

**AFRICAN FUNGUS-GROWING TERMITES AND OTHER  
INSECTS FOR HUMAN AND POULTRY NUTRITION**

by

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## ABSTRACT

Food insecurity can contribute to the advancement of diseases such as growth stunting and HIV/AIDS. A holistic approach to addressing food insecurity includes reviewing local resources; including indigenous food stuffs. Six studies investigate the potential of insect nutrition to meet dietary needs in rural South Africa. A novel trapping method for *Trinervitermes* sp. is examined by parameters of time, sustainability and bait used. Local grass (*Themeda triandra* Forssk.) seemed to be the most effective bait, being significantly more attractive than loose mound soil ( $p=0.01$ ), wet maize stalks ( $p=0.01$ ) or cardboard ( $p=0.05$ ). The trapping device was demonstrated as an effective tool in assessing the feeding preferences of *Trinervitermes* sp., which compete directly with cattle for grazing food resources.

The chemical composition of *Macrotermes natalensis* alates (winged, wingless and fried), soldiers, and *Odontotermes* sp. alates (wingless) was determined. Alates were rich in fat, ranging between 49.2-60.6% (dry matter basis). The protein content of *M. natalensis* and *Odontotermes* sp. alates compared favourably to pork and chicken. Alates were high in glutamic, aspartic and alanine amino acids and low in methionine, serine and threonine. Amino acid digestion for broiler chickens was high, ranging between 87.6-96.1%.

In an era where rural and urban cultures are rapidly merging, entomophagy may be discarded as an embarrassment or nonsensical practice. The high nutritional content of *M. natalensis* and *Odontotermes* sp. should be publicised both to increase the awareness of their high quality as a food source for both poultry and human consumption and to avoid the abandonment of cultural practices that make sense.

**KEY WORDS:** entomophagy, fungus-growing termites, insects, *Macrotermes*, nutrition, *Odontotermes*, poultry, *Trinervitermes*.

## PREFACE

In this dissertation each study is presented independently and completely. Standard U.K. English (Microsoft Word 2002) was used throughout the manuscript. All citations follow the format set by *African Entomology* ISSN 1021-3589 for the year 2004.

## DISCLAIMER

These studies were completed at the University of KwaZulu-Natal, Pietermaritzburg, South Africa, during the academic year of 2003. The research was supervised by Professor Frits Rijkenberg (Centre of Rural Development Systems) and Doctor Ray M. Miller (School of Botany and Zoology).

This dissertation represents my own original work. Where the work of others has been used, it has been duly acknowledged. Furthermore, it has not been submitted for a degree or diploma to any other University.



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# CHAPTER 1. NUTRITION IN RURAL SOUTH AFRICA

## 1.1 Introduction

This chapter provides a short description of the human nutrition crisis in rural South Africa. The attributes and shortcomings of rural scavenging chickens (*Gallus gallus domesticus* L.) are discussed. In conclusion, several suggestions are made including the increased utilization of invertebrates for both human food and poultry feed.

## 1.2 Human disease

Several studies have found low income and/or nutritional levels in rural South African populations (Ndaba & O'Keefe 1985, Van Zyl 1994, Mekuria & Moletsane 1996, Kirsten *et al.* 1998, Leroy *et al.* 2001, Ferrer 2002, SA HealthInfo 2002). In fact, "food insecurity is a serious problem for most African countries" (Lewa 1998). Nutritional deficiencies can contribute to the advancement of a number of health maladies, such as 'growth stunting,' human immunodeficiency virus (HIV) and acquired immunodeficiency syndrome (AIDS).

A study in South Africa reported that 35% of households surveyed in rural KwaZulu-Natal had children who were growth stunted (Kirsten *et al.* 1998). Growth stunting is a nutritional disorder that is a result of 'chronic undernutrition' (Vitamin Information Centre 2001). There is a substandard intake in a myriad of vitamins and minerals, including vitamins A and D, in many South African children, and rural areas are suffering most (SAVACG 1995, Vitamin Information Centre 2001). In rural areas, 62-73% of children (9 and younger) received less than half of their Recommended Dietary Allowances in vitamin A (Vitamin Information Centre 2001). "Vitamin A deficiency is associated with increased child mortality, and is a prime cause of child blindness" (FAO 1995).

Deficiencies in vitamins, such as A and D, are also common in persons who are HIV-positive. "Sub-Saharan Africa has been the worst-affected region [in the world], accounting for three-quarters of all the deaths caused by AIDS since the beginning of

the epidemic” (Piot 2001). Nutrition and food play significant roles in HIV/AIDS care and prevention (ACC/SCN 2001). The vitamins that HIV/AIDS patients lack are often imperative to the maintenance of a healthy immune system (Dannhauser *et al.* 1999, ACC/SCN 2001). For those who already have immune system deficiencies such as HIV/AIDS, vitamin deficiencies can decrease life expectancy. For example, HIV-positive women have a greater chance of being vitamin A deficient. This deficiency has been significantly linked to an increased risk of squamous intraepithelial lesions (SIL) and cervical cancerous lesions (French *et al.* 2000). While HIV-positive individuals are lacking in vitamins, they also have increased energy and protein requirements (ACC/SCN 2001).

### 1.3 Poultry eggs

Ndaba & O’Keefe (1985) suggested an increase in egg consumption to combat poor nutritional levels found in adults of rural districts in KwaZulu-Natal, South Africa. Chicken eggs are rich in vitamins (A, D, E, K and B), minerals (Mg, Ca, Fe, Zn, P) and highly digestible protein that contains almost all of the essential amino acids (see **Table 1.1**, Cotterill *et al.* 1977, MacGregor & Abrams 1996, Branckaert *et al.* 2000, Mine 2000). According to Branckaert *et al.* (2000) “one egg provides 11,5 % of the daily needs in proteins and 5 % of the daily energy requirements” of humans.

**Table 1.1<sup>1</sup>**. Amino acid requirements of infants, children and adults and amino acid composition of eggs (mg per g of protein).

Amino Acid	Infant <sup>2</sup>	Child 10-12		Reported Composition
		yrs.	Adult	Egg <sup>3</sup>
Histidine	14	-	-	22
Isoleucine	35	37	18	54
Lysine	80	56	25	86
Leucine	52	75	22	70
Methionine + cystine	29	34	24	57
Phenylalanine + tyrosine	63	34	25	93
Threonine	44	44	13	47
Tryptophan	8.5	4.6	6.5	17
Valine	47	41	18	66

<sup>1</sup>Table from MacGregor & Abrams (1996).

<sup>2</sup>Infant older than six months.

<sup>3</sup>Reported by Lunven *et al.*

Traditionally many black South Africans, including Zulu peoples, have viewed egg consumption as taboo; particularly in “females of childbearing age, boys and young

men” (Crous & Borchardt 1982, Van Wyk 1990, Viljoen & Gericke 2001, citing Cassel 1957). MacGregor & Abrams (1996) reported that most families surveyed consumed all of the eggs produced by their own flock. These studies may indicate a partially growing demand for eggs from rural poultry in South Africa. However, while eggs may be more popular in South Africa, the rural African chicken is a weak egg-layer, producing between 20-100 eggs annually (Guèye 1998).

### 1.3.1 Chicken production

South African Resident, KwaZulu-Natal 2000- “I have kept Zulu chickens all my life...since I was a child. I learnt all about them from my parents...I feed them every day and they are important to me because they are part of my culture and they provide food and money for my family...” (Naidoo 2000)

Rural poultry systems in Africa are dominated by the scavenging or village chicken (Kitalyi 1998). The domestic chicken is an important staple in African and South African fiscal and food security (Guèye 1998, Kirsten *et al.* 1998, Kitalyi 1998, Sonaiya 1998, Naidoo 2000). “It is an important component of the family income, especially of women and children” (Sonaiya 2003). For instance, a survey of Nkandla, KwaZulu-Natal, reported that 93.4% of households surveyed owned chickens (Cairns & Lea 1990). Poultry flocks can represent capital or household savings (Sonaiya 1998). One rural South African poultry owner said “...when I need quick cash for grocery such as sugar or tea or money needed to pay school fees and to buy books...then I sell some of my chickens” (Naidoo 2000). Bisschop (1997) reported that 83% of households, in the former Zululand, South Africa, kept free-range chickens. Cocks can have roles in religious and cultural life (Sonaiya 1998). In the former Zululand, 12.5% of the yearly flock were given to traditional healers (Bisschop 1997). In KwaZulu-Natal, family chickens served as *Mphako*, provision for visitors, and were cooked upon the arrival of ‘important or unexpected guests’ (Naidoo 2000).

While rural chickens are heavily relied on in rural Africa, providing “20 percent of animal protein intake in most African countries” (Fujita, in foreword of Kitalyi 1998), they are characterized by low inputs (Guèye 1998, Kitalyi 1998) and low outputs (Huchzermeyer 1973, Guèye 1998, Kitalyi 1998, Ahlers 2000). Mortality

rates are high because the scavenging chicken is exposed to many perils, such as animal predators, larcenists and diseases from neighbouring flocks (Bisschop 1997, Guèye 1998, Sonaiya *et al.* 1999, Ahlers 2000, Naidoo 2000). The potential of the scavenging chicken is further retarded by a variety of circumstances including suitable or non-existent shelter, inadequate supply of high quality feed and a lack of disease prevention mechanisms. The solutions to these problems in village chicken production are steps to promote more efficient poultry production and therefore increased nutrition/food security in rural Africa.

### 1.3.2 Poultry feed supplementation

The principal asset of the scavenging chicken is its ability to feed itself, thereby eliminating feed costs (Gunaratne 2000). As the scavenging system is inefficient due partially to inadequate nutrition, feed supplementation can help improve production rates in rural poultry. Common supplements include rice, maize, brewer's grain and household scraps (Gunaratne *et al.* 1993, Bisschop 1997, Naidoo 2000, Mwalusanya *et al.* 2002). Due to crop failure or unavailability of local supplements, farmers often have to purchase commercial feed. Commercial feeds are very expensive and it becomes imperative to identify alternative low-cost feed resources.

The feed supplements should partially meet the nutritional needs of the chicken. The highest nutrient requirement of chickens is carbohydrate. Carbohydrates are commonly provided through maize, barley, wheat or oats. The typical criterion is that the grain is high in starch and easily digestible. A plethora of alternative energy sources have been investigated including industrial by-products, fruits, roots/tubers and leaf meals (Tillman & Waldroup 1988, Reddy & Qudratullah 1996, Kabuge *et al.* 2002). Though some energy sources have additional benefits, feed grains require supplementation of fats, vitamins, minerals and protein (Austic & Nesheim, 1990).

Proteins are essential for the synthesis and repair of tissue and are the foundation of eclectic products (e.g., muscles, antibodies and hormones). Any excess protein in a chicken's diet is converted into energy. Protein is the most expensive part of a feed

formula. When one considers that a layer's diet is only around 17% protein (See **Table 1.2**), such clichés as “it's worth its weight in gold” may come to mind. Finding alternative sources of protein for resource-poor poultry farmers is important (Wethli & Paris 1995, Reddy & Qudratullah 1996).

Protein sources cannot be labour intensive as HIV/AIDS has undermined the workforce in many rural African areas. Food sources should not increase the risk of disease transmission. They cannot be costly as this defeats the purpose of finding alternative feeds.

**Table 1.2<sup>1</sup>.** Example of nutrient rations for layers

	Layers
Protein, %	17
Metabolizable energy, kcal/kg	2,925
Calcium, %	3.3
Available phosphorus, %	0.58
Fat, %	5.7
Fiber, %	2.3
Linoleic acid, %	1.5
Xanthophyll, mg/kg	19.8

<sup>1</sup>Table Modified from Austic & Nesheim (1990).

### 1.3.3 Invertebrates as poultry feed

When scavenging, the chicken often consumes earthworms and insects (Guèye 1998). Accordingly, some researchers have explored invertebrates as a source of protein for chickens with great success (Reddy & Qudratullah 1996). In a feed substitution trial, DeFoliart *et al.* (1982) found that maize/soybean-fed broiler chicks grew more slowly than maize/cricket (*Anabrus simplex* Haldeman)-fed broilers. This indicated that crickets can, with no negative effect, replace soybeans in the diet of broiler chicks. Cricket-based diets did not affect the taste of broiler meat when compared to soybean-based diets.

## 1.4 Conclusion

The inhabitants of rural South Africa are plagued by food insecurity and financial insecurity. Malnutrition can contribute to the advancement of HIV/AIDS. Rural African peoples rely heavily on the scavenging chicken for protein and financial stability. Productivity of the scavenging chicken is limited by a lack of low-cost feed supplements. The most expensive component of poultry feed is protein. Insects can be a rich source of protein. Accordingly, the increased exploitation of insect protein

could provide both financial relief to those who have to pay for commercial feed and improved nutrition for the scavenging chicken.

More examples of invertebrates for livestock feed will be explored in Chapter 2 when I review the relationship of humans and invertebrates, and discuss methods of production and harvest.

## CHAPTER 2. INVERTEBRATES AS A FOOD SOURCE

### 2.1 Introduction

This chapter introduces invertebrates as food, mainly focusing on insects though at times covering other invertebrates such as earthworms. After an introduction to insects, a basic review of proteins is presented. The next section reviews modern examples of human entomophagy, the consumption of insects, highlighting their nutritional and palatable assets. The discussion on entomophagy leads into insects as food for livestock. Both practices are scrutinized by a nutritional review of insects; grounding practice in reason. In conclusion, issues pertaining to insect production and harvest are addressed.

Insects are ubiquitous and superabundant on terrestrial earth. Southern Africa alone is reported to contain around 80,000 species (Scholtz & Holm 1985). Insects account for over three-fourths of all described organisms and are virtually omnipresent, living in almost every ecosystem and at every latitude. They consume diverse substances through physical and behavioural adaptations; consuming dead and alive, plant and animal. As insects consume other animals, other animals consume insects (Scholtz & Holm 1985). Insects meet the dietary needs of many animals, including humans.

It is known (Naidoo 2000) that rural farmers from KwaZulu-Natal, South Africa, feed their chickens (*Gallus gallus domesticus* L.) earthworms from kraal manure, ticks (Arachnida: Acarina) from their cattle and ants (Hexapoda: Hymenoptera) /termites (Hexapoda: Isoptera). Local knowledge such as this and the ever-present need for less expensive feed of the commercial poultry industry has prompted researchers to investigate the nutritional value of invertebrates. Several authors have compiled reviews of invertebrates for human food or livestock feed (Bodenheimer 1951, Kok 1983, Redford & Dorea 1984, DeFoliart 1989, Reddy & Qudratullah 1996) and in recent decades invertebrates are receiving more attention for their potential as a source of nutrition. This growing awareness resonates in the literature.

DeFoliart (1989) wrote: “The fact that food insect serve not only as a direct source of needed nutrients available to the poorest of the poor in cultures retaining strong elements of the gatherer society but also add importantly to the rural economy should be a matter of great interest to individuals, organizations, and agencies concerned with alleviating world hunger and in developing greater food self-sufficiency among rural populations at risk of malnutrition.” Ng *et al.* (2001) added: “With the escalating costs of conventional protein sources, such as fish meal and soybean meal, it will only be a matter of time before the economic advantages of producing worms as a cheap source of protein becomes apparent to many aquaculturists and feed producers.”

The above arguments for invertebrates as food are two of a corpus that includes the practical - invertebrates for zoo animals (Barker *et al.* 1998), and the bizarre - insects for futuristic space stations (Kok *et al.* 1988). Whichever the slant, it is undeniable that invertebrates can be a superb source of nutrients, especially protein (Phelps *et al.* 1975, Santos Oliveira *et al.* 1976, Ashiru 1988). Ramos-Elorduy (1997) asserted that insects can convert low-quality protein sources (8-9%) into “good quality insect protein” (44-61%) (cited by Ramos-Elorduy *et al.* 2002).

## 2.2 Protein

Proteins are imperative to the healthy growth of any organism and are present in every living cell. They are essential parts of tissue synthesis and repair and are found in diverse products such as antibodies and muscle fibre. Proteins are macromolecules comprised of any combination of more than 20 amino acids. Amino acids are organic molecules and thus contain carbon, oxygen, nitrogen, sulphur and hydrogen combining in long chains that when linked together by peptide bonds form proteins. When a protein is digested, it is broken back down into individual amino acids. These are then absorbed and used as needed. Amino acids are classified as either essential or nonessential. Essential amino acids cannot be synthesized, by humans or poultry, from simple compounds and nonessential amino acids can be synthesized provided that a good source of nitrogen is available. A list of the essential and nonessential amino acids for the growing chick is found in **Table 2.1**.

Those amino acids that are essential to humans are asterisked. While cystine and tyrosine are listed as essential amino acids, it should be noted that they can be created by chickens from other amino acids (Austic & Nesheim 1990). For this reason they are often left out of essential amino acid analyses.

When formulating a balanced diet, it is important to know the amino acid requirements of the intended recipient. Often one protein source is deficient in an essential amino acid while a different source isn't. For this reason farmers and nutritionists commonly create a nutritional supplement that has multiple sources of protein (Austic & Nesheim 1990).

**Table 2.1.** The amino acids required by the growing chick, and their classification as dietary essentials<sup>1</sup>

Essential	Nonessential
*Arginine	Alanine
Cystine	Aspartic acid
*Histidine	Glutamic acid
*Isoleucine	Glycine
*Leucine	Hydroxyproline
*Lysine	Proline
*Methionine	Serine
*Phenylalanine	
*Threonine	
*Tryptophan	
Tyrosine	
*Valine	

<sup>1</sup>Table modified from Austic & Nesheim (1990).  
\*Essential Amino Acids Shared by Humans.

Invertebrate analyses frequently neglect individual amino acids, reporting only total nitrogen or protein. Since proteins contain about 16% nitrogen, the protein in a given substance is often estimated by multiplying the total nitrogen by 6.25. Protein estimated by this method is commonly referred to as crude protein (Austic & Nesheim 1990).

In most cases, some nonprotein nitrogen is included in reported protein values. This nonprotein nitrogen most likely represents nucleic acids in plants and chitin in insects. Chitin is a complex carbohydrate that is the major constituent of the arthropod's rough exoskeleton. Usually, chitin-bound nitrogen cannot be hydrolyzed by mammals or chickens (Dreyer & Wehmeyer 1982, Gallaher *et al.* 2000), as most do not possess the appropriate digestive enzyme, chitinase (Dreyer & Wehmeyer 1982). One exception is the African White-Bellied Hedgehog (*Atelerix albiventris* Wagner), which was shown to be capable of digesting chitin (Graffam *et al.* 1998). Though indigestible to most and therefore seemingly of no nutritional value, chitosan

(a derivative of chitin) is a hypocholesterolemic, effectively reducing levels of cholesterol in animals (Cheung 1998, Gallaher *et al.* 2000). Therefore, insects could be a natural alternative to pharmaceuticals. The contribution of chitin to the total nitrogen is rarely reported by authors.

One exception is a study by Barker *et al.* (1998) that attempted to account for the amount of chitin-bound nitrogen in several insects that are normally bred for pet-food. As previously mentioned, crude protein is commonly estimated by multiplying total nitrogen by 6.25. However, some of this nitrogen may actually represent nitrogen bound by chitin. In order to accommodate for chitin-bound nitrogen, acid detergent fibre (ADF) nitrogen, which may represent sclerotized (hardened) protein as well as chitin (Finke 2004), is subtracted from total nitrogen before multiplying by 6.25. In this manner, chitin levels can be excluded from crude protein values (see **Table 2.2**).

Invertebrates reported in **Table 2.2** contained between 6.3%, (fruit fly, *Drosophila melanogaster* Mergen) and 1.9% (earthworm, *Lumbricus terrestris* L.) chitin and sclerotized protein. While this range is certainly not representative of all invertebrates, it may serve as a very rough guide when scrutinising crude protein values of insects.

**Table 2.2.** Using ADF-N values to account for chitin-bound nitrogen in crude protein values<sup>1</sup>.

Species	% Dry matter basis			Corrected crude protein
	Uncorrected crude protein	Total nitrogen	ADF-N	
Mealworm <sup>2</sup> ( <i>Tenebrio molitor</i> )	50	8	0.5	46.9
Crickets ( <i>Acheta domesticus</i> )	64.4	10.3	0.7	60
Waxworm ( <i>Galleria mellonella</i> )	41.3	6.6	0.4	38.8
Fruit fly ( <i>Drosophila melanogaster</i> )	56.3	9	1	50
Earthworms <sup>3</sup> ( <i>Lumbricus terrestris</i> )	50.6	8.1	0.3	48.8

<sup>1</sup>Table calculated from Barker *et al.* (1998) using expression: (Total nitrogen-ADF)\*6.25=Corrected protein value.

<sup>2</sup>Total nitrogen and ADF-N values represent the average of 'Mealworm' and 'Mighty Mealys<sup>TM</sup>' (Barker *et al.* 1998).

<sup>3</sup>Values for 'commercial' earthworms were used (Barker *et al.* 1998).

To create an appropriate context for protein values, authors often provide the reader with protein requirements of various organisms such as humans or livestock. For poultry, protein requirements fluctuate depending on many factors, which can include sex or age. For instance, while a 1-week old broiler chicken needs 3.4 grams/day, an 8-week old broiler needs 22.6 grams/day (Austic & Nesheim 1990).

### 2.3 Entomophagy, past and present

Marconi *et al.* (2002)- Earthworm (*Andiorrhinus (Amazonidrilus) motto* Righi) recipe by the Makiritare of the Amazon:

Put in hot water (60-80 °C) and squeeze out gut content.  
Eaten with cassava and pepper or smoked overnight  
over the fireplace for later consumption.

Humans have had a long relationship with insects and other arthropods. Some scholars suggest that our relationships with the bed bug began during the ice ages. As we shared caves with bats, so too did we share their parasites (Pedigo 1996). As pests, insects have infested our crops and transmitted diseases to our livestock. Regarding the latter, South Africans need not think hard to remember trypanosomiasis, or nagana, and the destructive tsetse fly (*Glossina morsitans morsitans* Westwood) campaigns. The honeybee (*Apis mellifera* L.) has produced our honey, the silkworm (*Bombyx mori* L.) our silk (Scholtz 1984, Pedigo 1996). Humans have probably raided honeybee nests for around 7,000 years and now practise apiculture (beekeeping) to sustain a huge honey industry. Diverse products come from the industry including car wax, medicines, confectionery, and of course, honey (Scholtz 1984, Pedigo 1996).

Silk production can be dated back to between 2200 and 2500 BC when it was recorded in the Chinese Chou-King chronicles (Scholtz 1984, Pedigo 1996). Each year 2 trillion silkworms are reared to produce over 45,000 metric tons of silk (Pedigo 1996)! Other popular insect products, which have been used by humans, are shellac from the lac insect (*Laccifer lacca* Kerr) and cochineal for baking dye (Scholtz 1984, Pedigo 1996). Some of these products are still used by those of European ancestry who ironically abhor the idea of eating insects. Indeed, how strange, considering they are the only major group of humans that do not consume insects to a significant degree (Pedigo 1996).

However, entomophagy runs deep in human history, particularly in the Mediterranean, Middle East and Africa (Mark 1:6, Leviticus 11:20-23, Holt 1885, DeFoliart 1989, Pedigo 1996). Roman epicures ate Cossus (likely *Lucanus cervus* L.) with wine and flour and their Greek cousins did likewise. Holt (1885) paraphrased Aristotle: “the most polished of the Greeks enjoyed them (Cicadidae)..., considering the pupae, or chrysalids, the greatest tid-bits, and after them the females heavy with their burden of eggs.” Much later Erasmus Darwin, the grandfather of evolution, was reported to have eaten insects and “found them to be delicious” (Holt 1885).

While evidently historic, entomophagy still contributes to many human diets today. In developing nations, adequate nutrient supplies are often deficient and insects help fill nutritional voids (Bodeheimer 1951, Pedigo 1996). However, as Paoletti *et al.* (2003) pointed out, in those indigenous populations where use of insects as food is not discouraged in the culture, these organisms are used not just during times of shortage of other food items.

Among those insects most widely consumed are: caterpillars (most commonly larvae of Hexapoda: Lepidoptera), grasshoppers (Hexapoda: Orthoptera) (Pedigo 1996), locusts (Hexapoda: Lepidoptera) and termites (Hexapoda: Isoptera) (DeFoliart 1989, Pedigo 1996). These however only represent a fraction of the diversity of insects consumed. For scale, DeFoliart (1989) recounted that more than 500 insect species from more than 260 genera and 70 families have been used as food for humans. Among these, more than 100 species are consumed by the people of Amazonia (Marconi *et al.* 2002).

Not all insects are appropriate for human consumption though, and some are poisonous. Indeed, Fuller (1918) reported that some people died from consuming “nearly mature nymphs of *Hodotermes*.” However, death from entomophagy is rare; hardly a deterrent to the Pedi of South Africa who preferred one-quarter pound of mopane (*Gonimbrasia belina* Westwood, see **Figure 2.1**) caterpillars to 1 pound of fresh beef (*Bos Taurus* L.) (Quin 1959).

Other cultures also find many insects highly palatable. In the U.S. and Europe, insects such as the house cricket (*Acheta domesticus* (L.)) may be gaining popularity as a gourmet or novelty food (Nakagaki & DeFoliart 1991). “In many non-Western” nations, the main dish and/or delicacy is often an arthropod (Marconi *et al.* 2002).



**Figure 2.1.** Mopane worms (Skaife 1979). Fully grown mopane worms are about 80mm in length.

(Bodenheimer 1951, Quin 1959, Coetzee 1982, Ashiru 1988, Marconi *et al.* 2002, Gardiner & Gardiner 2003).

In developing nations, there is a wide variety in preparation of insects for food. For instance, many farmers in Nigeria prepared African silkworms (*Anaphe venata* Butler) by roasting them in sand to remove setae, body hairs (Ashiru 1988). A termite (*Macrotermes subhyalinus* Rambur) in northern and eastern Angola was de-winged and ‘fried in palm oil’ before consumption. A flavourful oil reminiscent of hazelnut was extracted from some termites of the Lake Leopold II district, Central Congo (Bodenheimer 1951). The viscera of *Imbrasia ertli* Rebel and *Usta terpsichore* Massen & Weymer were removed and the remaining bodies were ‘either cooked in water, roasted or sundried’ (Santos Oliveira *et al.* 1976). Termite alates (winged sexuals) in KwaZulu-Natal, South Africa are sometimes fried before

Recently Gardiner & Gardiner (2003) reported that those insects collected by the inhabitants of the mid-Zambezi Valley, Zimbabwe, were almost always selected for their flavour. Most insects were eaten immediately and those leftover were preserved by various methods. Most commonly, insects were “boiled in salt water and fried in oil.” Recipes for insects have been well documented for many cultures and cookbooks are available on the market

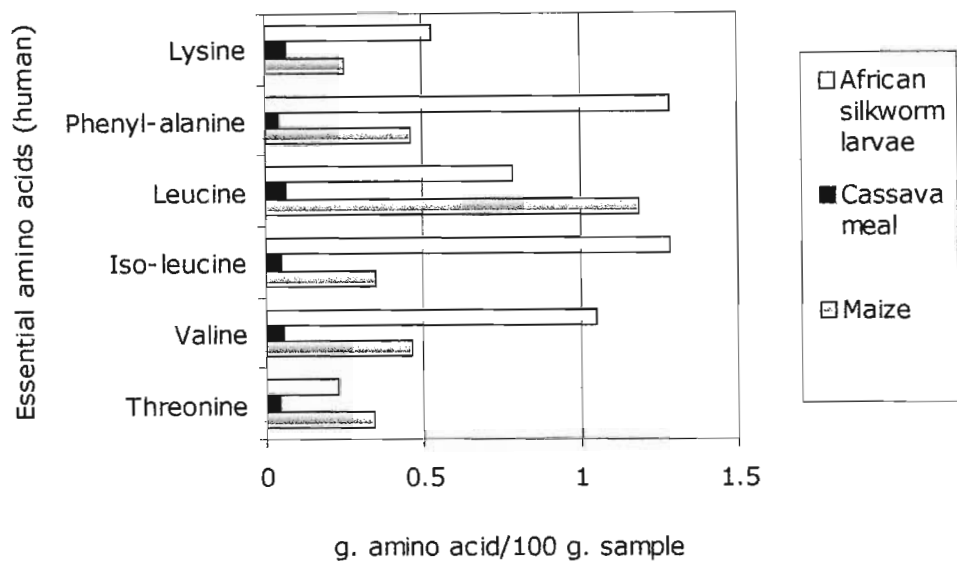
consumption (personal communications with local residents). ‘Stink bugs’ (*Eucosternum delegorguei* (Spin.)) were eaten by locals of the Pilgrimsrest district in South Africa (Faure 1944). The chemical irritant was first removed from the insect by gently squeezing on its thorax (Faure 1944).

In South Africa, mopane worms are dried and packaged in 40-kilogram bags. The South African Bureau of Standards estimated ‘annual sales through agricultural cooperative markets’ at 40,000 bags (Dreyer & Wehmeyer 1982). Reportedly, some families in Zimbabwe made a living from selling mopane worms for human food (Chavunduka 1975, cited by DeFoliart 1989). The cases above show the substantial role of entomophagy in some regional economies.

Many authors have lauded the nutritional value of edible insects supporting that insects can be both saporous and nutritious (Santos Oliveira *et al.* 1976, Ashiru 1988, DeFoliart 1989). Termites and grasshoppers can contain more than 500 calories for every 100 insect grams (Pedigo 1996). The nutritional value of the house cricket has been compared to standard livestock. When protein and fat values were reviewed, the house cricket had proportionally less carcass waste than all animals examined. It was comparable to pig (*Sus scrofa* L.) in percent protein and lower in fat than broiler chicks, pigs, sheep (*Ovis aries* L.) and cattle (Nakagaki & DeFoliart 1991). Low-fat food is great for the gourmet market where consumers are watching their weight, but may not be an asset for subsistence nutrition. When eating for subsistence, an almost archaic notion in many industrialized societies, it should be considered that “fats have a higher caloric content (9 kcal/g) than proteins (4 kcal/g) or carbohydrates (4 kcal/g), thus providing a more concentrated energy source” (Barker *et al.* 1998). Insect fat levels are often affected by their age (Lipsitz & McFarlane 1971, Redford & Dorea 1984). Accordingly some insects are consumed during their larval or pupal stages when they are fattest. Other morphological developments or physical differences can affect the nutritional value of insects (Lipsitz & McFarlane 1971, Phelps *et al.* 1975, Barker *et al.* 1998) and therefore physical transitions must be considered when rating an insect’s nutritional value.

Lepidoptera larvae, commonly known as caterpillars, have been a popular and highly nutritious foodstuff in Africa and beyond (Bodenheimer 1951, Quin 1959, Santos

Oliveira *et al.* 1976, Silow 1976, Landry *et al.* 1986, Kodondi *et al.* 1987). For instance, the mopane worm, consumed by the Pedi people of southern Africa, was reported to contain proportionally more crude protein than cooked dry beans (Dreyer & Wehmeyer, 1982). While percent digestibility proved to be lower than that of egg (94.5%) or beef (98.8%), the mopane worm (average 84.9%) was quite comparable to dry beans (average 82%) (Dreyer & Wehmeyer, 1982). In addition, the mopane worm is rich in essential fatty acids ( $\alpha$ -linolenic and linoleic), calcium, iron, magnesium, manganese, zinc and its amino acid spectrum was comparable to soybean seeds (Glew *et al.* 1999).



**Figure 2.2.** Composition of six essential amino acids from African silkworm larvae (*Anaphe venata* Butler) (Ashiru 1988) compared with two staple foods (FAO 1970).

The amino acid composition of the African silkworm larvae (*A. venata*), a species commonly consumed by Nigerian rural farmers, was reported by Ashiru (1988). The silkworm without setae (body hairs) contained 6 of the 8 essential amino acids required by humans. *A. venata* was richer in the same six amino acids than maize (except leucine) or cassava, two major crops in Nigeria (FAO 1970, Ashiru 1988, author's comparison, see **Figure 2.2**).

Other insects were also shown to have substantial amino acid compositions. The *Usta terpsichore* caterpillar contained a slightly higher amount of amino acids per 16gN than a whole chicken egg (Santos Oliveira *et al.* 1976). Concurrent analyses investigated *U. terpsichore* and three other Angolan insects. Among the parameters tested were fatty acids, vitamins and minerals. While highly nutritious, insects have lost their allure in the ‘west.’ However, in recent decades, many researchers have taken a fresh look at invertebrates for livestock feed.

## **2.4 Livestock feed, a closer look at poultry**

Insects have forever been a chosen meal among scavenging poultry. Gunaratne *et al.* (1993) investigated the feed composition of scavenging chickens in Sri Lanka. The chickens ate mostly household refuse (72%) and supplemented their diet with metazoans (7%). The natural prevalence of insectivory has led many to research the nutritional quality of insects and their energy potential for livestock. Many feeding trials have investigated the potential of various insects as livestock feed. The typical measurements of ‘success’ are weight gain and digestibility.

In 1917, J.S. McHargue published a paper detailing the protein of June bugs (*Lachnosterna* sp.) and grasshoppers (*Melanoplus* spp.) with “reference to their value as food for poultry.” This was the earliest study that I found that investigated insects as an alternative protein resource for poultry production. He reported high values of protein (75.28%) and fat (7.21%) for grasshoppers. Nineteen years later, Morris (1936, cited by Milby & Penquite 1940) may have been among the first to test insects for livestock by a controlled feeding experiment. Initially grasshoppers proved toxic to turkey poults. The following year, Milby & Penquite (1940) repeated the experiment, this time detoxifying the grasshoppers by three methods prior to the feeding trials. They found no significant growth reduction between poults fed grasshopper meal and poults fed a formulated control-feed. There was significantly greater growth in those poults fed a whole-frozen grasshopper diet than in those fed the control diet. In this last instance, it is possible that the increased growth was a result of increased consumption of the experimental diet and not its increased nutritional value.

In some cases, insects were found to be poor dietary sources when compared to commercial feed. The inadequacies were often due to toxins/diseases present in the insect or a lack of certain nutrients. One example is the study already mentioned by Morris (1936) that found grasshoppers to be 'toxic to turkey poults' (Milby & Penquite 1940). In another study housefly larvae seemed to be deficient in methionine, an essential amino acid, when fed to rats (Onifade *et al.* 2001).

In many other cases, insects were excellent feed replacements for animals. Three examples are the channel catfish (*Ictalurus punctatus*), blue tilapia (*Tilapia aurea*) and the Asian catfish (*Clarias batrachus*) that fed exclusively on insect larvae without any negative effects on body weight (Bondari & Sheppard 1981, Habib *et al.* 1994). Fish generally appear to respond extremely well to insect larvae (Bondari & Sheppard 1981, Nandeeshia *et al.* 1989, Habib *et al.* 1994, Ng *et al.* 2001).

Some insects were good for one animal and bad for another. For example, while turkey poults had lower growth rates when fed darkling beetle larvae (lesser mealworm, *Alphitobius diaperinus* Panzer), broiler chicks had significantly higher growth rates when choice-fed the larvae (Despins & Axtell 1994, Despins & Axtell 1995). Whether a particular invertebrate will satisfy the nutritional requirements of an animal greatly depends on its amino acid composition.

## 2.5 Amino acids

While an extensive table has been compiled by Fagan *et al.* (2002) detailing the percentage of total nitrogen in over 150 insects, there is scant literature describing the amino acids of most invertebrates (Barker *et al.* 1998). A table of the nutritional composition of many insects has been compiled from the available literature (**Table 2.3**). For an even more extensive table refer to the Encyclopaedia of Entomology (Finke 2004). The table lists the amino acid compositions of 18 invertebrate samples. Towards the bottom of **Table 2.3**, soybean meal and maize are provided for comparison. Just below these are the amino acid requirements of broiler chickens and layer hens. The amino acid values that meet or exceed the requirements of the layer hen are bold-faced and the percentage of those invertebrates that meet the needs of layer hens for each amino acid is shown last.

<b>Table 2.3. Amino acid compositions of selected invertebrates compared to chicken requirements (% of protein).</b>												
Invertebrate	Arginine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophan	Valine	Variance	Rank
Ground soldier fly larva <sup>1</sup>	2.2	1.9	2	3.5	3.4	0.9	2.2	0.6	0.2	3.4	5.08	16
House fly pupa <sup>2</sup>	3.7	2	2.4	3.4	3.8	1.6	3	2.1	-	2.7	3.69	14
Darkling beetle <sup>3</sup>	3.4	2.6	2.6	4	3.9	1.9	2.8	2.3	1.1	3.3	2.67	11
Mealworm larva <sup>4</sup>	2	1.5	4.2	5.4	4.7	1.8	-	-	1.7	5.2	2.48	9
Bee meal <sup>5</sup>	3.5	1.5	3.9	6.3	4.9	1.6	2.6	2.9	2.6	5.1	1.5	2
Termite alate <sup>6</sup>	-	-	3.7	8	3.5	1.3	4.3	4.2	3.7	5.1	1.63	3
Termite alate <sup>7</sup>	6.2	3.1	4.1	7.5	6.8	1.6	4.6	4	-	5.4	1.71	4
House cricket <sup>8</sup>	3.7	1.6	2.6	4.5	3.5	0.9	1.4	2.2	0.4	3.7	3.13	13
Mormon cricket <sup>9</sup>	4.5	3.3	5.3	8.6	6.2	1.3	2.8	4.8	0.5	6	2.04	6
Saturniidae pupa <sup>10a</sup>	5.3	2.7	3.3	5.1	4.4	1.4	4.3	4.1	-	4.5	1.24	1
Saturniidae pupa <sup>10b</sup>	4.2	2.9	2.9	4.4	4.3	1	3.4	3.9	-	4.1	2.15	7
Sphingidae larva <sup>10c</sup>	5.3	3.7	4.3	6.8	7.1	1.8	4.7	4.1	-	6.6	2.44	8
Noctuidae <sup>10d</sup>	6.7	3.8	4.4	7.7	7.7	2.4	4.9	5.1	-	5.2	2.9	12
Noctuidae <sup>10e</sup>	4	3.1	4.5	7.2	7.4	2.1	4.1	5.3	-	5.8	2.54	10
Noctuidae <sup>10f</sup>	5.4	2.9	3.8	6.4	18	2.3	3.9	4.6	-	4.7	24.21	5
Silk worm pupa meal <sup>11</sup>	6.8	2.5	5.7	8.3	7.5	4.6	5.1	5.4	5.4	5.6	5.73	17
African silkworm larva <sup>12</sup>	0.3	0.8	2.1	1.3	0.9	-	2.1	0.4	2.5	1.8	12.81	18
Earthworm meal <sup>5</sup>	7.2	3.7	5.2	6.4	7.2	2	5	6.1	4.6	4.3	4.65	15
Soybean meal 44% <sup>5</sup>	7.5	2.6	5.4	8	6.7	1.5	5.2	4.1	1.4	5.3	1.97	5
Maize <sup>13</sup>	4.2	2.7	3.7	12.5	16.7	1.9	4.9	3.6	0.7	4.8	19.77	19
Broiler chicken requirements <sup>14</sup>	5	2	4	6	5	2	3.2	3.2	0.9	3.2		
Laying hen requirements <sup>14</sup>	5	2	4	7.8	4.3	2	4.6	3.2	0.9	4		

References to **Table 2.3.**

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- 1, *Hermetia illucens* L., Newton *et al.* 1977.
  - 2, *Musca domestica* L., Teotia & Miller 1974.
  - 3, *Alphitobius diaperinus* Panzer, Despins & Axtell 1995.
  - 4, *Tenebrio molitor* L., diet E, Ramos-Elorduy *et al.* 2002.
  - 5, Ravindran & Blair 1993.
  - 6, *Macrotermes subhyalinus* Rambur, Santos Oliveira *et al.* 1976.
  - 7, *Macrotermes falciger* Gerstäcker, Phelps *et al.* 1975.
  - 8, *Aceta domesticus* L., Nakagaki *et al.* 1987.
  - 9, *Anabrus simplex* Haldeman, DeFoliart *et al.* 1982.
  - 10, (a) *Hyalophora cecropia* L., (b) *Callosamia promethea* Drury, (c) *Manduca sexta* L. (diet a), (d) *Spodoptera frugiperda* J.E. Smith, (e) *Spodoptera eridania* Cramer, (f) *Pseudaletia unipuncta* Haworth, Landry *et al.* 1986.
  - 11, Rao 1994.
  - 12, *Anaphe venata* Butler, Ashiru 1988.
  - 13, *Zea mays* L., FAO 1970.
  - 14, Austic and Nesheim 1990.
- 

Most of the invertebrates reported were to some degree deficient in isoleucine (56%), arginine (59%), phenylalanine (59%), methionine (71%) and leucine (83%). The best-represented amino acid was valine, the requirements of which for laying hens were met by 72% of the invertebrates.

Using the layer hen requirements as a baseline, all of the invertebrates were compared as to their proximity to the baseline. For this, an expression is developed based on the standard sample variance equation (Devore 1982):

$$V = \frac{\sum (x_i - y_i)^2}{n-1}$$

where V is the variance of the amino acid composition with reference to layer hen requirements, x is the percent composition of each amino acid for each invertebrate, y is the percent of each amino acid required for the layer hens, and n is the sample size. The equation evaluates the quality of an amino acid distribution by how closely it meets the requirements of its consumer. The equation favours the bell curve, assuming that excess concentrations in an amino acid are not preferable nor are deficiencies. This is defended by the assertion that excess amino acids are converted to fats or carbohydrates which can come from a more available resource such as maize.

Next to the variance values column is a column which ranks each invertebrate based on its score. The pupae of the *Hyalophora cecropia* L. moth ranked highest suggesting that it may prove an excellent feed for layers. When investigated, feed/gain ratios were similar for New Hampshire x white leghorn chicks when fed either soybean meal or *H. cecropia* (Landry *et al.* 1986).

The next best invertebrate feed was dried bee (*Apis mellifera* L.) meal. Kok *et al.* (1988) citing Taylor (1975) suggested that the bee body is so nutritious that production should focus on producing them for protein and not for the saccharide-rich honey. Contrarily, Salmon and Szabo (1981) found that young turkeys grew poorly when fed bee meal in place of fish meal or soybean meal (cited by Ravindran & Blair 1993). This was attributed to residual bee venom.

The third and fourth highest-ranked amino acid supplements for layers were both termite alates. *Macrotermes subhyalinus* Rambur was deficient in lysine, methionine, phenylalanine and isoleucine and *Macrotermes falciger* Gerstäcker was slightly deficient in methionine and leucine. Overall, however, the termites matched the layer hen's essential amino acid requirements quite closely. Both termite (*M. subhyalinus* and *M. falciger*) alates are consumed voraciously by humans. Therefore, it is unlikely that they will be fed to chickens. However, if collection techniques for the termite alates can be improved, there is the potential for increased human nutrition and industry as a result. Furthermore, the nutritional value of the soldier caste is unknown and they are rarely harvested due to tedious collection techniques (Gardiner & Gardiner 2003). If the soldier caste proves to be as nutritious as the alates, and efficient collection methods can be distributed to the people, the utilization of the termite as a human food and livestock feed source could be further maximised.

## 2.6 Invertebrate production and harvest

Civilizations around the world have developed and refined methods of harvesting a high variety of insects. “The insects most widely consumed by humans are larvae from three species of palm weevils (Curculionidae: *Rhynchophorus*)” (Finke 2004). Peoples from a wide geographical and cultural range have developed a remarkably

similar harvesting technique. They cut down certain species of palm trees and return “6-10 weeks later to harvest the larvae from the fallen trees” (Finke 2004). Locals of the mid-Zambezi valley, Zimbabwe, collect seasonal populations of insects such as grasshoppers and caterpillars. The captives are usually eaten immediately (Gardiner & Gardiner 2003). An example of trapping insects was reported from the Lower Murray River, Australia by Angas (1847) and Tindale (1938) (cited by Bodenheimer 1951). A fire set by the trappers lured the emerging moths which fluttered into its light whereupon “the natives made a capital supper on the scorched and roasted bodies.” Bodenheimer (1951) described a trapping device employed in Stanleyville (what is now named Kisangani, Democratic Republic of the Congo) to trap termite alates. The indigenous peoples covered entire termite mounds with large boxes. The boxes were made of leaves and sticks. Between the inside walls of the box and the edges of the mound, the peoples dug grooves in the earth. As the alates emerged from the mound, they bumped into the ceiling and walls of the box and then fell into the grooves. When the grooves were full, the termites were emptied and roasted before consumption.

Insects normally have relatively short gestation periods and can often contain high quality protein. Several papers have been written on the large-scale production of invertebrates for nutrition (Calvert 1979, Kok 1983, Kok *et al.* 1988, Kok *et al.* 1990, Parajulee *et al.* 1993, Ramos-Elorduy *et al.* 2002). Kok *et al.* (1988) attempted to develop a method to raise the confused flour beetle (*Tribolium confusum* J. du Val) on an industrial scale. A ‘farm/chemical reactor’ was developed for ‘conversion and propagation.’ The unit was elaborate, possessing both temperature and humidity controls. Insects were fed unbleached flour and yeast, an expensive feed. However the confused flour beetle had a relatively high gross yield ratio (total weight gain: total feed intake) of 0.32 (Kok *et al.* 1988) when compared to a white leghorn pullet (0.18) (calculated from Austic & Nesheim 1990), encouraging further investigations. Future research should seek cheaper cellulose-based feeds and assess their effects on insect that have value as a food or feed (Kok *et al.* 1988).

Manure and cellulose wastes are large problems in some areas. Many systems that utilize living organisms can serve as efficient management tools in this area, turning waste into highly nutritious protein. In Calvert’s (1979) article on excrement

converters, he presented a thorough review of insects and earthworms as protein synthesizers. Possibly the most thoroughly studied insect of this category is the housefly (*Musca domestica* L.) (Calvert *et al.* 1969, Teotia & Miller 1973, Teotia & Miller 1974, Papp 1975, Ocio & Vinaras 1979, Onifade *et al.* 2001, El Boushy 1991, Ravindran & Blair 1993). Housefly pupae (*Musca domestica*) are certainly nutritious, effectively replacing soybean meal as a protein source in chick diets. However, yields are low (Calvert 1979) and harvesting pupae from manure is inefficient (El Boushy 1991). Other flies that have been investigated for animal feed include *Musca autumnalis* (De Geer) and *Hermetia illucens* (L.) (Dashefsky *et al.* 1976, Newton *et al.* 1977, Koo *et al.* 1980, Ravindran & Blair 1993)

Earthworms (*Lumbricus terrestris*) have also been studied for large-scale waste transformation, and Fosgate & Babb (1972) found that earthworms fed cattle manure and lime (to maintain pH of 7.0) produced a potting soil that is suitable for plants and in some ways more beneficial than 'normal soil mixture' in regards to effect on flowering plants. The earthworm was 58% protein and 2.8% fat and could be converted from cattle manure to earthworm at a ratio of 10 to 1. The worms also digested carcasses, cloth, paper, and burlap without problems. Many other organisms can digest organic wastes including fungi, bacteria, termites, cockroaches, and ruminants.

## 2.7 Conclusion

During chapter 2, insects and their appeal as a nutritional resource were introduced to the reader. A basic review on proteins followed, paying particular attention to amino acids. Then the history, present practice, and value of entomophagy were covered. Examples were discussed which highlighted certain insects and their niches in human livelihood. Stories of humans segued to invertebrates as livestock feed. In the section entitled Invertebrates as Food: Livestock Feed, A Closer Look at Poultry, it was clearly demonstrated through ample data and a thorough examination that insects, especially termites, have a high potential as a quality source of protein for layer hens. To bring insects to rural poultry it was then necessary to briefly review

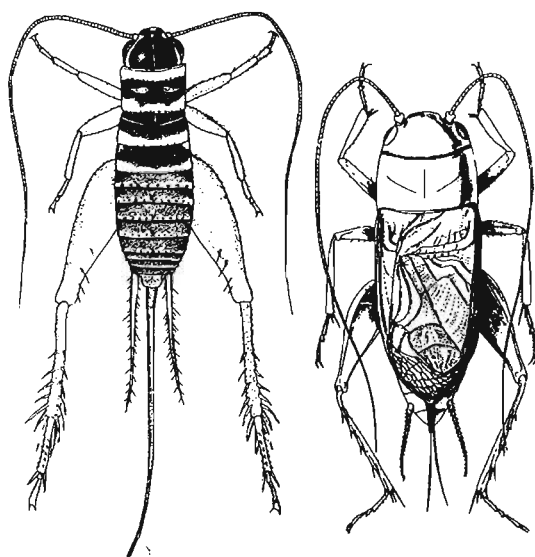
various means of insect production and harvest, which is where the chapter concluded.

Chapter 3 presents a study on cricket production for rural poultry feed. Relevant issues, pertaining to the fiscal and material limits of raising crickets in rural South Africa, are discussed.

## CHAPTER 3. CRICKET REARING

### 3.1 Introduction

The garden cricket (*Gryllus bimaculatus* (de Geer), see **Figure 3.1**) of South Africa will damage garden seedlings and vegetables as well as cash crops such as maize and fruit trees (Myburgh & Rust 1986, Smit 1964). For this it is considered by many a pest (Smit 1964). *G. bimaculatus* is not alone. The mole cricket (*Gryllotalpa*



**Figure 3.1.** *Gryllus bimaculatus* adults: female (left) and male (right) (Sholtz & Holm 1985). Adults range from 30-40mm in length.

*africana* de Beauvois) eats the roots of plants and seriously threatens potato crops (Smit 1964). During the months of March and April, another cricket (*Gryllodes sigillatus* Walker) will enter houses and cupboards to consume clothing (Smit 1964). While some of these crickets (e.g. *G. africana*) can be easily poisoned (Myburgh & Rust 1986, Smit 1964), many people today are looking for alternative pest control. Several authors have reported high nutritional values of crickets for animal feed (DeFoliart *et al.* 1982, Finke *et al.* 1987, Parajulee *et al.* 1993). In the

present study, it was postulated that crickets could be caught, raised inexpensively and fed to poultry in rural areas.

DeFoliart *et al.* (1982) mass-harvested the Mormon cricket (*Anabrus simplex* Haldeman) from Colorado, USA, for commercial-scale broiler chick feed. The Mormon cricket is found in large high-density populations and is therefore a likely candidate for seasonal harvest. The authors found that it was a substantial protein source for broiler chicks, which actually grew better on cricket-based diets than soybean-based diets (DeFoliart *et al.* 1982). In another, the Mormon cricket was also

found to be a suitable protein source for rats (Finke *et al.* 1987). Finding wild population densities of 15 to 20 per square meter, DeFoliart *et al.* (1982) proposed that the harvested crickets might compete on the feed market. However, to date no efficient method for large-scale harvesting has yet been discovered and it is therefore unrealistic that harvested wild populations of Mormon crickets will compete with conventional feed sources for large-scale poultry operations in geographical areas where conventional feeds are available. These results, however, do encourage the investigation of cricket rearing and harvesting in rural areas where financial resources are scarce.

The house cricket (*Acheta domesticus* L.) is a rich protein source for broiler chicks (Parajulee *et al.* 1993). A house cricket production unit sustainably yielded around 4000 or 6000 crickets/day from around 50 pairs of crickets (Parajulee *et al.* 1993). However, maintenance was high and the crickets, which were being raised for broiler chicks, were paradoxically being fed broiler chick food.

In 1987, Nakagaki *et al.* reported a preliminary finding that crickets may have the ability to recycle poultry manure. If this were true, crickets could be intercropped with poultry in rural South Africa.

The present author conducted a feasibility study in order to investigate if crickets could be raised in an uncontrolled environment with minimal human and material inputs. Many variables were tested qualitatively including temperature, food type and egg laying media.

## **3.2 Materials and methods**

### **3.2.1 Site description**

The practicality of raising crickets for poultry feed depends on its cost and degree of simplicity. Crickets are largely dependent on temperature for metabolism and reproduction. External heating by electricity is expensive and it was therefore necessary to establish whether or not crickets could be raised in a rustic shelter without external heating. Two rooms of the insectary, at the School of Botany and

Zoology, University of Natal, Pietermaritzburg, were chosen for the experiment. Both rooms measured 5m X 2.5m X 3m (L X W X H). The room used for rearing had screened windows which were left open during the trials, keeping the room at seasonal temperature and photoperiod. The experiments took place during May-July 2003 while average daily temperatures ranged from 3 to 24°C. The other room, used solely for egg incubation, was maintained at 23°C, 12hr light, 12hr dark.

### **3.2.2 Crickets**

For convenience, unidentified crickets, from a local pet shop, were purchased. They were immediately transferred by hand into rearing units. The sex of each cricket was not recorded. However, during the manual transfer, every other male (constituting 50% of the total male population) was discarded so as to reduce cannibalism and increase the chance of mating.

On the University of Natal, Pietermaritzburg Campus, 32 local crickets (24 females and 8 males), were caught and identified as *G. bimaculatus* by Dr. Ray Miller and the author. To catch *G. bimaculatus* holes were found amidst the cut grass on the Science and Agriculture Campus of the University of Natal, Pietermaritzburg. Water was poured into the holes until the crickets emerged or could be coaxed out with a stick and netted.

While it was not reported how significant light cycles were in the growth and development of crickets, a 12 hr day: 12 hr night schedule was used by Woodring *et al.* (1979) and Clifford *et al.* (1977). The present study was conducted under natural light cycles and the extent to which this may have influenced the study is unknown.

### **3.2.3 Housing materials and construction**

The exotic crickets were divided into 7 cricket-rearing units of 200 crickets each and the eighth rearing unit was filled with 32 *G. bimaculatus* crickets. All of the rearing units were aquariums except for one exotic unit which was made of cardboard. The dimensions of each aquarium were 60cm (length) x 31.5cm (width) x 30cm (height) and the unit was made of 4mm thick glass. To prevent escape, the aquariums were

fitted with metal screen (1mm<sup>2</sup> mesh, stainless steel) lids. The cardboard box was of the same dimensions with the exception of thickness. The cardboard box was unroofed and plastic packing tape (48mm wide) was laid 5cm below the inner rim to create a slippery surface thereby preventing escape. Each aquarium was fitted with a water dispenser (see 3.2.3.3), food dish (see 3.2.3.2), egg laying dish filled with substrate (see 3.2.3.4) and a shelter (see 3.2.3.1).

### 3.2.3.1 Shelter

The shelter was a modified one-dozen egg cardboard carton. The bottom half of an empty one-dozen cardboard egg carton, where the chicken eggs usually rest, was cut free of the lid and placed upside down in the aquarium. The top half, or lid, was then placed, right-side-up, on top of the bottom half. The two halves fit loosely together like two series of stacked hats, leaving shelter for the crickets.

### 3.2.3.2 Food dish

The food dish (1/cage) was the lid of a polystyrene Petri dish (100mm diameter). A variety of foods were given to the crickets *ad lib.* and their consumption rates were visually observed. Foods investigated were: chicken manure (local free-range), local weeds [blackjack (*Bidens pilosa* L.), gallant soldier (*Gallinsoga parviflora* Cav.), and various local grasses], commercial animal feed (rat pellets and layer mash), human food (carrots), and indigenous crops (*Amaranthus* sp. and amadumbe (*Colocasia esculenta* (L.) Schott)). Each food was offered to the eight rearing units in conjunction with two other foods.

### 3.2.3.3 Water dispenser

Two water dispensers were developed and installed in each aquarium. One of the water dispensers was a modified 250ml plastic milk bottle. A hole, 1cm in diameter, was cut into side of the bottle just above its bottom. The bottle was filled with water and the cap was screwed on tightly. The filled bottle was placed inside a polystyrene Petri dish (100mm diameter) lid. When the hole was of the correct diameter and the lid of the proper depth, the lid filled and the water level stopped before overflowing.

The other water dispenser was a 340ml glass bottle which was filled with water. A 4cm wide strip of tightly knit cotton from a clean rag was rolled up and fitted like a cork in the bottle. The bottle was then placed on its side in the aquarium. In this way the cotton served as a wick. Twice during the experiment the crickets in half of the aquaria (excluding *G. bimaculatus*) were deprived of water for approximately 3 days save that which could be extracted from their food. This was to estimate the need for water dispensers.

#### 3.2.3.4 Egg trays and laying medium

Polystyrene Petri dish (100mm diameter) bottoms served as egg trays. The egg trays were filled with a laying medium (also called oviposition substrate). Several media were tested: potting soil, local soil, sand and pea gravel (<3mm in diameter). Usually two egg trays, each containing different laying media, were introduced to each rearing unit at the same time. Each medium was tested both moist and air dry. Moist media was prepared by pouring tap water in the medium-filled dish until saturation and then pouring out excess water.

Eggs were transferred from egg trays into a variety of plastic containers (i.e., plastic Petri dishes (100mm diameter) and plastic 500ml collection jars) for incubation. Some of the containers had closed lids for moisture retention and others were left open. Two of the closed containers holding eggs were shifted into an adjacent room that maintained a more consistent temperature.

#### 3.2.4 Egg counting

Usually daily the egg trays were examined and the eggs were counted. Two perpendicularly bisecting lines were drawn in the laying material, effectively delineating the surface into four equal quadrants. The eggs in one quadrant were counted and observed. It was assumed that eggs were laid in the trays at random and therefore that the count from one quadrant accurately reflected the number of eggs in each tray. The number was multiplied by four to estimate the total number of eggs laid. The counts were recorded and used to support qualitative observations.

### **3.3 Results**

#### **3.3.1 Feeding**

Crickets did not feed on the layer mash, black jack, gallant soldier and various local grasses. They fed lightly on amadumbes and fresh chicken manure, especially when deprived of water. Carrots and rat pellets were most consumed followed by *Amaranthus* spp. Of the *Amaranthus* sp. only the seeds were consumed, a fractional part of the plant's mass. Food consumption increased dramatically with increased temperature and to a lesser extent with increased water availability (excepting amadumbes and fresh chicken manure as stated above).

#### **3.3.2 Egg production**

Qualitative observation showed that as the temperature of the tank increased, so did egg laying rates. The egg laying was also related to the egg laying medium available. The exotic crickets preferred porous media, such as the potting soil, to less porous media, such as the clay-based local soil. A moist medium was more attractive than a dry or over-saturated medium. While the potting soil was by far the preferred oviposition substrate, the crickets kicked the soil out of the laying dish more than with the other substrates. Populations that were water-deprived ceased laying eggs altogether.

Six weeks after purchase of the exotic crickets, under all conditions, the crickets lost weight and showed a decreased in egg-laying rates. At the time of purchase the crickets were around 3-4 weeks old and so it seems that their egg laying ceased at around 9-10 weeks of age.

#### **3.3.3 Incubation**

Aside from the two batches which were kept at a more consistent temperature, none of the eggs hatched. Those crickets that did hatch were raised to the age of two weeks on layer mash and tightly knit cotton from a clean rag that had been dampened

with water. They were then brought into the open-windowed room where they died within three days.

### 3.4 Discussion

Both the local and exotic crickets exhibited temperature sensitivity. Lower temperatures reduced feeding, growth, and egg laying. Other authors have noted similar temperature sensitivities in *A. domesticus* (Hoffmann 1973, Clifford *et al.* 1977). The haemolymph of crickets is affected by atmospheric temperature; variations of temperature can alter haemolymph concentrations of important substances such as lipids, carbohydrates, and oxygen (Hoffmann 1973, Clifford *et al.* 1977). For future rearing studies temperatures should be held constant at 28-35°C with a maximum fluctuation of  $\pm 0.5^\circ\text{C}$  if possible (Clifford *et al.* 1977).

Temperature seemed to be the greatest limitation of cricket growth and fecundity. Therefore, if crickets are to be raised in environments where electricity and/or insulated housing are scarce, other developments into heating solutions should be investigated. One possibility is a modified solar oven with thick insulation for night time heat retention. Another possible solution would be the planting of the cricket house inside a compost heap, taking advantage of the heat produced during the anaerobic breakdown of waste.

Further explanations for poor growth and fecundity of the crickets involve dietary components. The “optimum growth and %-survival (for the house cricket) requires specific dietary components” (Clifford *et al.* 1977). Clifford *et al.* (1977) fed house crickets a special mix that was similar in composition to layer mash. It is therefore unusual that the crickets in this study ignored the layer mash altogether. Calcium, potassium and especially sodium all affect the growth of house crickets (Nakagaki *et al.* 1987, McFarlane 1991). The concentrations of these nutrients were not known in any of the test diets. In future studies these nutrients should be carefully observed and regulated.

Of all of the egg laying media, moist potting soil induced the most egg laying. However, it was observed that the crickets kicked the potting soil out of the dish

thereby making it difficult to collect the eggs and maintain a consistent laying medium. Potting soil mixed with moist sand inhibited the kicking behaviour but also reduced egg laying. Parajulee *et al.* (1993) stated that the kicking of egg laying media could be a symptom of high population density or the wrong area of oviposition substrate area. While Parajulee *et al.* (1993) stated that neither cage density nor the available egg laying area was likely a limiting agent of population growth, this relationship between behaviour and habitat quality should be further explored.

The exotic crickets showed decreased egg laying and weight at about 9 weeks. “House crickets have a short life cycle” (Clifford *et al.* 1977), living to around 8½ weeks (Woodring *et al.* 1979) and so it is not surprising that the exotic crickets should lose vitality at around 9 weeks. However, increased feed quality and temperature regulation could likely prolong activity and age expectancy to a degree.

During the 6 week trial, crickets were prolific only when provided external heating and a diet of rat pellets and carrots. It was concluded that without innovative heating methods and alternative low-cost feeds, rearing crickets for poultry feed in rural South Africa is impractical.

In light of the impracticality of raising crickets in rural South Africa, other invertebrates were considered. Cases of termite consumption have been reported for many cultures (DeFoliart 1989). Chapters 4-8 focus on termites and their potential roles in human and poultry nutrition. Chapter 4 introduces the reader to termites by reviewing their morphology, life cycle, social structure, nest structure, ecological roles, relationship to humans, economic significance, methods of control and select genera.

## **CHAPTER 4. TERMITES**

### **4.1 Introduction to Isoptera**

Uys, V. (2002)- The word Isoptera, “equal winged,” describes the “similarity of the fore- and hind wings of the winged adult.”

Termites belong to the order Isoptera. The order contains seven families, five of which are found in southern Africa; a habitat to at least 54 genera and 165 species (Uys 2002) of the over 2600 worldwide. In fact, Africa boasts “the richest termite fauna in the world (Skaife 1979).” They are mostly tropicopolitan, but are also present in temperate nations (Scheffrahn *et al.* 2002, Creffield 1996). Between 1956 and 1979, a survey found termites to be virtually omnipresent in southern Africa (Uys 2002). Such a broad geography of colonization may be partially explained by both an uncanny ability to build microclimatic nests and to fill unique ecological niches. The termite is one of the relatively few animals that can, with the help of a variety of digesters such as fungi, enzymes, and symbiotic flagellates, metabolize cellulose (Nutting 1990). These helpers are so successful that termites assimilate cellulose with a similar degree of efficiency as ruminants (Nutting 1990)! “Since cellulose is the major constituent of most plant tissues (Creffield 1996)” termites are not very limited geographically by food resources.

“Termites are nearly as well known for their basic ability to digest cellulose as for their consequent capability of destroying wood and wood products (Nutting 1990).” As pests of cellulose-based products they are rivalled by few.

### **4.2 White ants, misnomers and identification**

Cape of Good Hope Department of Agriculture (1909)- “The houtkapper white ant or rijsmier is familiar to most Cape farmers...”

Termites are not ‘white’ ants. Termites (Isoptera) and ants (Hymenoptera) are different in many significant ways, including evolutionarily where similarities are coincidental (Skaife 1979). As described by their nickname, white ant, termites are often light in colour, especially their abdomens, whereas ants are usually darker, appearing red or black. However, there are many and eclectic differences between

these two colonial insect groups. For a closer look at the differences refer to Creffield (1996).

Termites are relatively difficult to identify (Uys 2002). Common methods for identification include: measuring physical characteristics (internal or external), nest type and food (Pearce 1997). As termites are a very old group (perhaps over 100 million years), they are evolutionarily primitive in comparison to other insects (Skaife 1979).

### 4.3 Social structure

Snyder, T.E. (1924)- “Adaptations to social life among the termites can be seen most clearly by their responses to the three primal urges-hunger, sex, and fear. Unlike man, with a double nervous system, insects have no inhibitions.”

Perhaps simple physically, socially termites are very complex. Colonies are comprised of three major castes: workers, soldiers and reproductives. Castes are morphologically and functionally different (Uys 2002) and can be visually identified (see figure 1, Pearce 1997). Unlike other insects such as bees or ants, termites do not pass through larval or pupal stages. Once hatched, juveniles appear as smaller versions of adults.

#### 4.3.1 Workers

Workers are the most abundant cast. They gather food and tunnel, earning their order the nefarious reputation amongst wood lovers. They are soft-bodied, light-coloured and generally blind (Pepper & Gesell 1952, Pearce 1997) with the exception of the family Hodotermitidae, which use their eyes to forage in the open (RSADA 1993). Worker termites have versatile domestic responsibilities that can include nest building, cleaning or feeding other castes, and caring for the young (Pearce 1997). Responsibilities can be age-dependent (Pearce 1997). For example, during the winter months in southern Africa, mature harvester termite workers (*Hodotermes mossambicus* (Hagen)) can be observed in the open, foraging for grass and shrubs (RSADA 1993). Younger termites stay in the nest attending to domestic needs (RSADA 1993). Tasks can also be sex-dependent as is the case with

*Macrotermes* and *Odontotermes* where female workers attend the queen and male workers forage (Pearce 1997).

In lower termites, those identified as primitive due to the cellulose-digesting protozoa found in their hind gut, the workers are commonly referred to as pseudergates or pseudoworkers (Pearce 1997). Families included in the lower termite group are Rhinotermitidae, Termopsidae and Mastotermitidae (Pearce 1997). In most primitive termites, castes are plastic and pseudoworkers can change caste when necessary (Darlington & Ritchie 1987, Pearce 1997)

#### 4.3.2 Soldiers

Soldiers and workers are much the same in size and appearance, the most prominent distinction being an enlarged head and set of mandibles on the soldiers (Pepper & Gesell 1952). Soldiers, true to their namesake, are defenders (**Figure 4.1**, Skaife 1979). For increased pugnacity, they can have morphological features such as a more muscular head or glands that secrete toxins (Pearce 1997).



**Figure 4.1.** *Macrotermes* soldier biting into human finger (Skaife 1979)  
Major soldier body length ranges from 15-18mm.

Sexuality ratios of termite soldiers vary (Pearce 1997). For instance, whereas males and females are equally represented in *Amitermes evuncifer*, Macrotermitidae are predominantly females (Pearce 1997).

### 4.3.3 Reproductives

There are several reproductive forms in termites. Alates are winged adults which may become kings or queens (Pearce 1997) after successful nest settlement. Alates take flight from colonies in large groups searching for a mate. Prior to flight, they gather at ‘runways’ that have been built away from the colony and are guarded by workers and soldiers (see **Figure 4.2**, Darlington 1985a, Pearce 1997). Following an environmental catalyst such as rain, hundreds or thousands of alates emerge in swarms (Pearce 1997). “Most termites are poor fliers and therefore do not fly great distances” (Pearce 1997).



**Figure 4.2.** *Macrotermes natalensis* workers protecting alates during emergence (Skaife 1979). Alates range from 25-30mm in body length.

Upon landing or ‘contact with the opposite sex’ they shed their wings (Pearce 1997, Pepper & Gesell 1952). Flying alates are vulnerable to predation (Nutting & Jones 1990) and few succeed in establishing themselves in a suitable breeding place (Pepper & Gesell 1952).

Paired alates burrow and form a copularium. If they succeed in establishing a nest, they become the king and queen. The establishing of a nest is strenuous. In the case of *Hodotermes mossambicus*, of those few pairs that established a copularium, only 58% survived the first week (Darlington *et al.* 1977). In the beginning, the royal pair lives on fat stores or sometimes on newborns (Pearce 1997).

Often the queen’s abdomen becomes large and distended (Pearce 1997). Morphologically they are so adapted to reproduction that the queens of *Odontotermes* and *Macrotermes* have been described as “egg laying machines” (Pearce 1997). The king grows but a little and can be as small as 1/5 the size of the queen (Pearce 1997) and stays mated for life. When the queen degenerates or dies,

she may be replaced by other reproductives (Coaton 1949, Sieber & Darlington 1982, Pearce 1997). There are often multiple queens (Coaton 1949, Thorne 1982, Darlington 1985b).

#### 4.4 Nest structure

Aelian (1959) 1st Century AD- “The Indian Ant (termite) too, it seems, is a clever creature. True, the Ants of our country excavate their holes and burrow below ground and construct hidden lairs, as it were, by digging in the earth, and wear themselves out with their mysterious and secret mining operation, so to speak. But the Ants of India construct little houses of material brought together, and these are not in low-lying, level country, which is easily flooded, but high up on rising ground. And there, with indescribable skill they bore passages and what you might call Egyptian galleries of Cretan labyrinths and make a place for themselves not straight ahead or easy to penetrate but out of the way past a maze of tunnels.”

Termites may live in nests in trees, dead logs, and underground or in mounds. Nests are imperative to their survival as they provide defence and create a microclimate. In this microclimate the metabolic activity of the termites and the decomposition of organic matter create heat and humidity. In the case of mound termites, the thick mound wall insulates the colony from the external atmosphere (Lüscher 1961). “Mound-dwelling termites need air to survive” (Pearce 1997). Through air vents environmental factors are controlled and adjusted as needed. There are three major designs of ventilation systems built by mound-dwelling termites: the closed system which relies primarily on convection through small pores in the mound exterior, the multi-holed mound which draws air through holes at its base and releases air through holes at its apex, and the single holed mound which draws most of its air from a hole at the top of its mound (Darlington 1984a, 1984b, Pearce 1997). Lüscher (1961) suggested that “termites survive only because their elaborate social organization enables them to build nests in which they establish the microclimate suited to their needs.”

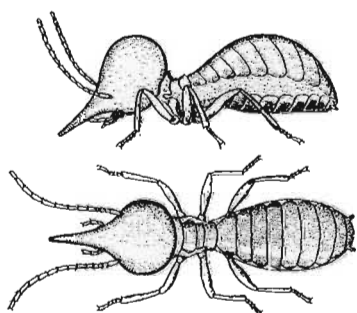
Not all sites are good for termite nests. The presence of mounds dead or alive is ‘determined by environmental factors’ (Darlington 1989). Nests are not always built by the owner and a fair bit of ‘squatting’ occurs. Prefabricated mounds make attractive nest sites (Darlington 1985a). If mounds of two species are of a similar size such as in the case of *Odontotermes* spp. and *Macrotermes* spp., one species

may colonize another's abandoned mound (Darlington 1985a). Drought or overgrazing pushes *Trinervitermes* sp. colonies to build additional nests for grass storage (Smit 1964). When the pressures lift, the colony may abandon the extra mound (Smit 1964). Later, a pair of alates may establish a new colony in the abandoned mound (Smit 1964).

## 4.5 Genera of the present study

### 4.5.1 *Trinervitermes*

Scheffrahn, R.H. *et al.* (2002)- “a conical nasus from which a defensive secretion is emitted.”

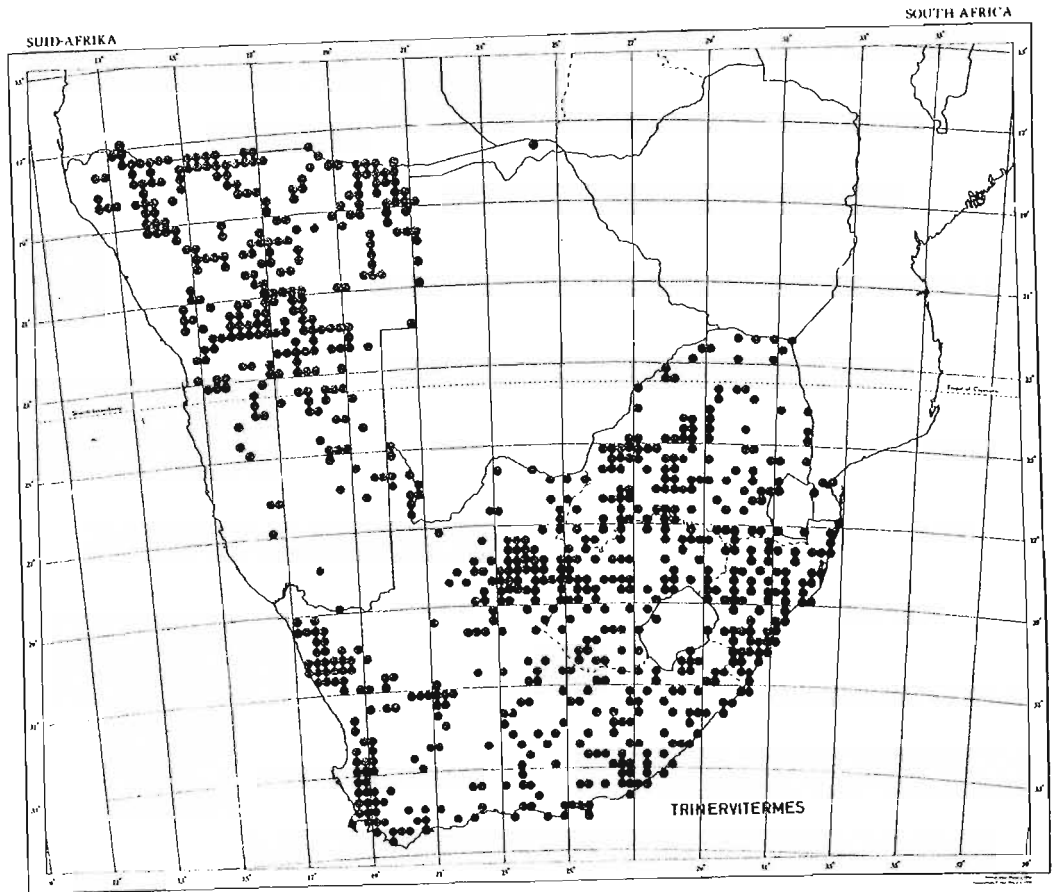


**Figure 4.3.** *Trinervitermes* sp. soldier (Skaife 1979). Adult soldier bodies are about 5mm long.

The snouted termite (*Trinervitermes* spp.) is of the Termitidae family, Nasutitermitinae subfamily. The word *nasus* is Latin for nose and describes the distinctive gland that is prominently displayed on the head of the soldier (see **Figure 4.3**, Guralink 1982). The gland holds a chemical irritant, often containing terpenes (Pearce 1997), that is secreted during defence. Soldiers of the snouted termite are responsible for guarding the nest while the workers

are responsible for everything else besides reproduction (Skaife 1979).

The subfamily is common throughout African grasslands (**Figure 4.4**, Skaife 1979) and is found in many parts of the tropical New World including a recent discovery of *Nasutitermes costalis* in the USA in 2001 (Scheffrahn *et al.* 2002). *N. costalis* is thought to be the first establishment of a termitid species outside of its endemic range, showing that Termitidae are roaming geographically.



**Figure 4.4.** Distribution of the genus *Trinervitermes* in South Africa and Namibia (Coaton & Sheasby 1973).

In South Africa, Smit (1964) reported 17 species of genus *Trinervitermes*, all species of which are herbivorous, preferring “grasses that are most valuable as food for [live]stock” (Skaife 1979) but also infesting buildings and subsequently causing structural damage (Scheffrahn *et al.* 2002). During droughts, *Trinervitermes* spp. can consume up to 60% of the grass cover per annum, thereby reducing the veld’s carrying capacity dramatically (Smit 1964). Due to the negative economic potential of the subfamily Nasutitermitinae both in southern Africa and the New World, it is important that their bait preference and trapping technologies be established.

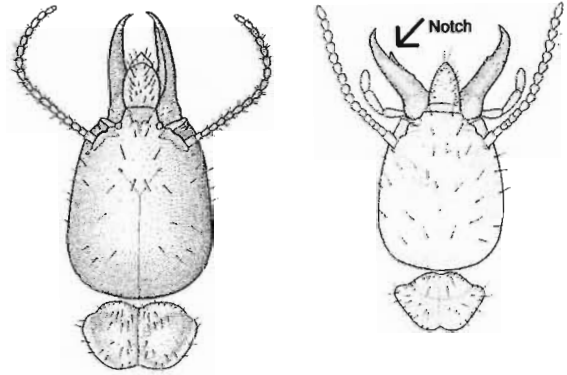
*Trinervitermes* spp. build apically rounded conical mounds which can densely cover the veld (rangelands). Smit (1964) reported that one species (*Trinervitermes havilandi*) was found at a density of ‘200 mounds per morgen.’ The mounds are sponge-like inside and homogeneous to the casual eye (Smit 1964). Upon further inspection, storage areas may be found, depending on species, where grass is kept

(Smit 1964, Ferrar 1982a). The nest lacks a royal cell and accordingly the principal reproductives can be found anywhere (Smit 1964).

#### 4.5.2 *Odontotermes*

The genus *Odontotermes* is in the subfamily Macrotermitinae, family Termitidae. Like most, if not all, genera of Macrotermitinae, *Odontotermes* grow a fungus of the *Termitomyces* genus (Sieber 1983). The fungus is grown on faecal combs. During the rainy season, the fungi from *Odontotermes* nests may be seen on the soil surface (Coaton 1961). These agarics come from one of two known sources (Coaton 1961). Either they arise from fragments of fungus comb that have been deposited on the soil above the nest or they arise from the fungus comb inside the nest (Coaton 1961).

Termites of *Odontotermes* forage primarily on wood (Scholtz & Holm 1985) and diverse waste (Pearce 1997). *Odontotermes* can be distinguished from *Macrotermes*, the other major fungus-growing genus in South Africa, by the presence of a prominent notch or tooth on the left mandible of the soldier caste (see **Figure 4.5**, Scholtz & Holm 1985, Uys 2002). In addition, while *Macrotermes* have dimorphic



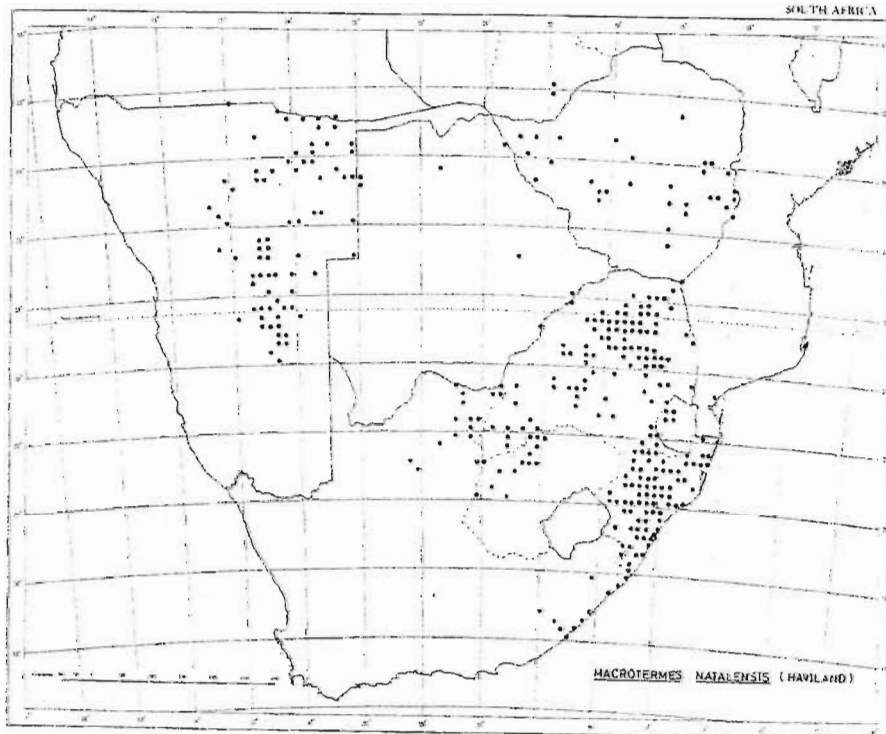
**Figure 4.5.** Heads of *Macrotermes natalensis* (left) and *Odontotermes* sp. (right) soldiers. Notice notch in left mandible of *Odontotermes* (Coaton & Sheasby 1972, not to scale).



**Figure 4.6.** *Macrotermes* sp. have a Dimorphic soldier caste. Major soldiers are approximately 40% larger than minor soldiers.

soldiers (see **Figure 4.6**) called major and minor soldiers. *Odontotermes* soldiers are relatively all the same size.

The distributions of *Odontotermes badius* (Haviland) and *Odontotermes latericius* (Haviland) are similar to the distribution of *Macrotermes natalensis* (**Figure 4.7**, Scholtz & Holm 1985). *O. badius* and *O. latericius* are the two greatest pests of



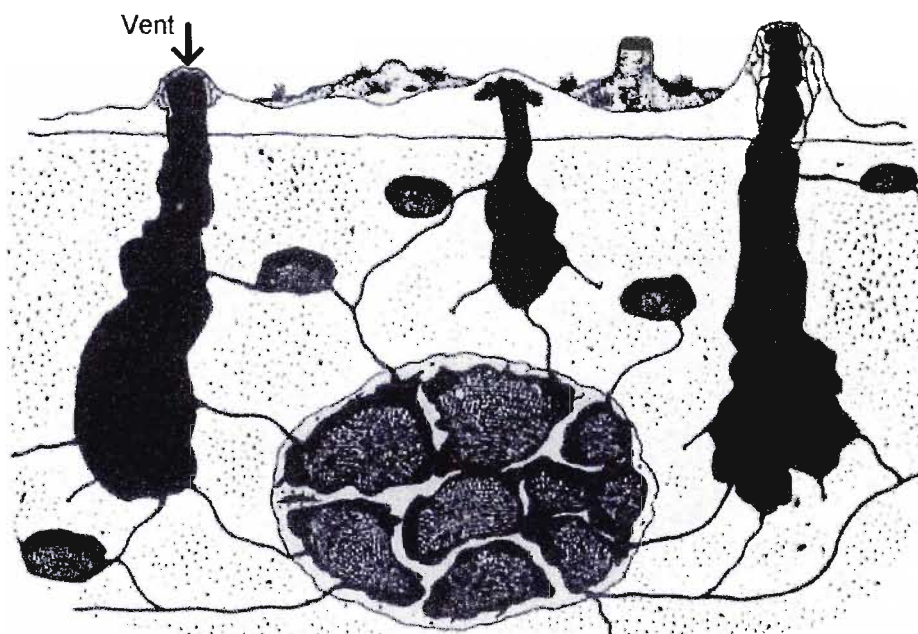
**Figure 4.7.** Distribution of *Macrotermes natalensis* in southern Africa (Ruelle *et al.* 1975).

the *Odontotermes* genus (Scholtz & Holm 1985). In fact, Skaife (1979) suggested that because of the substantial damage that it does to buildings, its large geographic range, and its high population, *Odontotermes badius* may be the ‘worst pest among all termites.’ Scholtz & Holm (1985) agreed saying that *O. badius* may cause “more damage to timber in buildings in South Africa” than all other subterranean termites combined.

*Odontotermes* and *Macrotermes* can forage at least 50m from the nest (Pearce 1997). However, for increased efficiency and safety from predators, *Odontotermes* may build their fungus comb near or within a food source (Pearce 1997). When outside the nest, *Odontotermes* forage under runways where they are protected from

predators and the external climatic conditions (Pearce 1997). Inside the runways the “water-holding capacity... is higher than in mound soil” so that the termites can remain outside the nest foraging for longer periods of time (Pearce 1997). If they do encounter predators, the soldiers of *Odontotermes* can defend themselves by releasing a ‘white sticky’ secretion from their mouths (Pearce 1997).

While the soldiers are responsible for the defence of the nest, the workers are responsible for its construction and maintenance. Large workers usually expand the nest and galleries and the small workers make repairs (Pearce 1997). The nests of *Odontotermes* can vary largely according to geography and species (Pearce 1997). While some *Odontotermes* spp. may have vents or chimneys which increase ventilation, others may not (Pearce 1997). *O. latericius* has clay chimneys ‘around wide air shafts’ (Scholtz & Holm 1985). These descend through the soil and into the ‘central nest cavity’ (Scholtz & Holm 1985).



**Figure 4.8.** Central nest cavity. *Odontotermes latericius* nests have several vents or chimneys (Scholtz & Holm 1985).

Inside the central nest cavity, the primary reproductives are found. The queen’s abdomen is usually much larger than the king’s, maybe 100:1 (Pearce 1997). The largest termite queen reported until 1985 was an *Odontotermes* queen that weighed 26g

(Darlington 1985a). *Odontotermes* queens can be “thumb-sized egg laying machines” (Pearce 1997); laying, in the case of *Odontotermes obesus*, ‘one egg every few seconds’ (Pearce 1997). Egg laying causes increased energy requirements. The queen has physical adaptations to cope with the physiological stresses associated with egg laying. For example, the queen breathes through an enlarged trachea while peristaltic body movements assist circulation and respiration (Pearce 1997).

#### 4.5.3 *Macrotermes*

Lüscher, M. (1961)- “By far the most advanced of the species we studied was *Macrotermes natalensis*. Its enormous pinnacled mounds, with curious ridges running like veins down their outer walls, are familiar to anyone who has traveled through equatorial Africa. The mounds sometimes reach a height of 16 feet and can have a diameter of 16 feet at the base. *Macrotermes* builds its mounds in the forest and in the open over much of the continent. The architecture of the mounds is far from uniform and can be quite different in various parts of Africa.”

Along with *Odontotermes*, the genus *Macrotermes* belongs to the subfamily Macrotermitinae and the family Termitidae. The family Termitidae has an especially



**Figure 4.9.** *Macrotermes* mounds can be very large or have irregularly shaped pinnacles (Skaife 1979).

high level of diversity in Africa (Uys 2002) and “*Macrotermes* has the widest distribution of all African termites” (Lüscher 1961).

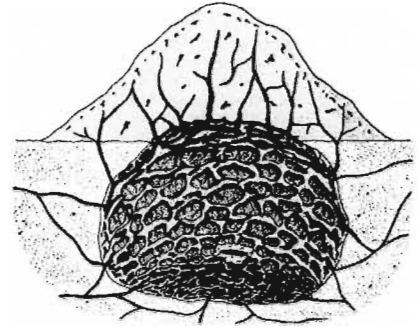
*Macrotermes* mounds can also be found ‘throughout tropical south-east Asia’ (Harris 1961). These facts are important when considering the greater implications of this project.

*Macrotermes natalensis* has a broad geographical distribution in Africa (Coaton 1947, Hesse 1955, Lüscher 1961, Sands 1962, Skaife

1979, Mitchell 1980, Ferrar 1982a) thereby making the findings of this project immediately applicable in other nations. Moreover, the *M. natalensis* alate is the

largest and most widely consumed alate in the KwaZulu-Natal province (local knowledge).

In the grasslands of southern Africa, domed mounds with irregular pinnacles litter the horizons (see **Figures 4.9, 4.10**, Skaife 1979). *M. natalensis* mounds are commonly 2-3ft. (0.6-0.9m) high, and can have galleries as deep as 10-12m (Lee & Foster 1991). Kitto (1997) excavated 30 *M. natalensis* nests near the University of Natal, South Africa. The average nest height was 0.73m tall with a circumference of 5.75m (Kitto 1997). Kitto (1997) described the nests as epigeal, like a flattened sphere where an average of 87% of each nest was



**Figure 4.10.** Cross-section of *Macrotermes natalensis* mound (Scholtz & Holm 1985).

‘completely below the external soil surface.’ Large air passages started at the mound’s apex and continued just below the surface until they branched away laterally beneath the soil surface (Kitto 1997). Beneath the air passages are fungus combs (*Termitomyces* spp.), which *M. natalensis* cultures for food (Kitto 1997).

After summer rains, fruiting bodies grow from the fungus combs. Large mushrooms (like the *Termitomyces* sp. in **Figure 4.11**) grow from the mound’s crust. The two *Termitomyces* sp. mushrooms in **Figure 4.11** had cap diameters of 10 and 16cm. These mushrooms are edible to humans and are considered to be a great delicacy.

The fungus combs found in Kitto’s (1997) study encompassed a nursery and commonly at the epicentre was the royal cell. The royal cell was protected by a dense shell of earth and often contained multiple queens in various life stages.

The nests were estimated to be between 1 and 40 years old while the queens were approximated to be between the ages of 2 and 40 years (Kitto 1997). The heaviest queen weighed over 8 grams and measured at over 55mm long (Kitto 1997). Impressive yes, but Skaife (1979) reported that queens can be as long as 10cm!

## 4.6 Ecological importance

Nutting, W.L. and Jones, S.C. (1990)- “the usual role of termites in the detritus cycle of natural ecosystems is overshadowed by their destructive role in man’s economy.”

Ecologically termites play important roles as a food resource (Du Plessis 1931, Skaife 1979, Nutting & Jones 1990) and in nutrient cycles (Pomeroy 1976, Bagine 1984, Zimmerman & Darlington 1986, Beckmann 1987/88, Nutting & Jones 1990). For a review of the nutritional value of termites, see Chapter 2. Whitford & Parker (1989) estimated that “termites process more than half of the surface litter in hot deserts.” The digestion of organic matter releases methane, a greenhouse gas (Zimmerman & Darlington 1986).



**Figure 4.11.** Author with mushrooms (*Termitomyces* sp.)

Mound-building termites alter soil composition, both physically and chemically (Nye 1955, Pomeroy 1976, Omo Malaka 1977, Nutting & Jones 1990, Husson & Séguy 2003). In the flood plains of the Okavango Delta, Botswana, “silt builds up around termite mounds,” creating islands (Lanting 1990). Mound material is rich in organic matter and nutrients and it has been suggested as a fertilizer (Coaton 1951, Hesse 1955, Beckmann 1987/88). Pomeroy (1976) suggested that termites can also play a negative role in the environment by withholding valuable nutrients underground.

## 4.7 Relationships to humans

Gunther, J. (1953)- “On death, a Bakutu [tribe member] is put into a termite hill, a simple procedure and quite sanitary.”

Termites are the oldest social insect[s] by about 100 million years and outdate both the development of the flowering plant[s] and the primate[s] (Pearce 1997). Over the years, humans have developed diverse and complex relationships with termites. They have both fed us and consumed our crops. “Evidence from archeological digs

suggests the use of tools by early hominids to dig termites from their mounds” (Finke 2004). Termite mound soil “has been used for making roads, tennis courts, pottery and bricks. 450,000 bricks have been made from one mound” (Howse 1970).

A resident of Sweetwaters, Pietermaritzburg, South Africa told the author of how he cooked chickens inside old termite mounds. A hole was dug with a spade in the side of a “dead” mound and a whole chicken was inserted. After sealing the hole, a fire was built on top of the mound. Due to the excellent heat retention of the mound soil, multiple chickens can be cooked in succession even after the fire has gone out. “[The system is] very nice, it’s better than the pot.”

#### **4.7.1 Economic impact**

“Harvester ants have invaded this farm to such an extent that we will be compelled to trek with our stock unless we can do something to control them.”  
(a South African farmer, Coaton 1958)

From the literature, it seems that termites will eat just about anything: buildings, timber, fungi, dung, humus, crops, curtains, etc. (Cape of Good Hope Department of Agriculture 1909, Coaton 1943, Pepper & Gesell 1952, Mitchell 1980, Nutting 1990). “In urban areas gardens are frequently ravaged by these species [Hodotermitid]- lawns, vegetable and flower beds are stripped, while leaves and less woody twigs of hedges, shrubs and young trees are cut off and carried underground” (Coaton 1958). Their food doesn’t even have to be organic and can include plastic water pipes, buried telephone wire and linoleum (Creffield 1996).

Because they are cryptic foragers they often go unnoticed by humans until serious damage has occurred (Pepper & Gesell 1952, Nutting & Jones 1990, Uys 2002). The damage bill sent by termites to the USA, including cost of chemical treatment, was estimated at 2.5 billion dollars per annum (Nutting & Jones 1990, citing Fellman 1985). While no current figures were found, historically, the reported damage in southern Africa has been Herculean.

Large financial damage to gardens, structural timber, buildings, vineyards, crops and pastures have been documented (Du Plessis 1931, Broekhuysen 1941, Coaton 1943,

1951, 1958, Uys 2002). In pastures, termite populations may be encouraged by overstocking/overgrazing (Coaton 1958, Nutting 1990).

The amount of damage caused also depends on the species of termite. Of all the species in South Africa, only 3 or 4 were identified as being of major economic significance (Broekhuysen 1941, Coaton 1949). *Macrotermes natalensis*, the focus *Macrotermes* species of this study, was one of them (Broekhuysen 1941, Coaton 1949). In fact, “*Macrotermes* as a genus are all potential pests of standing crops” (Mitchell 1980).

#### 4.7.2 Methods of control

Luke, W.J. (1952)- “Fields totalling 355 acres were selected for treatment. The cane trash was first burned and the land was then plowed twice...After plowing it was knifed to a depth of fourteen to eighteen inches in a hope of breaking up the termite tunnels...The land was harrowed to a depth of four or five inches prior to applying the insecticide.”

As always, the best method for control, and probably the least used, is prevention. Pastures should be appropriately managed. Buildings should be built on dry, debris free soil (Pepper & Gesell 1952). No wood from the building should be in contact with the soil but should instead be protected by seamless concrete or metal (Pepper & Gesell 1952, Canadian Wood Council 2001). The foundation should be regularly checked for evidence of infestation and appropriate measures should be taken.

During the first half of the 20<sup>th</sup> century, termites were mainly treated with noxious chemicals. Many of these chemicals while potentially contaminating ground water and killing livestock, were ineffective in completely exterminating termite nests (Coaton 1958). Among the most noxious were dichlorodiphenyltrichloroethane (DDT), benzene hexachlorin (BHC), Aldrin and arsenic (Coaton 1943, 1947, Luke 1952, Sands 1962).

The first model of a termite air pump was introduced to South Africa in 1909 (Cape of Good Hope Department of Agriculture 1909). Arsenic was heated into fumes which were then pumped into the termite nests (Cape of Good Hope Department of Agriculture 1909). This practice became popular and was again described in 1941 by Broekhuysen who also mentioned three other methods for termite control: pouring

petroleum into nests, fumigating exit holes during prenuptial flight, and treating the soil of the affected plants with arsenate of lead. Since the 1950s chemical barriers have been used (Creffield 1996). The purpose of chemical barriers is to repel termites from an area by surrounding it with termiticide. More recently, termiticides utilizing horizontal transmission are being studied (Ibrahim *et al.* 2003, Shelton & Grace 2003). Horizontal transmission termiticides are time-delayed so that those infected can take the poison into the nest and expose others before dying.

Biological agents such as fungal pathogens and nematodes have been used with success against certain termites (Pearce 1997). Biological agents are often unsuccessful in Macrotermitinae because infected individuals are quickly quarantined, by isolation or burial, from the rest of the colony (Pearce 1997).

Chemical treatments are expensive and can be dangerous (Nutting & Jones 1990). Physical methods such as queen removal (Coaton 1949) and mound destruction (Coaton 1951) are laborious and in the case of queen removal, ineffective (Coaton 1949). New, physical control methods and non-toxic baits need to be developed.

Du Plessis (1931) suggested one ecological control method that should be revisited; certain birds and other natural predators of termites should be protected by farmers (Du Plessis 1931). Among those listed were fowls, aardvarks, and the Stone Plover (Du Plessis 1931).

One example of a non-destructive control method was reported by Husson & Séguy (2003) at a Soil Health and Remediation Workshop, University of Natal, Pietermaritzburg. The farmer intercropped plants which are not attractive to termites (i.e., *Brachiaria ruziziensis* Germain & Evrard), but increase earthworm populations, alongside his target crop. The earthworms both increase soil fertility and effectively exclude termites (Husson & Séguy 2003).

### 4.7.3 Studying termites

Bulmer, M.S. & Traniello, J.F.A. (2002)- “termites often forage cryptically.”

Areas of study related to termites include bait/trap design, behaviour, and termiticide efficacy. Termites are discreet, secretive animals and are therefore challenging to study (La Fage *et al.* 1973, Nutting 1990, Nutting & Jones 1990, Uys 2002). They are hard to keep alive in the laboratory (Skaife 1955), and the royal pair can only be examined by excavation of the nest. Many nests are subterranean and are therefore difficult to locate (Bulmer & Traniello 2002). Moreover, workers cannot be identified to colony by any behavioural method (Bulmer & Traniello 2002). Due to all of these complications and more, little is known about the social structure and foraging habits of termites (Bulmer & Traniello 2002). It is known that most termites are sensitive to sunlight, UV and desiccation, so they are therefore not normally above ground during daylight.

In order to study termites under these conditions, many techniques have been developed.

### 4.7.4 Monitoring and collection techniques

De Woronin, U.G. (1973)- “Each man settled comfortably by his up-turned basket, a branch laid by his side... At a nod, he began tapping his basket in slow time, with a stroking movement, the others joining in. The rhythm was deliberately broken, and, as I listened, the sound became a rustle. On closing my eyes, I heard the fall of rain...

All around, ants began to emerge, fluttering like snowflakes. With twists of grass, Joseph hurriedly plugged their escape-holes, his one hand never pausing in its tapping... Quickly he covered the seething mass with the sack, mouth down. Similar activity was going on at the other anthills.”

Alates can be collected by light traps as they are attracted to light (Pepper & Gesell 1952, Thompson 1985). One light trap was contrived by the people inhabiting the region of Lake Leopold II. On a rainy day during the season that alates take flight, the locals dug troughs at the base of termite mound. At night, when the termites emerged, the harvesters posted a torch in each mound at a 45 degree angle. The termites were attracted to the light and dropped into the troughs, probably following a nasty scorching. Later the termites were collected and dried for storage and

consumption. Termites have been consumed throughout most of Africa and various trapping methods have been developed regionally (Bodenheimer 1951).

Some other basic techniques used to study termite populations involve nest fumigation and (or) excavation, soil coring and searching for termites in infested wood or under rocks (Ferrar 1982a, Rajagopal 1985, Darlington 1984a, 1984b, 1988, 1990, Kitto 1997). Although excavation can fruit reproducible results, it is destructive and laborious. The collection of termite-infested wood is site-dependent but can be a great way to identify and collect large samples of foraging termites. Shallow soil cores provide a limited subsample of the population, only representing those termites foraging in the upper soil layers (Ferrar 1982c). Activity in the upper layer of soils is moisture-dependent and “can vary greatly over short periods of time” (Ferrar 1982c). The more sophisticated non-trapping method, named Mark-Release-Recapture, is commonly used to estimate populations (Nutting & Jones, 1990).

#### **4.8 Conclusion**

Termites, with their wide geographic distribution and love for wood and wood products, can cause significant economic damage. Termites also play crucial roles in natural ecosystems; as a food resource for predators and as active decomposers. Despite their impacts on humans and the natural world, little is known about these socially sophisticated insects.

The focus genera of this study, *Macrotermes*, *Odontotermes*, and *Trinervitermes*, are widespread insect pests. Furthermore, *Macrotermes* and *Odontotermes* are consumed by humans in South Africa. These important relationships with humans warrant further investigation.

Chapters 5-8 explore various trapping methods of trapping in greater depth with a study addressing the chemical composition of *Odontotermes* sp. and *Macrotermes* sp. in Chapter 8.

## CHAPTER 5: STUDY ON THE EFFECT OF TIME ON TERMITE TRAPPING

### 5.1 Introduction

28 August – October 30, 2003

Often traps are used by humans for studying termites. Traps can be below ground (Grace 1989) or above ground (Farina *et al.* 1991) depending on local threats such as weather or vandalism (Grace 1989). Successful trap designs can yield thousands and even tens of thousands of termites (Tamashiro *et al.* 1973, Grace 1989) and large quantities of bait can disappear in a matter of days (Ferrar 1982b, Grace 1989).

Most termite collection techniques deliver termites which are mixed with soil or other debris. Often debris-free termites are needed in the laboratory for various research such as disease transmission studies, compositional analyses and termiticide research. In response, several authors have devised techniques for termite separation (Tamashiro *et al.* 1973, Jones & Mauldin 1983, Myles 2001). Tamashiro *et al.* (1973) built termite bridges out of moist tongue depressors. In search of moisture, termites left the dry debris and crossed the tongue depressors to moist wood. Myles (2001) developed a variation of this concept called the tray-in-box separator. Vacuum powered and mouth-powered aspirators were also tested; the vacuum-powered model was significantly faster than the mouth-powered model (Jones & Mauldin 1983). Termites have been separated by floatation (Darlington 1982, 1984, Rajagopal 1985), sieves (Myles 2001), baffle separator (Myles 2001), and hand sorting (Abe & Matsumoto, 1979).

A novel termite trap was developed and investigated to catch termites for poultry feed or future ecological studies. *Trinervitermes* sp. termites were selected due to their economic significance and broad distribution in South Africa (see Chapter 4).

### 5.2 Materials and methods

The trap was developed and adapted from a termite trap that was described by Farina *et al.* (1991), using plastic 2 litre bottles instead of clay pots. In brief, the clay pot was filled with bait, placed open end down and sealed to the termite nest. The

present study assumed that plastic 2 litre bottles are more common in rural areas than clay pots and that plastic 2 litre bottles would adequately replace the clay pots, even allowing more continual access through the screw-on top.

Waller & Curtis (2003) reported that two species of *Reticulitermes* consumed more paper when it was laced with sugar. Assuming that mound-building termites also have an affinity for sugar, the plastic 2 litre bottles were un-rinsed to take advantage of any residue sugars. The bottom 5cm of each plastic 2 litre bottle was removed by knife and discarded.



**Figure 5.1.** The runways at Oribi Airport are bordered by grasslands.

### 5.2.1 Baiting and installing traps

Oribi Airport (29 39' S; 30 24' E), Pietermaritzburg, KwaZulu-Natal, was selected for the study because of its high density of termite mounds and secure location. The runways at Oribi are surrounded by grasslands (see **Figure 5.1**), rooted in rocky soil. The airport is bordered by the Bisley Nature Reserve and agricultural land. The selected field was selected for its high number of



**Figure 5.2.** Ant attacking termite soldier (Skaife 1979)

established termite (*Trinervitermes* sp.) mounds, a total of 25. To select the mounds, starting at the western most end of the field the author walked in a straight line due east (as measured by GPS compass) and selected every mound in sight until he reached the quota of 15. One trap per mound was installed at Oribi Airport between 28 August and 2 September, 2003. All 15 traps were left unattended.

Ants can be major predators of termites (see **Figure 5.2**, Smit 1964, Howse 1970, Lepage & Darlington 1984, Darlington 1985c). For this reason, their effects on

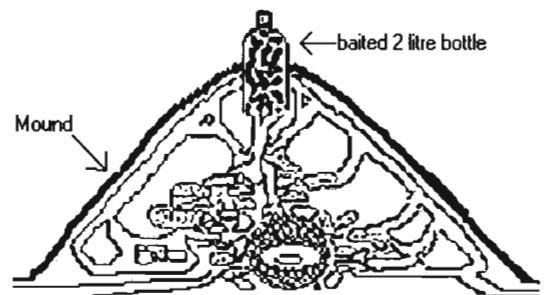
termite colony populations were investigated. During the installation of each trap, the presence or absence of ants on the mound crust was recorded. In order to determine the effects of the presence of ants on the efficacy of the trapping device, a multiple linear regression was run. Again, because the termite numbers have an abnormal distribution, the log values were used. To denote whether a mound showed ant presence, it was either assigned a factor of 1 or 0.



**Figure 5.3.** Maize stalks were broken into small pieces.

A hole (18cm deep) was dug into the top of the mound with a pickaxe and hand trowel and widened to the circumference of the plastic 2 litre bottle. The excavated crust (including termites) was mixed with maize stalks and dekernelled cobs. The maize stalks and dekernelled cobs had been left uncovered outside since the fall harvest of 2002. After collection, the maize parts were torn by hand into 10cm pieces and soaked in water for 24 hrs

(see **Figure 5.3**). The mixture of maize and crust was then stuffed into the bottle until it was as full as possible and the cut bottom was placed into the hole (see **Figure 5.4**). For shade, a plastic-mesh produce bag was folded inside itself to create a double-layered bag. The double-layered bag was then slipped over the exposed section of the trap and staked in place with a bent piece of wire.



**Figure 5.4.** A baited plastic 2 litre bottle was installed in each mound.

After 2-3 weeks 10 traps were collected randomly and after 7-8 weeks the remaining 5 traps were collected randomly.

When the traps were removed from the mounds, a hole was left behind. When collecting the 2-3 week old traps, the depth and diameter of the remaining hole was measured as a baseline from which to chart the speed of mound repair. One week later the holes were visited for observation.

## 5.2.2 Termite collection and separation

After 2-3 weeks, the traps from 10 mounds were collected. After 7-8 weeks, the remaining 5 traps were collected. The 2-3 week collections were made at sunrise and just after between 5:49 and 6:25 AM on the 21<sup>st</sup> of September and the 7-8 week collections were made between 5:25 to 5:45 AM on the 30<sup>th</sup> of October. Each plastic 2 litre bottle and its contents was removed and placed in its own plastic bag. The plastic bag was labelled with the date and mound number. The bottles were then transported to a laboratory at the University of Natal where the contents of each bottle were examined. One incision was made down the length of each bottle and one across the top so that the two incisions met perpendicularly to form a 'T.' Next, the author placed a metric straight ruler alongside the bottle to estimate the percentage of each bottle that had been filled with structured mound soil (SMS). SMS was defined as mound soil that had been hardened and was full of tunnels.

### 5.2.2.1 Berlese funnel

The contents of each plastic 2 litre bottle were then placed in individual Berlese funnels under 60 watt bulbs at 28°C for primary separation. The Berlese funnel was made of two square funnels (250 X 250mm) with a total height of 600mm. The bottom extraction section was 100mm deep with a total height of 350mm. The inverted top light source section was 250mm in height. A substrate such as soil which contains insects, is placed in the funnel. A globe (light bulb) is suspended above the substrate and a lid covers the globe and funnel. At the bottom of the funnel is a plastic 500ml collection jar for the separated insects. As the substrate is desiccated by the heat from the globe, the insects move down away from the heat and into the collection jars. In this case, termites are soft-bodied insects and are therefore vulnerable to desiccation and so wet paper cardboard was provided in the collection jar to expedite the immigration and prevent desiccation. After separation by Berlese funnel, the termites were not entirely debris free which would render subsequent weighing of the termites somewhat inexact.

#### 5.2.2.2 Tray-in-box separation

The not entirely debris-free termites from the Berlese funnels were separated by an adaptation of Myles' (2001) tray-in-box method. Again, the samples from each plastic 2 litre bottle were separated independently in their own separation device. The tray-in-box method requires: a tray that is large enough to hold the termite-substrate mixture, a plastic or other non-stick container that is large enough for the tray to fit inside comfortably, masking tape, and cardboard. The cardboard is dampened and placed in the bottom of the non-stick container. The edges of the tray are covered with masking tape providing a surface that the termites can crawl over. The tray is then placed into the container so that it lays flat on the cardboard. The debris and termites are then placed onto the tray. The method takes advantage of the termites' need for water. As the debris dries, the termites leave the tray in pursuit of moisture.

In the present study, due to a lack of access to suitable trays, a modification was made to the tray design. Masking tape was applied to the upper surface of a plastic plate (20cm in diameter) in the shape of an 'X.' The rest of the method was as described above.

During all separations, a small number of termites died. These were removed with tweezers to be counted along with the live termites.

#### 5.2.3 Weighing and counting termites

The live and dead termites were counted by hand. The termites collected from one of the mounds were air dried for 1-2 days and weighed by an analytical scale (Denver Instrument Company, model TR-403) which was accurate to 0.001g.

The student's t-test and summary analyses of the number of termite harvested were completed on GenStat, version 6.1.0.200 (2002).

### 5.3 Results

Those traps that were employed for 3-4 weeks harvested a mean of 213.6 and a median of 195.0 termites per trap. The standard deviation was 102.6 and the sum of all termites harvested for the nine traps was 1,922. Of these, 376 termites weighed a total of 0.474g (dry weight).

The 7-8 week traps harvested a mean of 336.6. The standard deviation was 315.5 and the median value was 199.0. The sum of harvested termites for the five traps was 1683.

After 2-3 weeks, 58% (mean) of the wet maize had been consumed. After 7-8 weeks, 70% (mean) had been consumed.

60% of all of the mounds used had ants present before installation. Ant presence on the mound surface had no significant effect ( $t=0.672$ ) on the number of termites harvested by each trap. No ants were found inside the traps.

There was no significant difference between the mean volume of wet maize consumed after 3-4 weeks or 7-8 weeks of trapping ( $t = -1.71$ ).

An unpaired two-sample t-test showed no significant difference in termite numbers harvested between those 3-4 week traps and those 7-8 week traps ( $t = -0.59$ ). To be certain, the two groups were also analyzed by a multiple linear regression. Again there was no significant difference ( $t=0.341$ ). The data are not normally distributed and therefore log values were used for each test.

The data were also obscured by the small sample size, making outliers difficult to understand. For this reason, medians may be more appropriate than means. The traps under the 3-4 week treatment collected a median of 195 termites while the traps under the 7-8 week treatment collected a median of 199 termites. If only four additional termites are caught per trap for an extra 4 weeks of time invested, it is

certainly more efficient to bait traps for 3-4 weeks or less. As each termite weighed 0.001g (dry weight), a discrepancy of 4 termites per trap was negligible.

#### **5.4 Discussion**

The extremely low body weight of the dried termites raises a question. Is the experimental trap an efficient means for procuring poultry feed? The most productive trap only harvested 876 termites or 0.88g (dry weight). Austic & Nesheim (1990) reported data from an earlier study (Heywang & Vavich 1962) which showed that the average laying hen consumed around 106 g of balanced feed per day throughout the year. Therefore, ten traps at 0.88g/trap is not enough feed one chicken and trapping *Trinervitermes* spp. by this method is impractical in the context of rural poultry nutrition. The trap should be tested on larger termites such as *Macrotermes* species. In addition, the trap design may be used in investigating such topics as mound repair rates and colony populations, information imperative to understanding *Trinervitermes* spp. and their effects on grassland productivity.

To better understand the low harvest, the plastic 2 litre bottle should be compared to clay, the material of the trap in the study by Farina *et al.* (1991). While Farina *et al.* (1991) did not record the mass of termites harvested per trap, he noted that the method produces a considerable number of termites. Clay has a higher insulation capacity and is non-translucent. Farina *et al.* (1991) described the clay as having a cooling effect on the trap's contents, thereby securing a suitable microclimate in the face of the sun. As termites are both temperature and light sensitive, clear, thin plastic could reduce the ability of the trapping mechanism.

From the choice feeding study presented in this dissertation (Chapter 6), it was found that wet maize, the bait used in this trial, was less attractive than dry maize to the snouted termite. Had the traps been baited with more attractive bait such as dry maize, the trap may have been more effective.

The installation method itself is an unknown variable that should be investigated in the future. Should the bottle be installed at a different depth or in a different part of the mound? Future studies should investigate trap placement further.

### 5.4.1 Mound repair

Within a half an hour after collection of the traps, the remaining holes were swarming with termites (see **Figure 5.5**); workers rebuilding the breach and soldiers posted sentry on the rim, heads and antennae held high. Upon inspection one week later, all of the holes had been completely repaired.



**Figure 5.5.** Hundreds of termites hurry to repair a hole left by the removal of a plastic 2 litre bottle trap.

If the mound is repaired so quickly, why not just harvest termites by digging up the mound like the rural peoples are already doing (Naidoo 2000)? This question will be addressed in Chapter 7, when the sustainability of trapping termites is investigated.

## CHAPTER 6. CHOICE FEEDING

### 6.1 Introduction

The snouted termite (*Trinervitermes* spp.) consumes grasses, thereby competing directly with cattle and other grazers for food (see Chapter 4). It is therefore very important to researchers, extension workers and farmers to know their feeding preferences. This chapter presents two studies which examine the ability of a novel trapping device to compare the attractiveness of various baits to a *Trinervitermes* sp.

Traps have been used to study subterranean termites the behavioural patterns or habits of which are hard to observe as they live underground (Grace 1989). Various baits have been used including: wooden stakes (Grace 1989, Lewis *et al.* 1998), toilet paper rolls (La Fage *et al.* 1973, Ferrar 1982b), cardboard (Grace 1989), crushed mound material (Skaife 1955), wood bundles (Tamashiro *et al.* 1973), pine needles (Coaton 1958), maize, sorghum and other cereals (Farina *et al.* 1991).

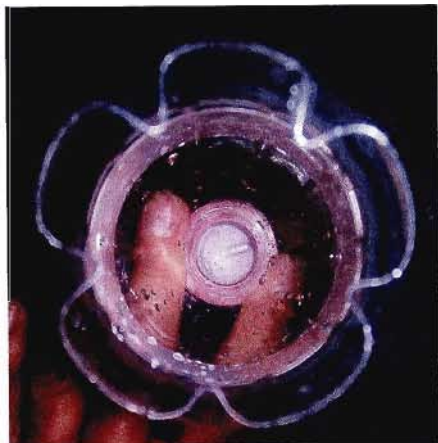
Farina *et al.* (1991) reported success in trapping termites with maize stalks and dekernelled cobs as bait. Maize (*Zea mays* L.) was found by Cairns & Lea (1990) to be by far the predominant crop in the Nkandla district of KwaZulu-Natal, South Africa and it therefore was chosen as a test bait for this study. Another bait tested was mound soil. Mound soil has been used to expedite termite colonization in traps and laboratory nests (Skaife 1955, Farina *et al.* 1991). Because wet cardboard is a commonly used bait for subterranean termites (Grace 1989, Fei & Henderson 2002) it was used as a baseline from which to compare the other baits. The local predominant grass was also tested.

### 6.2 Materials and methods

#### 6.2.1 Experiment I

*11-23 September, 2003*

Experiment I, a preliminary experiment, was conducted at Oribi Airport (see Chapter 5 for site description) to estimate the potential of various baits to lure termites into

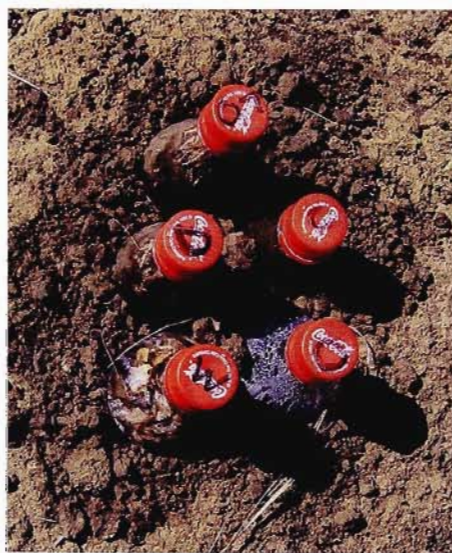


**Figure 6.1.** The bottom of the plastic bottle is removed, creating a five-pointed star.

the previously described trapping device (see Chapter 5). In the experimentation described here, a plastic 250 ml bottle was used instead of a plastic 2 litre bottles to increase the number of replicates on the mound. The bottom of the bottle was cut off. As little was cut off as possible so that the resulting opening looked like a five-pointed star (see **Figure 6.1**). The

star acted as a barrier, effectively keeping the bait inside the trap when turned so that the opening faced the ground.

One snouted termite mound was picked randomly and used in the study. Five plastic 250 ml bottles were emptied and rinsed. Their bottoms were removed by knife and 4 of them were stuffed to maximum capacity by hand with either wet maize, dry maize, local grass (*Themeda triandra* Forssk) or cardboard.



**Figure 6.2.** Five baited bottles were installed adjacently in the mound.

Dry maize and wet maize stalks and dekernelled cobs were tested to compare the effects of moisture on trap efficacy. The stalks and dekernelled cobs were manually divided into 10cm pieces, taking care to split the stalks in half. A portion of the pieces was set aside as dry maize and the remaining portion was soaked in water for 24 hours. Prior to insertion into the trapping device, any superfluous water was squeezed by hand until the maize stopped dripping. *T. triandra* samples were cut at the base and used whole, without added moisture. The cardboard was cut into 74x18cm rectangles and soaked until

pliable. As with the wet maize, all excess water was squeezed from it. The cardboard rectangle was rolled and stuffed into the 250 ml bottle. The fifth bottle was left empty as a control.

All five bottles were grouped adjacently so that their sides were touching as they stood upright. When viewed from above, they formed a row of three and a row of two (see **Figure 6.2**). In this formation, with the rows parallel to east and west, they were buried in the mound to a depth of 18cm so that only the necks of the bottles were left above the mound surface. The bottles were left unattended for 12 days. After thirteen days they were unburied and cut open for a visual count of the number of termites. A metric straight ruler was then placed alongside the bottle to estimate the percentage of each bottle that had been filled with structured mound soil (SMS; see 5.2.2 for definition).

#### 6.2.2 Experiment II (1 replicate, nine blocks) *13 September- 28 October, 2003*



**Figure 6.3.** Two holes were dug in each mound, with a hand trowel, during the treatment installation.

In Experiment II, 5 bait treatments and 1 control were installed in each mound. A total of nine randomly chosen mounds were used at Oribi Airport. Each mound was treated as a statistical block. By using a randomized block treatment, the author assumes that the treatment response will be more similar within blocks than between blocks. As in Experiment I, plastic 250ml bottles were used with their bottoms removed. In addition to the four treatments (wet maize, dry maize, *T. triandra*, and cardboard) and

control (empty) used in Experiment I, loose mound soil (LMS) was added. During installation two holes were dug in each mound (see **Figure 6.3**). The LMS that

came from each hole was inserted into one of the bottles to become a treatment on that mound.

The bottles were taped together into two groups of three. The control, wet cardboard and *T. triandra* were in one group and the LMS, wet maize and dry maize were in the other group. Both groups of three were installed less than 60cm apart in each mound (see **Figure 6.4**). Each group was randomly assigned to either the east or west side of the mound to reduce solar effects. Randomness was insured by first digging a hole on either the east or west side and then pulling a group of bottles out of a black trash bag and installing it into the hole.



**Figure 6.4.** The two groups of bottles were installed within 60 cm of each other.

After 45 days, all choice feeding units were removed and brought back to the University of Natal for processing. Each bottle was cut open and the SMS and leftover bait was removed and broken into small pieces by hand and placed in a white tray. Every termite was visually counted, identified to caste, removed from the debris via forceps to avoid counting it again.

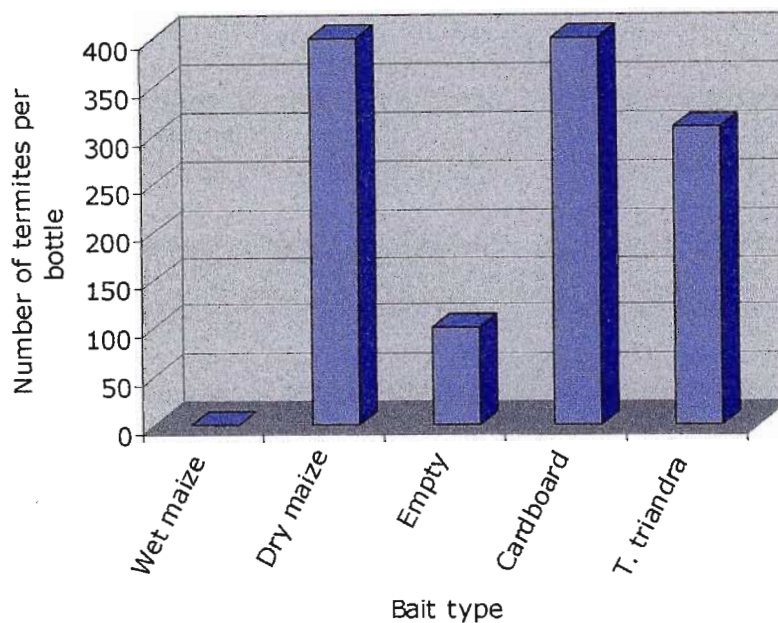
The percent (by volume) of each bait that had been consumed and replaced by SMS was estimated as in Experiment I.

As the two groups were installed on the same mound, less than 60cm from each other, they were treated as one unit statistically. A one-way ANOVA (in randomized blocks) was run on GenStat version 6.1.0.200 (2002) and all graphs were created on Microsoft Excel.

## 6.3 Results

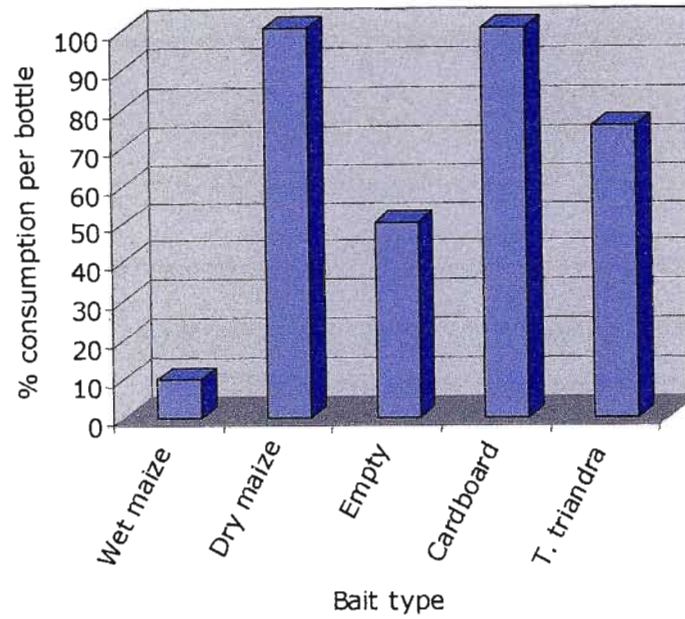
### 6.3.1 Experiment I

Dry maize and cardboard attracted the most termites (400 each), followed by *T. triandra* (308). Wet maize attracted 0 termites while the empty bottle attracted 100 (see **Figure 6.5**).



**Figure 6.5.** Experiment I: number of termites harvested per bait treatment per bottle.

The percent consumption of each bait follows the same pattern, with maize and cardboard both being about 100% consumed, followed by *T. triandra* (75%), and wet maize (10%) (see **Figure 6.6**). In the case of the empty bait treatment, on average, the empty bottles were half (50%) filled with SMS.

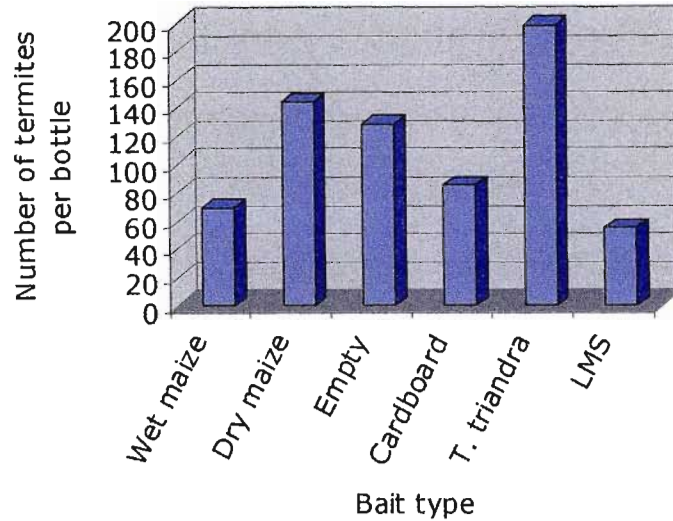


**Figure 6.6.** Experiment I: percentage of bait consumed per bottle.

### 6.3.2 Experiment II

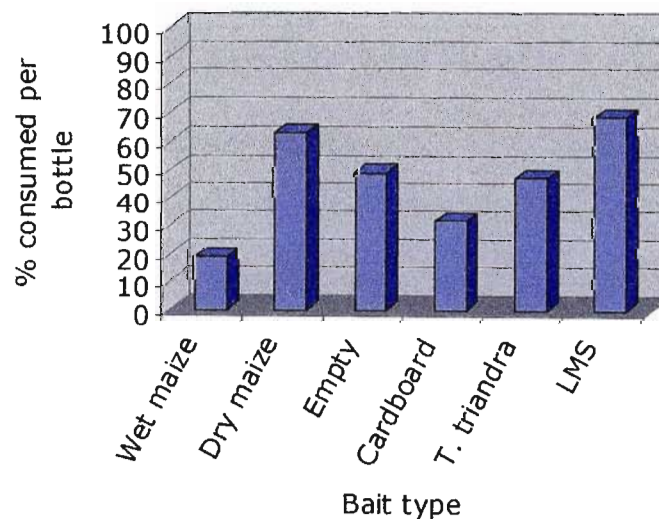
A total of 6121 termites were harvested by 54 traps in 45 days. The average number of termites harvested per treatment was 113 (including control): 105 workers, 6 soldiers, and 3 immatures. The most termites harvested by any trap was 541 by a trap baited with dry maize. Several bottles did not harvest any termites.

Of the baits, *T. triandra* had the highest mean harvest of 198 termites per bottle. The next highest mean was of dry maize (144), followed by the control treatment, the empty bottle (128), cardboard (85), wet maize (69), and LMS (55) (see **Figure 6.7**).



**Figure 6.7.** Experiment II: mean number of termites harvested per bait treatment per bottle.

An average of 46% of all the bait in each bottle was consumed. 68% of the mound soil in each bottle that was baited with LMS was replaced with SMS (see **Figure 6.8**). 63% of the dry maize was consumed. In contrast, only 19% of the wet maize in each bottle consumed.



**Figure 6.8.** Experiment II: mean percentage of bait consumed per bottle.

## 6.4 Discussion

### 6.4.1 Experiment I

While there appears to be a difference between the number of termites attracted by wet maize and all the number of termites attracted by all other treatments, the sample size ( $n=1$ ) was too small to note any significant trends. Similarly, while not statistically significant, there also appears to be a correlation between the number of termites harvested by each trap and the volume of bait consumed in each trap. The differences observed, while not statistically apparent, warranted further investigation. SMS was found regularly in the traps. In response, LMS was included as a bait during Experiment II.

### 6.4.2 Experiment II

Traps baited with *T. triandra* harvested significantly more termites than traps baited with wet maize ( $p= 0.01$ ) or cardboard ( $p= 0.05$ ). It is therefore likely that when *Trinervitermes* sp. termites are given the choice, they prefer *T. triandra* to wet maize or cardboard. As cardboard is a commonly used bait in subterranean termite trapping (Grace 1989), these results should be interesting to those researching trapping techniques and bait preference. While not significant, dry maize seemed to attract more termites than wet maize. With the exception of cardboard, wet maize was consumed and replaced with SMS least of all the bait treatments ( $p= 0.01$ , dry maize, LMS;  $p= 0.05$ , *T. triandra*). Even the empty control bottle, though it had no bait to consume proved to be a more attractive place for the termites to build SMS ( $p=0.01$ ). The low attractiveness shown by wet maize as a bait may be partially explained by the increased amount of fungi (*Penicillium* sp. and others unidentified) found in those traps that were baited with wet maize. These fungi might be toxic or threatening to *Trinervitermes* species. Further studies should investigate the role of moisture in baiting termites.

Traps baited with *T. triandra* were more effective in harvesting termites than those traps baited with LMS ( $p= 0.01$ ). On the other hand, LMS was more completely converted to SMS than *T. triandra* was ( $p= 0.05$ ). This may indicate that while LMS

was more quickly converted into SMS, *T. triandra* was more actively browsed, and therefore a more suitable bait, than LMS.

None of the treatments, with the exception of wet maize, could be differentiated from the control (empty). In both the number of termites harvested per bottle and the percentage of bait substrate converted into SMS per bottle, the control appeared to be just above the mean. While this does not negate the differences found between treatments, it does limit the power of the trapping mechanism to choice feeding trials. If one were to want to harvest termites for mass, then the empty bottle may be as effective as a baited one (excepting wet maize).

In conclusion, *T. triandra* was found to be more attractive than cardboard, an established termite bait. Moisture was determined to play a significant role in the effectiveness of the termite trap and its role should be further investigated. Overall, the novel trapping device was successfully demonstrated as a low-cost method of investigating the food preferences in *Trinervitermes* species.

The trapping method described in this study could be used as a way to identify local grasses which are natural termiticides or are less attractive than conventional forage. If the local grasses were also nutritious and palatable cattle feed, they could be intercropped with conventional forage to prevent localized termite damage.

## CHAPTER 7. COMPARED SUSTAINABILITY OF TRAPPING AND EXCAVATING *TRINERVITERMES* SP.

### 7.1 Introduction

A termite trap, used in Togo to increase protein rations for rural poultry, was described in 1991 (Farina *et al.*). In an attempt to broaden the implications and influence of the study, an adapted version of the trapping device was installed at Oribi Airport, Pietermaritzburg, South Africa (see Chapter 5). The trapping device was baited with maize (*Zea mays* L.) and harvested approximately 250 termites per trap over a period of 3-8 weeks. The traps were not monitored or re-baited during the trial. The ability of the device to sustain termite numbers over multiple baiting sessions is unknown (see Chapter 5) and is further investigated in this chapter.

Many termite-monitoring devices have struggled with maintaining constant termite numbers over an extended period (Lewis *et al.* 1998). If the device is intended to increase food security, then it is imperative to confirm its ability to harvest termites consistently over time.

Rural peoples in KwaZulu-Natal are already harvesting termites for poultry feed (Naidoo 2000). Mounds are sought out by farmers, dug up, placed in a bag, and brought home where the mixture of soil and termites is thrown to chickens (Naidoo 2000). The particulars of this practice, including its frequency, distribution, effects on poultry nutrition, and termite species used, have not been reported in the literature and should gain the attention of NGOs, the Department of Agriculture, universities, poultry farmers and anyone else interested in improving food security and agricultural development in southern Africa. The scope of the present study is limited to the comparative effects of harvesting termites (*Trinervitermes* sp.) by 'excavation' and 'trap' on the number of termites harvested per visit (over a series of two visits) and the number of ants (predators) present on the mound crust.

## 7.2 Materials and methods

### 7.2.1 Pre-installation

*Trinervitermes* sp. mounds were chosen in the western corner of Oribi airport. Twenty-two mounds were chosen as treatments and represented the total population of mounds in the selected area (~100m<sup>2</sup>).

Prior to the installation of each treatment various observations were made. The diameter and height of each mound were measured with a tape ruler. The number of ants on the external surface of each mound was estimated. The observer stood with the mound between himself and the sun so as to avoid casting a shadow on the mound that might influence ant behaviour. The observer then leaned over the mound and counted the number of ants by rotating his line of vision clockwise in three full circles around the each mound. On the first circle, the number of ants on the mound was tallied. On the subsequent two circles any ants that had not been noticed on the first circle were counted (e.g. those that had been in crevices). The entire visual search took less than 30 seconds. Often the procedure was repeated to check the method's accuracy.

### 7.2.2 Installation and baseline population survey

The treatments were installed on the 25<sup>th</sup> of September (0800-1300 hrs) at Oribi Airport (see Chapter 5 for site description). The mounds were assigned to each treatment uniformly. As the author walked through the designated plot, the treatments were alternated so that the first mound was assigned a trap-treatment, the second an excavation-treatment, the third a trap-treatment, the fourth an excavation-treatment and so on until all of the mounds had been assigned a treatment.

#### 7.2.2.1 Trap-treatment

A single two-litre bottle trap, was installed in each of 11 selected *Trinervitermes* mounds as described in Chapter 5 with one exception. The traps were baited with maize, because of its broad geographic distribution. An adjustment was made from

the results of Experiment I in Chapter 6 and dry maize (stalks and dekerneled cobs) was used as bait instead of wet maize (stalks and dekerneled cobs). The soil that was extracted from each hole during the installation of the trap-treatment was swept by hand and trowel into white plastic bags. The colour white provided a stark background to the red and cream coloured termites so that none could climb out unnoticed.

#### 7.2.2.2 Excavation-treatment

A hole of identical depth and circumference, with a volume of approximately  $1400\text{cm}^3$ , as the trap-treatment was dug in 11 additional mounds. The accuracy of each measurement was checked by the use of a tape measure and a 2 litre bottle. The soil that was extracted from each hole during the excavation was swept by hand and trowel into white plastic bags.

#### 7.2.2.3 Laboratory analysis

It was considered that in order to compare the progress of two populations as they are affected by time and harvesting treatment, a census must be conducted to determine baseline populations. The samples were brought back to the laboratory for analysis where each mound soil sample was filtered through three laboratory test sieves (Endecotts LTD., London, England) of different mesh gauge. The sieves were stacked together from largest to smallest mesh gauge ( $1680\mu\text{m}$  on top,  $1200\mu\text{m}$  in middle, and  $500\mu\text{m}$  on bottom). The content from each mound was placed on the top sieve in the stack and all three sieves were shaken vigorously from side-to-side for 25 seconds. Afterwards, the contents remaining in each sieve were examined and the termites were counted. Alates were counted separately from workers and soldiers.

Following separation the mound soil samples were air dried until the soil was loose or in easily crushed clumps (Leap 2003) and each mound soil sample was weighed (Industry analytical scale, 0.05/3100g). The bulk density of the dry mound soil was calculated by dividing the sample weight by  $1400\text{cm}^3$ , the approximate sample volume.

### **7.2.3 Five-week maintenance and data collection**

After 37 days each mound was revisited. On the trap-treatment mounds, the traps were removed and replaced with freshly baited traps of the same type. The old traps were placed in separate white plastic bags and transported back to the laboratory for separation and analysis. In the excavation-treatment mounds, a new hole (as in 7.2.2.2) was made adjacent to the previous hole. The excavated soil from each mound was placed in white plastic bags and transported back to the laboratory for analysis.

In the laboratory the traps were cut open and examined. The bait had been partially transformed into SMS and could not be passed through sieves like the excavated mound soil. Therefore the termites were separated by an adaptation of Myles' (2001) tray-in-box method (see Chapter 5). In addition to the previously described method a heat lamp was hung approximately 20cm above the debris/termite sample to expedite the exodus of termites from the debris. Following separation, the termites were counted. Alates were counted separately from workers and soldiers. The debris (comprised of either bait or SMS) was then dried and weighed as described above (see 7.2.2.3). The bulk density of the debris was calculated by dividing the sample weight by  $1400\text{cm}^3$ , the approximate sample volume.

### **7.2.4 Final, ten-week data collection**

After another 35 days, the traps were removed and brought back to the laboratory in separate white plastic bags for analysis. In the excavation-treatment mounds, a new hole (as in 7.2.2.2) was again made adjacent to the previous two holes. The excavated soil from each mound was placed in white plastic bags to be transported back to the laboratory for analysis. The mound soil and termites were processed in the same manner as after the 5-week collection.

### **7.2.5 Statistical analyses**

Students t-tests (two sample paired t-test, two sample unpaired t-test), standard deviations and summary statistics were run on GenStat version 6.1.0.200 (2002).

### 7.3 Results

The arithmetic means of all observations are provided in **Table 7.1**.

**Table 7.1.** Arithmetic means of termites harvested and ant presence over time in maize and excavation treatments.

	Maize treatment (n=11)			Excavation treatment (n=11)		
	Baseline population	5 week	10 week	Baseline population	5 week	10 week
Termites harvested (mean)	84.36	157.9	133.5	115.8	168.2	92.5
Ant presence (mean)	23.56 (n=9)	39	40.64	15.64	9.27	32.36

Baseline termite populations did not differ between mounds used in the trap-treatment and those used in the excavation-treatment. Likewise, there were no differences between treatments in the degree of baseline ant presence. Therefore, any treatment effects were not likely a result of disparate baseline populations.

### 7.4 Discussion

Neither the number of termites harvested nor the number of ants present on the mound crust was shown to differ between treatments. Time had no significant impact on the number of termites harvested by either treatment.

Alate release is dependent on seasonal or meteorological conditions. Successful alate emergence requires the cooperation of workers and soldiers, that build emergence tunnels and defend vulnerable alates. The study was installed and completed during the development and emergence of *Trinervitermes* alates in Pietermaritzburg. Eighteen alates were found in soil and maize treatment samples at

five weeks, while no alates were found initially (baseline) or at 10 weeks. Feeding habits may be affected by changing demands on the colony during the alate season.

Bulk densities were calculated for each excavation-treatment sample (weight/volume). A simple linear regression showed no correlation between bulk densities and mound populations. This was unexpected as Coaton (1951) recognized the density of the mound soil as indicator of a colony's vitality. The results may be explained by a subtle inaccuracy in the soil measuring procedure (see 7.2.2.2). It was difficult to create hole that precisely matched the prescribed depth and width and the hole should have been dug with a soil corer of appropriate depth and diameter.

In retrospect, because of the relatively low numbers of termites harvested per excavation in this study it is likely that rural poultry farmers excavate more than approximately 1400cm<sup>3</sup> (volume of soil excavated, see 7.2.2.2) per visit. Ten weeks is probably not enough time to determine which practice, excavation or trapping termites, is a more sustainable and effective means of procuring protein supplements for rural poultry. Future studies should document the practices of local farmers and their strategies employed in termite harvest. The researchers should note: the termite species currently being used for poultry feed, the frequency and degree of mound soil excavated per harvest, the geographical range of the practice, and its long-term effects on termite populations and effects on poultry nutrition.

## CHAPTER 8. NUTRITIONAL COMPOSITION OF *MACROTERMES NATALENSIS* AND *ODONTOTERMES* SP.

### 8.1 Introduction

Food insecurity threatens rural livelihoods in most African nations. Malnutrition, a symptom of food insecurity, can catalyse the advancement of health maladies such as growth stunting and HIV/AIDS. In order to address food insecurity, local resources must first be investigated; including indigenous food stuffs.

The practices related to entomophagy (insect eating) have been thoroughly described in many indigenous cultures of sub-Saharan Africa, including the Pedi people of northern South Africa (Quin 1959) (see Chapter 2). However, there remains a paucity of literature addressing the chemical composition of insects. This information is invaluable in assessing food resources at local and ecological levels.



**Figure 8.1.** *Macrotermes* alates are attracted to light.

Termites (Isoptera) are among those insects most widely consumed by humans (DeFoliart 1989). Alates, soldiers and even queens are eaten (Bodenheimer 1951, DeFoliart 2003, Gardiner & Gardiner 2003). For example, while the Makiritare Indians of Venezuela eat the heads of soldier termites (*Syntermes* sp.) (Marconi *et al.* 2002, Paoletti *et al.* 2003), rural peoples of Zimbabwe eat both soldiers and alates (*Hodotermes mossambicus* (Hagen) and *Macrotermes falciger* (Gerstäcker) Gomez 1988, Gardiner & Gardiner 2003). Although *Macrotermes* is the most commonly eaten termite genus in sub-Saharan Africa; only

three of six species (*M. bellicosus* (Smeathman), *M. falciger* and *M. subhyalinus* (Rambur)) that are endemic to southern Africa have been analysed nutritionally (Phelps *et al.* 1975, Santos Oliveira *et al.* 1976., Uys 2002, Finke 2004). Currently, in rural KwaZulu-Natal, alates of *Macrotermes natalensis* (Haviland), and some

other species to a lesser degree, are eaten by children, while the soldiers/workers are fed to local poultry (local knowledge).

Chickens are heavily relied on sources of nutrition in rural Africa (Kitalyi 1998). However, they are relatively unproductive (Huchzermeyer 1973, Guèye 1998, Kitalyi 1998, Ahlers 2000) due in part to poor nutrition. When scavenging, the chicken often consumes earthworms and insects (Guèye 1998). Accordingly, some researchers have explored invertebrates as a source of protein for chickens with great success (Reddy & Qudratullah 1996). In a feed substitution trial, DeFoliart *et al.* (1982) found that maize/soybean-fed broiler chicks grew more slowly than maize/cricket-fed broilers. This indicated that crickets can, with no negative effect, replace soybeans in the diet of broiler chicks. In areas where entomophagy is not accepted culturally, termite alates may serve as a seasonal protein supplement for scavenging chicken.



**Figure 8.2.** After being caught, *Macrotermes natalensis* alates were placed in plastic dishes where they dropped their wings.

In an attempt to provide a fuller understanding of the potential of termites as vehicles for human and poultry nutrition in KwaZulu-Natal, the compositions of *M. natalensis* and *Odontotermes* sp. alates and *M. natalensis* soldiers were determined.

## 8.2 Materials and Methods

Samples were collected at the University of Natal, Pietermaritzburg, South Africa, during November 2003. *Odontotermes* sp. alates emerged during morning hours (0700-1000 hrs) following evening precipitation. *Odontotermes* sp. alates (n=1489) were collected at emergence holes with a sweep net. The wings of the alates were removed with forceps prior to chemical analysis.



**Figure 8.3.** Alates being fried.

*Macrotermes* sp. alates emerged during warm evenings (0600-1000) following precipitation and shed their wings soon after landing. Great masses of alates were found near lights (see **Figure 8.1**) and 2026 alates were gathered manually from the ground and building walls and frozen within 2 hours of capture to await analysis (see **Figure 8.2**). 909 fully

winged alates were collected from damp pavement and fresh puddles the morning following the emergence where they had become stuck before dropping their wings. The specimens were frozen within 2 hours of collection to await analysis. Another group of *Macrotermes* sp. alates (250.05g wet wt) were rinsed in tap water and fried live in sunflower oil (9.45g, Sunflower Brand, Pietermaritzburg) for 5 minutes (see **Figure 8.3**). Afterwards they were frozen for subsequent analysis.

In both genera, alates were observed in or around mounds where soldiers could be gathered for identification by dichotomous key (Uys 2002). These specimens have been sent to Vivienne Uys (Plant Protection Research Institute, Pretoria) for species identification. As available distribution maps exclude all *Macrotermes* species except *M. natalensis* from Pietermaritzburg, the study was carried out under the assumption that the species is *M. natalensis* (Ruelle 1970, Coaton and Sheasby 1972, Kitto 1997).

One *M. natalensis* mound at Epworth High School (29° 25' S; 30° 24' E), Pietermaritzburg, was excavated during November, 2003. The mound soil was placed in white plastic bags and brought back to the laboratory where the soldier caste was separated using forceps. *M. natalensis* soldiers (n=1099) were fasted for 24 hours, before being frozen to await analysis.

All analyses were provided by the Discipline of Animal Science and Poultry Science, University of Natal, Pietermaritzburg. All samples were dried prior to analysis according to the procedure recommended by the AOAC (2002). Ash, crude protein, crude fat, crude fibre, acid detergent fibre (ADF) and phosphorus were determined

by AOAC (2002) procedures. Calcium was determined with a Varian Spectra AA-200 Atomic Absorption Spectrophotometer.

Energy (calorific value) for wingless *M. natalensis* was determined with a DDS isothermal CP500 bomb calorimeter (Digital Data Systems (Pty.) Ltd., 199 Arbeid Ave., Strijdom Park, Randburg, Johannesburg, RSA). The metabolizable energy for wingless *M. natalensis* was determined for chickens by the methods of McNab & Fisher (1984). Total amino acids (*M. natalensis* and *Odontotermes* sp.) and available amino acids (*M. natalensis*) were determined for wingless alates by the method described by Moore & Stein (1948) using a Beckman Amino Acid Analyzer System 6300 (Applications Data A6300-An-002. Beckman Instruments, Inc., Spinco Division, Palo Alto, California).

### 8.3 Results

**Table 8.1** Chemical composition of certain termites (dry matter basis).

	<i>M.</i> <i>natalensis</i> (soldiers)	<i>M.</i> <i>natalensis</i> (winged alate)	<i>M.</i> <i>natalensis</i> (fried alates)	<i>M.</i> <i>natalensis</i> (wingless alates)	<i>Odontotermes</i> sp. (wingless alates)
Number	1099	909	*	2026	1489
Wet Weight (mg/insect)	14.0	116.2	*	309.9	103.3
Moisture (%)	67.0	11.4	38.1	45.5	44.5
Crude Protein <sup>1</sup> (%)	72.8	34.9	32.7	36.9	47.1
Fat (%)	1.7	55.3	60.6	56.4	49.2
Crude Fibre (%)	20.8	5.5	3.4	3.7	2.7
Calcium	*	0.1	0.1	0.1	0.1
Phosphorus	*	0.6	0.4	0.6	0.5
ADF (%)	*	8.5	5.0	8.2	9.9
Ash (%)	*	3.4	2.3	3.2	2.9

<sup>1</sup>Calculated as total nitrogen x 6.25.

\*Not determined.

Number of termites per sample, mean wet weight per termite, moisture, protein, fat, crude fibre, acid detergent fibre (ADF) and ash are displayed in **Table 8.1**. All data, unless otherwise noted, are on a dry matter basis. Total calorific energy for *M. natalensis* alates (wingless) was 27 MJ/kg, 26.6 MJ/kg of which was available for digestion by broiler chickens. Calcium values (0.1%) for *M. natalensis* and *Odontotermes* sp. alates were more than twice as high as those values reported for *M.*

*subhyalinus* and *M. bellicosus* (0.4%) (Finke 2004). Phosphorus values (0.4-0.6%) were similar to values reported for *M. subhyalinus* (0.4%) (Finke 2004). Ash values were low (2.3-3.4%) reflecting the absence of calcified skeletons that are commonly present in vertebrates (Finke 2004).

**Table 8.2.** Amino acid composition of termites and amino acid requirements for laying hens (% of crude protein).

	<i>Odontotermes</i> sp.	<i>Macrotermes</i> <i>natalensis</i>	<i>Macrotermes</i> <i>bellicosus</i> <sup>1</sup>	Laying Hens <sup>2</sup>
Aspartine	6.8	7.9	10.5	5.0
Threonine	2.6	3.2	2.8	3.2
Serine	2.0	2.9	1.2	*
Glutamine	8.1	10.0	8.9	*
Proline	3.5	4.2	*	*
Glycine	7.5	5.5	3.9	*
Alanine	4.1	5.2	9.0	*
Valine	4.4	5.1	7.3	4.0
Methionine <sup>3</sup>	1.4	1.4	0.7	2.0
Isoleucine	3.5	3.8	5.1	4.0
Leucine	5.6	6.5	7.8	7.8
Tyrosine	4.2	5.1	3.0	*
Phenylalanine	3.8	3.8	4.4	4.6
Histidine	2.6	2.9	5.1	2.0
Lysine	4.0	4.8	5.4	4.3
Arginine	3.5	4.1	7.0	5.0
Ammonia	16.3	11.1	*	*

<sup>1</sup>Values reported by Finke (2004).

<sup>2</sup>Values reported by Austic & Nesheim (1990).

<sup>3</sup>Hydrolysed with rest of amino acids.

\*N/A

The results for the amino acid analyses are reported in **Table 8.2** as percent of crude protein (Total nitrogen x 6.25). The recovery rates were relatively low at 31.5% for *M. natalensis* and 38.9% for *Odontotermes* sp. Digestibility of amino acids by broiler chickens was high, ranging from 87.6-96.1% (see **Table 8.3**).

## 8.4 Discussion

*M. natalensis* soldiers had the highest moisture content at 67%. There was a large difference in moisture content between winged and wingless *M. natalensis* alates. Winged *M. natalensis* alates were collected the morning after emergence (12-14 hrs), and were probably desiccated during such time resulting in relatively low moisture

levels. Another possibility is that the winged alates used more moisture and energy than the wingless alates in their prolonged nuptial flight. Furthermore, the winged alates contained approximately 33% more crude fibre (DM basis) than wingless alates suggesting that the wings are mostly fibre and may be low in moisture. This is an important finding to those zoologists interested in estimating the contribution of wings to insectivore diets which rely heavily on termite alates.

Crude fibre and ADF are two means of estimating chitin values in insects. Chitin is a complex carbohydrate that is the major

constituent of the arthropod's rough exoskeleton. Usually, chitin-bound nitrogen cannot be hydrolyzed by mammals or chickens (Dreyer & Wehmeyer 1982, Gallaher *et al.* 2000), as most do not possess the appropriate digestive enzyme, chitinase (Dreyer & Wehmeyer 1982). Though indigestible to most and therefore seemingly of no nutritional value, chitosan (a derivative of chitin) is a hypocholesterolemic, effectively reducing levels of cholesterol in animals (Cheung 1998, Gallaher *et al.* 2000).

As the dietary effects of chitin have become known in recent years, ADF measurements have been included more frequently in nutritional analyses. Barker *et al.* (1998) attributed ADF nitrogen to chitin, and neutral detergent fibre (NDF) nitrogen to both an insect's chitin and cellulose-based matter left in its gut. Gut content can significantly affect the nutritional value of insects (Finke 2003). Finke (2004) recently stated that fibre (both ADF and crude fibre) in fasted insects probably "represents both chitin and sclerotized protein."

*M. natalensis* soldiers were fasted for 24 hrs prior to analysis and fibre values should not reflect residue cellulose in the digestive tract. All alate samples were not fasted and accordingly gut content is included in fibre values. The crude fibre and ADF values reported in **Table 8.1** are the first values for termite alates reported in the

**Table 8.3.** Digestibility of amino acids in *M. natalensis* (wingless) for broiler chickens.

	% digestible
Aspartine	95.0
Threonine	94.4
Serine	93.1
Glutamine	94.2
Proline	87.6
Alanine	87.8
Valine	90.7
Methionine	96.1
Isoleucine	94.1
Leucine	94.5
Tyrosine	93.6
Phenylalanine	94.3
Histidine	90.2
Lysine	91.3
Arginine	95.4

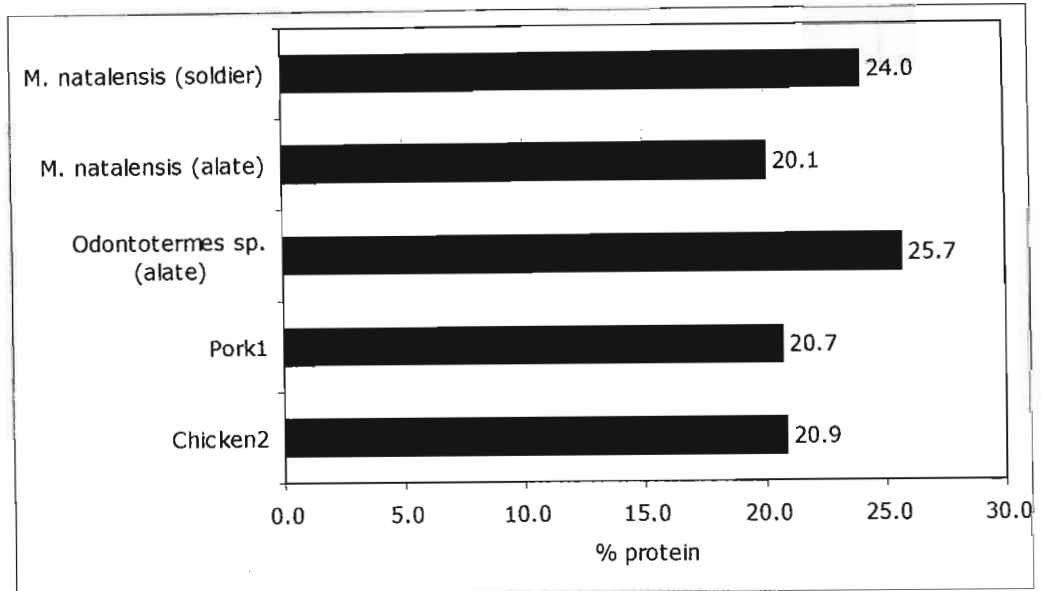
available literature. ADF values ranged between (5.0-9.9%) and appear to be high when compared to values reported for silkworms (*Bombyx mori* L.) (1.1%) or adult crickets (*Acheta domesticus* L.) (3.2%) (Finke 2002). *M. natalensis* soldiers comprised over 20% crude fibre, reflecting high levels of chitin levels and other undigestible fibre. Alates, which are soft-bodied, contained less crude fibre. Frying *M. natalensis* alates decreased their crude fibre content. Legs and other appendages may have been lost while they were being rinsed, or cooking heat may break down the chemical composition of fibre.

Termite soldiers are not high in fat calories and *M. natalensis* soldiers compare well to values available in the literature (Paoletti *et al.* 2003, Finke 2004). *M. natalensis* and *Odontotermes* alates contain proportionally more fat (49.2-60.6%) than *M. subhyalinus* (46.1%) and *M. falciger* (44.3%) (Phelps *et al.* 1975, Santos Oliveira *et al.* 1976). As expected from the literature (Finke 2004), the fat content of *M. natalensis* increased after being fried in oil. Whereas fat is avoided in many industrialized societies, in the context of malnutrition, fat is a rich source of energy; containing more than twice as many calories per gram as carbohydrates or protein (Barker *et al.* 1998).

*Odontotermes* sp. alates contain proportionally more protein than *M. natalensis* alates and may therefore be a better choice for human protein nutrition. In contrast, 'red' alates (likely *Macrotermes* sp.) are preferred to 'black' alates (likely *Odontotermes* sp.) (personal communication with local Zulu man). This may be a result of a difference in taste quality or ease of capture; *M. natalensis* alates are three times the mass of *Odontotermes* sp. are therefore much easier to catch in large quantities (see **Table 8.1**). When compared to protein values for chicken, both alates, *M. natalensis* and *Odontotermes* sp., contain protein levels that are comparable to pork and chicken. (see **Figure 8.4**, Posati 1979, Lawrie 1981, as cited by Bender 1992).

The amino acid compositions of *M. natalensis* and *Odontotermes* sp. alates were comparable to values reported for *M. bellicosus*. In general, alates seem to be high in glutamine, aspartine and alanine and low in methionine, serine and threonine. When

compared to dietary requirements of the laying hen, *M. natalensis* and *Odontotermes* sp. were both deficient, to some degree, in 5 of 10 essential amino acids for laying hens (see **Table 8.2**). *Odontotermes* sp. was deficient in lysine and threonine as well. However, deficiencies in most amino acids were small and overall the amino acid composition of the studied invertebrates matched laying hen requirements quite closely. Amino acid digestion by chickens was high, ranging from 87.6-96.1%.



**Figure 8.4.** Percent protein (WM basis) for termites, pork, and chicken.

<sup>1</sup>Lawrie, 1981, as cited by Bender 1992, (lean).

<sup>2</sup>Posati 1979, breast meat, with skin, (raw).

The nutritional values of *M. natalensis* and *Odontotermes* sp. demand the attention of extension workers, farmers and all others who are concerned with rural agriculture and development. In particular, the studied alates are rich in protein (comparing favourably to chicken and pork) and fat. While *M. natalensis* alates are slightly deficient in 5 of 10 essential amino acids for broiler chickens, the amino acids present are highly digestible. Future research should concentrate on developing more efficient harvesting methods for alates and soldiers. Current practices, including frequency and weight of harvested insects should be documented.

In what ways may termite protein be further used aid of fungi, enzymes or symbiotic flagellates, termites can convert cellulosic waste into highly nutritious insect body. Several other organisms have been demonstrated as waste converters. The most thoroughly researched is the housefly (*Musca domestica* L.) which can effectively replace soybean meal in chick diets (Calvert *et al.* 1969, Teotia & Miller 1973,

Teotia & Miller 1974, Papp 1975, Ocio & Vinaras 1979, Onifade *et al.* 2001, El Boushy 1991, Ravindran & Blair 1993).

Can termite farms be built on non-arable land where copulariums are intentionally planted? These colonies could be fed organic wastes such as yard refuse or used paper. Delectable mushrooms (*Termitomyces* spp.) could be harvested and marketed in addition to insect bodies. Insect bodies could be processed, preserved and sold as a human food or protein supplement for poultry. It is not the increased palatability, energy efficiency or environmental consciousness which places the chicken or cow above the insect in the human food chain, but instead cultural stigma. Before policy makers look abroad for food relief, let them assess the nutritional resources of South Africa.

In an era where rural and urban cultures are rapidly merging, entomophagy may be discarded as an embarrassment or nonsensical action. The high nutritional value of *Macrotermes natalensis* and *Odontotermes* sp. should be publicised.

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