, farmers report that they need to actively protect their trees to prevent them being cut and the wood stolen by neighbours desperate for cash.

⁷ Forester, CSIRO, Australia.

8.1.4 Highly Degraded Environments

The environment of much of the Sahel is highly degraded. Hundreds of years of human activity have destroyed much of the natural vegetation and the vast majority of the wildlife. From being a dense woodland region a century ago, much of the Sahel has become denuded and highly vulnerable to wind erosion. Drought in the 1980s, coupled with widespread clearing, resulted in catastrophic movement of sand that scalded some farms whilst burying others and which caused the abandonment of many villages. Widespread and severe famine followed, resulting not just in immediate suffering but in the depletion of productive and social assets across the community. These could have helped to ameliorate the famines that have followed every few years since that time (Leisinger et al., 1995).

Far from threatening the Sahelian environment, acacias offer a significant increase in productivity, and therefore an important boost to livelihood security and household resilience. Cunningham (2009) shows that the use of Australian acacias can more than double farm income, a finding that is supported by Pasternak et al. (2005). Pasternak et al. (2009) show that Australian acacias can also be very effective in establishing productive systems on scalded, lateritic or degraded lands. Indigenous species, such as *A. senegal*, that have been widely used in similar applications have been consistently disappointing (Cunningham, P. pers.com.).

8.2 *Acacia colei* and *torulosa* in Maradi District, Niger: A rapid survey of weediness

In June 2010, I conducted a rapid appraisal of acacia weediness at the 300 hectare Danja Hospital farm site, around 30 kilometres from Maradi, where *Acacia colei* and *A. torulosa* have been grown in trials for over 15 years. The area I examined was a mix of farmland, typically growing annual crops of pearl millet, with most field edges demarcated with rows of *A. colei* or *A. torulosa*, and on highly degraded pastoral land (in fact, a stock route). My survey was at the end of the dry season. Early rains had fallen, but these would have been insufficient to produce any new season germinants. Thus any trees and seedlings observed would be at least one year old. I set out to conduct a formal survey, counting the occurrence of volunteer trees and seedlings along a set of transects. On the ground, however, it quickly became clear that systematic survey was inefficient. It was readily observable that the only volunteers were in specific microhabitats. Hence I changed my methods to purposively target those habitats.

The observations I was able to make were as follows:

- The vast majority of seedling volunteers were *A. colei* (>95%). There were very few seedlings of *A. torulosa*, and the few I found looked to be struggling though, with the rains due, these could be expected to revive before long.
- Germination occurred both within fields and on field borders. However, for seedlings to survive within fields required that the farmer chose to retain the tree – a small seedling is easily chopped out with the hoe along with other ‘weeds’. Seedlings on field borders could presumably survive without such a conscious management decision.

- Where older trees occurred within fields, there was clear evidence that most of these trees were wanted by the farmer; they had often been pruned to encourage a tall stem suitable for use in building.
- Seedlings found in field borders were weak and spindly, apparently struggling to compete with the pre-existing, mature trees (a mix of *A. senegal*, *A. nilotica*, *Guiera senegalensis*, *Bauhinia reticulata* and *Prosopis* spp).
- The few seedlings I found on the pastoral land were weak and stressed. All showed signs of having been grazed, and all were germinants of the previous season only; there were no trees in these areas older than 12 months, suggesting that tree persistence is very difficult in such areas of 'commons', where ownership and rights are both dispersed and contested.

The results of this small survey left me feeling confident that the potential invasiveness of *A. colei* and *A. torulosa* in Niger is more than balanced by the pressures applied directly by humans through hoe and axe, or indirectly through livestock grazing. Though seedlings were present, they were not common, and in most cases continued to exist by virtue of a management decision *not* to chop them out. This is substantially in agreement with observers such as Rinaudo et al. (2002) and Thomson et al. (1997).

8.3 The weediness potential of Australian Acacias: Some concluding remarks

There is no doubt that some Australian acacias have proved to be invasive in some environments around the world (Kull et al., 2011). However, invasiveness in one situation is not necessarily a predictor of invasiveness in another (Kull and Tassin, 2012). A number of social factors can greatly modify the risks. The combined effect of grazing and agriculture in

Niger serve to virtually eliminate fire from the region where *A. colei* is grown, thus removing one of the strongest drivers of acacia recruitment. Grazing also has a direct effect on seedling survival, so that rather than seedlings growing unwanted and profuse, young plants need to be actively protected from livestock to have any chance of survival. Were a seedling to survive the impact of grazing to reach maturity, the high value of wood in Niger would ensure that it is cut down before long.

Ecologically-centred arguments against the use of species such as Australian acacias ignore the social factors that modify risk, harkening as they do after an imagined pristine environmental state. They also ignore the counter-factual question of *what would happen without the introduction of such trees?* The answer is easily found in the far-from pristine environments that dominate semi-arid Africa. Without acacia, what would the poor in Southern Africa use to build their homes? With what would they cook their food? In the 'control' of the natural experiment in those areas of the Sahel where acacias are unknown, poverty and hunger are persistent, soils are depleted and prone to erosion and human development is under threat.

If it is true that social and environmental conditions can mediate the risk of weediness, it is also true that a different set of conditions might lead to a very different result. Moving acacia seed, for example, from the dry and marginal fringes of agricultural land in the Sahel to more humid areas of the Sudano-Sahel might increase the weediness risk dramatically and is a decision that should not be taken lightly. The decision to introduce new acacia species from Australia into semi-arid Africa should involve an assessment process that takes into account both ecological values and potential social benefits. It should also involve a plan both for monitoring the introduction over at least two decades plus a plan for eradication, should the species prove invasive or otherwise problematic. Seed dispersal

may be undertaken by governments or NGOs, as part of development projects, but may also be undertaken by individuals who see a potential benefit to their livelihoods. In the latter case, monitoring of, and an adequate response to invasiveness, may be very difficult to achieve.

9. Acacia Seed as Food

Acacia seed has a long history of use as a food. Many Australian acacia species from all geographic regions of that continent are regarded as edible and were important in Aboriginal diets in Australia for at least four thousand years. Though Aboriginal usage has all but ceased, acacia has experienced something of a renaissance recently in Australia, as a high value spice. It may also promise a nutritious, drought-tolerant new crop for semi-arid Africa. In the Maradi region of Niger, for example, acacia has been regularly consumed by villagers for the past fifteen years.

Acacia is a legume and, as such, the seed is broadly comparable to dry beans and lentils. It is quite rich in carbohydrate and protein, and some species contain useful amounts of unsaturated fats. Most vitamins and minerals are present in acacia seed, though none in quantities that are noteworthy. Acacia seed protein complements the protein in cereals.

9.1 Aboriginal Usage of Acacia Seed in Australia

Acacia seed of several species have been consumed as food by humans for many thousands of years (Devitt, 1992, Smith, 1986, Harwood and House, 1992, Midgley et al., 1991, Thomson, 1992, Harwood et al., 1999, Brand-Miller et al., 1993, Brown et al., 1987, Lister et al., 1996, Orr and Hiddens, 1987, Harwood, 1994, Latz and Green, 1995). Though much is known as to which species were consumed, and how these seeds were prepared, little is known about how much seed was eaten or what effects (if any) were known or attributed to eating acacia seed (O'Connell and Hawkes, 1981). In the semi-arid and desert regions of Australia alone there are at least forty species that have been reported to have been 'food'. Such a classification is not in fact a straightforward measure of edibility, since other factors

such as ease of harvest and processing are implied in the term 'food'. A species such as *Acacia estrophiolata*, for example, may perhaps be 'edible', but it would take a long day's work to collect a meal of the seeds because they are scarce, high in the tree and held firmly in a recalcitrant pod. No-one is likely to consider them a good return on food gathering investment.

9.1.1 Availability

In a given area, acacia seed from any one species was typically available from the tree for a few weeks each year. This was generally in the months between September and January, depending on species and latitude, though some species, such as *Acacia aneura* are opportunistic and can yield seed at any time in response to rain (Latz and Green, 1995). Seed of some species could be gathered outside of the 'harvest' period by winnowing it from the leaf litter beneath the trees, or in some cases by collecting it from ant nests, where it has been collected and discarded by ants after removal of some favoured portion (Auld, 2006, Latz and Green, 1995, Goddard, 1995). The need for mobility in the desert environment meant that Aboriginal people tended not to store and carry foods. Nevertheless, the existence of these stores of acacia seed spread the availability of seed over many more months and potentially the whole year.

9.1.2 Preparation

Most acacia seed was collected as mature dry seeds, though some species such as *A. coriacea* were also collected as semi-mature seed pods, which were then roasted on the hot coals of a fire. The seeds, tasting somewhere between roasted peanuts and green peas, were stripped from the pods and eaten as a snack. This usage is still common today in the

Aboriginal communities north of Alice Springs (O'Connell and Hawkes, 1981, Latz and Green, 1995).

Mature acacia seed was processed by 'roasting'. Seed was placed in a wooden bowl, and hot coals were introduced. The mix was then stirred to ensure even exposure to the heat. After roasting, any ash and remainders of the coals were winnowed out, and the seed was placed in water for several hours, where it would swell and soften. The seed was then placed on a flat stone, called a *tjiwa*, (in Pitjantjatjara), and was pulverized with a pestle stone called a *tjungari*. This resulted in a paste known as *latja* that was eaten, scooped with a finger directly off the *tjiwa* (Goddard, 1995). In several years of working with Aboriginal people and their traditional foods in central Australia, I saw the process demonstrated a few times, but never saw acacia seed prepared as a real meal. In my experience the 100% acacia content of *latja* made the paste very heavy and gritty to eat. Though it would certainly have filled the stomach, the rudimentary roasting technique left a proportion of the seeds undercooked.

9.1.3 The Dietary Importance of Acacia

It is difficult to determine the importance that acacia seed had in the traditional Aboriginal diet, as its use was discontinued early in the colonial period. This may be because the much more palatable and low labour alternative of wheat flour replaced acacia, though it is my experience that most foods, even some that are less than palatable, have been maintained in use until the present day, if only for nostalgic reasons. I suggest, therefore, that acacia may have been a less favoured food, one that was eaten when the hunters had failed and when there was little else. We could conjecture that acacia was eaten in significant quantities in those periods when it was plentiful and could be readily harvested direct from trees if little else were available. The seed would certainly have been second in preference

to any animal food and many other vegetable foods (some of which remain popular today). Consequently consumption may not have been on a daily basis. In other times of the year, acacia seed was probably a stop-gap food. At times of drought, when food shortage could be severe, acacia seed collected from ant nests may have been a crucial survival food.

9.2 Current Usage of Acacia Seed in Australia

Acacia seed usage in Australia over the past twenty-five years has been exclusively as a spice known locally as “wattleseed”. Despite the large number of edible species, only around five species are currently used to any significant degree. The most important is *A. victoriae* which may account for over 80% of acacia seed consumed (Cherikoff, 2000). Other species used are *A. colei*, *A. coriacea*, *A. pycnantha* and *A. longifolia* subsp. *sophorae*, though Bryceson (2008) adds *A. retinoides* and *A. murrayana* to this list, perhaps confusing potential with actual harvest. The use of species has been determined primarily by availability. *A. victoriae*, which is regarded by some as the ‘industry standard’, has been particularly important due to its reliable yield, ease of harvest, and wide geographic spread, (including in relatively accessible dry temperate regions and outside of Aboriginal controlled lands). *Acacia colei* and *A. coriacea* grow in the remote tropical north of Australia and harvest has generally required negotiation with, and involvement of Aboriginal landowners (Morse, 2005, Yates, 2008, Walsh and Douglas, 2011).

9.2.1 Preparation

Acacia seed in contemporary Australia is roasted as a whole seed and then usually ground. Roasting is a very important part of the processing in Australia and, without sufficient time or heat, the seed can impart an unpleasant aftertaste when eaten. Roasting, therefore,

tends to be very heavy, producing a chocolate-brown colour and a flavour that is reminiscent of coffee and hazelnut. The strongly flavoured powder is then used as an additive in a wide range of culinary applications including meat sauces, breads, pastries, biscuits, desserts, coffee substitute and even icecream.

9.2.2 Dietary Importance

Nutrition is not a consideration in the way acacia seed is used in contemporary Australia. Wattleseed is essentially a spice and the amounts used are very small. Furthermore, the degree of roasting involved could be expected to destroy most of the proteins.

9.3 Usage of Acacia Seed in Niger

Acacia colei has historically been the main species grown and consumed in Niger, having been subject to comprehensive safety testing. In the past five years, however, two further species have been trialed with some success, these being *A. torulosa* and *A. tumida*. *A. torulosa* has been increasingly eaten and is favoured for its large seed size and ease of processing.

Farmers I interviewed reported acacia harvests ranging between tens and hundreds of kilograms. Harvests were reported to vary widely from year to year, in line with rainfall. Harvests were also generally better in the southern districts where rainfall is more reliable.

In an informal survey, Rinaudo found that when men grew the trees, they kept 10% of the crop for their own consumption, and sold 90%. Where women were growing the trees, they tended to retain 50% for home use, and sell the remainder (unpublished field notes). The

vast majority of seed sold prior to 2009 was bought by SIM, which was trying to encourage production by simulating a market (Rowlands, 2009). Most of this seed stockpile has since been sold, for use in training, to other NGOs operating in Niger.

9.3.1 Preparation

In Niger acacia seed is typically pounded to a flour and then sieved to remove the hard, indigestible seed coating before being incorporated into a range of traditional foods at a proportion between 10-20% (Adewusi et al., 2006a, Harwood et al., 1999, Cunningham et al., 2008). The husk that is sieved off comprises around 40% of the seed mass, and this is fed to sheep or goats, which eat it with relish.

SIM workers reported that rural women have incorporated acacia seed into more than twenty recipes in the Maradi district. In all cases the adaptation is a simple substitution of a portion of the cereal flour with acacia meal, after which the recipe is prepared in the normal manner.

I was shown the acacia preparation procedures commonly used in Niger by members of my research team. Seed preparation in Niger tends not to involve pre-roasting and it is interesting that the unpleasant aftertaste common in Australian-grown seed tends to be markedly less in seed grown in Niger. The reason for this has not been investigated; one could conjecture that specifics of provenance, or differences in soil or climate or microbial associations are responsible for the difference. Acacia seed in Niger, though it is not pre-roasted, is still subject to cooking, and so most anti-nutrients should be reduced or removed.

9.3.2 Dietary Importance

It is difficult to be certain about how much acacia seed is harvested and eaten in the Maradi region. In villages that have been involved in SIM's acacia training, attitudes to the food are generally very positive. In village interviews I was often told that people like to eat acacia seed and that they eat it every day, when they have access to it. However the willingness with which producers sold their seed to SIM does tend to suggest that acacia is valued as a cash crop as much or more than it is valued as a subsistence food.

People who eat Acacia regularly speak enthusiastically about the seed. They enjoy the flavour, but particularly they love the lasting feeling of satiety that they get from a meal of Acacia (Cunningham and Abasse, 2005b). It is common to hear people say that they are able to work all day in the fields if they add it to their usual breakfast of millet *fura*. Another very common observation is that Acacia "brings down a mother's milk". Whether this property is simply a result of better nutrition being available to the mother, or whether there is another bio-chemical property at play (similar effects have been widely documented for other legumes including fenugreek (Gabay, 2002)), this is a quality for which Acacia is highly appreciated.

9.4 Nutritional value of Acacia seed

Screening conducted by the Australian Tree Seed Centre in 1994 indicated that *Acacia colei*: "... has good nutritional value and that known toxic and anti-nutritional factors were absent or at levels below those that would cause any concern" (Harwood et al., 1999). This section is concerned with nutrition. Toxic and anti-nutritional concerns will be addressed in Chapter

The seed of *A. colei* has been subjected to testing for nutritional potential and food safety from the early 1990's (Adewusi et al., 2006b, Adewusi et al., 2006a, Adewusi et al., 2003, Falade et al., 2005, Falade et al., 2008). Functional aspects of *A. victoriae* were investigated in some detail by a team from Charles Sturt University (Ee et al., 2009, Ee et al., 2008a, Ee et al., 2011, Ee et al., 2008b, Agboola et al., 2012). Testing on *A. saligna* was conducted in 2012 by Youzbachi et al. (2012) and by Ee and Yates (2013).

The amino acid balance in acacia seed is similar to other legumes, such as lentils, and as such acacia is an excellent complement to cereals, which are generally low in lysine. Adewusi et al. (2006a) tested Protein Efficiency Ratios and found the best complementarity was between acacia seed and the traditional cereal fonio (*Digitaria exilis*). Sorghum (*Sorghum bicolor*) was the next best complement, with pearl millet (*Pennisetum glaucum*) third. This was primarily due to the relatively low levels of methionine in acacia seed and compounded by the apparent interference of S-carboxyethyl cysteine (a non-protein amino acid) on methionine absorption (Falade et al., 2012). This issue with methionine means that acacia seed is best eaten with a supplementary source of methionine. Since animal source protein is scarce (and its scarcity is the reason for much malnutrition), alternative sources such as moringa leaf may offer a viable alternative that will yield other nutritional benefits, such as calcium, iron and Vitamin A.

A nutritional analysis of key species of acacia seed is presented in Table 9-1, 9-2 and 9-3.

Table 9-1. Proximate analysis of seed of four acacia species (raw, whole seed)

	Unit	<i>Acacia colei</i> ¹	<i>Acacia cowleana</i> ²	<i>Acacia tumida</i> ³	<i>Acacia saligna</i> ⁴
Protein (N x6.25)	g/100g	27.4	23.8	22.6	26.3
Ash	g/100g	4.3	3.5	-	4.43
Carbohydrates	g/100g	21	57.1	-	-
Total Sugars	g/100g	3.6	-	-	-
Total Dietary Fibre	g/100g	24.3	44.9	32.7	18.3
Moisture	g/100g	7.6	5.6	7.2	7.0
Energy	kJ/100g	1580	1246	-	2204
Total Fats	g/100g	15.3	11.0	-	10.52

¹ National Measurement Institute, Australia 2009; ² Brand and Maggiore (1992); ³ Adewusi et al (2003); ⁴ Ethiopian Ministry of Health (Unpublished Data) 2012.

Table 9-2. Amino acid analysis of seed of three acacia species (raw, whole seed)

Amino Acid	Unit	<i>Acacia coleii</i> ¹	<i>Acacia tumida</i> ²	<i>Acacia saligna</i> ³
Alanine	mg/g	9	9.0	8.6
Arginine	mg/g	16.9	15.2	16.1
Aspartic acid	mg/g	21.9	21.9	21.4
Glutamic acid	mg/g	36	30.5	36
Glycine	mg/g	9.4	12.1	13.3
Histidine	mg/g	6.4	7.1	5.3
Isoleucine	mg/g	8.9	8.4	7.4
Leucine	mg/g	17.4	16.1	14.7
Lysine	mg/g	14.9	15.2	12.4
Methionine	mg/g	1.9	2.6	1.7
Phenylalanine	mg/g	9.9	8.9	8.3
Proline	mg/g	10.6	9.9	8.6
Serine	mg/g	11.1	12.3	10.9
Threonine	mg/g	7.7	8.0	7.1
Tyrosine	mg/g	7.8	7.9	9.1
Valine	mg/g	10	13.4	8.8
Cysteine	mg/g	nd	2.8	2.7
Tryptophan	mg/g	nd	2.5	2.3

¹ National Measurement Institute, Australia 2009; ² Adewusi et al (2003); ³ Australian Proteome Analysis Facility 2012.

Table 9-3 Micronutrients present in *Acacia colei* seed (raw, whole seed)

Nutrient	Unit	Result	Nutrient	Unit	Result
Calcium	mg/100g	180	Ascorbic Acid	mg/100g	<1
Copper	mg/100g	1.5	Beta-Carotene	µg/100g	130
Iron	mg/100g	52	Thiamin	mg/100g	0.08
Magnesium	mg/100g	200	Total Folates	µg/100g	190
Phosphorus	mg/100g	280	Riboflavin (B2)	mg/100g	0.06
Potassium	mg/100g	1100	Niacin (B3)	mg/100g	1.1
Sodium	mg/100g	3.7	Retinol (Vit A)	µg/100g	<5
Zinc	mg/100g	2.9	Pyridoxine (B6)	mg/100g	0.29
Alpha-carotene	µg/100g	<5			

National Measurement Institute, Australia 2009.

10. Acacia Seed – Food Safety

From the early 1990's, in line with internationally recognised protocols for the introduction of novel foods, acacia seed has been subjected to a wide range of investigations to ascertain its safety for use as a food. Most of the research has centred on *A. colei* as this was the species selected as having the best agricultural/silvicultural potential for Niger. The principle anti-nutritional and toxic concerns are outlined below. The tests and trials conducted prior to 2008 are summarised in Table 10-1; Tests and trials conducted after 2008 are presented in Table 10-2, *other than* those commissioned by the author in the conduct of this study, which are presented in Table 10-3.

Following a workshop held at Glen Helen in 1991 (House and Harwood, 1992), Adewusi undertook a series of trials designed to assess the safety of *A. colei* as a human food. These included systematic *in-vitro* analyses, animal feeding trials and a human volunteer trial. Adewusi's human volunteer trial (Adewusi et al., 2006a) concluded that *A. colei* seed was safe for human consumption at 25% of the diet. For more than fifteen years since that time, the seed has been used as a food in several villages around Maradi, in Niger (Cunningham et al., 2008).

Whilst the nutritional work slowed between 1995 and 2009, agronomic research continued and Peter Cunningham's team at SIM had great success, in both seed and wood production, with a second species, *Acacia torulosa*. People already familiar with *A. colei* began to eat *A. torulosa* despite a complete lack of testing. Meanwhile, a number of extremely dry years resulting in failure of the acacias to set seed around Maradi highlighted the climatic limits of the *A. colei* genetic material, leading to the collection and agronomic trialling of a range of new acacia provenances and species thought to be better adapted to drier areas. This research arose from a sense that the adoption of acacia was not progressing as had been

hoped, and that part of the reason for this might lie in the lack of a market for the seed. The production of an acacia-based food product was seen as a promising way of creating such a market. Meanwhile, World Vision Australia began a project looking at the potential of *A. saligna* as a multi-use tree in Tigray, Ethiopia. For these reasons there has been something of a renewal of interest in acacia as a food since 2009.

10.1 Anti-nutritional considerations in acacia seed.

A substance is considered to be anti-nutritional when it interferes with the digestion or absorption of food (Shahidi, 1997). The impact may be general, causing a loss of most or all nutrients, or may be specific to a single type of nutrient (Shahidi, 1997). The effects of anti-nutritrients are dose dependent, and low levels of exposure may be harmless. The presence of anti-nutritional components in foods is common, but these substances are usually reduced to safe levels through processing or cooking (Hotz and Gibson, 2007).

Phytate

Phytate is the main form in which plants store phosphorus (Lott et al., 2000). Indigestible to humans, phytate is mostly found in the hulls and bran of cereals, seeds and nuts (Lott et al., 2000). Phytate is known to reduce the absorption of micronutrients, including zinc, iron and calcium and niacin (Hurrell, 2003). It can also interfere with the action of some digestive enzymes such as pepsin (Adewusi et al., 2011). Phytate occurs in relatively low levels in acacia seed. Adewusi et al. (2011) reported levels of 0.03 – 0.1 mg/g in *Acacia colei*, whilst Ee and Yates (2013) found 0.9 – 0.2 mg/g in *A. saligna*. A short period of roasting is sufficient to reduce phytate levels to negligible values (Ee and Yates, 2013).

Oxalate

Oxalate tends to form bonds with metal ions to produce an insoluble precipitate (Streitweiser and Heathcock, 1976). One such is calcium oxalate that has been linked to the development of kidney stones (Coe et al., 2005). Adewusi et al. (2011) report moderate levels of oxalate in *Acacia colei* seed (2.17 – 2.39 g/100g), much lower than that found in common vegetable such as cabbage and sweet potato. Ee and Yates (2013) report similar values for *A. saligna* with a range of 2.2 - 3.35 g/100g. The roasting process was found to reduce this oxalate present by around 30%.

Fibre

Whilst fibre is an essential part of the diet that works to maintain intestinal health, it is also known to reduce the availability of many micronutrients (Greger, 1999). Given the high levels of micronutrient malnutrition in the developing world, WHO recommendations are to limit fibre in foods intended for infants and young children (WHO, 2004b). Acacia seed is quite high in fibre, particularly so if the seed husk is not adequately removed. Adewusi et al. (2011) found dietary fibre in acacia seed to range between 28.5 – 32.7% though it is not clear whether this is whole seed or the husk has been removed. Yates (2010) reported total dietary fibre in whole *A. colei* at 24.3% with the husk present, whilst Ee and Yates (2013) reported fibre in *A. saligna* at a range between 12.8 and 15.4% with the husk present. Fibre content appeared to increase by around 3% as a result of roasting, probably due to the loss of moisture.

Saponins

Saponins are a class of glycosides with a soap-like structure (Streitweiser and Heathcock, 1976). Saponins are reputed to reduce the availability of iron (Hostettmann and Marston, 1995). Saponins also have many health benefits, including the reduction of blood

cholesterol (Oakenfull and Sidhu, 1990). Saponin levels in *Acacia saligna* seed are relatively low at 2.5 – 3%, with this value reduced by around 30% by cooking (Ee and Yates, 2013).

Tannins

Tannins are another class of compound that bestow both positive and negative health effects depending on their particular chemistry and the dose (Habauzit and Morand, 2011). Amongst the anti-nutritional effects are inhibited digestion and binding of some micronutrients, in particular non-haem iron (Matuschek and Svanberg, 2002). The tannin-rich diets of India have been implicated in the high levels of anaemia in that region (Rao and Prabhavathi, 1982). Tannins can also reduce protein availability by binding with amino acids and rendering them indigestible. This effect can be lessened where the amino acid proline is plentiful, as it is in *A. colei*, being present at 10.6 mg/g (McArthur et al., 1995, Yates, 2010). Adewusi et al. (2011) report improbably high tannin levels in *A. colei* at 86.7 mg/g, and an average of three seedlots of *A. tumida* at 76.4 mg/g. It is likely that the correct measurement unit should be mg/100g, which would be in line with results from the Ethiopian Nutrition and Health Research Institute (unpublished data) which reports a range of 41.5 – 157.5 mg/100g for tannin in two samples of *A. saligna* seed. Such levels, whilst high, are low compared to black gram (*Vigna mungo*), which ranges between 930 – 1165 mg/100g (Zia Ur and Shah, 2001). Tannin levels in acacia seed can be reduced significantly through soaking and cooking (Ee and Yates, 2013).

Protease Inhibitors

Protease inhibitors include compounds such as trypsin inhibitor and chymotrypsin inhibitor, which interfere with protein digestion and absorption (Ee et al., 2008b). Such compounds are commonly found in legume seeds, and acacia is no exception. Adewusi et al. (2011) report relatively low levels of trypsin inhibitor in *Acacia colei* with levels ranging between 18 - 24.5 TUI/g, whilst Ee and Yates (2013) report between 2500 – 3200 TUI/g in *A. saligna*.

Cooking was shown to be very effective in reducing trypsin inhibitors to negligible levels (Ee and Yates, 2013).

Non-protein amino acids

Non Protein amino acids are a diverse group of compounds, some of which are quite toxic, whilst others merely interfere with digestion or absorption of other nutrients and can be considered therefore to be anti-nutritrients (Hunt, 1985). Non-protein amino acids probably exist as nitrogen stores in the seed, and/or offer protection against predation by insects (Bell, 2003). Testing by Harwood (1994) indicated insignificant levels, or absence of toxic non-protein amino acids commonly found in legumes (lathyrogenic amino acids, djenkolic acid, S-carboxyethyl cysteine, albizzine) across five species of acacia seed. Testing by Metabolomics Australia (commissioned by the author) was able to detect carboxymethyl cysteine, lanthionine, homocysteine, putrecine, cadaverine, djenkolic acid and phenethylamine (Table 10-6). All of these amino acids were in negligible quantities except djenkolic acid, which was found at an order of magnitude greater than was reported by Harwood (1994). Djenkolic acid, which is potentially toxic at such concentrations, is discussed at length below.

Carboxyethyl Cysteine

Harwood (1994) reports carboxyethyl cysteine at a range of 3.62 – 4.45 mg/g across five acacia species, (*A. colei*, *A. cowleana*, *A. tumida* *A. neuracarpa* and *A. holosericea*). Falade et al. (2012) investigated the effects of carboxyethyl cysteine and concluded that the compound interferes with the availability of methionine in a dose-dependent fashion. This effect is potentially quite significant, since methionine is already in very short supply in most poor rural diets. A shortage of absorbable methionine will limit the efficiency of protein use, possibly tipping vulnerable people into deficiency. Falade suggests that the problem could probably be overcome if high methionine foods such as the traditional grain

acha (*Digitaria exilis*) are eaten along with acacia (2012). Moringa leaf would also provide excellent methionine supplementation (Price, 2007).

Toxic considerations in acacia seed.

A serious concern regarding potential toxicity in acacia seed emerged when two sub-acute toxicity trials run by the Ethiopian Health and Nutrition Research Institute (EHNRI) encountered animal deaths after only a few days. In the first trial, mice were fed 100% raw *A. saligna* seed. This seed would have had its full complement of protease inhibitors and other predation defenses intact. The seed may have been highly unpalatable, and the mice may have died of hunger, since no feeding data was collected. EHNRI staff suspected cyanide toxicity, but declined to share any information on symptoms or post-mortem examinations if indeed these were conducted.

In the second trial, *A. saligna* seeds processed by a range of methods were fed to rats in an effort to discover whether the toxin could be denatured, and if so in what manner. Feeding was again 100% acacia seed. In this trial, rat deaths began after 6 days and only one group survived the 14 days, though they lost weight and appeared 'restless and depressed'. Again no feeding data seems to have been collected, and no histopathological examination was conducted to explore the etiology of the toxin.

Notwithstanding the inadequate design (and rather opaque conduct) of the Ethiopian study, I felt it of paramount importance to identify the cause of the rat deaths and so, as a matter of urgency, I commissioned, from the Surface and Chemical Analysis Network (SCAN), and the University of Melbourne, a screen of several species of Australian acacia for cyanide content. Tests on a total of seventeen species and provenances of acacia were

conducted by the Surface and Chemical Analysis Network of the University of Melbourne (SCAN), using a technique described by Bradbury (2009), wherein picrate paper is introduced to a container along with the test material which has been treated to activate the conversion of cyanogenic glycosides into Hydrogen cyanide. The tests revealed only negligible levels of cyanide (unpublished data – see Table 10-1). The highest measurement was for *Acacia adsurgens* at only one third of the 10ppm acceptability level set by the WHO (WHO, 2004a).

Table 10-1. Cyanide content of seed of selected acacia species. Surface and Chemical Analysis Network, University of Melbourne, commissioned by the author.

Species	Average HCN Response (PPM)	Species	Average HCN Response (PPM)
50ppm Standard	39.25	<i>A. tumida</i>	1.04
<i>A. adsurgens</i>	3.12	<i>A. torulosa</i>	0.94
<i>A. baileyana</i>	0.94	<i>A. pycnantha</i>	0.84
<i>A. melliodora</i>	0.89	<i>A. microbotrya</i>	0.74
<i>A. aneura</i>	1.14	<i>A. saligna</i> ssp <i>saligna</i>	0.25
<i>A. elacantha</i>	1.29	<i>A. saligna</i> ssp <i>lindleyi</i>	1.34
<i>A. cowleana</i>	0.55	<i>A. saligna</i> ssp <i>stolonifera</i>	1.68
<i>A. colei</i> var <i>ilocarpa</i>	0.74	<i>A. saligna</i> ssp <i>prunescens</i>	1.04

With cyanide thus ruled out, I commissioned a screen for fluoroacetate from SCAN at the University of Melbourne. Fluoroacetate is known to occur in some Australian plants, including *Acacia georginae*, and was considered a possible cause of rat deaths in the Ethiopian trial. Tests by SCAN using X-ray reflectance revealed no fluoroacetate in either *A. colei* or *A. saligna* (unpublished data).

I next asked Metabolomics Australia to test for known toxic amino acids in several species of acacia seed. The amine results revealed moderate levels of CEC and low levels of CMC.

However, one surprising result was the discovery of significant levels of djenkolic acid in all the acacia species tested, with a range between 0.49 – 1.8% (Boughton and Yates, Forthcoming). Prior to this research, djenkolic acid had not been identified as present in significant quantities in the seed of Australian acacias.

10.1.1 Djenkolic Acid

Djenkolic acid is a toxic amino acid that is best known as the apparent cause of 'djenkolism', an acute illness that can occur following the consumption of djenkol beans (*Archidendron pauciflorum*). Djenkolism was first attributed to djenkolic acid by van Veen and Hyman (1933). Symptoms seem to be related to the precipitation and crystallisation of the compound within the urinary system, and include acute renal failure, hematuria, painful loins, nausea, vomiting and abdominal pain (Wong et al., 2007, Wiwanitkit, 1995, Iam-Ong and Itpritja, 1998, Adler and Weening, 2006, D'Mello et al., 1991).

The djenkol bean is regarded as a delicacy in South East Asia, and has also been used medicinally, most notably for the treatment of diabetes mellitus (type ii) (Shukri et al., 2011).

The precise triggers for djenkolic acid toxicity episodes remain unknown. According to Adler and Weening: "The preparation of the beans doesn't seem to be implicated in the idiopathogenesis. The affliction status of individuals is different, so at a large gathering of people eating the same beans, some will develop acute renal failure while others won't. Furthermore, an individual's susceptibility to acute renal failure from the bean is not fixed from one exposure to the next" (Adler and Weening, 2006). Vingneaud and Patterson (1936) report that: "...individuals differ greatly in their sensitivity, some becoming sick after eating as little as one-half of a bean weighing about 15 gm., while others may eat up to ten

or more beans before the occurrence of pathological symptoms such as abdominal and lumbar pains accompanied by painful micturition" (Vingneaud and Patterson, 1936). A range of environmental and dietary conditions may be important in predisposing a person to djenkolism. A person's hydration status could be a major factor, so physical activity and/or ambient temperature could play a part (Iam-Ong and Itpritja, 1998, Barceloux, 2008). Similarly, dietary influences that increase the pH of the urinary system may favour solubility of the djenkolic acid, and thus reduce the risk of illness. According to Adler and Weening (2006) the condition mainly affects men, though it is not clear whether this is due to gendered eating habits or some other factor.

The literature is scant on the chronic effects of djenkolic acid. Areekul et al. (1978) suggest that crystals formed in the kidneys could form the basis for the development of kidney stones. Vachanichsanong and Lebel (1997) report a study of 609 Thai school children that found four times the likelihood of haematuria in children that regularly consumed djenkol beans, The incidence of crystalluria and pyuria in the children was unaffected, however. The observation of "mild to severe acute tubular necrosis with some glomerular cell necrosis" in the kidneys of rats and mice fed djenkolic acid by Areekul et al. (1976) also suggests that the chronic effects of djenkolic acid consumption may be of concern. In another study, Shukri et al. (2011) fed rats a diet equivalent in humans to 5-6 grams/day of whole djenkol bean over a fifteen week period, and observed toxic effects on the heart, liver, kidneys and pancreas. A comparable human dose, calculated on available data translates to only 100mg of djenkolic acid per day.

A further potential toxic effect related to djenkolic acid and worthy of consideration is the production of carbon disulphide through the effect of cysteine lyase (an enzyme) on djenkolic acid in many species in the Fabaceae family, including many acacias (Piluk et al.,

2001). Carbon disulphide is a well-known neurotoxin that has an LD50 of 3188mg/kg (WHO, 2002). Djenkolic acid exists in *A. saligna* at 1.9%, and only a modest proportion of this would need to be hydrolysed to generate dangerous levels of carbon disulphide. It is not known at this time whether this process occurs, or to what degree, in any of the Acacia species under consideration. Nevertheless, the phenomenon would be consistent with the rat deaths observed in experiments in Ethiopia and should be considered a real possibility.

10.1.2 Djenkolic acid in acacia seed

Djenkolic acid has been reported in the seed of several acacias in Australia, Asia and the Americas (Maslin et al., 1998, Seigler, 2002, Or and Ward, 2004), where they are believed to be a defense against predation. The actual levels of djenkolic acid in acacia seed has either been of mere academic interest, since the seed was not widely eaten by humans, or else the levels present were generally considered to be sub-toxic (Maslin et al., 1998, Seigler, 2002, Harwood, 1994). The analysis by Metabolomics Australia indicated that levels of djenkolic acid are comparable to, or possibly exceed those found in the djenkol bean. Djenkolic acid content in djenkol beans is reported by Areekul et al. (1976) to be 0.3 - 1.3 grams per 100g. Lucas et al. (1988) report a higher range of 1-2 grams per 100 grams.

Of the Australian acacias tested as part of this research, *A. saligna* was the highest, with 1.8 grams per 100 grams, and *A. colei* the lowest, with 0.49 grams per 100gram.

It is very difficult to determine a safe dose of djenkolic acid in acacia seed. On the one hand, a mere 15 gm of djenkol bean, containing as little as 0.3 grams of djenkolic acid (assuming 2% toxin, the upper limit reported by van Veen and Hyman (1933), can cause

illness in one person, whilst another person can consume perhaps 6 grams before symptoms emerge - a twentyfold difference.

Calculating from the Metabolomics Australia results, the lower dose of this range would be met by 17.5 grams of raw *A. torulosa* seed, or 61 grams of raw *A. colei* seed, whilst the higher dose would need 346 grams of *A. torulosa* seed, or 1224 grams of *A. colei* seed. Whilst it may be difficult to imagine a person eating over a kilogram of seed at a sitting, at the other extreme, 17.5 grams of *A. torulosa* is a mere few spoonfuls, and this amount would be exceeded regularly by many people in Niger.

These results indicate that some acacia seeds may well pose a serious risk to human health. Nevertheless, it is important to point out that there has never been any report from anywhere, Africa or Australia, linking the consumption of acacia seed with any illness.

The results of processing trials show that roasting *A. colei* and *A. torulosa* seed for 6 minutes at 180° Celsius seed reduces djenkolic acid levels by over 90% (Boughton and Yates, Forthcoming).

10.1.3 Acacia seed (djenkolic acid) safety trial November 2013

In November 2013, a study by the Florey Institute for Neuroscience and Mental Health was completed. This study was commissioned by the author, but is not a part of the present research (Featherby and Yates, Forthcoming). In this 14 day study (n=100), rat diets were supplemented with processed acacia seed (*A. colei*, *A. torulosa* and *A. saligna*) at either 30% or 60% of diet. The acacia seed was processed by roasting to achieve the optimal method for djenkolic acid reduction (Boughton and Yates, Forthcoming) and the seed husk

removed. A further three cohorts were fed diets supplemented with synthetic djenkolic acid at levels equal to the highest djenkolic acid dose delivered by the acacia seed, at 25% below this, and at 25% above this.

Preliminary results, including histological examination of the kidney and liver, indicate no toxic effect in any of the animals. Though the results of the study are insufficient to categorically conclude that properly processed acacia seed is safe for humans to eat, the absence of any sign of toxicity, even at relatively high levels of intake, is a strong indicator that acacia seed can be a safe food.

Further studies are planned as follows:

1. A study to determine a safe exposure ceiling for djenkolic acid in acacia seed; and
2. A study over 90 days to examine the effects of chronic dietary exposure to high doses of djenkolic acid in acacia seed.

Table 10-2. Summary of acacia seed studies prior to 2008.

Analysis	Year	Species	Reference	Comments
Macronutrient composition	1991	<i>A. cowleana</i> <i>A. holosericea</i> <i>A. tumida</i>	Brand and Maggiore (1992)	Average over 3 species (g/100g): Protein: 22.1 Carbohydrate: 15 Fat: 8.3
Non protein amino acids	1992	<i>A. colei</i> <i>A. cowleana</i> <i>A. tumida</i> <i>A. neuracarpa</i> <i>A. holosericea</i>	Harwood (1994)	Average over 5 species (mg/100g): Djenkolic acid: 1.8 S-carboxyethyl cysteine: 4.7 Albizzine: 6.28
Macronutrients/Micronutrients Anti-nutritionals (tannins, saponins, oxalate, phytate, tripsin inhibitors)	1992 – 2008	<i>A. colei</i> <i>A. tumida</i>	Adewusi et al. (2003) Adewusi et al. (2006b) Falade et al. (2008) Falade et al. (2005)	See Table 9-1, Table 9-3 and Table 10-5.
Toxicity trial (using rats)	1993	<i>A. colei</i>	Adewusi et al. (2011)	28 day trial feeding 42-50% <i>A. colei</i> seed in protein-free and casein control diets.
Rat reproduction trial	1994	<i>A. colei</i>	Adewusi et al. (2006b)	Methionine shown to be limiting amino acid
Human volunteer trial	1995	<i>A. colei</i>	Adewusi et al. (2006a)	Human volunteers were fed 15 and 25% <i>A. colei</i> seed with traditional diet in Maradi, Niger. Study concluded there are no negative health effects with 25% acacia seed in the diet.

Table 10-3. Acacia nutrition and toxicology research since 2009: *excluding* work commissioned by the author as part of this study.

Analysis	Year	Species	Reference	Comments
Effect of s-carboxyethyl cysteine on amino acid utilisation	2012	<i>A. colei</i>	Falade et al. (2012)	Demonstrates that s-carboxyethyl cysteine interferes with methionine availability or absorption.
Functional properties of <i>Acacia victoriae</i>	2008-2012	<i>A. victoriae</i>	Agboola et al. (2012) Ee et al. (2009) Ee et al. (2008a) Ee et al. (2011) Ee et al. (2008b)	
Sub-acute toxicity	9/2012	<i>A. saligna</i>	Unpublished data Trial conducted by Ethiopian Food, Medicine and Health Care Administration and Control Authority.	Inadequate trial. Mice were fed 100% raw, whole <i>A. saligna</i> seed. Trial was abandoned after 4 days when animals started dying.
Sub-acute toxicity	11/2012	<i>A. saligna</i>	Unpublished data. Trial conducted by Ethiopian Food, Medicine and Health Care Administration and Control Authority.	Inadequate trial. 15 days feeding rats 100% <i>A. saligna</i> seed prepared in a variety of ways. Animal deaths in most treatments after 6-8 days. No post-mortem examination. No histology examination.
Sub-Acute toxicity trial Verification of djenkolic acid as the active toxin.	November 2013	<i>A. saligna</i> <i>A. colei</i> <i>A. torulosa</i>	Florey Institute for Neuroscience and Mental Health	14 day trial feeding acacia seed processed using optimally processed seed. Three treatments feeding different doses of synthetic djenkolic acid. Histological examination of all animals.

Table 10-4. Research commissioned by the author as part of this study

Analysis	Year	Species	Reference	Comments
Macronutrients/Micronutrients	2009	<i>A. colei</i>	Yates (2010)	See Table 9-1 and Table 9-3
Amino acid characterisation	2009	<i>A. colei</i>	Yates (2010)	See Table 9-2.
Non-protein amino acids	2012	<i>A. colei</i> <i>A. torulosa</i> <i>A. saligna</i> <i>A. tumida</i> <i>A. elacantha</i>	Unpublished data Analysis conducted by Metabolomics Australia. (Boughton and Yates, forthcoming).	See Table 10-6 .
Cyanide	2012	<i>A. colei</i> <i>A. adsurgens</i> <i>A. torulosa</i> <i>A. tumida</i> <i>A. elacantha</i> <i>A. microbotrya</i> <i>A. saligna</i> : <i>ssp saligna</i> <i>ssp lindleyi</i> <i>ssp pruinescens</i> <i>ssp stolonifera</i>	Unpublished data SCAN University of Melbourne	Cyanide content in the acacia species sampled was highest in <i>A. adsurgens</i> at around 4ppm. WHO allowable levels for HCN in food is 10ppm. See Table 10-1 .
Macronutrients	2012	<i>A. saligna</i> <i>ssp saligna</i> <i>ssp lindleyi</i> <i>ssp pruinescens</i> <i>ssp stolonifera</i>	Ee and Yates (2013)	See Table 9-1.
Anti-nutritional factors (phytate, oxalate, protease inhibitors, saponins, phenolics). Processing methods to reduce anti-nutritrients	2012	<i>A. saligna</i> : <i>ssp saligna</i> <i>ssp lindleyi</i> <i>ssp pruinescens</i> <i>ssp stolonifera</i>	Ee and Yates (2013)	All anti-nutritrients tested reduced to insignificant levels by 10 minutes roasting
Fluoroacetate	2013	<i>A. saligna</i> <i>A. colei</i>	Unpublished data. SCAN University of Melbourne	No fluoroacetate detected.
Djenkolic acid reduction through processing	2013	<i>A. saligna</i> <i>A. colei</i> <i>A. torulosa</i>	Metabolomics Australia (Boughton and Yates, Forthcoming)	90% reduction in djenkolic acid after 6 minutes at 180°C in <i>A. colei</i> and <i>A. torulosa</i> .

Table 10-5. Anti-nutritrients and toxins in seed of selected acacia species

Anti-nutrient or Toxin	Unit	<i>A. colei</i>	<i>A. torulosa</i>	<i>A. tumida</i>	<i>A. elacantha</i>	<i>A. saligna</i>
Oxalate	g/100g	2.40 ¹	-	2.30 ¹	-	2.30 ²
Phytate	mg/g	0.09 ¹	-	-	-	0.08 ²
Saponins	g/100g	-	-	-	-	3.01 ²
Tripsin Inhibitor	TIU/g	23.0 ¹	-	24.5 ¹	-	3000 ²
Tannin	mg/g*	86.7 ¹	-	80.3 ¹	-	-
S- Carboxyethyl Cysteine	mg/g	4.40 ³	-	7.23 ³	-	-
Djenkolic acid	g/100g	0.49 ⁵	1.70 ⁵	0.94 ⁵	0.53 ⁵	1.80 ⁵
Cyanide	ppm	0.74 ⁴	0.94 ⁴	1.04 ⁴	1.29 ⁴	0.25 ⁴
Fluoroacetate		nd ⁴	nd ⁴	nd ⁴	-	nd ⁴

¹ Adewusi et al (2003); ²Ee and Yates (2013); ³Harwood (1994); ⁴SCAN University of Melbourne;

⁵Metabolomics Australia.

*Note likelihood of an error.

Table 10 6. Amino acids and potentially toxic or anti-nutritional amines in seed of selected Acacia species. (Pmole/mg material). Metabolomics Australia, commissioned by the author. Note: carboxyethyl cysteine could not be quantified due to lack of a standard.

Component	Soy (for comparison)	<i>A. torulosa</i>	<i>A. elacantha</i>	<i>A. colei</i>	<i>A. tumida</i>	<i>A. saligna</i> (raw)	<i>A. saligna</i> (roasted)
Carboxy-methylcysteine	7.5	255.4	150.1	191.6	165.5	57.7	47.1
Djenkolic acid	22.3	68251.9	21169.3	19366.3	37113.7	72749.9	64134.4
4-hydroxy-proline	33.2	69.4	102.0	51.9	32.0	61.1	43.6
Histidine	149.4	396.6	1337.8	1596.5	1083.4	398.1	311.1
Asparagine	364.8	6569.1	3462	2645.4	9856	2849.4	4057.8
Arginine	2008.1	6023.9	7899.1	6500.9	7177.9	8691.2	8255.4
Serine	112.1	151.4	289.3	386.7	152.3	260.4	342.7
Glutamine	23.8	184.7	365.7	565.7	243.9	235.7	122.8
homoserine	7.3	11.5	57.5	51.8	31.8	40.0	27.6
Taurine	29.6	32.5	32.0	30.7	32.1	31.3	36.4
Glycine	195.4	324.3	331.2	356.2	274.3	702.8	391.2
Sarcocine	11.1	10.9	11.1	11.2	10.7	12.1	12.8
Aspartamine	1283.2	2547.7	1604.7	1696	2423.3	1148.3	1587
beta-Alanine	185.4	533.5	20.9	28.8	236.1	56.3	120.9
Glutamic acid	2609	2059.7	1049.3	1156.1	2229.6	1907.7	1400.6
Threonine	73.9	260.8	263	331.5	350.3	395	364
Alanine	810.5	912.6	1285.6	2115.4	2327.9	1418.3	2494.8
Glutathione	-	2757.2	1737.1	1637.4	2151.8	1988.1	886.2

Component	Soy (for comparison)	<i>A. torulosa</i>	<i>A. elacantha</i>	<i>A. colei</i>	<i>A. tumida</i>	<i>A. saligna</i> (raw)	<i>A. saligna</i> (roasted)
gamma-Aminobutyric acid	269.6	552.5	220.4	550.9	527.9	11.3	45.2
Proline	138.1	769.7	526.9	439.5	406.2	858.7	634.7
Cysteine	53.7	74.8	62.6	61.6	68.0	114.8	316.3
Homocysteine	-	268.3	-	-	149.0	157.2	145.7
Ornithine	-	86.9	101.2	121.7	137.0	258.7	350.0
Putrescine	13.4	11.7	12.9	15.8	12.1	19.7	34.0
Lysine	40.9	308.8	575.8	634.5	306.4	427.8	461.3
Cadaverine	13.2	1.5	-	-	-	1.2	2.1
Spermidine	23.9	15.4	20.2	20.9	16.2	14.4	16.3
Tyrosine	40.3	76	92.7	88.4	80.5	124.4	102
Methionine	82.7	47.7	55	52.9	47.9	43.4	41.8
Valine	132.7	162.2	268.8	309.5	198.3	262.5	338.5
Leucine	100.2	81.2	144.4	192.8	96.5	128.6	140.4
Isoleucine	138.2	76.5	151.6	203.3	119.3	173.2	143.8
Phenelalanine	122	91.5	138.5	154.5	102.9	209.8	158.3
Tryptophan	381.6	357	136.9	200.1	446.9	281.8	275.9
Phenethylamine	-	33.5	33.8	33.8	42.2	-	35.8

10.2 Implications for an Acacia based food

The viability of an acacia based complementary food and indeed acacia seed as a food in general, is in the balance pending the resolution of the toxicity issues as part of a benefit-risk assessment process (Tijhuis et al., 2012). If quantities of djenkolic acid can be reduced sufficiently through processing, then the risks of a small exposure to the toxin may be greatly outweighed by the health benefits of increased access to food and reductions in exposure to malnutrition both for individuals and for society as a whole. The potential nutritional benefits of acacia seed have been demonstrated in Chapter 9. Further research will need to focus on verifying that djenkolic acid is the only toxin operative, on identifying

a safe level of dietary exposure (which may vary according to age and gender), on identifying processing and cooking techniques appropriate to developing world settings.

It should be borne in mind that *A. colei* has been subjected to a rigorous testing process, and consumed in Niger for over fifteen years with no reports of any related health problems. The latest test results from the Florey Institute for Neuroscience and Mental Health are consistent with these observations. The wide range of djenkolic acid content between species may still mean that some species are suitable whilst others are not.

11. Potential modes of production for an *Acacia kunu*

I argue that an *acacia kunu* could be promoted at three distinct levels, the household/subsistence level, the urban/microenterprise level and the formal/food aid level. At the Household/subsistence level the concept and recipe for an *acacia/moringa kunu* is promoted, as part of a package that provides nutritional education, encourages the planting of *acacia* and *moringa* trees, and includes measures to ensure that *acacia* seed is available to those who wish to buy it. The urban/microenterprise level involves supporting and replicating small enterprises and will do much to alleviate malnutrition in urban areas. At the formal/food aid level, a process of further refinement, validation and large scale production of a highly nutritious *acacia kunu* that is composed mainly of local ingredients will allow nutritional support to vulnerable families during dry years.

These levels enable access to distinctly different elements of the food system, and each is most operative under a particular set of environmental/social circumstances. The tiered conception draws on existing social and economic institutions in the production of both household food and food aid, and through the embedded action of building rural livelihoods and resilience, ameliorates the conditions that call for food aid in the first place.

The *acacia kunu* offers an integrated model wherein everyday forms of food are improved – with that improvement driving refinements to the agricultural system – and are employed at several levels in a mutually supporting way. Thus in a good year, a mother might make *acacia kunu* for household use, using mainly products grown on the family farm, and school feeding programs might utilise an *acacia kunu* mix produced by a local enterprise. In the inevitable bad year, a very similar product may be distributed to vulnerable families by a

humanitarian agency to prevent child malnutrition. Meanwhile, all levels of consumption directly support local agricultural production and rural livelihoods, thus strengthening other aspects of nutrition and health.

11.1 Acacia/*Moringa kunu* for households in rural villages

Realisation of acacia *kunu*'s potential to reduce child malnutrition requires promoting the idea to rural women. The importance of the approach lies not only in the number of children that could be reached thereby, but also in that this would be a fundamentally preventative action, entirely within the means of rural people. It could be expected to improve basic child nutrition levels, especially with regard to children's access to quality protein, fats and vitamin A. In effect, this approach also reduces Niger's dependence on the international community for that most basic human need – food. This approach would also empower women to take an active role in improving the feeding of their children, with a focus on improving current practice and outcomes with available resources. The resulting food would not be perfect in every respect – for example, it remains low in calcium, and so the continuation of breastfeeding should be strongly encouraged until a child is at least 12 months of age. Alternative livelihoods strategies, especially those that involve raising small livestock also have much to contribute.

Promotion of acacia *kunu* in rural areas would be initially restricted to those villages where acacia seed is already grown and is well accepted as food. In these areas it would be an extremely simple and cheap undertaking. As acacia as a crop is further promoted and adopted, and also as its availability in the market grows, so too will the number of potential beneficiaries. An effective delivery package would need to incorporate both agricultural

and nutritional elements, with tree seed and silvicultural training provided to farmers, and nutritional training provided to families.

It is important that acacia *kunu* be promoted as a flexible concept. Our purpose should be to take a set of existing (if flawed) practices and show how they can be modified in order to produce a better outcome. The objective is not to help mothers produce a perfect food (something that is effectively out of reach of the target population), only a better one. The nutritional education provided would need to emphasize ingredient substitution within categories, according to price and availability, rather than adherence to a strict recipe.

Table 11-1. suggests a set of nutritional categories and roughly analogous foods that can be substituted to maximise nutrition in a food prepared for infants and young children.

The message needs to be that substitutions are preferable to omissions. If a family has run out of acacia seed, it is better by far to replace it with cowpea or soybean than to leave the pulse out altogether. The preference would be for the ingredient ranked highest in each column that is both available and affordable. A *kunu* made from only top ranked ingredients will be close to optimal, given the range of available foods. A *kunu* made from ingredients ranked at 2-3 would still be very good, and dramatically better than a *kunu* made solely of pearl millet.

Table 11-1. Ingredient preference chart for improved child feeding at the village level.

	% of Diet	Contribution to Diet	First choice	Second choice	Third choice
Grains:	55-70	Carbohydrate, protein	Pearl millet Sorghum	Maize Rice	Cassava
Pulses:	0.15	Protein, carbohydrate	Acacia seed	Cowpea Soybean	
Oilseeds	0.15	Energy	Peanut	Peanut oil	
Green leaves:	3-8	Micro-nutrients esp. vitamin A, iron and folic acid	Moringa leaf	Baobab leaf Cassava leaf Marula leaf (<i>Sclerocarya birrea</i>)	Roselle leaf Sweet potato leaf
Fruit:	3-7	Micro-nutrients esp. vitamin C	Baobab fruit pulp	<i>Ziziphus mauritania</i> fruit	Marula fruit Date (<i>Phoenix dactylifera</i>)
Salt	0.01	Electrolyte	Iodised	Native salt	
Sugar	Up to 10	Energy	As available	As available	As available

11.2 Potential challenges to implementation

The potential for promotion of acacia *kunu* in rural households is initially limited to those villages where acacia is currently grown. At a minimum people must have an awareness of acacia seed as food, and some ability to obtain acacia seed either from their own trees, from a cereal bank or from the market.

The potential of the concept is at present limited by the low availability of acacia seed. Seed needs to be made more available, firstly by encouraging village cereal banks to keep a supply as part of their stock, by encouraging (and if necessary financing) petty traders to keep acacia seed stock for sale to villagers (c.f. Rowlands, 2009), and ultimately, by increasing tree numbers on smallholder farms.

This is an initiative that, if implemented, could be expected to yield most of its benefits during the relatively good years, when rural people are able to provide for most of their food needs themselves. It will probably help to some extent in poor years by informing buying choices, so that household food purchases may extend beyond just basic grains, to include other important food groups. There will be years, however, when people have no capacity to feed themselves, and at these times, further support will certainly be needed.

11.3 Acacia/Moringa *kunu* production by micro-enterprise

As shown in Chapter 7, the semi-commercial production of acacia *kunu* within a micro-enterprise was a direct outcome of the research (though sporadic efforts to create and sell acacia products have also occurred in the past). At the time of writing, the enterprise group in Maradi have been in production for almost four years. The *kunu* mix is being marketed under the name “*Kunnun gina jiki Vitamin*”, or “*Kunu* that builds the body with vitamins”. For my own part, I would be happier with the name if the moringa leaf content was higher. Nevertheless it is still a big improvement on pearl millet *kunu* and is not in any case intended to be the sole food intake of any child.

My initial support for the micro-enterprise production was based on the belief that this would be an effective way of making a better complementary food available in urban areas. Despite the greater range of food available, and the higher average wealth levels in urban areas, malnutrition levels are as high in many of Niger’s towns as they are in rural areas (Cooper, 2009). This may be because towns attract very poor people who, having lost their

livelihoods, are no longer able to live in their own villages⁸. These urban migrants tend to bring with them and replicate the asymmetrical social relationships and detrimental weaning practices that are implicated in rural malnutrition.

The micro-enterprise production of acacia/moringa *kunu* has good potential for expansion and replication into new regions, where it could provide income and independence to entrepreneurial women. Micro-enterprise production utilises and builds on local community assets and capacities. Since most ingredients can be locally produced, such enterprise strengthens the local agricultural economy and food production system. The start-up capital required is small, and the entire process uses widely available, simple technologies is simple and familiar to Hausa women. using widely available technologies. An investment in labour saving technology may improve production quality and efficiency, but because labour costs are so low there may be little pay-off in terms of lower prices. The almost complete lack of access to electricity in rural areas also limits the possibilities for technological investment.

The major limiting factor for any acacia *kunu* production over the next several years will be acacia seed availability. Expanding micro-enterprise production of acacia/moringa *kunu* would help to create an immediate market for acacia seed that is highly visible to the potential growers – the farmers – and thus should strongly encourage increased plantings. This mode of production can be undertaken very quickly and at very little cost. It is thus a viable way of improving the availability of improved foods without the time-lag of waiting for formal production to start.

⁸ Livelihood or health crises may force people to sell their land; drought might reduce opportunities to sell labour; women may be divorced or otherwise abandoned.

The micro enterprise approach would require widespread replication. The production potential of each enterprise will be limited by labour availability and distribution reach, so many enterprises would be needed. Each enterprise would require investment, and each need to be built around the right set of assets: women, buildings, training opportunities and markets. Replication could, however, potentially lead to problems with the quality and consistency of the product. It may be necessary for micro-enterprise production to be operated on a franchise basis, with producers offered start-up capital and technical assistance and also subject to quality assurance standards and procedures.

11.3.1 Challenges in micro-enterprise production

During a return visit to Maradi in June 2010, I followed up on the experiences of the *kunu* producers in some depth. Whilst all rhetoric pointed to a successful enterprise, the reality that emerged was that only 50kg of acacia seed had been used in the preceding year, which translated to a mere 650 X 300g bags of *kunu* over the nine months: sales equivalent to approximately AUD\$430. This is not a volume of production and sales that is going to make any difference to child nutrition, create an acacia market or indeed provide anyone with a livelihood! Hadiza and Mariama reported a number of reasons for the slow development of the business, which included:

- A lack of time. Both of the key women have families and other sources of income that take up a lot of their time. In an environment such as that in Niger, livelihood diversity and risk minimisation are sensible strategies, and neither of the women involved were willing to forego the employment/income-generating activities they already have for an unproven business.
- Shortage of working capital.

- A lack of confidence in the product. Though all the ingredients of the *kunu* are well-known, there is a reticence about promoting it, since it is unproven and untested. The maker's confidence in the product was not bolstered by the constant talk of 'needing to test' for larger scale production.
- A lack of marketing expertise. Neither of the women had a clear sense of where their best market opportunities lay. Advice and subsequent assistance from SIM pushed them towards the rural villages, whilst the potential of the urban market was virtually ignored.
- Logistical blockages. With major market outlets being accessed with assistance from SIM (travel in rural areas is difficult and expensive), problems have occurred with regard to cash flow. Even obtaining a new bag of Acacia seed needed the cooperation of SIM staff, for whom this was not 'core business' and was thus liable to be pushed to the bottom of the list.
- Technical and capital. The business can operate at a very low level of technology quite successfully, as long as sales remain at a low level and remain predominantly informal in nature. There would come a time, however, in its expansion when a substantial investment would be required. Equipment such as a dedicated mill, sieving machine and bagging equipment would improve efficiency and quality assurance dramatically. There would also come a time in the expansion of the business – such as when institutional customers take an interest – when premises suited to food handling would become essential. The efficient use of capital is also very important, and this essentially means being able to purchase ingredients at harvest time when prices are at their lowest, and store these until they are needed.

11.4 Formal production of acacia/moringa *kunu*

The third tier of an effort to expand the use of acacia/moringa *kunu* would involve the formal production of the mix, at quantities sufficient to impact malnutrition across a significant portion of a population.

A *kunu* produced in this way should be seen primarily as a preventative food and targeted, through early identification and intervention, at vulnerable families with small children aged between six months and five years. Product distribution could be through health clinics – where records of children’s nutritional status are also kept – or through other regular contact points. Such systems of health surveillance already exist in areas served by government clinics.

Acacia *kunu* should not be seen as a therapeutic food. Plumpy'Nut already serves this purpose and its efficacy has been extensively documented. It is, however, a real alternative to Plumpy'Doz, and one that is entirely consistent with local cuisine and could contribute much more to local livelihoods, since all main ingredients are purchased locally. For distribution under the aegis of humanitarian agencies it would be necessary to adjust the *kunu* formulation for optimal nutrition; for this application merely 'better' is not good enough. The food needs to be as close to perfect as any single food can be. The product would still be based as far as possible on local ingredients, but additional nutrient components would need to be imported. Based on the analysis of the first recipe, this would include vitamin A, zinc, calcium, iron, and most 'B' group vitamins at a minimum.

11.4.1 Potential challenges to implementation

- The unproven nature of the product means that significant expenditure will be required on safety, efficacy and preference testing before the product can be considered ready for distribution;
- The market for supplemental food products is crowded, with many products well established. Thus very good arguments encompassing both price and nutrition (and hopefully issues of sustainability, resilience and development) will be required to bring about a change of preferred product;
- The capital required for start-up, both in terms of equipment and feedstocks will be significant and may be difficult to mobilise without an assured market.

For these reasons, it is unlikely that any Nigerien food processing enterprise would assume the risk alone, and the product development and initial production runs may need to be sponsored or partnered by an NGO which has a role in food aid distribution or child health, and which could provide an assured market for the product.

Despite the clear potential of this approach, the formal production (or indeed micro-enterprise production) of acacia *kunu* or any other complementary food does carry risks. Mothers may be led to believe that the processed product is superior (as in truth, it would need to be), and divert scarce household cash toward obtaining a product that they can prepare themselves. Palmer writes:

“If elite mothers in any community buy and use industrially processed complementary foods this creates a two tier food system and motivates poor mothers to buy such foods. The marketing of these foods exploits parental

aspirations, exaggerates the nutritional benefits of the foods and obliterates impartial messages about locally available foods”(Palmer, 2009).

A further concern is that an enterprise successfully undertaking industrial production and marketing of a complementary food will be a prime target for a takeover by multinational food producing companies, raising the risk of further loss of local control over the food supply system to an entity primarily motivated by profit (Palmer, 2009; 36).

Given that channels for the storage and distribution of food aid are well developed in countries such as Niger, the major challenge facing a plan to produce acacia/moringa *kunu* at a large scale will be in scaling-up acacia seed production to the required levels. Formal production is very cost sensitive, and economies of scale are likely to dictate that minimum production in the order of 100 tonnes of *kunu* per annum is required (P. Dibari, pers. comm). To achieve this, around 20 tonnes of acacia seed would be required in addition to domestic consumption needs, requiring a dramatic increase in acacia production levels. After the 2009 harvest only about 1300 kg was available for purchase. This low figure partly reflects poor rainfall in the 2008 rainy season (50% of the 30 year average), but more importantly attests to disappointing adoption rates that can probably be attributed to the lack of a functioning market for the seed (Rowlands, 2009). Most households that were involved in acacia production reported that they ate at least some of the seed that they produced. Rowlands (2009) estimates that domestic consumption may account for around 31% of the seed crop (see also Cunningham and Abasse, 2005b).

Once the product is established, the resulting acacia seed market can be expected to greatly stimulate the planting of acacias on farms. Active promotion and adequate follow-up extension would be critical to the initial expansion in plantings. This amounts to a

significant investment, though it is entirely consistent with the livelihood and food security objectives of organisations such as World Vision (and indeed such programs have been in place for several years). Acacias will produce their first seed crop after only 18 months, if conditions are favourable. Nevertheless, there are tight timing considerations for tree planting, that dictate the beginning of a planting cycle and a need for farmer training to support the expansion, so that a realistic timeframe for formal production would be 3-4 years.

11.4.2 The potential of the food aid market

The food aid 'market' has significant potential as a driver of acacia plantings. The UN WFP Regional Bureau for West Africa expects to provide assistance to over twelve million beneficiaries in 2013, with a projected operating budget of US\$77,952,362. Total food distributions of 443,546 metric tonnes are planned for 2013, with 101,162 metric tonnes – almost twenty-three percent of the total – being 'blended foods' (WFP, 2013). Were even a tiny proportion of this amount spent on acacia, the benefits to farmers could be significant, with a major stimulus to tree planting that would generate multiple income streams and build resilience. The funds, furthermore, would tend to cycle multiple times through the local economy, so increasing income potential and reducing poverty. Through projects such as this, food aid can be so much more than a 'band-aid' solution; it has the potential to be transformative.

Internationally funded food aid has taken many forms across Africa over the past five decades. Some approaches to the procurement and distribution of food have been strongly criticised for the ways in which they fail to deliver the foods that are needed in a timely fashion (Young et al., 2004, Barrett and Maxwell, 2005), or for the fact that they may create

dependency in recipient populations (Bar-Yam, 2004), or even undermine rural economies and livelihoods (Sphere Project, 2011), thereby making the advent of famine more likely in the future.

To address some of these concerns, WFP has attempted to purchase a significant proportion of the food it distributes from within Africa. The success of this policy is hard to ascertain as figures are hard to obtain. But it is also important to note that, although a large proportion of food purchases may be made in Africa, the suppliers are overwhelmingly industrial farm enterprises, many located in South Africa or Mozambique, whilst small producers – that is to say, the vast majority of African farmers – have little opportunity to participate or benefit (Coulter, 2007). Subsequently, a small WFP sub-program called P4P, or ‘Purchase for Progress’ is attempting to pilot a way in which smaller producers can benefit through food aid production and sales (WFP, 2012). It is also interesting to note the March 31st 2010 announcement of the European Union that “Handing out cash or vouchers for food, or *buying food aid in or near the country in need of emergency food assistance*, has become official policy” (IRIN, 2010a, emphasis added). The proposal explored in this research is entirely consistent with the latter approach, and seeks to harness the economic opportunity of food aid as a transformative force for rural communities in the most marginal areas.

11.4.3 Cost Considerations

The cost of a commercially produced acacia *kunu* is difficult to determine with any certainty. Ingredient prices and availability vary considerably within and between years. The cost of local production is certain to be lower than for an imported product, though issues such as compliance with WFP specifications and Codex Alimentarius standards will

tend to increase costs. WFP requires that the blended food products it purchases from private enterprise in developing countries be comparable in terms of nutrition, quality and cost to the products it can purchase from countries such as the US. In 2000, such products from the US cost US\$500/tonne, whilst similar products produced in Bangladesh, Ethiopia or Kenya averaged US\$370/tonne (Dijkhuizen, 2000). In 2013, in Kenya UNIMIX costs US\$1,254/tonne (Omundu, 2013). Table 11-2 provides an estimate of the cost of acacia *kunu* production per tonne, showing that acacia *kunu* is likely to be a cost effective product, with a price 18% less than that of imported UNIMIX.

Table 11-2. Production cost estimate per tonne acacia *kunu* (dry weight) in Niger

Component	Price Range US\$/tonne	Nominal price US\$/tonne	Proportional Cost per tonne of <i>kunu</i> US\$
Acacia seed (+40% on base price to allow for loss in dehulling)	1120 – 1400	1260	189
Millet	200 – 500	300	165
Peanut	500 – 1200	800	120
Moringa	600 – 1000	800	24
Sesame	750 -1000	900	45
Soya Bean	540 – 570	560	22.4
Baobab Fruit Pulp (dried)	2400 – 2600	2500	50
Sugar	350 – 450	400	40
Salt (Iodised)	110-120	110	1.1
Sahel Produced Total Ingredients Cost			656.50
Micronutrient fortification (estimate 15% of other ingredient costs)			98.47
Milling and Packing		20%	131.3
Overheads		10%	65.65
Profit margin		10%	65.65
Total			1,017.57
Price Difference to UNIMIX			-18%

12. The *Kunu* recipe

The recipe for Acacia/moringa *kunu* was developed through an iterative process over several months. The key steps are summarised as follows:

- Consideration of *need* led to a focus on a complementary food;
- Consideration of local cuisine and taste preferences and how these might accommodate the use of acacia.
- An evaluation of local innovations containing acacia seed against published nutritional data (linear programming using NutriSurvey (NutriSurvey, 2010));
- Re-formulation and adjustment with reference to nutritional, cultural and sensory factors;
- Empirical nutritional measurement of the final recipe;
- Consideration of the financial costs and nutritional benefits of various ingredients;
- Adjustment of the recipe to maximise nutrition, taking into account both nutrition and cost (this was a non-collaborative part of the process).

12.1 The *kunu* ingredients (other than acacia)

The *kunu* recipe that was developed by my group contained 15% acacia meal. The balance of the food was made up of ingredients that were both well-known and readily available in the Maradi region. As far as possible, they are ingredients that are likely to be grown on a family farm. Nutritional details are to be found in Table 12-1.

Pearl millet

Pearl millet is a cultural 'keystone' food of the Hausa, and is eaten at virtually every meal.

Pearl millet remains the basis of the children's food *kunu*. It delivers important energy, protein and micro-nutrients, but lacks the nutritional density on its own to deliver sufficient quantities of any of these to a growing child. I have been arguing in this thesis, therefore, that several additional ingredients need to be added to provide what cannot be found in millet.

Pearl millet is widely grown, and is available in markets, both large and small. Millet prices fluctuate dramatically both within and between years, with annual peaks in the period July-September, when prices can be up to three times the average (RESIMAO and WAMIS-Net, 2013). Harvest is in October-November and it is at this time that prices are at their lowest. The purchase of pearl millet for inclusion in an acacia/moringa *kunu* would need to balance the following considerations:

- A minimum production run of 100 tonnes of *kunu* would require 55-60 tonnes of pearl millet.
- The productivity of the harvest. What quantity of product is excess to local requirements?
- Are there important semi-institutional markets such as cereal banks that could be adversely impacted by purchases?
- What quantities to farmers *need* to sell?
- Is the objective to obtain cereal at the lowest price, or to pay a fair price?
- Is it preferable to purchase from individual farmers, or will this incur excessive transaction costs?

- A large proportion of Niger's cereals are imported, and the pearl millet available in the larger markets is likely to originate in Nigeria or Burkina Faso. Is this consistent with the desire to utilise local products as far as possible?

Moringa leaf

There are several species within the genus *Moringa*, and two of these have particular value in human nutrition: *Moringa oleifera* has been highly developed as a crop in India and the Philippines, whilst *Moringa stenopetala* has until recently been largely restricted to Ethiopia. Both species are well adapted to the semi-arid tropics, being able to shed their leaves in the dry months in order to conserve moisture. When trees are grown commercially for leaf, irrigation can be used to extend production throughout the dry season. The leaves of *Moringa* spp, especially *M. oleifera* and *M. stenopetala*, are exceptionally high in vitamin A, iron and calcium, and are also very high in protein, with an excellent amino-acid balance that includes the highest levels of methionine found in any vegetable matter (Price, 2007, Gamatie and de Saint Sauveur, N.D.)

In India, *Moringa oleifera* is valued for its nutritious leaves, young seed pods and quality oil. A wide range of cultivars, variously selected for leaf or pod production, or for drought tolerance or other qualities, have been developed in India. One of these, an elite fast growing high pod-producing⁹, variety called PKM1 is being widely promoted in the Sahel by ICRISAT. In Niger the tree is well known, and is widely grown in agroforestry systems and as singular trees in family compounds. Gametie and de Saint Sauveur, (N.D.) describe *M. oleifera* production methods for a region near Niamey, Niger and demonstrate that with irrigation the economics of *M. oleifera* production are very encouraging. In Niger even,

⁹ Also produces dramatically improved leaf yields.

without irrigation, there are compelling reasons for growing Moringa. As humidity increases before the onset of the first rains moringa bursts into leaf, often providing the only food locally available during the hunger gap (from when grain stores are depleted and the next harvest is still months away). Moringa leaves are commonly available in Niger in the marketplace as a semi-prepared food: the leaf is boiled and pressed into a ball prior to being dried in the sun. In this way the vegetable is made available throughout the dry season (though the nutritional value of the product preserved in this way is doubtful).

Moringa stenopetala is a graceful tree from Ethiopia, with a somewhat weeping habit from Ethiopia. Abuye et al. (2003) estimate that in excess of “five million people depend on this plant as a vegetable source...one plant of *M. stenopetala* is able to support a large family¹⁰” (2003; 247). A nutritional analysis by Abuye et al. (2003) indicates that *Moringa stenopetala* is lower in protein and most micro-nutrients than *M. oleifera*, though it still contains very significant quantities of the key micro-nutrients, vitamins A and C, and iron. *Moringa stenopetala* is more drought tolerant than *M. oleifera*, and produces an impressive volume of large, easily harvested leaves (though Jiru et al (2006a) found *M. oleifera* dramatically more productive than *M. stenopetala* in Ethiopia, probably due to the latter’s vulnerability to pest attack). No work has been published on the economics of *M. stenopetala* production in Niger; however early suggestions are that it will be more profitable in the dry environment (P. Cunningham, pers. comm).

Moringa has been subject to a great deal of promotion in recent years, and has been lauded as a ‘miracle tree’ and cures for any number of diseases are rather dubiously

¹⁰ Given the importance of *M. stenopetala* in Ethiopia, an estimate of fifty million people dependent on the species would be more accurate!

attributed to its consumption in numerous internet sites – see for example Aqasikesat (2012). Whilst there is no doubt that Moringa is a valuable vegetable for very many people in the semi-arid tropics, a degree of caution is appropriate. Moringa may have some medicinal values, although its main benefit to humans is in providing nutrition that is otherwise lacking in the diet. However, even this needs to be approached with a degree of caution since so little is known as to the bioavailability of the nutrients in Moringa. For example, the iron is non-haem and therefore of low quality and absorbability compared to iron from an animal source. In another note of caution, Abuye et al. note the presence of cyanogenic glycosides in the leaf material of *M. stenopetala* at certain times of year, which may potentially be a problem in areas with endemic goitre and hypothyroidism if large quantities of leaf are consumed over long periods¹¹ (2003; 250, see also Bennett et al., 2003).

Information supplied by Dr Tougiani Abasse of INRAN indicates that commercial production of Moringa is well advanced in Niger, with significant areas planted in the Niamey region, especially where irrigation is available. There would be little difficulty in filling orders of even several tonnes so long as sufficient lead time is given (T. Abasse, pers. comm.). It would be essential, however, to specify shade drying of the leaf in order to minimise the nutritional losses incurred in processing (Price, 2007). A minimum production run of 100 tonnes of *kunu* would require around 3-5 tonnes of dried, crushed Moringa leaf. Dried, ground Moringa leaf ranges in price between 200 cfa and 400 cfa (AUD\$0.40-85) per kilogram, depending on seasonal factors. Contracting Moringa production will almost certainly stabilise prices, whilst assuring quality at the same time.

¹¹ The Sahel zone is a region of relatively low risk of goitre (50-150 Age-standardised disability-adjusted life year/100000 people)(WHO, 2002).

Moringa is also being actively promoted by many NGOs in Niger as a household tree. Its increasing availability at the household level can be expected to yield significant nutritional benefits, especially to children. The demand for seed is high and ICRISAT has large areas dedicated to the replication of seed for both *M. oleifera* (PKM1), and *M. stenopetala*.

Peanut

Peanut is a common local crop that is rich in fat (52.7g/100g), and therefore much needed energy (NUTTAB, 2010). Peanut is vulnerable to moulds (*Aspergillus flavus* and *Aspergillus parasiticus*) that produce carcinogenic aflatoxins, and for this reason harvest and storage conditions are crucial. Any nuts showing signs of mould must be rejected. If the *kunu* is to be produced commercially at scale using local peanuts, a regular aflatoxin testing regime is highly recommended (Dickens, 1977).

Peanut is an important cash crop in the Maradi region of Niger and peanuts are easily obtained in both large and small markets. Procurement protocols would need to be developed to minimise the presence of aflatoxins. A large volume of peanuts are crushed for oil at a plant in Maradi. A minimum production run of 100 tonnes of *kunu* would require around 15 tonnes of peanuts. Peanut prices in Niger vary considerably according to quality and season with a likely range between AUD\$500-1200/tonne.

Sesame

Sesame seed offers a rich source of calcium (62mg/100) and also fat (55g/100g) (NUTTAB, 2010). Sesame needs to be toasted lightly to reduce phytate which would otherwise reduce the bioavailability of the micronutrients.

Soya Bean

Soya bean is rich in protein (36.5g/100g) (USDA, 2013). Soya bean is a relatively expensive product in Niger. It is generally imported from Nigeria.

Sugar

Sugar adds palatability and a source of energy. Though this ingredient is not grown on farms in Niger, it is widely available in the marketplace. In the design process, sugar was a major point of contention. I was of the opinion that sugar should be minimised or omitted altogether. This was for reasons of cost reduction, maximisation of local ingredients and because it is surely better not to cultivate a taste for sweet foods in infants. I was acutely aware of arguments such as those of Palmer, who said that: "Taste preferences are formed in early life and the content and manner of feeding may establish lifelong cravings for overly sweet, salty or energy-dense/nutrient-poor foods and drinks" (Palmer, 2009; 9). The team insisted that sugar, (and lots of it) was crucial for flavour. In the end I found that I could not achieve the required energy density without the use of sugar, and so it was included at 8-10% of the recipe¹². Sugar is readily available, though it is entirely imported. A minimum production run of 100 tonnes of *kunu* as currently formulated would require 10 tonnes of sugar. Price range is AUD\$350-450/tonne.

Iodised salt

Iodised salt provides electrolytes and iodine as a preventative to hypothyroidism. WHO mandates the use of iodised salt in any food product distributed under their aegis.

¹² Rolled oats 1%; Weetbix 4.4%; Kellogg's Crunchy-nut cornflakes 35% WHICH? 2012. *Briefing: What's in your bowl? The most popular breakfast cereals compared* [Online]. Which? Available: <http://www.childrensfoodcampaign.net/Which%20Cereals%20Report%20Feb%202012.pdf> [Accessed 29th April 2013].

Baobab fruit pulp

Baobab fruit pulp is rich in vitamin C (290mg/100g) and calcium (293mg/100g) (Manfredini et al., 2002). Baobab fruit pulp is produced commercially in Nigeria and sold in specialty food stores in Maradi. It is not widely available in rural areas. Baobab trees are not common in the Maradi region, but this is gradually changing as they are being widely promoted by development NGOs such as SIM for their nutritious leaves as well as the fruit. The value of including the baobab pulp in a *kunu* mix is questionable, since much of the vitamin C will be lost in the cooking process. If the product is to be used (and it should be), it would be better used as a sprinkle.

Baobab fruit pulp is produced in significant quantities in Nigeria, Burkina Faso, Mali and Senegal. Baobab trees are widespread in the wetter areas of Niger, though the trees in that country are generally heavily harvested for their nutritious leaves. If the decision were made to include baobab pulp in the mix, a minimum production run of 100 tonnes of *kunu* would require 2 tonnes of fruit pulp. This would certainly need to be imported from Nigeria.

Table 12-1. Nutritional content of potential ingredients for a complementary food (from published sources).

Component		Carb g/100g	Protein g/100g	Fat g/100g	Energy Kj/100g	K Mg/100g	P Mg/100g	Ca Mg/100g	Fe Mg/100g	Zn Mg/100g	Vit. C Mg/100g	β-carotene μg/100g	Vit. A μg/100g	Source
<i>Moringa oleifera</i>	fresh leaf	13.4	6.7	1.7	385	259	70	440	7	--	220	--	6800	(Price, 2007)
	dry leaf	38.2	27.1	2.3	858	1324	204	2003	28.2	--	17.3		16300	(Price, 2007)
<i>Moringa stenopetala</i>	fresh leaf	51.8	9.0	5.8	1236	453	65.6	792	3.08	0.53	28.07	160	--	(Abuye et al., 2003)
<i>Adansonia digitata</i> (Baobab)	fruit pulp	75.6	2.3	0.27	--	2.31	100	293	--	--	290	--	--	(Manfredini et al., 2002)
<i>Pennisetum glaucum</i> (Pearl Millet)	Seed	63.3	11.1	4.2	1489	195	--	8	3.0	1.7	0	0	0	(NUTTAB, 2010)
<i>Acacia colei</i>	seed *	21	27.4	9.2	1580	1100	280	180	52	2.9	<1	130	<5	National Measurement Institute, Sept 2010. (Author commissioned)
Soya bean	Seed	30.2	36.5	19.9	1741	1797	704	277	15.7	4.9	6.0	--	2.0	(USDA, 2013)
Sesame	Seed	0.9	22.2	55.6	2530	170	--	62	5.2	5.5	0	5.0	--	(NUTTAB, 2010)
Peanut	roasted	14.1	25.1	52.7	2661	620	--	40	1.2		0	4.0	2.8	(NUTTAB, 2010)
Sugar		100	0	0	1600	2	--	1	0	0	0	0	--	(NUTTAB, 2010)

*Lightly roasted and with seed coat removed.

12.2 Three versions of *kunu*

This complex process resulted in the creation of a number of *kunu* recipes. Two versions of the recipe are described in Table 12.2. I describe these recipes as ‘first iteration’ and ‘final’. The former is the recipe as designed and agreed upon by the Hausa team and myself. The latter includes the adjustments I made in light of cost considerations and actual nutritional analysis. There is no final and ‘correct’ recipe for all people and all times. Rather, I stress the need for maximising nutrition with the available ingredients, so that the best recipe for a family in a rural village will not be the best recipe for a commercial producer. An alternative recipe for general use in rural areas is presented in Table 12-2. The optimal recipe for commercial production is in practical terms beyond the scope of this thesis.

Table 12-2. Three acacia *kunu* recipes

Ingredient	First iteration (%)	‘Recommended’ version (%)	Remote rural version (%)	Comment	Reason for change
Pearl millet or sorghum	55	55	60		
Peanut (roasted)	15	14	14	Good quality essential - moulds must be avoided	
Acacia seed	15	15	15		
Moringa leaf	3	6	5.5	Must be shade dried and milled to powder	3% moringa yielded insufficient Vitamin A.
Sesame seed	5	0	0	Sesame is roasted to reduce phytate	Calcium in sesame hard to access. Seed is expensive
Soybean	4	0	0	Roasted to reduce protease inhibitors	Soybean is imported; effectively replaced by acacia seed
Boabab fruit powder	2	0	0		Expensive imported product. Vitamin C compromised by cooking. Better sprinkled on top.
Sugar	10	9.5	0		Expensive imported product.
Salt (iodised)	1	0.5	0.5		

Production Method

1. Acacia seed is roasted and ground. The seed meal is sieved to remove the husk.
2. Cereal ingredients are lightly toasted and then ground. The meal is sieved to remove fibrous material.
3. Ingredients are mixed thoroughly.

Preparation in the household

1. The desired quantity of *kunu* mix is combined with cold water.
2. The mixture is placed on the heat, brought to the boil and simmered for 3-5 minutes.

Water content is adjusted to achieve the desired consistency – *kunu* is usually a drinkable porridge.

3. The *kunu* is served in a bowl with additions as desired and/or available: milk, sugar, vitamin sprinkles.

Table 12-3 Nutritional analysis of first iteration *kunu mix*. Analysis conducted by National Measurement Institute, Melbourne, Australia, September 2010.

Proximates	Units	Amount	Trace elements	Units	Amount	Vitamins	Units	Amount
Protein (N x6.25)	g/100g	15.2	Calcium	mg/100g	66	alpha-carotene	µg/100g	<5
Ash	g/100g	2.8	Copper	mg/100g	0.64	Ascorbic Acid	mg/100g	2
Carbohydrates	g/100g	55	Iron	mg/100g	8.3	beta-Carotene	µg/100g	29
Total Sugars	g/100g	14	Magnesium	mg/100g	120	Thiamine	mg/100g	0.14
Total Dietary Fibre	g/100g	8.8	Phosphorus	mg/100g	260	Total Folate	µg/100g	130
Moisture	g/100g	5.7	Potassium	mg/100g	460	Riboflavin (B2)	mg/100g	0.03
Energy	kJ/100g	1740	Sodium	mg/100g	240	Retinol (Vit A)	µg/100g	<5.0
Total Fats	g/100g	13	Zinc	mg/100g	2.4	Pyridoxine (B6)	mg/100g	0.46
Amino acids	Units	Amount	Amino acids	Units	Amount	Amino acids	Units	Amount
Alanine	mg/g	6.9	Isoleucine	mg/g	5	Serine	mg/g	5.8
Arginine	mg/g	9.7	Leucine	mg/g	10.7	Threonine	mg/g	4.1
Aspartic acid	mg/g	12.5	Lysine	mg/g	4.5	Tyrosine	mg/g	3.5
Glutamic acid	mg/g	25.4	Methionine	mg/g	1.7	Valine	mg/g	5.8
Glycine	mg/g	4.5	Phenyl-alanine	mg/g	6.3	Total	mg/g	116
Histidine	mg/g	2.9	Proline	mg/g	6.6			

Table 12-4. Comparison of selected nutrients in initial *Acacia/Moringa kunu* against international standards and millet *kunu*. Based on 100g *kunu* (dry) daily intake for an infant aged 6-8 months. FAO and WHO (2002), unless otherwise indicated.

Nutrient	Unit / day	Acacia/Moringa <i>kunu</i> measured Content	Recommended Daily Intake (RDI)	% of RDI provided by Acacia/Moringa <i>kunu</i>	Pure pearl millet nutrition values	% of RDI provided by pure pearl millet <i>kunu</i>
Energy	Kj	1740	2574 [▼]	67%	1489	58%
Protein	g	15.2	9.1 [▲]	167%	11.1	122%
Total Fat	g	13	30 [*]	43%	4.2	14%
Carbohydrate	g	55	95 [*]	58%	63.3	67%
Vitamin A (Retinol Equivalents)	µg	<5	400	1%	0.0	0%
Vitamin C	mg	2.0	30	7%	0.0	0%
Iron	mg	8.3	9.3	89%	3.0	32%
Zinc	mg	2.4	4.1	60%	1.7	41%
Nutrient	Unit/day	Acacia/Moringa <i>kunu</i> measured Content	Recommended Daily Intake (RDI)	% of RDI provided by Acacia/Moringa <i>kunu</i>	Pure pearl millet nutrition values	% of RDI provided by pure pearl millet <i>kunu</i>

12.3 Comparing *Acacia/Moringa kunu* with millet *kunu*

The *Acacia/Moringa kunu* is superior to the pure millet *kunu* in all respects except carbohydrate content. In the case of protein content, the overall protein levels of the *Acacia/Moringa kunu* are superior, but so too is the balance of amino acids (though this is

▼ Lutter and Dewey (2003) LUTTER, C. & DEWEY, K. 2003. Proposed nutrient composition for fortified complementary foods. *Journal of Nutrition*, 133, 3011S-20S.

▲ WHO 1998. Preparation and use of food-based dietary guidelines. In: CONSULTATION, J. F. W. (ed.) (*WHO Technical Report Series 880*). Nicosia, Cyprus.WHO.

* NHMRC 2013. Australian Dietary Guidelines (2013). National Health and Medical Research Council.

not evident in Table 12-4), so that a much greater proportion of the protein content can be used by the body. Whilst the millet *kunu* appears to offer 79% of daily protein requirements, the shortage of the essential amino-acid lysine limits the overall usability of the protein to well below that figure. By contrast, the good range of essential amino acids contained in the Acacia/Moringa *kunu* (see) means that most if not all of the protein can be utilised.

Other significant improvements are evident in terms of energy and fat content, up by 9% and 29% of RDI respectively. Adequate energy is of critical importance since in case of chronic energy shortfall, an infant's body will begin to burn proteins for energy, leading to protein deficiency, wasting and stunting. Significant improvements are also evident in the Acacia/Moringa *kunu* in terms of micro-nutrients, especially iron (+57%), calcium (+14%), zinc (+19%) and potassium (+38%).

The actual analysis of the Acacia/Moringa *kunu* is clearly well short of international standards in many respects. Most notable of these shortfalls were vitamin A (1% of RDI), calcium (16% of RDI), and vitamin C (7% of RDI). The first point that needs to be made regarding these nutritional shortfalls is that a child of 6-8 months old should still be receiving breastmilk, and ideally, a portion of the solids introduced to a child's diet from 6 months of age should include foods of animal origin. The responsibility of all humanitarian agencies involved in child nutrition to promote these key points must not be overlooked.

Low levels of Vitamin A

The very low levels of Vitamin A in the Acacia/Moringa *kunu* was surprising, given the reported high levels of Vitamin A in moringa leaf. The 3% Moringa leaf content of the *kunu* should theoretically have yielded 50.4 µg of vitamin A, (or 12% of RDI for a 6-8 month infant), however the analysis reported less than 5µg (<1% of RDI), of vitamin A. It seems

likely that the principal cause of the discrepancy is the use of poor quality moringa leaf powder in the mix. This had perhaps been dried in the sun or substituted with low nutrition (non-moringa) plant materials. It will be essential that such quality issues be addressed in the future. It would also be highly desirable that food colour sensitivities be overcome and moringa content of the *kunu* be elevated to at least 6% to deliver a substantial portion of vitamin A. Increased moringa content will also elevate levels of iron and calcium.

Likely changes to the recipe arising from the analysis

The Acacia/Moringa *kunu* recipe would benefit from the following changes:

- Increased Moringa leaf content - to 6%, to increase vitamin A, iron and calcium content.
- Increasing Moringa leaf content will allow the removal or reduction of sesame seed (reducing both cost and phytate content) whilst increasing calcium content.
- Removal of Baobab fruit pulp – vitamin C levels are too low to warrant the additional expense, and in any case, much of the vitamin C will be lost in cooking.

13. Implementation: Issues and the potential for scale-up, scale-out.

This penultimate Chapter deals with the practical issues of how an acacia project might be implemented in semi-arid Africa, with particular attention to Niger. Australian acacia trees are not currently widespread in Niger, being largely restricted until recently to an area within a radius of 40km around the city of Maradi. In the period since the fieldwork for this research was completed, significant plantings have occurred under programs run by the NGOs Samaritans Purse (to the North-East of Niamey), and Adventist Development and Relief Agency (mainly South of Niamey).

The acacia plantings around Maradi exist primarily as a result of the research and promotional work of SIM over the past two decades, and of World Vision Niger over the past five years. Promotion of acacias has been patchy at best, and many villages in the Maradi region do not grow acacia and know almost nothing of its benefits. Yet the potential for acacia to improve child and general nutrition in Niger (and elsewhere in the Sahel) is of course completely dependent on the seed being available. Successful realisation of interventions involving acacia will need to take note of existing knowledge, of the factors such as markets that are necessary to stimulate a critical mass of farmer interest, for ongoing research and for adequate investment.

I include this implementation material in the thesis because my research has been intensely practical in nature and oriented to the realisation of a set of real-world outcomes. I do not see 'implementation' to be a single set of actions. Rather, I see it as an evolving set of interventions, with successive elements building on what has gone before, and expanding

impact both spatially and topically. For the purposes of this Chapter I present four broad elements, each with their own particular issues, impacts and institutional needs. These elements have been discussed in earlier sections of the thesis, and I will not repeat this material here beyond a simple description. The four elements are as follows:

1. Promote Acacias on Smallholder Farms;
2. Promote Acacias on Degraded Lands;
3. Develop Acacia *Kunu* as a Food Aid Product; and
4. Develop BioChar/Electricity Co-generation.

For the sake of simplicity and brevity, the development of micro-enterprise production of acacia *kunu* is not specifically addressed here, it being in practical terms, somewhere between smallholder production and food aid product development.

I have argued in this thesis that there are sound economic and nutritional reasons supporting a significant expansion in acacia production within agroforestry and degraded land reclamation systems. The design and implementation of an intervention requires an understanding of both the types of actions and the appropriate scale of those actions required for best effect. What amounts of acacia seed would be needed to make an acacia nutrition project meaningful and viable? How could these levels of production be achieved? A further set of questions concerns the range of social and environmental benefits that the project is expected to generate, and how these might be maximised; which people or organisations would be responsible; where financial support may be found; and what risks need to be considered in design and implementation?

13.1 Institutional Engagement

Social institutions are often conceived by ‘functionalist’ and ‘structural functionalist’ anthropologists to be social adaptations that are specific to cultural and environmental milieus, which serve a normative and governing role with respect to human behaviour, resource use and economic interaction (Durkheim, 1994, Malinowski, 1944, Mauss, 1922). Institutions are specific to cultural, economic and environmental situations, and emerge, or are created to serve purposes particular to their situation (Hechter, 1987). With the spread of modern systems of government and the development paradigm, institutions have taken on a more diverse range, to include NGOs and multilateral service organisations (Martin and Simmons, 1998).

Though institutions are *prima facie* instruments of governance, they do not necessarily serve the interests of all, or indeed any members of a society. Institutions may serve particular interests to the detriment or exclusion of others. Institutions can be rooted in a social/environmental situation that is long past, or is distant (physically, functionally or culturally) from the society in question (Ihonybere, 1994), resulting in dysfunctional or inappropriate governance (Cleaver and Franks, 2005) and as Maru et al. (2012) point out, some institutions can work against ‘desirable’ social change, creating or reinforcing poverty traps.

The importance of institutions at multiple levels in the development and implementation of a complex intervention cannot be underestimated. In development economics, institutional reform is considered crucial to the transition of a society from ‘traditional’ to ‘modern’ (Platteau, 2000, Acemoglu et al., 2005, van Arkadie, 1989). Any intervention must necessarily engage with, and possibly seek to reform any number of institutions, since

these structures provide the governance through which resources and risks are managed in a society through time (Bingen, 2000). If a change is to be effected upon livelihood parameters in a community, this inevitably involves reform of the structures of governance or practice that have led to a need for change. Institutions exist at multiple levels, and engagement may be necessary across several of these levels to create the change required. Table 13.1 describes the types, character, limitations and relevance to the implementation of the intervention described here of institutions at various levels. Table 13-2 describes the key actions in implementation for institutions at various levels.

The potential benefits of acacia systems for the arid lands include improved agricultural production, improved human health and wellbeing, improved rural livelihood opportunities, and improved environmental conditions. The pathways to impact of the four intervention elements are mapped in Figure 13-1. An assessment of the risks pertaining to each intervention strategy is presented in Table 13-2.

Table 13-1. Institutional Levels Relevant to the Research

Institutional level	Character/operation	Limited by	Relevance to the research
Local/village	Kinship; mutual obligation; customary rights; reciprocity; bound by tradition, yet able to adapt to adversity	Location, isolation, lack of financial capacity, lack of influence	Cuisine; local food production; agricultural systems; local knowledge; local species/varieties
National and International NGOs	Diverse 'project' interventions; small scale, local interventions with policy and priority usually set externally; emergency relief; some research capacity; sometimes very quick to adapt/respond to new situations; Ideological and/or religious motivation is common	Narrow scope, donor finance, local human resources for implementation, research capacity, limited capacity to influence beyond operational area	Agronomic research; knowledge dissemination; advocacy; fieldwork support; financial support of the research
Regional	Formalised land tenure; clinics; markets; transport systems; implementation (or not) of national policy	Resources, national legislation, local agendas	Agricultural extension resources/policy; implementation of environmental programs; availability of key food types in markets
National government	Resource management policy; social safety net policy; economic and development policy; markets, education; health; some research; defence. Usually ideologically driven	Finance, tied and contingent funding, slow to adapt, partiality (sometimes), skills shortage, bureaucratic capacity	Agricultural policy; New foods policy; research permissions; famine response
International and Multilateral Organisations	Coordinating relief and development functions; fund raising at government levels; major research; control client governments' policy, set acceptable risk standards, disperse funds to governments, NGOs and research institutions; diverse ideological motivations.	Size/scale, Slowness to respond, Capacity to translate policy to the ground, capacity to understand conditions on the ground, finance	Risk management policies; Food aid policies; food safety standards; ultimate approval (or not) of an acacia food; decisions to fund further research

Table 13-2. Key Actions in Implementation of Acacia Interventions

Scale	Promote Acacias on Smallholder Farms	Promote Acacias on Degraded Lands	Develop Acacia <i>Kunu</i> as a Food Aid Product	BioChar/Electricity Co-Generation
Research Institutions	Ensure Best Possible Tree Genetics.	Research and Trial Acacia Species with Potential Benefit to Livestock.	Complete Food Safety Testing of Acacia Species with Potential. Develop Product Formulation to Meet International Standards (Sphere Standards). Undertake Appropriate Effectiveness Trials.	Conduct Feasibility Study Identify Technology Suited to Purpose, Location and Scale.
Local Proponent NGOs and Enterprises	Develop Farmer Exchange Programs Around Demonstration Farms Develop and Fund Weed Management Plan. Support Market Development for Acacia Seed Engage Effective In-Country NGO Support.	Establish Protocols for Stakeholder Consultations Develop Effective Multi-Stakeholder Management Plan Collaborate with Relevant Agency to Allow Use of Food-For-Work Funds to Support Water-Harvesting Earthworks and Tree Planting. Support Market Development for Acacia Seed. Identify Pilot Areas. Target 1000Ha-10000Ha in First Two Years Develop and Fund Weed Management Plan Engage Government	Ensure Sufficient Acacia Seed is Produced. Negotiate Supply of Product to an NGO, Government Agency or International Agency. Develop Appropriate Quality Assurance Systems and Standards. Identify In-Country Production Partner	Develop Organisational Structure to Engage Landholders and Ensure Equitable Participation. Engage with International Carbon Trading Entities. Pilot Scheme on Degraded Lands (Small, Stand-Alone Would be Appropriate Engage with Government

Scale	Promote Acacias on Smallholder Farms	Promote Acacias on Degraded Lands	Develop Acacia <i>Kunu</i> as a Food Aid Product	BioChar/Electricity Co-Generation
International Community and Government	Ensure Adequate Extension: i. Tree Nurseries ii. Silviculture/ Agroforestry iii. Culinary Uses for Acacia Seed	Engage Effective in-Country NGO Support	Provide Adequate Funding	Provide Adequate Funding

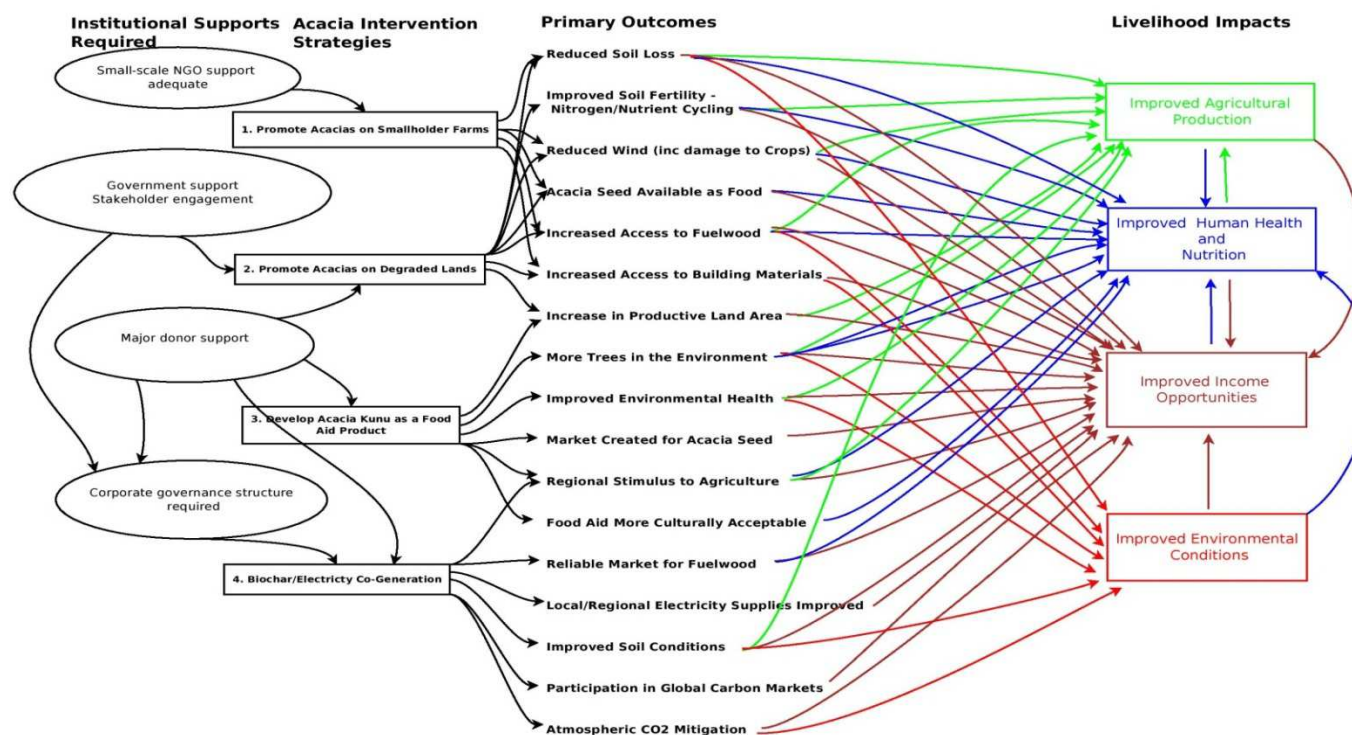


Figure 13-1. Acacia intervention strategies: Pathways to impact

Table 13-3. Risks in Implementation of Acacia Interventions

Intervention Level	Risk	Potential Effect	Estimated Likelihood*	Estimated threat level**	Mitigation Strategy
1. Promote Acacias on smallholder farms	Invasiveness	Encroachment of exotic woody trees on agricultural and grazing lands.	<450mm/annum rainfall.....1	5	Thorough weed risk management plan.
		Significant costs incurred in future control measures	>450mm/annum rainfall.....4	5	Must include surveillance and funding. Selection of plant material to minimise risk.
	Drought: Tree establishment failure	Loss of part or all of trees planted in any one year	4 (In any one year) 10 Overall	3	Largely unavoidable risk. Best practice nursery training provided. Care to plant only at optimal times
		Delay in project implementation	7	3	
	Poor tree management	Many trees lost	8 (local)	3	Training provided to farmers on on-going basis.
		Trees producing below expectation	7	3	Continued refinement of agricultural systems
		Negative attitudes develop toward acacias	5	7	Adopt farmer research group methodologies.
	Excessive competition with annual crops	Reduced annual crop yields	4	4	
2. Promote acacias on degraded lands	Invasiveness	As Above→	→	→	→
	Conflict over land tenure/resource access	Violence	2	10	Comprehensive stakeholder analysis.
		Unwillingness to participate	7	9	Comprehensive and inclusive stakeholder consultations
		Poor tree management due to ownership issues	5	8	Inclusive Plan of Management Commitment to long term engagement Cooperation with government in designing Plan of Management

Intervention Level	Risk	Potential Effect	Estimated Likelihood*	Estimated threat level**	Mitigation Strategy
	Drought: Tree establishment failure	As Above→	→	→	→
3. Develop acacia <i>kunu</i> as a food aid product	Corruption	Inefficient implementation	5	5	Minimise exposure though sound organisational design with appropriate checks and balances
		Failure to meet required standards	4	8	
		Dishonest or exploitative trading	4	8	
	Rejection of <i>kunu</i> by international authorities	Failure to meet required standards results in unsaleable product	4	8	Engage with international authorities and NGOs with the potential to distribute the product at the earliest opportunity. Undertake rigorous tests and trials. Ensure product meets international standards (Sphere Project).
	Failure of acacia crops	Insufficient acacia seed available in any one year	7 (particularly in early phase)	5	To a large extent unavoidable. Ensure wide geographic spread in the areas materials are sourced to take advantage of spatial variations in rainfall.
	Failure of annual crops	Low availability of annual crop components High prices	4	3	To a large extent unavoidable. Source ingredients from a wide geographic area. Import in case of severe shortages.
4. Biochar/ Electricity Co-generation	Corruption	As Above→	→	→	→
	Failure of Technology	Technology unsuited to task/environment Expensive maintenance issues	2	7	Careful evaluation of technological options prior to implementation. Ensure adequate maintenance budgets. Train local maintenance staff.

Intervention Level	Risk	Potential Effect	Estimated Likelihood*	Estimated threat level**	Mitigation Strategy
4. Biochar/ Electricity Co- generation (cont.)	Low carbon price internationally	Carbon trade is limited by global trade conditions	1	7	Engage with World Bank Clean Development Mechanism from the outset.
		Failure of international authorities to recognise biochar for carbon sequestration	2	8	Engage with International Biochar Institute. Support research into carbon sequestration through biochar
	Failure of carbon markets locally	Failure to adequately record/attribute carbon stored in soils	6	7	Ensure robust and effective trading organisation.
		Transaction costs too high	2	7	Minimise opportunities for corruption.
		Carbon leakage (verification means too carbon intensive)	3	7	Ensure high levels of reliability in measurement of CO2 sequestered.
	Fuelwood markets too strong	Farmers receive a better price in normal fuelwood markets	3	7	Delay widespread implementation. Implement in regions more distant from urban centres.
	Drought	Slow tree growth	3	3	Drought is inevitable, but acacias generally survive and even produce wood under sub-optimal conditions if appropriate silvicultural management is applied.
		Widespread tree loss Slowed project expansion			

* 1 = unlikely, 10 = inevitable; **1 = insignificant, 10 = catastrophic

13.2 Amounts of seed currently produced and required

Despite many years of promotion and planting, acacia seed production remains disappointing in Niger. Figures collected by Rowlands (2009) for four villages to the north of Maradi indicate that acceptance of the crop remains low. In total, for the four villages, only 2600 trees were reported to have been planted in 2008, and of these around 2000 were estimated to have survived¹³. Assuming maximum recommended planting densities of 100 trees/hectare were utilised, this indicates that only 26 hectares out of a possible many thousand were planted to acacia in that year. I was able to discern several possible reasons for this apparent reticence:

- Early acacia plantings were too closely spaced, leading to short tree life-spans and low productivity;
 - Tree management knowledge has only gradually emerged, and many trees died at younger ages than they should have;
 - Until sophisticated agroforestry understandings and practices were developed, competition with annual crops could be severe;
 - Early perceptions that *A. colei* has a short lifespan have persisted, and some Government forestry agents have been actively discouraging the planting of *A. colei* for this reason.
- Where significant plantings have been undertaken by some NGOs, there has often been a serious lack of follow-up to ensure that proper silvicultural techniques were understood by the growers.

¹³ Rainfall in 2008 was low at around 200mm.

- There has been no ‘natural’ market for the seed.
- Hausa farmers tend to be very conservative, and try to avoid doing anything that could set them apart from their neighbours for fear of derision or jealousy.
- Staff changes at SIM, which has been the primary organisation promoting acacias, led to changes in program emphasis, and some neglect of the acacia program at times.
- Farmers choosing to grow acacias are more risk taking ‘early-adopters’ (Rogers, 1983). More cautious farmers are waiting for encouragement before taking any risks.
- Acacias have not been promoted in all villages.
- Seedling availability in villages is limited. SIM policy has been that seedlings should be grown and tended by a volunteer in each village. Success has therefore been understandably patchy.
- Years of poor rainfall have limited both seedling survival and seed production by mature trees, thus undermining motivation.
- Though the acacia seed harvest does not compete for labour with the agricultural calendar, it does compete with the ‘exodus’, and there may in fact be a shortage of labour to harvest the seed, especially in dry years where more men have migrated in search of work¹⁴.

The seed amounts needed for each element in this *kunu* proposal are very difficult to predict since they will be determined by the mode and scale of promotion. In the case of household use, it is difficult to imagine acacia being available for use in children’s food and

¹⁴ Acacia seed harvest in Niger is in March-April.

not being used for general family consumption as well; therefore a per family estimate is presented in

Figure 13-2. Note that the estimate assumes only 1kg of seed per tree per annum, which may underestimate production, and therefore overstate land needs, by as much as 500%.

In a plentiful season, a typical family of 8 people (6 children) will consume 5.4kg of pearl millet per day (delivers an average of 10680kJ per person).

Replacing 20% of this pearl millet with acacia (with approximately 30% of the initial weight removed as bran) would require 1.4kg of acacia.

Multiplied by 356 days, this means an annual requirement for a typical household of 511kg.

Assuming reasonable seasons and good management, at the minimum expected harvest (1kg/tree) this amount could be supplied by around 500 trees. At maximum harvest levels (5kg/tree), this amount could be supplied by only 100 trees.

This could be achieved within an agroforestry system, along with pearl millet and cash crop production, on 5 hectares of land. Average farm size in the Maradi region was estimated by Haglund et. al. (2011) to be a little over 9 Hectares.

Figure 13-2. Estimated household acacia seed needs and land required for production

For micro-enterprise production, the acacia need is even more difficult to estimate, since factors of market size, consumer's ability to pay and the time available to the producers will all influence the production of any one enterprise. The estimate also needs to take into account the number of production enterprises that are created. In Maradi, a good living for 2-3 people making acacia *kunu* could be achieved by using 2-4 tonnes of acacia seed per year.

13.3 Promote Acacias on Smallholder Farms

The promotion of acacias on smallholder farms requires concurrent promotion of acacia within an agroforestry system and as a food. Sponsoring NGOs will need to establish effective tree nurseries, and research institutions will need to ensure that the best possible tree genetics are available. Extension will be critical, and must be ongoing, to ensure that farmers have a thorough understanding of the best silvicultural practices, and can be supplied with the improved seed varieties as they become available.

Markets for acacia products will be important. Products such as wood are easily sold, but the market for seed has been very slow to develop. In interviews, farmers indicated to me that they would embrace acacias far more readily if a market for the seed existed.

Continued promotion of acacia as food for the household will help, but market building exercises such as supporting micro-enterprise production of acacia *kunu* will also be important. Encouraging cereal banks to keep a stock of acacia seed along with the usual cereals may help to stimulate markets whilst simultaneously improving people's access to acacia seed.

13.4 Scale-up of Acacia production using degraded lands

Formal production of acacia *kunu* as described in Chapter 10 would require a minimum of 20 tonnes of seed per annum, requiring around 20,000 trees, on 200ha of land. This seed requirement could be purchased from small farmers, from their household excess. Another, possibly more reliable approach, would be to establish acacia plantations on degraded

lands by offering training and material support to disadvantaged groups, who ultimately gain ownership over the productive resource.

One of the great values of the Australian acacias is that they will thrive even on very poor land, and restore its soil condition over time (Pasternak et al., 2009). According to the Regional Director of Environment in Maradi, in some regions of Niger (Tahoua and Illéla), up to 50% of the arable land is severely degraded (K. Aboubacar, Pers. Comm.). In the Maradi region, the proportion is smaller, though vast areas of scalded, weed infested¹⁵ lands are to be found. Some of these land areas could potentially be made available for acacia production. A basic model for this has been developed by ICRISAT, with their 'Bio-reclamation of degraded lands' concept (Pasternak et al., 2009). The concept has the potential to assist particularly disempowered groups (such as women) by helping them to obtain a productive asset, produce a cash crop, and grow a better range of foods for the family.

The success of such an approach is entirely dependent upon the successful negotiation of issues of land tenure and on-going management. Ownership and responsibility for land and trees must be absolutely clear or the project will not be sustainable; young trees will not be protected from livestock, whilst older trees will be subject to uncontrolled cutting. There is, furthermore, a very real potential for serious conflict if the perception arises that pastoral lands – which make up the majority of the severely degraded lands – are being taken over by settled, agricultural groups.

¹⁵ Most notably *Sida cordifolia* .

Access to degraded land in Niger is controlled by the Regional Director of the Environment, and this office has the power to impose restrictions on grazing as required (K. Aboubacar, pers. comm.). Given the low levels of government resourcing, the practical ability to monitor and police such arrangements is doubtful. Upon application, negotiations will be joined by the various stakeholders including the Department of Environment, the local 'chief' and the headmen of the surrounding villages, as well as the 'chief' of the relevant Fulbé (Fulani) pastoral community.

Consideration should be given to the possibility of involving the Fulbé in acacia production. Such an approach may involve some challenges around management continuity and tree protection, due to the transhumance of many Fulbé groups. This must be viewed against the reality that a large proportion of degraded land is notionally (at least) 'pastoral' and that amelioration of damage to these lands will require the engagement and participation of the pastoral stakeholders.

In an interview with the Regional Director for the Environment in Maradi, Mr Kossoukoye Aboubacar, I was told that between 2010 and 2012 the Government was implementing a policy designed to reduce the amount of degraded land in the Maradi region to 10% of the total land area¹⁶. The program involves building 'banquettes' and/or 'demi-lunes' for water capture, and the wide scale planting of trees, principally *A. senegal*, with a view to building livelihoods through gum arabic production. Despite his commitment to *A. senegal*, Mr Aboubacar was supportive of use of Australian acacias due to their multiple uses. The

¹⁶ Unfortunately I was unable to discover from Mr Aboubacar an estimate of the current area of degraded land (or indeed to elucidate the Government's definition of degraded land).

program mobilises labour through a ‘Cash-for-Work¹⁷’ arrangement that has been given additional impetus by the famine conditions of 2010.

13.5 Develop acacia *kunu* as a Food Aid product

The development of acacia *kunu* as a Food Aid product would involve the collaboration of NGOs, government, the private sector and international authorities, and would require significant investment in research and development. I refer the reader to Chapter 10 for a detailed description of the process, potential and limitations.

13.6 Biochar/electricity co-generation

Developing an industry that utilises Australian acacias for the production of biochar, electricity and for carbon sequestration would require collaboration between farmers, NGOs, government and the private sector. The viability of the concept is particularly dependent on the continued development of carbon markets in the developed world, and also the adequate demonstration and acceptance of biochar as a means of long term carbon sequestration. Initial funding needs would be relatively high, but may attract private sector investment. This type of intervention is considered briefly in Chapter 4.4, and it is presented as an important future potential rather than a priority for action.

¹⁷ The approved pay rate on ‘Cash-for-Work’ projects is 1500cfa per 8 hour day, (approximately AUD\$3.34 at the time of writing).

13.7 Summary of Future Research Needs

Future research needs regarding Australian acacias can be broadly placed under three headings. The first concerns the domestication of acacias and the effectiveness of their integration into agroforestry systems. Though these areas have not been the main focus of this thesis, progress on these matters is a crucial element in the development of acacia seed as a food. The second heading concerns research into the safety of acacia seed as a food. The third heading is about the institutional arrangements needed to implement aspects of the intervention described in this thesis.

Acacia domestication and the use of acacias in agroforestry systems.

1. Collection and trialling of acacia species and provenances from drier parts of Australia that may perform better in target environments in Africa. (This research is underway. Collections have been completed in Australia, and trials are in progress in Niger and Ethiopia, sponsored by WVA and SIM).
2. Selection and trialling of acacia species with potential for livestock feed production.
3. On-going monitoring of acacia plantings for invasiveness.
4. Piloting of agroforestry systems that include acacias.

Acacia Seed Food Safety

1. Trial in an animal model to determine safe dietary djenkolic acid exposure.
2. Trial in an animal model to understand effects of chronic exposure to acacia seed in the diet (90 days).
3. Human volunteer trials (subject to successful field trials and finance):
 - a. *A. torulosa* and *A. tumida* in Niger.

- b. *A. saligna* in Ethiopia. This trial must be approved and supervised by the Ethiopian Health and Nutrition Research Institute. *A. colei*, *A. torulosa* and *A. tumida* may also be required. These latter two species may be able to be run conjointly with trials required by the government of Niger.

Institutional Arrangements

1. Develop multi-stakeholder agreement models for acacia plantings on degraded lands.
2. Develop more effective agroforestry extension methodologies.
3. Develop effective governance structure for *kunu* production and distribution.
4. Feasibility study for electricity/biochar co-generation
 - a. Governance structure
 - b. Technical systems
 - c. Wood production systems
 - d. Effectiveness of biochar as carbon storage in semi-arid soils.

14. Conclusion

Niger, along with other Sahelian countries, faces growing food insecurity due to a combination of rapid population growth, resource degradation and climate change. Traditional agricultural systems, based primarily on pearl millet, are failing to produce to expectation as often as two years in three, with near total crop failures that lead to famine occurring approximately every five years.

The regular recurrence of production shocks has reduced the viability of family farms and the resilience of small farmers by eroding both financial and natural capital. The result is a rural population that lives ever closer to the edge, for whom even small food price rises or production losses can be catastrophic. The impact of this food insecurity falls disproportionately upon the young, and levels of child malnutrition in Niger are at a level that has been described as a 'permanent emergency'.

In this thesis I have assessed the feasibility of an acacia seed based complementary (weaning) food for Niger and other semi-arid regions of Africa. The feasibility of such a proposal is inevitably a complex and many-faceted thing, and in the course of the study I have considered aspects of culture and cuisine; how acacias can fit into and transform existing agricultural systems; the risks of weediness; the ways acacia seed has been, and is being, used as food; the suitability of acacia seed for human consumption as well as the intensely practical questions of how an acacia-based food could be employed to improve nutrition, and how adoption of acacias into farming systems could be accelerated.

Australian acacias in the agricultural system

Agroforestry systems incorporating acacias have been shown to improve farm income by 200-500% over traditional farming systems in the Maradi region of Niger (Cunningham, 2009). Some of this improvement in return comes from the production of saleable fuelwood and building poles (including from trees other than acacias) and the production of acacia seed, but a significant portion of the improved income derives from improvements in cereal crop yields due to improved nutrient cycling, nitrogen fixation and lessened abrasion and desiccation of crops through the reduction of wind.

These environmental services can be harnessed for the equally important task of restoring severely degraded lands in the semi-arid tropics. If supported with micro-water harvesting structures, Australian acacias can grow as much as four times faster than indigenous trees, and can yield wood and food on scalded land. Over time the trees contribute mulch and nitrogen, and the foliage can trap windblown sand and accumulate a soil layer, returning productivity to the land.

Two decades of research and development has produced superior provenances, and it is hoped that on-going collections and trials led by World Vision Australia will yield more drought tolerant species and varieties. This should result in acacia varieties more targeted to particular purposes, such as high wood yield or more reliable seed production, particularly in drier years.

Further potential for acacia to contribute to livelihoods lies in the use of excess wood for biochar and electricity co-generation. Whilst this concept is speculative at this time, such an approach could provide income streams to farmers from wood sales, carbon sequestration

payments, seed production and improved annual crops due to the beneficial effects of biochar on the soil. The widespread planting of Australian Acacias thus has the potential to be an important step in rural communities adapting to, and helping to mitigate, climate change.

Weediness

Australian acacias have a history of invasiveness in regions such as southern Africa, and the cost of control can be very high. Though none of the species thus far used in semi-arid West Africa have shown any cause for concern, a degree of caution is appropriate in selecting species for introduction to new areas. NGOs introducing Australian acacias into Africa have a responsibility to carefully assess their selections for invasiveness, and to have in place a clearly defined and funded weediness management plan. Species and provenances with high risk reproductive attributes such as an ability to germinate without a trigger such as fire, or a tendency to sucker should be avoided. Species selections should be based on a risk-benefit analysis that takes into account the characteristics of the species in question as well as the social/agricultural realities of the introduction area.

Acacia seed and human nutrition

In the course of this research I commissioned detailed analyses of selected species of acacia seed in order to ascertain nutritional content, the presence of anti-nutritional factors and potential toxins. In line with the findings of previous studies, acacia seed was found to be a good source of carbohydrate and is relatively rich in proteins, especially in the amino acid lysine, which makes it a good complement to cereal diets. Acacia seed contributes negligible amounts of Vitamin A, and may reduce absorption of the amino acid methionine,

so acacia seed should be promoted along with foods that are rich in these substances.

Given that meat and milk are largely beyond the reach of the poor, moringa leaf may be the best option to achieve this complementarity.

Where anti-nutritional compounds and toxins were found, I determined that roasting was the best processing method for the reduction of those substances, with protease inhibitors completely destroyed after only 2 minutes, and djenkolic acid reduced by over 90% after 6 minutes. A determination of a safe level of exposure to djenkolic acid was beyond the scope of this research.

Acacia seed and child nutrition

The plight of the young in Niger is exacerbated by a set of customary child care practices that deepens vulnerability to malnutrition. Foremost of these is the practice of weaning infants early and precipitously, onto a diet comprised almost exclusively of millet prepared as a porridge known as '*kunu*'. A diet of millet provides insufficient energy and protein and is deficient in many micro-nutrients, especially Vitamin A, zinc and iron. Acacia seed can be added to traditional cereal foods that are given to infants at weaning. The addition of acacia seed (and moringa leaf) to cereal foods (such as *kunu*) can increase the availability of energy, quality protein and many micro-nutrients to children.

An acacia-based weaning food could be promoted in three distinct, but complementary modes. The greatest impact is likely to be achieved where acacia is promoted at a household level, with trees planted on family farms, and acacia seed processed in the household and included regularly in meals, including those prepared specifically for children. Success with this approach will be dependent upon increasing the supply of acacia

seed in the community. This demands concurrent promotion of acacias on smallholder farms and education of women as to the best ways to prepare and use acacia seed. Efforts of increase the presence of acacia seed in the marketplace may also be helpful.

The second mode of promotion is to support the development of micro-enterprises producing acacia *kunu* for sale in village and urban markets. This approach will help to create markets for acacia seed, and in turn stimulate further planting of acacia trees on smallholder farms.

The third, and most challenging mode, and the one that is the *raison d'être* for this thesis, is to further develop the acacia *kunu* at commercial scale as a food aid product that can be stockpiled and distributed to vulnerable families to prevent child malnutrition. I have shown in this thesis that there is little impediment to this approach in terms of the production of acacia seed or procurement of other ingredients. Furthermore, a simple economic calculation shows that a locally produced food aid product is likely to be competitive with imported versions, and this takes no account of the significant livelihood and developmental benefits that would flow from local production, purchase and processing.

The challenges to be surmounted all relate to the food safety of acacia (particularly in understanding the significance of djenkolic acid), and in the exhaustive testing and trialling required by international authorities in order to meet the required standards and give donors and agencies such as the World Food Program confidence in the safety and efficacy of the product.

Climate change has been dramatic over the past several decades in the Sahel, and records show a significant reduction in rainfall as well as a dramatic change in the temporal patterns of rainfall, both factors impacting severely on the viability of traditional annual cereal agriculture. Given this climatic background, countries like Niger have done well to maintain growth in per capita food production, albeit with the experience of periodic crop failure and famine. The likelihood of continued growth in cereal production if a 'business as usual' approach is continued is small, given the additional factors of (viable) land shortage, land degradation and soil depletion and continued rapid population expansion. Countries like Niger need alternative crops that can add resilience to agricultural systems, and add diversity and nutrition to the diet of the rural poor. Australian acacias are an excellent option in this respect, offering a suite of benefits to land and people. Though they are little known and respected by few in their native land, these trees have the potential to be Australia's greatest gift to the world.

The acacia/moringa based *kunu* that I investigate through this research is not presented as a perfect food. It is not a food that is complete in itself or that could or should replace breastfeeding. Nor is it to be considered a therapeutic food. What it is, though, is a food that is dramatically better than what is current practice (i.e. pure pearl millet *kunu*), and which can (in theory) be entirely produced within rural villages, under prevailing climatic conditions by the poorest of people. It is, furthermore, a product that may ripple benefits through the community and farming landscape, increasing resilience and supporting livelihoods in many ways.

15. References

- ABDULAI, A., BARRETT, C. B. & HODDINOTT, J. 2005. Does food aid really have disincentive effects? New evidence from sub-Saharan Africa. *World Development*, 33, 1689-1704.
- ABUYE, C., URGAS, K., KNAPP, H., SELMAR, D., OMWEGA, A., IMUNGI, J. & WINTERHALTER, P. 2003. A compositional study of Moringa stenopetala leaves. *East Afr Med J.*, 80, 247-52.
- ACEMOGLU, D., JOHNSON, S. & ROBINSON, J. A. 2005. Institutions as a fundamental cause of long-run growth. *Handbook of economic growth*, 1, 385-472.
- ACTION CONTRA LA FAIM & FAO. Maximizing the Nutritional Benefits of Food Security Interventions in West Africa. Regional Workshop on linkages between nutrition and food security, 2011 Dakar.
- ADAM, D. 2008. Food price rises threaten global security - UN. *The Guardian*, Wednesday 9 April 2008.
- ADAMS, A. 1993. Food Insecurity in Mali: Exploring the Role of the Moral Economy. *IDS Bulletin*, 24, 41-51.
- ADAMS, A. M., CEKAN, J. & SAUERBORN, R. 1998. Towards a conceptual framework of household coping: reflections from rural West Africa. *Africa*, 68, 263-283.
- ADAMS, W. M. & MORTIMORE, M. J. 1997. Agricultural Intensification and Flexibility in the Nigerian Sahel. *The Geographical Journal*, 163, 150-160.
- ADEBAYO, A. 1989. Interaction between structuralism, structural adjustment and food security policies in development policy management. *ECDPM Occasional Paper*, Maastricht.
- ADELEKAN, D. 2003. Childhood nutrition and malnutrition in Nigeria. *Nutrition*, 19, 179-181.
- ADEWUSI, S., FALADE, O. & HARWOOD, C. Wattle as food: Nutritional and Toxic Considerations. In: FRANCIS, R., ed. Wattle We Eat for Dinner? Australian Acacias for Food Security Workshop, 2011 Alice Springs 16-18th August 2011. World Vision Australia.
- ADEWUSI, S. R. A., FALADE, M. S., OYEDAPO, B. O., RINAUDO, T. & HARWOOD, C. 2006a. Traditional and Acacia colei Seed-Incorporated Diets in Maradi, Niger Republic. *Nutrition and Health*, 18, 161-177.
- ADEWUSI, S. R. A., FALADE, O. S. & HARWOOD, C. 2003. Chemical composition of Acacia colei and Acacia tumida seeds—potential food sources in the semi-arid tropics. *Food Chemistry*, 80, 187-195.
- ADEWUSI, S. R. A., FALADE, O. S., NWOHA, P. U., CAXTON-MARTINS, A. E. & HARWOOD, C. 2006b. Reproductive performance of Wistar rats fed Acacia colei seed-based diets. *Journal of Arid Environments*, 66, 16-26.
- ADGER, W. N. 2000. Social and ecological resilience: are they related? *Progress in human geography*, 24, 347-364.
- ADLER, S. & WEENING, J. 2006. A case of acute renal failure. <http://cjasn.asnjournals.org/content/1/1/158.full>.
- ADU-AFARWUAH, S., LARTEY, A., BROWN, K. H., ZLOTKIN, S., BRIEND, A. & DEWEY, K. G. 2008. Home fortification of complementary foods with micronutrient supplements is well accepted and has positive effects on infant iron status in Ghana. *The American Journal of Clinical Nutrition*, 87, 929-938.
- AGBOOLA, S., EE, K. Y. & HUHN, A. 2012. Functional properties of processed Australian wattle (Acacia victoriae Benth) seed extracts. *Food Chemistry*, 133, 990-997.

- AGNEW, C. & CHAPPELL, A. 2000. Drought in the Sahel. *GeoJournal*, 48, 299-311.
- AHRENFELDT, J., THOMSEN, T. P., HENRIKSEN, U. & CLAUSEN, L. R. 2013. Biomass gasification cogeneration—A review of state of the art technology and near future perspectives. *Applied Thermal Engineering*, 50, 1407-1417.
- ALAM, M. 2006. *Factors affecting yield gap and efficiency in rice productions in some selected areas of Bangladesh*. PhD, Jahangir Nagar University.
- ALEXANDRATOS, N. & DE HAEN, H. 1995. World consumption of cereals: will it double by 2025? *Food Policy*, 20, 359-366.
- ALI, A. & LEBEL, T. 2008. The Sahelian standardized rainfall index revisited. *International Journal of Climatology*, 29, 1705-1714.
- ALLEN, L. 2003. Interventions for micronutrient deficiency control in developing countries: Past present and future. *Journal of Nutrition*, 133, 3875s-3878s.
- ALLINNE, C., MARIAC, C., VIGOUROUX, Y., BEZANCON, G., COUTURON, E., MOUSSA, D., TIDJANI, M., PHAM, J.-L. & ROBERT, T. 2008. Role of seed flow on the pattern and dynamics of pearl millet (*Pennisetum glaucum*) genetic diversity assessed by AFLP markers: A study in south-western Niger. *Genetica*, 133, 167-178.
- AMTHOR, R., COLE, S. & MANARY, M. 2009. The use of home-based therapy with ready-to-use therapeutic food to treat malnutrition in a rural area during a food crisis. *Journal of the American Dietetic Association*, 109, 464-467.
- ANDERSON, D. & FISHWICK, R. 1984. *Fuelwood Consumption and Deforestation in African Countries (Vol 704)*, Washington DC, World Bank.
- ANDERSON, K. & MASTERS, W. 2009. *Distortions to Agricultural Incentives in Africa*, Washington DC, World Bank.
- APODACA, C. 2008. Preventing child malnutrition: Health and agriculture as determinants of child malnutrition. *Journal of Children and Poverty*, 14, 21-40.
- AQASIKESAT, A. 2012. *RaHealingSpa* [Online]. Available: <http://www.rahealing.com/MORINGA.html> [Accessed 14th June 2013].
- AREEKUL, S., KIRDUDOM, P. & CHAOVANAPRICHA, K. 1976. Studies on djenkol bean poisoning (djenkolism) in experimental animals. *Southeast Asian J Trop Med Public Health*, 7, 551-8.
- AREEKUL, S., MUANGMAN, V., BOHKERD, C. & SAENGHIRUN, C. 1978. Djenkol bean as a source of urolithiasis. *Southeast Asian J Trop Med Public Health*, 9, 427-32.
- ARIMOND, M. & RUEL, M. 2004. Dietary Diversity Is Associated with Child Nutritional Status: Evidence from 11 Demographic and Health Surveys. *The Journal of Nutrition*, 134, 2579-2585.
- ASHLEY, C. & CARNEY, D. 1999. *Sustainable livelihoods: Lessons from early experience*. London: DFID.
- AULD, T. 2006. Population dynamics of the shrub *Acacia suaveolens*. *Australian Journal of Ecology*, 11, 235-254.
- AUNE, J. B. & BATIONO, A. 2008. Agricultural intensification in the Sahel – The ladder approach. *Agricultural Systems*, 98, 119-125.
- AUSTRALIAN GOVERNMENT. 2013. *Weed Risk Assessment System* [Online]. Department of Agriculture Fisheries and Forestry. Available: http://www.daff.gov.au/ba/reviews/weeds/system/weed_risk_assessment [Accessed 3rd April 2013].
- BAR-YAM, Y. 2004. *Making Things Work: Solving Problems in a Complex World*, NECSI Knowledge Press.
- BARCELOUX, D. 2008. Djenkol Bean [*Archidendron jiringa*] In: NIELSEN, I. (ed.) *Medical Toxicology of Natural Substances: Food, Fungi, Medicinal Herbs, Plants and Venomous Animals*. Hoboken, NJ: John Wiley and Sons.
- BARO, M. & DEUBEL, T. 2006. Persistent hunger: Perspectives on vulnerability, famine and food security in Sub-Saharan Africa. *Annual Review of Anthropology*, 35, 521-538.

- BARRETT, C. 2006. Food Aid's Intended and Unintended Consequences *ESA Working Paper No. 06-05*
- BARRETT, C. & MAXWELL, S. 2005. *Food Aid After Fifty Years: Recasting its Role*, Oxon, Routledge.
- BARRETT, C. B. 1998. Food aid: Is it development assistance, trade promotion, both, or neither? *American Journal of Agricultural Economics*, 80, 566-571.
- BEBBINGTON, A. 1999. Capitals and capabilities: a framework for analyzing peasant viability, rural livelihoods and poverty. *World development*, 27, 2021-2044.
- BECQUEY, E., MARTIN-PREVEL, Y., TRAISSAC, P., DEMBÉLÉ, B., BAMBARA, A. & DELPEUCH, F. 2010. The Household Food Insecurity Access Scale and an Index-Member Dietary Diversity Score Contribute Valid and Complementary Information on Household Food Insecurity in an Urban West-African Setting. *The Journal of Nutrition*, 140, 2233-2240.
- BEER, F. 1990. Cereal Banks In Niger. Niamey: USAID.
- BELCHER, B., RUÍZ-PÉREZ, M. & ACHDIAWAN, R. 2005. Global patterns and trends in the use and management of commercial NTFPs: implications for livelihoods and conservation. *World development*, 33, 1435-1452.
- BELL, E. A. 2003. Nonprotein Amino Acids of Plants: Significance in Medicine, Nutrition, and Agriculture. *Journal of Agricultural and Food Chemistry*, 51, 2854-2865.
- BEN YAHMED, S. & KAWAGUCHI, Y. 1996. Reducing vulnerability. *World Health*, 49.
- BENNETT, R., MELLON, F., FOIDL, N., PRATT, J., DUPONT, M., PERKINS, L. & KROON, P. 2003. Profiling glucosinolates and phenolics in vegetative and reproductive tissues of the multi-purpose trees *Moringa oleifera* L. (horseradish tree), and *Moringa stenopetala* L. *Journal of Agriculture and Food Chemistry*, 51, 3546-3553.
- BERG, E. & KENT, L. 1991. *The economics of cereal banks in the Sahel*, DAI.
- BERKES, F., FOLKE, C. & COLDING, J. 2000. *Linking social and ecological systems: management practices and social mechanisms for building resilience*, Cambridge University Press.
- BERNHOLT, H., KEHLENBECK, K., GEBAUER, J. & BUERKERT, A. 2009. Plant species richness and diversity in urban and peri-urban gardens of Niamey, Niger. *Agroforestry Systems*, 77, 159-179.
- BINGEN, J. Institutions and Sustainable Livelihoods. In: DFID, ed. *Forum on Operationalizing Participatory Ways of Applying Sustainable Livelihoods Approaches: Proceedings*, 2000 Rome. FAO.
- BIVINS, M. 2007. *Telling Stories, Making Histories: Women, Words and Islam in Nineteenth-Century Hausaland and the Sokoto Caliphate*, Portsmouth, Heinemann.
- BLUM, L. 1997. Community assessment of natural food sources of Vitamin A in Niger: the Hausas of Filingue. In: KUHNLEIN, H. & PELTO, G. (eds.) *Culture, Environment and Food to Prevent Vitamin A Deficiency*. Canada: International Nutrition Foundation for Developing Countries.
- BOERS, T. M. & BEN-ASHER, J. 1982. A review of rainwater harvesting. *Agricultural Water Management*, 5, 145-158.
- BOSERUP, E. 1981. *Population and technological change : a study of long-term trends*, Chicago, University of Chicago Press.
- BOSERUP, E. 2005. *The conditions of agricultural growth : the economics of agrarian change under population pressure*, New Brunswick, NJ, Aldine Transaction.
- BOUGHTON, B. & YATES, P. Forthcoming. Djenkolic acid in acacia seed and processing methods to minimise toxicity. *Food and Chemical Toxicology*.
- BOUIS, H. & ISLAM, Y. 2012. Biofortification: Leveraging Agriculture to Reduce Hidden Hunger. In: FAN & PANDYA-LORCH (eds.) *Reshaping Agriculture for Nutrition and Health*. Washington, DC: International Food Policy Research Institute.

- BRADBURY, H. 2009. Development of a sensitive picrate method to determine total cyanide and acetone cyanohydrin contents of gari from cassava. *Food Chemistry*, 113.
- BRAND-MILLER, J., JAMES, K. W. & MAGGIORE, P. M. A. 1993. *Tables of composition of Australian Aboriginal foods*, Canberra, Aboriginal Studies Pr.
- BRAND, J. & MAGGIORE, P. 1992. The nutritional composition of Australian Acacia seeds. In: HOUSE, A. & HARWOOD, C. (eds.) *Australian Dry-Zone Acacias for Human Food*. Canberra: Australian Tree Seed Centre: CSIRO.
- BRAND, J. C. & CHERIKOFF, V. 1985. Australian Aboriginal bushfoods: the nutritional composition of plants from arid and semi-arid areas. *Australian Aboriginal Studies*, 2, 38-46.
- BRAUN, J., HAEN, H. & BLANKEN, J. 1991. *Commercialization of agriculture under population pressure: effects on production, consumption, and nutrition in Rwanda*, Washington, IFPRI.
- BRIEND, A. 2001. Highly nutrient-dense spreads: a new approach to delivering multiple micronutrients to high-risk groups. *British Journal of Nutrition*, 85, 175.
- BRIEND, A. 2002. Possible use of spreads as a FOODlet for improving the diets of infants and young children. *Food & Nutrition Bulletin*, 23, 239-243.
- BRIEND, A. & PRINZO, Z. W. 2009. Dietary management of moderate malnutrition: Time for a change. *Food & Nutrition Bulletin*, 30, 265.
- BROCK, J. & AUTRET, M. 1952. Kwashiorkor in Africa. *Bulletin of the World Health Organisation*, 5.
- BROMLEY, D. W. & CERNEA, M. M. 1989. *The management of common property natural resources: Some conceptual and operational fallacies*, World Bank Publications.
- BROWN, A., CHERIKOFF, V. & ROBERTS, D. C. K. 1987. Fatty acid composition of seeds from the Australian Acacia species. *Lipids*, 22, 490-494.
- BRYCE, J., COITINHO, D., DARNTON-HILL, I., PELLETIER, D. & PINSTRUP-ANDERSEN, P. 2008. Maternal and child undernutrition: effective action at national level. *The Lancet*, 371, 510-526.
- BRYCESON, K. 2008. Value Chain Analysis of Bush Tomato and Wattleseed Products. Alice Springs: Desert Knowledge CRC.
- BUCHANAN, R. 1969. The Australian Milk Biscuit. *Dairy Industries*, 34, 729-30.
- BUTLER, S. J., VICKERY, J. A. & NORRIS, K. 2007. Farmland Biodiversity and the Footprint of Agriculture. *Science*, 315, 381-384.
- CARNEY, D. 1998. *Sustainable Rural Livelihoods: What contribution can we make?*, London, Department for International Development.
- CARNEY, D. 2003. Sustainable Livelihoods Approaches: Progress and Possibilities for Change. London: DFID.
- CARRUTHERS, J. & ROBIN, L. 2010. Taxonomic imperialism in the battles for Acacia: Identity and science in South Africa and Australia. *Transactions of the Royal Society of South Africa*, 65, 48-64.
- CARTER, C., RAUSSER, G. & SMITH, A. 2012. The Effect of the U.S. Ethanol Mandate on Corn Prices. *agecon UCDAVIS*.
- CHADHA, M. & OLUOCH, M. 2003. Home-based vegetable gardens and other strategies to overcome micronutrient malnutrition in developing countries. *Food, Nutrition and Agriculture*, 32, 17-23.
- CHAMBERS, R. 1983. *Rural Development - Putting The Last First*, Essex, Longmans Scientific and Technical Publishers.
- CHAMBERS, R. Sustainable rural livelihoods: a strategy for people, environment and development. Sustainable Rural Livelihoods: A strategy for People, Environment and Development, 1987.
- CHAMBERS, R. 1989. Vulnerability: How the poor cope. *IDS Bulletin*, 20.

- CHAN, K. Y., VAN ZWIETEN, L., MESZAROS, I., DOWNIE, A. & JOSEPH, S. 2007. Agronomic values of greenwaste biochar as a soil amendment. *Soil Research*, 45, 629-634.
- CHERIKOFF, V. 2000. Marketing of the Australian Native Food Industry. *RIRDC Publication No. 00/61*. Canberra: Rural Industries Research and Development Corporation.
- CLEAVER, F. & FRANKS, T. 2005. *How institutions elude design: River basin management and sustainable livelihoods*, University of Bradford. Bradford centre for international development (BCID).
- CLIMATE DATA. 2013. *Climatedata.eu: Climate Maradi, Niger* [Online]. Available: www.climatedata.eu/climate.php?loc=ngxx0006&lang=en [Accessed 9/April 2013].
- CLOUGH, T. J. & CONDRON, L. M. 2010. Biochar and the nitrogen cycle: Introduction. *Journal of environmental quality*, 39, 1218-1223.
- COE, F., EVAN, A. & WORCESTER, E. 2005. Kidney stone disease. *Journal of Clinical Investigation*, 115.
- COLLINS, S. 2001. Changing the way we address severe malnutrition during famine. *The Lancet*, 358, 498-501.
- CONROY, C. & LITVINOFF, M. 1988. *The greening of aid: sustainable livelihoods in practice.*, London, Earthscan.
- COOPER, B. 2009. Chronic Malnutrition and the Trope of the Bad Mother. *A not-so natural disaster: Niger 2005*. Columbia Univ Pr.
- COPPOLA, P. 1991. Document De Travail: Impact des Banques cereales sur la securite alimentaire. Geneva: Bureau International du Travail.
- COSSALTER, C. 1986. Introduction of Australian acacias into dry Tropical West Africa. *Forest Ecology and Management*, 16, 367-389.
- COULTER, J. 2007. Local and Regional Procurement of Food Aid in Africa: Impact and Policy Issues. *Journal of Humanitarian Assistance*, October 2007.
- CUNNINGHAM, P. 2009. Food security, environmental restoration and income generation in the semi arid tropics: The Farmer Managed Agroforestry Farming System (FMAFS). *ECHO 16th Annual Conference*. Educational Concerns for Hunger Organisation (ECHO).
- CUNNINGHAM, P. & ABASSE, T. 2005a. Annex 10: Reforesting the Sahel: farmer managed natural regeneration. In: KALINGANIRE, A., NIANG, A. & KONE, A. (eds.) *Domestication des espèces agroforestières au Sahel: situation actuelle et perspectives. Working Paper*. Nairobi: World Agroforestry Centre.
- CUNNINGHAM, P. & ABASSE, T. 2005b. Domestication of Australian Acacias for the Sahelian zone of West Africa In: KALINGANIRE, A., NIANG, A. & KONE, A. (eds.) *Domestication des especes agroforestieres au Sahel: situation actuelle et perspectives*. Nairobi: ICRAF.
- CUNNINGHAM, P., NICHOLSON, C., YAOU, S., RINAUDO, T., AUSTRALIA, N. & HARWOOD, C. Utilization of Australian acacias for improving food security and environmental sustainability in the Sahel, West Africa. Proceedings of the International Symposium on 'Underutilized Plants for Food, Nutrition, Income and Sustainable Development, 2008.
- D'MELLO, F., DUFFUS, C. & DUFFUS, J. 1991. *Toxic Substances in Crop Plants*, Cambridge, Royal Society of Chemistry.
- DASGUPTA, P. 2001. Human well-being and the natural environment. *OUP Catalogue*.
- DE LUKA, T., MACKENZIE, M. & GUNDALE, M. 2009. Biochar Effects on Soil Nutrient Transformations. In: LEHMANN, J. & JOSEPH, S. (eds.) *Biochar for Environmental Management*. London: Earthscan.
- DE MIRANDA, R., BAILIS, R. & VILELA, A. 2013. Cogenerating electricity from charcoaling: A promising new advanced technology. *Energy for Sustainable Development*, 17, 171-176.

- DE NEERGAARD, A., SAARNAK, C., HILL, T., KHANYILE, M., BERZOSA, A. M. & BIRCH-THOMSEN, T. 2005. Australian wattle species in the Drakensberg region of South Africa—An invasive alien or a natural resource? *Agricultural Systems*, 85, 216-233.
- DE WAAL, A. 1991. *Evil Days: Thirty Years of War and Famine in Ethiopia*, New York & London, Human Rights Watch.
- DEFOURNY, I., SEROUX, G., ABDELKADER, I. & HARCZI, G. 1994. Management of moderate acute malnutrition with RUTF in Niger. *perspective*, 124, 2043S-2046S.
- DEL NINNO, C., DOROSH, P. A. & SUBBARAO, K. 2007. Food aid, domestic policy and food security: Contrasting experiences from South Asia and sub-Saharan Africa. *Food Policy*, 32, 413-435.
- DEVITT, J. Acacias: a traditional Aboriginal food. Australian Dry-zone Acacias for Human Food: Proceedings of a Workshop Held at Glen Helen, Northern Territory, Australia, 7-10 August 1991, 1992. CSIRO Publishing, 37.
- DIAO, X., HEADEY, D. & JOHNSON, M. 2008. Toward a green revolution in Africa: What would it achieve, and what would it require? *Agricultural Economics*, 39, 539-550.
- DIBARI, F., EL HADJI, I. D., COLLINS, S. & SEAL, A. 2012. Low-Cost, Ready-to-Use Therapeutic Foods Can Be Designed Using Locally Available Commodities with the Aid of Linear Programming. *The Journal of Nutrition*, 142, 955-961.
- DICKENS, J. 1977. Aflatoxin control program for peanuts. *J. American Oil Chemists Soc.*, 54, 225-228.
- DIJKHUIZEN, P. 2000. Processed complementary foods in the World Food Program. *Food and Nutrition Bulletin*, 21.
- DORWARD, A., KYDD, J., MORRISON, J. & UREY, I. 2004. A Policy Agenda for Pro-Poor Agricultural Growth. *World Development*, 32, 73-89.
- DORWARD, A., POOLE, N., MORRISON, J., KYDD, J. & UREY, I. Critical linkages: livelihoods, markets and institutions. Supporting institutions, evolving livelihoods' seminar, Bradford Centre for International Development, University of Bradford, UK, May, 2002.
- DUNLOP, R., BAIRNES, R., NIXON, K. & HAGEDORN, S. 2003. A breeding strategy for *Acacia mearnsii* (Black wattle) in South Africa. *The Southern African Forestry Journal*, 199, 55-63.
- DURKHEIM, E. 1994. *Emile Durkheim on institutional analysis*, University of Chicago Press.
- EDKINS, J. 2000. *Whose Hunger?: Concepts of Famine, Practices of Aid*, Minnesota, University of Minnesota Press.
- EDKINS, J. 2002. Mass Starvations and the Limitations of Famine Theorising. *IDS Bulletin*, 33, 12-18.
- EDWARDS, M. & HULME, D. 1996. *Beyond the Magic Bullet? NGO Performance and Accountability in the Post-Cold War World*, West Hartford, CT Kumarian.
- EE, K., REHMAN, A., AGBOOLA, S. & ZHAO, J. 2009. Influence of heat processing on functional properties of Australian wattle seed (*Acacia victoriae* Benth.) extracts. *Food Hydrocolloids*, 23, 116-124.
- EE, K., ZHAO, J., REHMAN, A. & AGBOOLA, S. 2008a. Characterisation of trypsin and α -chymotrypsin inhibitors in Australian wattle seed (*Acacia victoriae* Benth.). *Food Chemistry*, 107, 337-343.
- EE, K., ZHAO, J., REHMAN, A. & AGBOOLA, S. 2011. Glycosylation, amino acid analysis and kinetic properties of a major Kunitz-type trypsin inhibitor from *Acacia victoriae* Benth. seeds. *Food Chemistry*, 129, 1224-1227.
- EE, K. Y. & YATES, P. 2013. Nutritional and antinutritional evaluation of raw and processed Australian wattle (*Acacia saligna*) seeds. *Food Chemistry*, 138, 762-769.
- EE, K. Y., ZHAO, J., REHMAN, A. & AGBOOLA, S. 2008b. Characterisation of trypsin and α -chymotrypsin inhibitors in Australian wattle seed (*Acacia victoriae* Benth.). *Food Chemistry*, 107, 337-343.

- EHRlich, P. & EHRlich, A. 2009. The Population Bomb Revisited. *Electronic Journal of Sustainable Development*, 1, 63-71.
- EHRlich, P., EHRlich, A. & DAILY, G. 1993. Food Security, Population and Environment. *Population and Development Review*, 19, 1-32.
- ERICKSEN, P., BOHLE, H. & STEWART, B. 2010. Vulnerability and Resilience of Food Systems In: INGRAM, J., ERICKSEN, P. & LIVERMAN, D. (eds.) *Food Security and Global Environmental Change*. London: Earthscan.
- ESCOBAR, A. 1995. *Encountering Development: the Making and Unmaking of the Third World*, Princeton NJ, Princeton University Press.
- ESTEVA, G. 1992. Development. In: SACHS, W. (ed.) *The Development Dictionary*. London: Zed Books.
- ETKIN, N. & ROSS, P. 1982. Food as medicine and medicine as food: An adaptive framework for the interpretation of plant utilization among the Hausa of northern Nigeria. *Social Science and Medicine*, 16, 1559-1573.
- EVANS, L. 1998. *Feeding the Ten Billion: Plants and Population Growth*, Cambridge, Cambridge University Press
- EVENSON, R. & GOLLIN, D. 2003. Assessing the Impact of the Green Revolution, 1960 to 2000. *Science*, 300, 758-762.
- FABER, M. & LAURIE, S. 2011. A Home Gardening Approach Developed in South Africa to Address Vitamin A Deficiency. In: THOMPSON, B. & AMOROSO, L. (eds.) *Combatting Micronutrient Deficiencies: Food Based Approaches*. Rome: FAO and CABI.
- FAFCHAMPS, M. 2004. *Market institutions in Sub-Saharan Africa: theory and evidence*, MIT Press.
- FALADE, M. S., OWOYOMI, O., HARWOOD, C. & ADEWUSI, S. R. A. 2005. Chemical composition and starch hydrolysis of Acacia colei and Acacia tumida seeds. *Cereal chemistry*, 82, 479-484.
- FALADE, O. S., ADEKUNLE, A. S., ADEROGBA, M. A., ATANDA, S. O., HARWOOD, C. & ADEWUSI, S. R. 2008. Physicochemical properties, total phenol and tocopherol of some Acacia seed oils. *Journal of the Science of Food and Agriculture*, 88, 263-268.
- FALADE, O. S., ADEWUSI, S. R. A. & HARWOOD, C. E. 2012. S-carboxyethylcysteine (a constituent of Acacia seed) negatively affects casein protein utilization by rats. *Nutrition*, 28, 785-792.
- FANNY, R., MARTINE, A. & SIGRID, A. 2012. Social-ecological Functions and Vulnerability Framework to Analyze Forest Policy Reforms. *Ecology and Society*, 17, 21.
- FAO 1995. Sorghum and Millets in Human Nutrition. Rome: Food and Agriculture Organization of the United Nations.
- FAO. 2003. *La Region de Maradi* [Online]. Available: www.fao.org/dcrep/006/y4957F/y4957f0j.htm [Accessed 23 April 2013].
- FAO 2008. Food Climate E-newsletter. Dec., 14 p.
- FAO 2009. How to feed the world in 2050. Discussion paper. *World Summit of Food Security*. Rome 12–13 October.
- FAO & WHO 2002. Human Vitamin and Mineral Requirements. Rome: FAO and WHO.
- FARRINGTON, J. & SLATER, R. 2006. Introduction: Cash Transfers: Panacea for Poverty Reduction or Money Down the Drain? *Development Policy Review*, 24, 499-511.
- FEATHERBY, T. & YATES, P. Forthcoming. An in-vivo assessment of sub-acute toxic effects of the seed of four species of acacia seed, with a comparison to similar levels of synthetic djenkolic acid. *Food and Chemical Toxicology*.
- FERNANDEZ, R., ARCHER, E., ASH, A. J., DOWLATABADI, H., HIERNAUX, P., REYNOLDS, J. F., VOGEL, C., WALKER, B. H. & WIEGAND, T. 2002. Degradation and recovery in socio-ecological systems: a view from the household/farm level. *Global desertification: do humans cause deserts*, 297-324.

- FEWSNET 2012. A Climate Trend Analysis of Niger. *Famine Early Warning System - Informing Climate Change Adaptation Series*. FEWSnet/USGS/USAID.
- FISHER, W. 1997. Doing good? The politics and antipolitics of NGO practices. *Annual Review of Anthropology*, 26, 439-64.
- FRANKEL, F. 1971. *India's green revolution. Economic gains and political costs.*, Oxford, Oxford University Press.
- FRISON, E., SMITH, I., JOHNS, T., CHERFAS, J. & EYZAGUIRRE, P. 2006. Agricultural biodiversity, nutrition and health: making a difference to hunger and nutrition in the developing world. *Food and Nutrition Bulletin*, 27.
- FROSSARD, E., BUCHER, M., MACHLER, F., MOZAFAR, A. & HURRELL, R. 2000. Potential for increasing the content and bioavailability of Fe, Zn and Ca in plants for human nutrition. *Journal of the Science of Food and Agriculture*, 80, 861-879.
- FRYER, J. 1981. *Food for Thought: The Use and Abuse of Food Aid in the Fight Against World Hunger*, World Council of Churches.
- GABAY, M. 2002. Galactagogues: medications that induce lactation. *Journal of Human Lactation*, 18, 274-279.
- GALTUNG, J. 1990. Cultural Violence. *Journal of Peace Research*, 27, 291-305.
- GAMATIE, M. & DE SAINT SAUVEUR, A. N.D. Technical and economic sheet on the conditions for production and marketing fresh Moringa leaves in Niger. Moringa News.
- GARRITY, D. Improved agroforestry technologies for conservation farming: Pathways toward sustainability. IBSRAM Proceedings, 1994 Bogor, Indonesia. International Centre for Research in Agroforestry.
- GARRITY, D. 2010. Creating an Evergreen Double-Story Agriculture in Africa for Food Security with Environmental Resilience: Recent advances & research needed. In: CENTRE, W. A. (ed.). Nairobi.
- GAUNT, J. L. & LEHMANN, J. 2008. Energy Balance and Emissions Associated with Biochar Sequestration and Pyrolysis Bioenergy Production. *Environmental Science & Technology*, 42, 4152-4158.
- GEBRU, G. 2012. *Effects of supplementing wheat bran and graded levels of dried Acacia saligna leaves on feed intake, body weight gain, digestibility, carcass and semen qualities of highland sheep* MSc, Mekelle University.
- GEOHIVE. 2013. *Niger Data* [Online]. Available: www.geohive.com/cntry/niger.aspx [Accessed 23 April 2013].
- GIBSON, R., FERGUSON, E. & LEHRFELD, J. 1998. Complementary foods for infant feeding in developing countries: their nutrient adequacy and improvement. *European Journal of Clinical Nutrition*, 52, 764.
- GIBSON, R., PERLAS, L. & HOTZ, C. 2006. Improving the bioavailability of nutrients in plant foods at the household level. *Proceedings of the Nutrition Society*, 65, 160-168.
- GIDÉ, A. 1925. *Les faux-monnayeurs*, Paris, Nouvelle Revue Française.
- GILLAND, B. 1988. [untitled]. *Population and Development Review*, 14, 511-514.
- GLAESER, B. 1987. *The Green Revolution Revisited: Critique and Alternatives.*, London, Allen and Unwin.
- GODDARD, C. 1995. *Punu: Yankunytjatjara plant use*, Alice Springs, Institute for Aboriginal Development.
- GOPALAN, C. 1968. *Kwashiorkor and marasmus: evolution and distinguishing features*, London, Churchill.
- GREGER, J. 1999. Nondigestible carbohydrates and mineral bioavailability. *J Nutr.*, 129, 1434S-5S.
- GRIFFIN, A., MIDGLEY, S., BUSH, D., CUNNINGHAM, P. & RINAUDO, A. 2011. Global uses of Australian acacias - recent trends and future prospects. *Divers Distrib*, 17, 837-847.

- GRIFFIN, K. 1974. *The Political Economy of Agrarian Change, an Essay on the Green Revolution.*, London, Macmillan.
- GRIGG, D. 1979. Ester Boserup's theory of agrarian change: a critical review. *Prog Hum Geogr*, 3, 64-84.
- GRIVETTI, L. 1981. *Perspectives on Dietary Utilisation of Wild Plants, Nutritional Status and Agricultural Development*, Fresno, California, International Geographical Union Commission on Rural Development.
- GRIVETTI, L. & OGLE, B. 2000. Value of traditional foods in meeting macro- and micronutrient needs: the wild plant connection. *Nutrition Research Reviews*, 13, 31-46.
- GROSS, R. & WEBB, P. 2006. Wasting time for wasted children: severe child undernutrition must be resolved in non-emergency settings. *The Lancet*, 367, 1209-1211.
- HABAUTZIT, V. & MORAND, C. 2011. Evidence for a protective effect of polyphenols-containing foods on cardiovascular health: An update for clinicians. *Therapeutic Advances in Chronic Disease*, 3, 87-106.
- HAGAZI, N. 2011. Potential and progress of *Acacia saligna* to reduce hunger in Tigray National Regional State, Ethiopia. In: FRANCIS, R. (ed.) *Wattle We Eat For Dinner?* Alice Springs: World Vision Australia.
- HAGENIMANA, V., OYUNGA, M., LOW, J., NJOROGI, S., GICHUKI, S. & KABIRA, J. 1999. The Effects of Women Farmers' Adoption of Orange-Fleshed Sweet Potatoes: Raising vitamin A Intake in Kenya. *Research Report Series 3*. Nairobi: International Centre for Research on Women.
- HAGLUND, E., NDJEUNGA, J., SNOOK, L. & PASTERNAK, D. 2011. Dry land tree management for improved household livelihoods: Farmer managed natural regeneration in Niger. *Journal of Environmental Management*, 92, 1696-1705.
- HAMPSHIRE, K., CASIDAY, R., KILPATRICK, K. & PANTER-BRICK, C. 2009. The social context of childcare practices and child malnutrition in Niger's recent food crisis. *Disasters*, 33, 132-151.
- HANCOCK, G. 1994. *The Lords of Poverty: The Power, Prestige and Corruption of the International Aid Business*, Atlantic Monthly Press.
- HANJRA, M. A. & QURESHI, M. E. 2010. Global water crisis and future food security in an era of climate change. *Food Policy*, 35, 365-377.
- HARWOOD, C. & HOUSE, A. 1992. *Australian Dry-zone Acacias for Human Food: Proceedings of a Workshop Held at Glen Helen, Australia*, Canberra, CSIRO.
- HARWOOD, C., RINAUDO, T. & ADEWUSI, S. 1999. Developing Australian acacia seeds as a human food for the Sahel. *Unasylva*, 50.
- HARWOOD, C. E. 1994. Human food potential of the seeds of some Australian dry-zone Acacia species. *Journal of Arid Environments*, 27, 27-35.
- HECHTER, M. 1987. The emergence of cooperative social institutions. *Paradox and society: the work of Bernard Mandeville*, 13.
- HO, K. 2007. Structural Violence as a Human Rights Violation. *Essex Human Rights Review*, 4.
- HODDINOTT, J. 2012. Agriculture, Health and Nutrition: Towards Conceptualising the Linkages. In: FAN, S. & PANDYA-LORCH (eds.) *Reshaping Agriculture for Nutrition and Health*. Washington DC: IFPRI.
- HODDINOTT, J. & YOHANNES, Y. 2002. Dietary diversity as a food security indicator. *FCND DISCUSSION PAPER NO. 136*.
- HOSTETTMANN, K. & MARSTON, A. 1995. *Saponins*, Cambridge, Cambridge University Press.
- HOTZ, C. & GIBSON, R. 2007. Traditional food-processing and preparation practices to enhance the bioavailability of micronutrients in plant-based diets. *J. Nutr.*, 137, 1097-1100.

- HOTZ, C. & MCCLAFFERTY, B. 2007. From harvest to health: challenges for developing biofortified staple foods and determining their impact on micronutrient status. *Food and Nutrition Bulletin*, 28, S271-S279.
- HOUSE, A. & HARWOOD, C. 1992. *Australian Dry-Zone Acacias for Human Food*, Canberra, Australian Tree Seed Centre, CSIRO.
- HUFFMAN, S. & STEEL, A. 1995. Do Child Survival Interventions Reduce Malnutrition? The Dark Side of Child Survival. In: PINSTRUP-ANDERSEN, P., PELLETIER, D. & ALDERMAN, H. (eds.) *Child Growth and Nutrition in Developing Countries: Priorities for Action*. Ithaca: Cornell University Press.
- HULME, M., DOHERTY, R., NGARA, T., NEW, M. & LISTER, D. 2001. African climate change: 1900-2100. *Climate research*, 17, 145-168.
- HUMPHRY, C. M., CLEGG, M. S., KEEN, C. L. & GRIVETTI, L. E. 1993. Food diversity and drought survival. The Hausa example. *International Journal of Food Sciences and Nutrition*, 44, 1-16.
- HUNT, S. 1985. The non-protein amino acids. *Chemistry and biochemistry of the amino acids*. Netherlands: Springer.
- HURRELL, R. 2003. Influence of vegetable protein sources on trace element and mineral bioavailability. *The Journal of Nutrition*, 133.
- IAM-ONG, S. & ITPRITJA, V. 1998. Tropical plant associated nephropathy. *Nephrology*, 4, 313-319.
- ICRISAT. 2012. *Pearl Millet Production and Practices* [Online]. ICRISAT. Available: www.vasat.icrisat.org/crops/pearl_millet/pm_production/html/m9_2/index.html [Accessed 12 April 2013].
- IHONVBERE, J. O. 1994. The 'irrelevant' state, ethnicity, and the quest for nationhood in Africa. *Ethnic and Racial Studies*, 17, 42-60.
- INRAN 2009. INRAN's Research Priorities: Presentation by the Director. Maradi: INRAN Open Day, September 2009.
- IRIN 2009. Somalia: Three teaspoons a day to keep starvation at bay? *IRIN NEWS*.
- IRIN 2010a. Niger: Acute child malnutrition increases by five percent. *All Africa*.
- IRIN 2010b. Niger: Acute malnutrition increases by 42%. *IRIN NEWS*.
- ISANAKA, S., ROEDERER, T., DJIBO, A., LUQUERO, F. J., NOMBELA, N., GUERIN, P. J. & GRAIS, R. F. 2010. Reducing wasting in young children with preventive supplementation: a cohort study in Niger. *Pediatrics*, 126, e442-e450.
- JACKSON, T. & EADE, D. 1982. *Against the grain: the dilemma of project food aid*, Oxfam.
- JALLOH, A., SARR, B., KUISEU, J., ROY-MACAULEY, H. & SEREME, P. 2011. Review of climate in West and Central Africa to inform farming systems research and development in the sub-humid and semi-arid agroecologies of the region. Dakar: CORAF/WECARD.
- JOSEPH, S. 2009. Socio-economic Assessment and Implementation of Small-scale Biochar Projects. In: LEMANN, J. & JOSEPH, S. (eds.) *Biochar for Environmental Management*. London: Earthscan.
- KABEER, N. 1990. Women, household food security and coping strategies. *Women and Nutrition*. Geneva: United Nations.
- KAPOOR, S. K. & ANAND, K. 2002. Nutritional transition: a public health challenge in developing countries. *Journal of Epidemiology and Community Health*, 56, 804-805.
- KEANE, P. 2013. Can We Feed 9 Billion People in 2050? La Trobe University: Australian Broadcasting Commission.
- KEATINGE, D. & EASDOWN, W. 2009. Hidden hunger: food security means balanced diets. *Issues*, 89.
- KEEN, D. 1994. *The benefits of famine: a political economy of famine and relief in southwestern Sudan, 1983-1989*, Princeton, New Jersey, Princeton University Press.

- KELLER, R., LODGE, D. & FINNOFF, D. 2007. Risk Assessment for invasive species produces net bioeconomic benefits. *Proceedings of the National Academy of Sciences, USA*, 104, 203-207.
- KENEALLY, T. 2011. *Three famines*, Sydney, Vintage.
- KHOGALI, H. & TAKHAR, P. 2001. Empowering women through cash relief in humanitarian contexts. *Gender & Development*, 9, 40-49.
- KONING, N. & SMALING, E. 2005. Environmental crisis or 'lie of the land'? The debate on soil degradation in Africa. *Land Use Policy*, 22, 3-11.
- KULL, C. & TASSIN, J. 2012. Australian acacias: useful and (sometimes) weedy. *Biological Invasions*, 14, 2229-2233.
- KULL, C. A. & RANGAN, H. 2008. Acacia exchanges: Wattles, thorn trees, and the study of plant movements. *Geoforum*, 39, 1258-1272.
- KULL, C. A., SHACKLETON, C. M., CUNNINGHAM, P. J., DUCATILLON, C., DUFOUR-DROR, J.-M., ESLER, K. J., FRIDAY, J. B., GOUVEIA, A. C., GRIFFIN, A. R., MARCHANTE, E., MIDGLEY, S. J., PAUCHARD, A., RANGAN, H., RICHARDSON, D. M., RINAUDO, T., TASSIN, J., URGENSON, L. S., VON MALTITZ, G. P., ZENNI, R. D. & ZYLSTRA, M. J. 2011. Adoption, use and perception of Australian acacias around the world. *Diversity and Distributions*, 17, 822-836.
- KUMAR, B. & NAIR, P. 2004. The enigma of tropical homegardens. *Agroforestry Systems*, 61-62, 135-152.
- LAGRONE, L. N., TREHAN, I., MEULI, G. J., WANG, R. J., THAKWALAKWA, C., MALETA, K. & MANARY, M. J. 2012. A novel fortified blended flour, corn-soy blend "plus-plus," is not inferior to lipid-based ready-to-use supplementary foods for the treatment of moderate acute malnutrition in Malawian children. *The American Journal of Clinical Nutrition*, 95, 212-219.
- LATZ, P. K. & GREEN, J. 1995. *Bushfires & bushtucker: Aboriginal plant use in Central Australia*, Alice Springs, IAD Press
- LAVY, V. 1990. Does food aid depress food production. The disincentive dilemma in the African context. *Document de travail, World Bank*.
- LE MAITRE, D. C., RICHARDSON, D. M. & CHAPMAN, R. A. 2004. Alien plant invasions in South Africa: driving forces and the human dimension. *South African Journal of Science*, 100.
- LEATHERS, H. & FOSTER, P. 2004. *The World Food Problem: Tackling the Causes of Undernutrition in the Third World*, London, Lynne Rienner.
- LEHMANN, J. & JOSEPH, S. 2009. *Biochar for Environmental Management*, London, Earthscan.
- LEISINGER, K., SCHMITT, K. & ISNAR 1995. *Survival in the Sahel*, The Hague, International Service for National Agricultural Research.
- LENTZ, E., BARRETT, C. & HODDINOTT, J. 1995. Food Aid and Dependency: Implications for Emergency Food Security Assessments. Washington DC: International Food Policy Research Institute.
- LIPTON, M. 1977. *Why poor people stay poor: a study of urban bias in world development*, Temple Smith London.
- LISTER, P. R., HOLFORD, P., HAIGH, T. & MORRISON, D. A. 1996. Acacia in Australia: Ethnobotany and potential food crop. *Progress in new crops*. ASHS Press, Alexandria, VA <http://www.hort.purdue.edu/newcrop/proceedings1996/v3-228.html> [Accessed 15 Apr. 2005], 228-236.
- LOFCHIE, M. & COMMINS, S. 1982. Food Deficits and Agricultural Policies in Tropical Africa. *The Journal of Modern African Studies*, 20, 1-25.
- LOFCHIE, M. F. 1986. The Decline of African Agriculture: An Internalist Perspective'. In: GLANTZ, M. (ed.) *Drought and Hunger in Africa*.

- LOTT, J., OCKENDEN, I., RABOY, V. & BATTEN, G. D. 2000. Phytic acid and phosphorus in crop seeds and fruits: a global estimate. *Seed Science Research*, 10, 11-34.
- LOW, J., ARIMOND, M., OSMAN, N., CUNGUARA, B., ZANO, F. & TSCHIRLEY, D. 2007. A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. *Journal of Nutrition*, 137, 1320-1327.
- LOW, J., KINYAE, P., GICHUKI, S., OYUNGA, M., HAGENIMANA, V. & KABIRA, J. 1997. Combating vitamin A deficiency through the use of sweet potato: Results from Phase 1 of an action research project in South Nyanza, Kenya. Lima Peru: International Potato Center.
- LOW, T. 2012. Australian acacias: weeds or useful trees. *Biological Invasions*, 14, 2217-2227.
- LUCAS, B., GUERRERO, A., SIGALES, L. & SOTELO, A. 1988. True protein content and non-protein amino acids present in legume seeds. *Nutr. Rep. Int.*, 37, 545-53.
- LUND, C. 2001. Seeking Certainty and Aggravating Ambiguity On Property, Paper and Authority in Niger. *IDS Bulletin*, 32, 47-53.
- LUND, C. 2006. Twilight institutions: public authority and local politics in Africa. *Development and Change*, 37, 685-705.
- LUTTER, C. & DEWEY, K. 2003. Proposed nutrient composition for fortified complementary foods. *Journal of Nutrition*, 133, 3011S-20S.
- MABUZA, M. L., HENDRIKS, S. L., ORTMANN, G. F. & SITHOLE, M. M. 2009. The impact of food aid on maize prices and production in Swaziland. *Agrekon*, 48, 85-105.
- MAHE, G. & PATUREL, J. 2009. 1896-2006 Sahelian annual rainfall variability and runoff increase of Sahelian rivers. *Geoscience*, 583-546.
- MAJOR, J., STEINER, C., DOWNIE, A. & LEHMANN, J. 2009. Biochar Effects on Nutrient Leaching. In: LEHMANN, J. & JOSEPH, S. (eds.) *Biochar for Environmental Management*. London: Earthscan.
- MALINOWSKI, B. 1944. *A Scientific Theory of Culture and Others Essays*, Chapel Hill, N. Carolina, The University of North Carolina Press.
- MALTHUS, T. 1999. An essay on the principle of population. In: GILBERT, G. (ed.) *Oxford world's classics*. Oxford: Oxford University Press.
- MAMOUDA, M. & DIOP, C. 2010. Climate Change Adaptation and Food Insecurity Maradi District - Niger. *22nd International Conference: Climate, Sustainability and Development in Semi-Arid Regions*. AUGUST 16-20, 2010, Fortaleza - Ceara, Brazil.
- MANFREDINI, S., VERTUANI, S. & BUZZONI, V. 2002. Adansonia Digitata Il Baobab Farmacista. *Integr Nutr*, 5, 25-29.
- MANJI, F. & O'COILL, C. 2005. NGO's: a tainted history. *New African*, 443, 16.
- MANNING, D. & LOPEZ-CAPEL, E. 2009. Test Procedures for Determining Quantity of Biochar in Soils. In: LEHMANN, J. & JOSEPH, S. (eds.) *Biochar for Enviromental Management*. London: Earthscan.
- MARANZ, S. 2009. Tree mortality in the Africal Sahel indicates an anthropogenic ecosystem displaced by climate change. *Journal of Biogeography*, 36, 1181-1193.
- MARCHIONE, T. J. 2002. Foods Provided through U.S. Government Emergency Food Aid Programs: Policies and Customs Governing Their Formulation, Selection and Distribution. *The Journal of Nutrition*, 132, 2104S-2111S.
- MARKANDYA, A. & PEARCE, D. W. 1991. Development, the environment, and the social rate of discount. *The World Bank Research Observer*, 6, 137-152.
- MARTIN, L. L. & SIMMONS, B. A. 1998. Theories and empirical studies of international institutions. *International Organization*, 52, 729-757.
- MARU, Y. T. 2010. Resilient regions: clarity of concepts and challenges to systemic measurement. CSIRO Sustainable Ecosystems.

- MARU, Y. T., FLETCHER, C. S. & CHEWINGS, V. H. 2012. A synthesis of current approaches to traps is useful but needs rethinking for indigenous disadvantage and poverty research. *Ecology and Society*, 17, 7.
- MASCIE-TAYLOR, C., MARKS, M., GOTO, R. & ISLAM, R. 2010. Impact of a cash-for-work programme on food consumption and nutrition among women and children facing food insecurity in rural Bangladesh. *Bulletin of the World Health Organization*, 88, 854-860.
- MASLIN, B., THOMPSON, L., MCDONALD, L. & HAMILTON-BROWN, S. 1998. *Edible Wattle Seeds of Southern Australia: A Review of Species for use in Semi-Arid Regions*, Canberra, CSIRO.
- MATLON, P. 1990. Improving productivity in sorghum and pearl millet in semi-arid Africa. *Food Res. Inst. Stud*, 22, 1-43.
- MATSON, P. A., PARTON, W. J., POWER, A. G. & SWIFT, M. J. 1997. Agricultural Intensification and Ecosystem Properties. *Science*, 277, 504-509.
- MATTINEN, H. & OGDEN, K. 2006. Cash-based interventions: lessons from southern Somalia. *Disasters*, 30, 297-315.
- MATUSCHEK, E. & SVANBERG, U. 2002. Oxidation of Polyphenols and the Effect on In vitro Iron Accessibility in a Model Food System. *Journal of Food Science*, 67.
- MAUSS, M. 1922. *The Gift: forms and functions of exchange in archaic societies*, London, Routledge.
- MAXWELL, S. & SMITH, M. 1992. Household Food Security: A Conceptual Review. In: MAXWELL, S. & FRANKENBERGER, T. (eds.) *Household Food Security: Concepts, Indicators, Measurements*. Rome and New York: IFAD and UNICEF.
- MCARTHUR, C., SANSON, G. & BEAL, A. 1995. Salivary proline -rich proteins in mammals: roles in oral homeostasis and counteracting dietary tannin. *Journal Chemical Ecology*, 21, 663-691.
- MCNIFF, J. & WHITEHEAD, J. 2002. *Action Research: Principles and Practice*, London and New York, Routledge/Falmer.
- MCPHAIL, L. L. & BABCOCK, B. A. 2012. Impact of US biofuel policy on US corn and gasoline price variability. *Energy*, 37, 505-513.
- MEDECINS SANS FRONTIERES 2007. Starved for attention: Wake up to the crisis of malnutrition. *Campaign for access to Essential Medicines*. MSF.
- MEZE-HAUSKEN, E. 2004. Contrasting climate variability and meteorological drought with perceived drought and climate change in northern Ethiopia. *Climate research*, 27, 19-31.
- MICRONUTRIENT INITIATIVE 2008. Vitamin and Mineral Deficiency: A Global Report. New York: UNICEF.
- MIDGLEY, S., BRAND, J., HARWOOD, C., ANNISON, G. & RICHARDSON, K. 1991. Human food value of Australia's dry zone acacia species. *Proceedings of the Nutrition Society - Australia*, 16, 118.
- MIDGLEY, S. & TURNBULL, J. 2003. Domestiction and use of Australian acacias: Case studies of five important species. *Australian Systematic Botany*, 16, 89-102.
- MONDAL, M. 2011. Causes of Yield Gaps and strategies for minimising the gaps in different crops of Bangladesh. *Bangladesh Journal of Agricultural Research*, 36, 469-476.
- MORSE, J. 2005. Bush Resources: Opportunities for Aboriginal Enterprise in Central Australia. Alice Springs: Desert Knowledge CRC and Central Land Council.
- MORTIMORE, M. 1989. *Adapting to Drought: Farmers, Famines and Desertification in West Africa*, Cambridge, Cambridge University Press.
- MORTIMORE, M. 2003. Long term change in African drylands: can recent history point towards development pathways? *Oxford Development Studies*, 31.
- MORTIMORE, M. 2005. Dryland Development: Success Stories from West Africa. *Environment: Science and Policy for Sustainable Development*, 47, 8-21.

- MORTIMORE, M., ARIYO, J., BOUZOU, I., MOHAMMED, S. & YAMBA, B. 2008. Niger and Nigeria: The Maradi-kano region. In: SHEPHERD, G. (ed.) *The Ecosystem Approach: Five Steps to Implementation*. Gland, Switzerland: IUCN.
- MORTIMORE, M., TIFFEN, M., BOUBACAR, Y. & NELSON, J. 2001. Synthesis of Long Term Change in Maradi Department, Niger, 1960-2000. *Working Paper 39e*. Crewkerne, UK: Drylands Research.
- MOSLEY, P. 2002. The African green revolution as a pro-poor policy instrument. *Journal of International Development*, 14, 695-724.
- MOSSE, D. 2005. Global governance and the ethnography of international aid. In: MOSSE, D. (ed.) *The Aid Effect: Giving and Governing in International Development*. HAP International.
- MUKHERJEE, A. 2004. *Participatory Rural Appraisal Methods and Applications in Rural Planning : (Essays in Honour of Robert Chambers)*, New Delhi, Concept.
- MYHRVOLD-HANSEN, T. 2003. Democracy, News Media, and Famine Prevention: Amartya Sen and The Bihar Famine of 1966-67.
- NACKERS, F., BROILLET, F., OUMAROU, D., DJIBO, A., GABOULAUD, V., GUERIN, P. J., RUSCH, B., GRAIS, R. F. & CAPTIER, V. 2010. Effectiveness of ready-to-use therapeutic food compared to a corn/soy-blend-based pre-mix for the treatment of childhood moderate acute malnutrition in Niger. *Journal of Tropical Pediatrics*, 56, 407-413.
- NESTEL, P., BOUIS, H., MEENAKSHI, J. & PFEIFFER, W. 2006. Biofortification of staple food crops. *Journal of Nutrition*, 136, 1064-1067.
- NHMRC 2013. Australian Dietary Guidelines (2013). National Health and Medical Research Council.
- NUTRISURVEY. 2010. *Nutrition Surveys and Calculations: Guidelines, Software and additional Information* [Online]. Available: <http://www.nutrisurvey.de/> [Accessed 14th June 2013].
- NUTTAB. 2010. *NUTTAB Database* [Online]. Available: www.foodstandards.gov.au/consumerinformation/nuttab2010/nuttab2010online searchabledatabase/ [Accessed 30th April 2013].
- O'CONNELL, J. F. & HAWKES, K. 1981. Alyawara plant use and optimal foraging theory. *Hunter-gatherer foraging strategies: Ethnographic and archaeological analyses*, 99-125.
- O'SULLIVAN, W. & GEORGE, N. 2007. Environmental Weed Risk Assessment: *Acacia saligna*. Future Farm Industries CRC.
- OAKENFULL, D. & SIDHU, G. 1990. Could saponins be a useful treatment for hypercholesterolaemia? *European Journal of Clinical Nutrition*, 44, 79-88.
- OGDEN, C. 1990. Building nutritional considerations into forestry development efforts. *Unasylva*, 41, 20-28.
- OMUNDU. 2013. *Why Kenyans4Kenya and #FeedKe Initiatives Must Exist Side by Side* [Online]. Available: www.omundukhumundu.wordpress.com/tag/feedke/ [Accessed 2nd May 2013].
- ONIAN'G'O, R., SHIUNDU, K., MAUNDU, P. & JOHNS, T. 2005. Diversity, nutrition and food security: the case of African leafy vegetables. In: BALA RAVI, S., I. HOESCHLE-ZELEDON, I., SWAMINATHAN, M. & FRISON, E. (eds.) *Hunger and poverty: the role of biodiversity*. Chennai, India.
- OR, K. & WARD, D. 2004. The effects of seed quality and pipercolic and djenkolic acids on bruchid beetle infestation in water deficit-stressed *Acacia* trees. *Journal Chemical Ecology*, 30, 2297-307.
- ORR, T. M. & HIDDEN, L. 1987. Contribution of Australian acacias to human nutrition. *Australian acacias in developing countries. Proceedings*, 16, 112-15.

- OSHAUG, A. 1985. The composite concept of food security. *Introducing Nutritional Considerations into Rural Development Programs with Focus on Agriculture*. Oslo: Institute for Nutrition Research, University of Oslo.
- OSTROM, E. 1990. *Governing the commons: The evolution of institutions for collective action*, Cambridge University Press.
- OSTROM, E. 2009. *Understanding institutional diversity*, Princeton University Press.
- PACIFIC PYROLYSIS. 2012. *Pacific Pyrolysis: Slow Pyrolysis* [Online]. Available: <http://pacificpyrolysis.com/technology.html#demonstration> [Accessed 15th May 2013].
- PALMER, G. 2009. What is complementary feeding? A philosophical reflection to help a policy process. IBFAN-GIFA.
- PASTERNAK, D., NIKIEME, A., FATONDJI, D., NDJEUNGA, J., KOALA, S., GOMA, A. & ABASSE, T. 2005. The Sahelian Ecofarm. *Lecons Tirees des Experiences de Lutte Contre la Desertification au Sahel*, 103.
- PASTERNAK, D., SENBETO, D., NIKIEMA, A., KUMAR, S., DOUGBEDJI, F., WOLTERING, L. & RATNADASS, A. 2009. Bioreclamation of degraded African lands with women empowerment. *. Chronica Horticulturae*, 49.
- PERNECKY, J. M. 1963. Action Research Methodology. *Bulletin of the Council for Research in Music Education*, 33-37.
- PERRINGS, C. Ecological resilience in the sustainability of economic development. Models of sustainable development: exclusive or complementary approaches of sustainability? International symposium, 1994. 27-41.
- PETERSON, G. 2000. Political ecology and ecological resilience:: An integration of human and ecological dynamics. *Ecological Economics*, 35, 323-336.
- PHELOUNG, P., WILLIAMS, P. & HALLOY, S. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management*, 57, 239-251.
- PHILLIPS-HOWARD, K. D. & LYON, F. 1994. Agricultural Intensification and the Threat to Soil Fertility in Africa: Evidence from the Jos Plateau, Nigeria. *The Geographical Journal*, 160, 252-265.
- PILUK, J., HARTEL, P., HAINES, B. & GIANNASI, D. 2001. Association of carbon disulphide with plants of the family Fabaceae. *Journal Chemical Ecology*, 27.
- PINSTRUP-ANDERSEN, P. 1983. Export crop production and malnutrition. *Food and Nutrition*, 9, 6-14.
- PINSTRUP-ANDERSEN, P. 2012. The Food System and its Interaction with Human Health and Nutrition. In: FAN, S. & PANDYA-LORCH (eds.) *Reshaping Agriculture for Nutrition and Health*. Washington DC: IFPRI.
- PLATTEAU, J.-P. 2000. *Institutions, social norms, and economic development*, Psychology Press.
- PRETTY, J. 1999. Can Sustainable Agriculture Feed Africa? New Evidence on Progress, Processes and Impacts. *Environment, Development and Sustainability*, 1, 253-274.
- PRETTY, J. N., MORISON, J. I. L. & HINE, R. E. 2003. Reducing food poverty by increasing agricultural sustainability in developing countries. *Agriculture, Ecosystems & Environment*, 95, 217-234.
- PRICE, M. 2007. The Moringa Tree. *Echo Technical Note*.
- PRUDHON, C., PRINZO, Z. W., BRIEND, A., DAELMANS, B. & MASON, J. B. 2006. Proceedings of the WHO, UNICEF, and SCN Informal Consultation on Community-Based Management of Severe Malnutrition in Children. *Food and nutrition bulletin*, 27, S99.
- RAIN, D. 1998. *Eaters of the Dry Season: The Changing World of Circular Labour Migration in Maradi, Niger*, Boulder, Colorado, Westview.

- RAMAKRISHNAN, U. 2002. Prevalence of micronutrient malnutrition worldwide. *Nutrition Reviews*, 60, S46-S52.
- RAO, B. & PRABHAVATHI, T. 1982. Tannin content of foods commonly consumed in India and its influence on ionisable iron. *Journal of the Science of Food and Agriculture*, 33, 89-96.
- REARDON, T., KELLY, V., CRAWFORD, E., DIAGANA, B., DIONÉ, J., SAVADOGO, K. & BOUGHTON, D. 1997. Promoting sustainable intensification and productivity growth in Sahel agriculture after macroeconomic policy reform. *Food Policy*, 22, 317-327.
- REARDON, T. A. A. B., CHRISTOPHER B., 1999. The Ambiguous Effects of Policy Reforms on Sustainable Agricultural Intensification in Africa: Renewed Threats to Fragile Margins? *SSRN*.
- REIJ, C., TAPPAN, G. & SMALE, M. 2009. Re-Greening the Sahel: Farmer Led Innovation in Burkina Faso and Niger. *Millions Fed: Proven Success in Agricultural Development*. Washington DC: IFPRI.
- REMIGI, P., FAYE, A., KANE, A., DERUAZ, M., THIOULOUSE, J., CISSOKO, M., PRIN, Y. & GALIANA, A. 2008. The exotic legume tree species *Acacia holsericea* alters microbial soil functionalities and the structure of the arbuscular mycorrhizal community. *Applied and Environmental Microbiology*, 74, 1485-1493.
- RESIMAO & WAMIS-NET. 2013. *Niger: marché - mil, ordinaire* [Online]. Available: http://www.resimao.org/html/fr/Niger/market/86/product_id/22 [Accessed 22 April 2013].
- REUTLINGER, S. 1999. From 'food aid' to 'aid for food': into the 21st century. *Food Policy*, 24, 7-15.
- RICHARDSON, D. & VAN WILGEN, B. 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? *South African Journal of Science*, 100, 45-52.
- RINAUDO, A. 2001a. Potential of Australian Acacias for Human Food. *Combating Desertification with Plants*. Springer US.
- RINAUDO, A. 2002. The Green Famine. *Echo Development Notes*.
- RINAUDO, A. Keynote Speech. In: FRANCIS, R., ed. *Wattle We Eat for Dinner?*, 2011 Alice Springs. World Vision Australia.
- RINAUDO, A. & CUNNINGHAM, P. 2007. Australian Acacias as multi purpose agroforestry species for semi arid regions of Africa. *Muelleria*, 26, 79-85.
- RINAUDO, A., PATEL, P. & THOMSON, L. 2002. Potential of Australian Acacias in combating hunger in semi-arid lands. *Conservation Science Western Australia*, 4, 161-169.
- RINAUDO, T. 2001b. Utilizing the Underground Forest: Farmer Managed Natural Regeneration of Trees. In: PASTERNAK, D. & SCHLISSEL, A. (eds.) *Combating Desertification with Plants*. New York: Kluwer Academic.
- ROGERS, B. 1995. Feeding Programs and Food-Related Income Transfers. In: PINSTRUP-ANDERSEN, P., PELLETIER, D. & ALDERMAN, H. (eds.) *Child Growth and Nutrition in Developing Countries: Priorities for Action*. Ithaca: Cornell University Press.
- ROGERS, E. 1983. *Diffusion of Innovations (3rd edition)*, New York, Free Press.
- ROWLANDS, C. 2009. Niger Acacia Market Analysis Report. Melbourne: World Vision Australia.
- SAKARA, M., LUFABA, F. & LUFABA, A. 2007. Agricultural intensification: feeding ourselves and sustaining Africa's land resources in the new millenium. *African journal of food, agriculture, nutrition, and development* 2.
- SALAMON, L. 1994. The rise of the non-profit sector. *Foreign Affairs*, 73, 109-122.
- SANCHEZ, P., BURESH, R. & LEAKEY, R. R. B. 1997. Trees, soil and food security. *Phil. Trans. R. Soc. B*, 949-961.
- SANCHEZ, P., DENNING, G. & NZIGUHEBA, G. 2009. The African Green Revolution moves forward. *Food Security*, 1, 37-44.

- SANCHEZ, P., PALM, C., SACHS, J., DENNING, G., FLOR, R., HARAWA, R., JAMA, B., KIFLEMARIAM, T., KONECKY, B., KOZAR, R., LELERAI, E., MALIK, A., MODI, V., MUTUO, P., NIANG, A., OKOTH, H., PLACE, F., SACHS, S. E., SAID, A., SIRIRI, D., TEKLEHAIMANOT, A., WANG, K., WANGILA, J. & ZAMBA, C. 2007. The African Millennium Villages. *Proceedings of the National Academy of Sciences*, 104, 16775-16780.
- SANCHEZ, P. A. & LEAKEY, R. R. B. 1997. Land use transformation in Africa: three determinants for balancing food security with natural resource utilization. *European Journal of Agronomy*, 7, 15-23.
- SCHANBACHER, W. D. 2010. The Politics of Food: The Global Conflict between Food Security and Food Sovereignty. Santa Barbara: Praeger Security International.
- SCHMIDHUBER, J. & TUBIELLO, F. N. 2007. Global Food Security under Climate Change. *Proceedings of the National Academy of Sciences of the United States of America*, 104, 19703-19708.
- SCHUBERT, J. 1981. The impact of food aid on world malnutrition. *International Organization*, 35, 329-354.
- SCHULTZ, T. 1960. Impact and implications of foreign surplus disposal on underdeveloped economies. *American Journal of Agricultural Economics*, 42, 1019-1030.
- SCOONES, I. 1998. Sustainable Rural Livelihoods: A Framework for Analysis *IDS Working Paper 72*.
- SCOONES, I., MELNYK, M. & PRETTY, J. 1992. *The Hidden Harvest: Wild Foods and Agricultural Systems. A Literature Review and Annotated Bibliography*, London, IIED.
- SEEVERS, G. L. 1968. An Evaluation of the Disincentive Effect Caused by P. L. 480 Shipments. *American Journal of Agricultural Economics*, 50, 630-642.
- SEIGLER, D. 2002. Economic potential from Western Australian acacia species: Secondary plant products. *Conservation Science Western Australia*, 4, 109-116.
- SEN, A. 1982. *Poverty and Famines : An Essay on Entitlements and Deprivation*, Oxford, Clarendon Press.
- SEN, A. 1999. *Development as Freedom*, Oxford, Oxford University Press.
- SENDZIMIR, J., REIJ, C. & MAGNUSZEWSKI, P. 2011. Rebuilding resilience in the Sahel: regreening in the Maradi and Zinder regions of Niger. *Ecology and Society*, 16.
- SHACKLETON, C., MCGARRY, D., FOURIE, S., GAMBIZA, J., SHACKLETON, S. & FABRICIUS, C. 2007. Assessing the effects of invasive alien species on rural livelihoods: case examples and a framework from South Africa. *Human Ecology*, 35, 113-127.
- SHACKLEY, S., HAMMOND, J., GAUNT, J. & IBARROLA, R. 2011. The feasibility and costs of biochar deployment in the UK. *Carbon Management*, 2, 335-356.
- SHAHIDI, F. 1997. *Antinutrients and phytochemicals in food*. , Columbus, American Chemical Society.
- SHAW, D. 2007. *World Food Security: A History Since 1945*, Palgrave MacMillan.
- SHEPARD, P. 1978. *Thinking Animals*, London, University of Georgia Press.
- SHEPHERD, B. 2012. Thinking critically about food security. *Security Dialogue*, 43, 195-212.
- SHETTY, P. 2011. Addressing Micronutrient Malnutrition to Achieve Nutrition Security In: THOMPSON, B. & AMOROSO, L. (eds.) *Combating micronutrient deficiencies : food-based approaches*. Rome: FAO and CABI.
- SHIVJI, I. 2007. *Silences in NGO Discourse: The Role and Future of NGOs in Africa*, Nigeria, Fahamu/Pambazuka.
- SHOLTO-DOUGLAS, J., HART, R. & SCHUMACHER, E. 1984. *Forest Farming: Towards and Solution to Problems of World Hunger and Conservation*, London, Intermediate Technology.

- SHUKRI, R., MOHAMED, S., MUSTAPHA, N. & HAMID, A. 2011. Evaluating the toxic and beneficial effects of jering beans (*Archidendron jiringa*) in normal and diabetic rats. *J. Sci. Food Agric*, 91, 2697-2706.
- SIEGENBEEK VAN HEUKELOM, T. 2011. A human security approach to food security: Land grabs in the limelight. *Journal of Human Security*, 7, 6-20.
- SMITH, M. 1986. The antiquity of seedgrinding in arid Australia. *Archaeology in Oceania*, 21, 29-39.
- SOHI, S. P., KRULL, E., LOPEZ-CAPEL, E. & BOL, R. 2010. Chapter 2 - A Review of Biochar and Its Use and Function in Soil. In: DONALD, L. S. (ed.) *Advances in Agronomy*. Academic Press.
- SOLESBURY, W. 2003. Sustainable Livelihoods: A Case Study of the Evolution of DFID Policy. London: Overseas Development Institute
- SPHERE PROJECT 2011. *The Sphere Handbook*, Rugby, Practical Action Publishing, Schumacher Centre for Technology and Development.
- STAATZ, J. & EICHER, C. K. 1990. Agricultural development ideas in historical perspective. In: EICHER, C. K. & STAATZ, J. (eds.) *Agricultural Development in the Third World*. Baltimore: Johns Hopkins University Press.
- STAPIEN, W. & GALLAGHER, S. 1993. Problem-based learning: As authentic as it gets. *Educational leadership*, 50, 25-25.
- STEWART, F. 1986. Food aid: pitfalls and potential. *Food Policy*, 11, 311-322.
- STEYN, N., NEL, J., NANTEL, G., KENNEDY, G. & LABADARIOS, D. 2006. Food variety and dietary diversity scores in children: are they good indicators of dietary adequacy? *Public Health Nutrition*, 9.
- STOCKING, M. A. 2003. Tropical Soils and Food Security: The Next 50 Years. *Science*, 302, 1356-1359.
- STREITWEISER, A. & HEATHCOCK, C. 1976. *Introduction to Organic Chemistry*, Macmillan.
- STRINGER, E. T. 2007. *Action research*, Sage Publications, Incorporated.
- STRYKER, D. 1978. Food Security, Self-Sufficiency and Economic Growth in the Sahelian Countries of West Africa. Stanford University for USAID.
- SVANBERG, U. & LORRI, W. 1997. Fermentation and nutrient availability. *Food Control*, 8, 319-327.
- SWALLOW, B. & OCHOLA, S. 2006. Understanding the links between agriculture and health for food, agriculture and the environment. *Focus 13: Agroforestry, Nutrition, and Health*. IFPRI.
- SWANSTROM, T. 2008. Regional resilience: a critical examination of the ecological framework. IURD Working Paper Series, Institute of Urban and Regional Development, UC Berkeley.
- SWIFT, J. 1989. Why are rural people vulnerable to famine? *IDS Bulletin*, 20.
- TADESSE, G. & SHIVELY, G. 2009. Food Aid, Food Prices, and Producer Disincentives in Ethiopia. *American Journal of Agricultural Economics*, 91, 942-955.
- TALUKDER, A., KIESS, L., HUQ, N., DE PEE, S., DARNTON-HILL, I. & BLOEM, M. 2000. Increasing the production and consumption of vitamin A-rich fruits and vegetables: lessons learned in taking the Bangladesh homestead gardening programme to a national scale. *Food and Nutrition Bulletin*, 21, 165-172.
- TENENBAUM, D. 1986. Traditional drought and uncommon famine in the Sahel. *Whole Earth Review*.
- TENENBAUM, D. 2008. Food vs Fuel: Diversions of crops could cause more hunger. *Environmental Health Perspectives*, 116, 254.
- THIELE, R. 2002. The Bias Against Agriculture in Sub-Saharan Agriculture: Has it Survived 20 Years of Structural Adjustment Programs? *Kiel Working Papers*. Kiel Institute for the World Economy.

- THIES, J. & RILLIG, M. 2009. Characteristics of Biochar: Biological Properties. *In*: LEHMANN, J. & JOSEPH, S. (eds.) *Biochar for Environmental Management*. London: Earthscan.
- THOMPSON, A. Sustainable livelihoods approaches at the policy level. *In*: DFID, ed. Forum on Operationalizing Participatory Ways of Applying Sustainable Livelihoods Approaches: Proceedings, 2000 Rome. FAO.
- THOMPSON, L., HARWOOD, C. & RINAUDO, A. 1996. Australian Acacias: Untapped genetic resources for human food production in dry tropical sub-Saharan Africa. *Forest Genetic Resources*, 24.
- THOMPSON, R. 1983. The role of trade in food security and agricultural development. *In*: JOHNSON, D. & SCHUH, G. (eds.) *The Role of Markets in the World Food Economy*. Boulder: Westview Press.
- THOMSON, L. 1992. Australia's subtropical dry-zone Acacia species with human food potential. *Australian Dry-zone Acacias for Human Food*. Glen Helen, Northern Territory. (Eds House, AP N. and CE Harwood). CSIRO, 3-36.
- THOMSON, L., HARWOOD, C. & RINAUDO, T. 1997. Australian acacias: untapped genetic resources for human food production in dry tropical Sub-Saharan Africa. *Recursos Geneticos Forestales*.
- THRUPP, L. 2000. Linking agricultural biodiversity and food security: the valuable role of agrobiodiversity for sustainable agriculture. *International Affairs*, 76, 265-281.
- THUROW, L. 1974. Cash Versus In-Kind Transfers. *The American Economic Review: Papers and Proceedings of the Eighty-sixth Annual Meeting of the American Economic Association*, 64, 190-195.
- TIELSCH, J. & SOMMER, A. 1984. The epidemiology of Vitamin A deficiency and xerophthalmia. *Annual Review of Nutrition*, 4, 183-205.
- TIJHUIS, M., DE JONG, N., POHJOLA, M., GUNNLAUGSDÓTTIR, H., HENDRIKSEN, M., HOEKSTRA, J., HOLM, F., KALOGERAS, N., LEINO, O., VAN LEEUWEN, F., LUTEIJN, J., MAGNÚSSON, S., ODEKERKEN, G., ROMPELBERG, C., TUOMISTO, J., UELAND, Ø., WHITE, B. & VERHAGEN, H. 2012. State of the art in benefit-risk analysis: food and nutrition. *Food Chem Toxicol*, 50, 5-25.
- TOLLENS, E. F. Market information systems in sub-Sahara Africa, challenges and opportunities. 2006 Annual Meeting, August, 2006. 12-18.
- TONTISIRIN, K., NANTEL, G. & BHATTACHARJEE, L. 2002. Foodbased strategies to meet the challenges of micronutrient malnutrition in the developing world. *Proceedings of the Nutrition Society*, 61, 243-250.
- TOOLE, D. 1989. Reaching the Poor in Africa: Household Food Security in Africa: An Overview of UNICEF Experience. New York: UNICEF.
- TOUGIANI, A., GUERO, C. & RINAUDO, T. 2009. Community mobilisation for improved livelihoods through tree crop management in Niger. *GeoJournal*, 74, 377-389.
- TOUMIEUX, E. 2004. Niger Trip Report. World Vision Senegal.
- TROWELL, H., DAVIES, J. & DEAN, R. 1954. *Kwashiorkor*, London, Edward Arnold.
- TURNBULL, J. 1987. Australian Acacias in Developing Countries: Proceedings of an International Workshop Held at the Forestry Training Centre. Gympie, Australia: ACIAR.
- TURPIE, J. 2004. The role of resource economics in the control of invasive alien plants in South Africa. *South African Journal of Science*, 100, 87-93.
- TURRALL, S. 2011. Sustainable livelihoods approaches: past, present and...future? How can sustainable livelihoods approaches be more successfully applied to future development challenges? . Knowledge Services IDS.
- UNDP 2013. Human Development Report. United Nations Development Programme.
- UNITED NATIONS. Report of the World Food Conference. World Food Conference , 1974, 1975 Rome. United Nations.

- USDA. 2013. *USDA Nutrient Database for Standard Reference, Release 18* [Online]. USDA. Available: www.nal.usda.gov/fnic/fodcomp/Data/SR18/sr8.html [Accessed 1st May 2013].
- VACHANICHANONG, P. & LEBEL, L. 1997. Djenkol beans as a cause of haematuria in children. *Nephron*, 76, 39-42.
- VALID INTERNATIONAL 2008. *Community Therapeutic Care Manual*, London, Valid Nutrition.
- VAN ZWIETEN, L., SINGH, B., JOSEPH, S., KIMBER, S., COWIE, A. & CHAN, K. 2009. Biochar and Emissions of Non-CO₂ Greenhouse Gases from Soil. In: LEHMANN, J. & JOSEPH, S. (eds.) *Biochar for Environmental Management*. London: Earthscan.
- VAN ARKADIE, B. The Role of Institutions in Development. World Bank Annual Conference on Development Economics, 1989 Washington. World Bank.
- VAN VEEN, G. & HYMAN, A. 1933. On the toxic component of the Djenkol Bean. *Geneesk. Tijdschr. Nederl. Indie*, 73, 991.
- VINGNEAUD & PATTERSON 1936. The Synthesis of Djenkolic Acid. <http://jbc.org/content/114/2/533.full.pdf>.
- WALSH, F. & DOUGLAS, J. 2011. No bush foods without people: the essential human dimension to the sustainability of trade in native plant products from desert Australia. *The Rangeland Journal*, 33, 395-416.
- WALTON, E. & ALLEN, S. 2011. Malnutrition in developing countries. *Paediatrics and Child Health*, 21, 418-424.
- WATERS-ADAMS, S. 2006. *Action Research in Education* [Online]. University of Plymouth. Available: <http://www.edu.plymouth.ac.uk/resined/actionresearch/arhome.htm#LIMITATIONSOFACTIONRESEARCH> [Accessed 7 March 2013].
- WATKINS, K. & VON BRAUN, J. 2003. Time to Stop Dumping on the World's Poor. *Annual Report Essays*. Washington DC: IFPRI.
- WATTS, J. 2007. Riots and hunger feared as demand for grain sends food costs soaring. *Guardian Weekly*, Tuesday 4 December 2007.
- WATTS, M. 1983. Hazards and Crisis: A political economy of drought and famine in Northern Nigeria. *Antipode*, 15, 24-34.
- WEBB, P., VON BRAUN, J. & Y, Y. 1992. Famine in Ethiopia: Policy Implications of Coping Failure at National and Household Levels. Washington, DC: International Food Policy Research Institute.
- WFP 2012. P4P Purchase for Progress: A Primer Rome: P4P Coordination Unit Publication, World Food Programme, .
- WFP. 2013. *Overview of Operations in 2013* [Online]. World Food Programme. Available: documents.wfp.org/stellent/groups/public/documents/op_reports/wfp252287.pdf [Accessed 1st May 2013].
- WHICH? 2012. *Briefing: What's in your bowl? The most popular breakfast cereals compared* [Online]. Which? Available: <http://www.childrensfoodcampaign.net/Which%20Cereals%20Report%20Feb%202012.pdf> [Accessed 29th April 2013].
- WHITMAN, T. & LEHMANN, J. 2009. Biochar—One way forward for soil carbon in offset mechanisms in Africa? *Environmental Science & Policy*, 12, 1024-1027.
- WHO 1998. Preparation and use of food-based dietary guidelines. In: CONSULTATION, J. F. W. (ed.) (*WHO Technical Report Series 880*). Nicosia, Cyprus.
- WHO 1999. *Management of Severe Malnutrition: A Manual for Physicians and other Senior Health Workers*, Geneva, WHO.
- WHO 2002. Concise International Chemical Assessment Document 46: Carbon Disulphide. Geneva: World Health Organisation.
- WHO 2004a. Hydrogen Cyanide and Cyanides: Human Health Aspects. *Concise International Chemical Assessment Document 61*. Geneva: World Health Organisation.

- WHO 2004b. Vitamin and mineral requirements in human nutrition Second edition. Geneva: World Health Organisation.
- WHO 2009. World Health Statistics 2009. World Health Organization.
- WHO 2011. Guideline: Use of multiple micronutrient powders for home fortification of foods consumed by infants and children 6-23 months of age. . Geneva: World Health Organization.
- WHO. 2013. *Global Health Observatory Data Repository* [Online]. Available: <http://www.apps.who.int/gho/data/node.main.ChildMort-2?lang=en> [Accessed 22 April 2013].
- WHO & FAO 2006. Guidelines on Food Fortification with Micronutrients. Geneva: Food and Agriculture Organization of the United Nations, World Health Organization.
- WHO, WORLD FOOD PROGRAMME, UNITED NATIONS SYSTEM STANDING COMMITTEE ON NUTRITION & UNITED NATIONS CHILDREN'S FUND 2007. Community-Based Management of Severe Acute Malnutrition. Geneva: World Health Organisation.
- WHO/UNHCR 2009. Guidelines for Selective Feeding: The Management of Malnutrition in Emergencies. Geneva: World Health Organization.
- WHYTE, W. F. E. 1991. *Participatory action research*, Sage Publications, Inc.
- WILSON, J. R. U., GAIRIFO, C., GIBSON, M. R., ARIANOUTSOU, M., BAKAR, B. B., BARET, S., CELESTI-GRAPOW, L., DITOMASO, J. M., DUFOUR-DROR, J.-M., KUEFFER, C., KULL, C. A., HOFFMANN, J. H., IMPSON, F. A. C., LOOPE, L. L., MARCHANTE, E., MARCHANTE, H., MOORE, J. L., MURPHY, D. J., TASSIN, J., WITT, A., ZENNI, R. D. & RICHARDSON, D. M. 2011. Risk assessment, eradication, and biological control: global efforts to limit Australian acacia invasions. *Diversity and Distributions*, 17, 1030-1046.
- WITT, A. 2010. Biofuels and invasive species from an African perspective - a review. *GCB Bioenergy*, 2, 321-329.
- WIWANITKIT, V. 1995. Renal failure due to djenkolism: an appraisal of previously reported Thai cases. *Clinical Exp Nephrol*, 9, 343.
- WONG, J., CHUA, J., TAN, C. & ONG, T. 2007. Acute anuric renal failure following Jerring bean ingestion. *Asian Journal of Surgery*, 30, 80-81.
- WOOLFE, J. A. 1992. *The Sweet Potato: An Untapped Food Resource*, Cambridge, Cambridge University Press.
- WORLD BANK 1980. Food Security in Food Deficit Countries. *World Bank Staff Working Paper*. Washington DC: World Bank.
- WORLD BANK 1986. Poverty and Hunger: Issues and Options for Food Security in Developing Countries. *World Bank Policy Study*. Washington DC: World Bank.
- WORLD BANK. Symposium on Household Food Security and the Role of Women. January 21-24, 1990. 1990 Harare.
- WORLD BANK 2012. State and Trends of the Carbon Market Report 2012. Cologne: World Bank.
- WORLD RESOURCES INSTITUTE 2008. Turning back the desert: How farmers have transformed Niger's landscapes and livelihoods. *World Resources: Roots of Resilience. Growing the Wealth of the Poor*. Washington DC: WRI.
- WORLD WIDE WATTLE. 2004. *Species Numbers* [Online]. Available: <http://www.worldwidewattle.com/infogallery/species/index.php> [Accessed 5 April 2013].
- YATES, P. 2008. The Bush Foods Industry and Poverty Alleviation in Central Australia. *Dialogue: Academy of Social Sciences Australia*, 28.
- YATES, P. 2010. Australian Acacias - The potential to combat child malnutrition, build agricultural resilience and support adaptation to climate change in semi-arid Africa. Melbourne: World Vision Australia.
- YELENIK, S., STOCK, W. & RICHARDSON, D. 2004. Ecosystem level impacts of invasive Acacia saligna in the South African Fynbos. *Restoration Ecology*, 12, 44-51.

- YOUNG, H., BORREL, A., HOLLAND, D. & SALAMA, P. 2004. Public nutrition in complex emergencies. *The Lancet*, 1899-909.
- YOUNG, H. & JASPARS, S. 1995. *Nutrition Matters: People, Food And Famine*, London, Intermediate Technology Publications.
- YOUZBACHI, N., ELFALLEH, W., TLILI, N., GREGOIRE, S., BERDEAUX, O., SALLES, C., TRIKI, S., KHOUJA, M.-L., KHALDI, A. & NASRI, N. 2012. Unexploited *Acacia cyanophylla* seeds: potential food sources of ω 6 fatty acids and antioxidants? *Journal of the Science of Food and Agriculture*, 92, 1526-1532.
- ZIA UR, R. & SHAH, W. 2001. Tannin contents and protein digestibility of black grams (*Vigna mungo*) after soaking and cooking. *Plant Foods for Human Nutrition*, 56.

Appendix 1: The Weed Risk Assessment System (Australia 2013) applied to *Acacia colei* in Niger and

A. saligna in Tigray, Ethiopia

Note: Scores are allocated to each question/answer according to specific instructions. In some cases these are explicit, in others a more complex calculation is required and is not reproduced here.

Trait	Question	<i>A colei</i> (Niger)		<i>A. saligna</i> (Tigray)		Comments re. agroforestry traits/potential etc
1 Domestication/ cultivation	1.01 Is the species highly domesticated? If answer is 'no' go to question 2.01	N	0	N	0	
	1.02 Has the species become naturalised where grown?	-	-	-	-	
	1.03 Does the species have weedy races?	-	-	-	-	
2 Climate and Distribution	2.01 Species suited to target climates? (0-low; 1-intermediate; 2-high)	Y	2	Y	2	An essential selection criterion for agroforestry.
	2.02 Quality of climate match data? (0-low; 1-intermediate; 2-high)	H	2	I	1	
	2.03 Broad climate suitability? (environmental versatility)	Y	1	Y	1	
	2.04 Native or naturalised in regions with extended dry periods?	Y	1	Y	1	Ability to withstand dry periods is essential
	2.05 Does the species have a history of repeated introductions outside its natural range?	N	0	Y	-	
3 Weed elsewhere	3.01 Naturalised beyond native range?	N	-1	Y	2	
	3.02 Garden/amenity/disturbance weed?	N	0	N	0	
	3.03 Weed of agriculture/horticulture/forestry?	N	0	N	0	
	3.04 Environmental weed?	N	0	Y	4	
	3.05 Congeneric weed?	Y	2	Y	2	
Biology/Ecology						
4 Undesirable traits	4.01 Produces spines, thorns or burrs?	N	0	N	0	
	4.02 Alleopathic?	N	0	N	0	
	4.03 Parasitic?	N	0	N	0	

Trait	Question	<i>A. colei</i> (Niger)		<i>A. saligna</i> (Tigray)		Comments re. agroforestry traits/potential etc
5 Plant type	4.04 Unpalatable to grazing animals?	Y	1	N	0	Palatable species would be destroyed by grazing animals. <i>Acacia. saligna</i> is being used as livestock fodder in 'cut and carry systems' in Tigray, Ethiopia.
	4.05 Toxic to animals?	N	0	N	0	
	4.06 Host for recognised pests and pathogens?	N	0	N	0	
	4.07 Causes allergies or is otherwise toxic to humans?	N	0	N	0	
	4.08 Creates a fire hazard in natural ecosystems?	N	0	N	0	
	4.09 Is a shade tolerant plant at some stage of its life cycle?	N	0	N	0	
	4.10 Grows on infertile soils?	Y	1	Y	1	Able to rehabilitate degraded and scalded land
	4.11 Climbing or smothering growth habit?	N	0	N	0	
	4.12 Forms dense thickets?	N	0	Y	1	
	5.01 Aquatic?	N	0	N	0	
	5.02 Grass?	N	0	N	0	
	5.03 Nitrogen fixing woody plant?	Y	1	Y	1	Nitrogen fixing makes the trees more useful. Woodiness adds valuable products
6 Reproduction	5.04 Geophyte?	N	0	N	0	
	6.01 Evidence of substantial reproductive failure in native habitat?	N	0	N	0	
	6.02 Produces viable seed?	Y	1	Y	1	
	6.03 Hybridises naturally?	N	-1	N	-1	
	6.04 Self-fertilisation?	Y	1	Y	1	
	6.05 Requires specialist pollinators?	N	0	N	0	
	6.06 Reproduction by vegetative propagation?	N	0	N	0	
	6.07 Minimum generative time (years)?	2	0	2	0	

Trait	Question	<i>A. colei</i> (Niger)		<i>A. saligna</i> (Tigray)		Comments re. agroforestry traits/potential etc
7 Dispersal mechanisms	7.01 Propagules likely to be dispersed unintentionally?	N	-1	N	-1	
	7.02 Propagules dispersed intentionally by people?	Y	1	Y	1	
	7.03 Propagules likely to disperse as a produce contaminant?	N	-1	N	-1	
	7.04 Propagules adapted to wind dispersal?	N	-1	N	-1	
	7.05 Propagules buoyant?	N	-1	N	-1	
	7.06 Propagules bird dispersed?	N	-1	N	-1	
	7.07 Propagules dispersed by other animals (externally)?	N	-1	N	-1	
	7.08 Propagules dispersed by other animals (internally)?	Y	1	Y	1	
8 Persistence attributes	8.01 Prolific seed production?	Y	1	Y	1	Prolific seed production is <i>a priori</i> an essential attribute.
	8.02 Evidence that a persistent propagule bank is formed (>1 yr)?	Y	1	Y	1	
	8.03 Well controlled by herbicides?	Y	-1	Y	-1	
	8.04 Tolerates or benefits from mutilation, cultivation or fire?	Y	1	Y	1	Fire is largely absent from agricultural systems in both Niger and Tigray, Ethiopia
	8.05 Effective natural enemies present in target region?	N	1	N	1	
Total Score			10		16	
Agricultural Score			6		9	
Environmental Score			8		16	