DISCUSSION

A. NUTRIENT CONTRIBUTION OF INSECTS

Data on the nutrition information of insects are important; it informs consumers about the quality and quantity of their intake. For international comparison, a common yardstick to assess the nutritional value of food is the weight of food, along with its nutrient content (Grigg, 1995). Insects are an integral part of culture and tradition for the tribes of Arunachal Pradesh, therefore, to understand the nutritional potential of the edible insects, eight edible insects such as *Chondacris rosea*, *Brachytrupes orientalis*, *Schistocerca* sp., *Aspongopus nepalensis*, *Oecophylla smaragdina*, *Odontotermes* sp., *Xylotrupes gideon*, *Anomala* sp. were considered to evaluate nutritional and antinutritional composition. Further, five insects *C. rosea*, *B. orientalis*, *A. nepalensis*, *O. smaragdina* and *Odontotermes* sp. were chosen to assess nutritional and nutraceutical potential.

*C. rosea* (Orthoptera: Acrididae) is commonly known as ‘mirbo’ or ‘takam kamrak’. The adult stage is consumed boiled, fried, smoked or as paste (chutney) after discarding wings and appendages. *Schistocerca* sp. (Orthoptera: Acrididae), commonly known as ‘komak joba’ or ‘takam soik’, is consumed fried and boiled with leafy vegetables after discarding wings, appendages. *B. orientalis* (Orthoptera: Gryllidae) is commonly known as ‘takam hilak’ or ‘takam pario tokcho’ and the adult stage is consumed as fried or mixed with boiled vegetables or as paste (chutney) after discarding antennae and limb appendages. These orthopteran species are collected from September to November or sometimes upto December when the species are abundant in agricultural fields. Local tribal people prefer to consume the insects with local alcohol (Aaron). Orthopteran species usually collected by ethnic people...
especially by women, children and often by men from surrounding bushes of agriculture land of villages and towns. However, in urban areas crickets (*B. orientalis*) are collected by light trap. In rural areas they are collected from their burrows. The ethnic people have the knowledge to identify the burrows/holes of cricket and pour water in the burrows until crickets come out and they pick them by hand and gather. *O. smaragdina* (Hymenoptera: Formicidae), the weaver ant, commonly known as ‘tonge’ or ‘babuk’ is available throughout the year. Both larval and adult stages are preferred but for the present study only the adult stages had been considered. Mostly it is consumed as raw by making ‘Chutney’ (mixing with other spicy ingredients). *A. nepalensis* (Hemiptera: Pentatomidae) is locally known as tari or gondhipuk and its adult stage is consumed and available from November to February. Stink bug is appreciated solely for its taste and has been regarded as a delicacy by ethnic people. Though ethnic people collect this insect mostly for their personal consumption, sometimes they also sell or trade it for profit. *Odontotermes* sp. (Isoptera: Odontotermitidae), the termite, commonly known as ‘takmin’ is available during May to June. In time of swarming local people collect them by hand picking. Adult stage is consumed either roasted or dry fried after discarding wings. *X. gideon* (Coleoptera: Scarabaeidae) and *Anomala* sp. (Coleoptera: Scarabaeidae), commonly known as ‘tapu yagay nym’ or ‘apu nine’, adult stages are preferred as roasted or boiled. Among all these species of insects only *A. nepalensis* is available some times in the local market at a price of Rs. 10/- per 5 g. Market sellers are mostly women and it is noted that dealing with insects is not their main activity, but supplements their sales of other foodstuffs like dried and smoked fish, local vegetables and fruits etc. All of these insects are highly appreciated as food among ethnic people of Arunachal Pradesh.
Moisture Content:

The moisture content of the entire insects under study was generally high but observed to agree with the published data for various insects species. At 42% to 48% moisture content in stink bug (*A. nepalensis*), short horned grasshopper (*C. rosea*), termite (*Odontotermes* sp.), locust (*Schistocerca* sp.), rhinoceros beetle (*X. gideon*) and and 69% to 72% in bush cricket (*B. orientalis*), weaver ant (*O. smaragdina*) and scarab beetle (*Anomala* sp.) was higher than the reported values: 0.96% to 1.13% for crickets, yam beetles, palm weevil, grasshopper (*Ekop et al., 2010*), 22.19% for army worms (*Abulude et al., 2008*), 10.85% for *Cirina forcata* (Lepidoptera) (*Omotoso, 2006*). 16.73% for *Oryctes rhinoceros* larvae (*Okaraonye and Ikewuchi, 2009*), 8.3% for pentatomid bugs (*Mariod et al., 2011*), 1.91% to 4.4% for various species of termite, grasshopper, beetles, honey bees and caterpillars (*Banjo et al., 2006*), 7.9% for larva of soldier fly *Hermetia illuceus* (*Newton et al., 1977*), 5.2% for house cricket *Acheta domesticus* (*Nakagaki et al., 1987*), 6.61% for *Anaphe venata* (*Ashiru, 1988*), 12.6% for *Macrotermes bellicosus*, 34.36% for *Imbrasia belina* larva (*Ekpo et al., 2009*). However, moisture values higher than these values had also been reported. Davis (1918) had earlier reported a moisture value (%) of 70.0 and 60.4 respectively for the larva and adult beetle of *Lachnosterna* species. Bodine (1923) reported a moisture value of 79% for the larva of *Chortophaga viridifasciata*, while studies by Ludwig and Landsman (1937) gave the moisture content for the larva of *Popillia japonica* in the range 78-81%. Moisture values for some other insects include: 67.4% for the adult beetle of *Popillia japonica* (*Fleming, 1968*), 69% for newly emerged housefly (*Musca domestica*) (*Teotia and Miller, 1974*), 60.7% for *Bombyx mori* (1972), 61.8% for *Rhynchophorus phoenicis* larva (*Ekpo and Onigbinde, 2005*), 62% for *Oryctes rhinoceros* larvae (*Ekpo et al., 2009*). Finke (2004) also reported
71.7% for *Rhynchophorus palmarum* larvae, 63.7 and 61.9% for *Tenebrio molitor* adult and larvae respectively. 77.1% for *Acheta domesticus* nymph, 76.7% for *Cytantheris tatarica*, 77.8% for *Cortaritermes silvestri*, 75.3% for *Nausitermes corniger*, 78.3% for *Oecophylla virescens*, 64% for *Pachili gigas*. While compared to the conventional food sources of animal origin i.e. pork, chicken, beef, egg and veal it has been found that the moisture content of the studied insects are comparable to them; however, much lower than that of vegetables like cabbage, cauliflower, mung beans, bamboo shoot (cf. Fig. 2a).

Moisture content of food is generally used as a measure of the stability and susceptibility to microbial contamination (Scott, 1980). The lower moisture content in food is known to improve the shelf life of food. Therefore, relatively high moisture value in the insects under study will not assist in keeping quality since they may prone to spoilage on careless keeping. Yet, high moisture content in the studied insects implies that the most of the essential nutrients in them will be in forms that will be easily available to the body after their consumption. Habitually, the ethnic tribes of Arunachal Pradesh consume these insects in fresh form, either as snacks after frying or as part of the meal in the form of “chutney” (grinding the fresh insects along with spicy ingredients) so that total moisture in the insects are ingested as such. However, when they catch the insects in large quantity they preserve them for future use as sun dried or smoke dried.

**Edible insects as source of Energy (Calorific value):**

Energy is required to maintain basal metabolism, to power physical activity (muscle movement) and to provide the thermic effect of food. The mean energy values (kcal/100g) of the studied insects i.e. in *Odontotermes* sp. (617.41 kcal), *A. nepalensis* (448.89 kcal), *X. gideon* (437.18 kcal), *Anomala* sp. (387.23 kcal), *O.
Smaragdina (385.26 kcal), B. orientalis (380.65 kcal), Schistocerca sp. (377.10 kcal), C. rosea (373.24 kcal) were within the range (293 to 762 kcal/100g) reported by Ramos-Elorduy et al. (1997) for seventy eight species of edible insects. The winged sexual forms of the African termite, Macrotermes falciger (Gerstacker), have been estimated to have a calorific value of 761 kcal (~3196 kJ/100g) (dry, ash-free, weight basis) while the winged forms of another African species, Macrotermes subhyalinus (Rambur), were 613 kcal (~2575 kJ)/100g (dry weight) (Oliveira et al., 1976). Ashiru (1988) reported a calorific value of 611 kcal (~2566 kJ)/100g for the caterpillar Anaphe venata (Butler) (Notodontidae) in Nigeria. It was further revealed that twenty-three species of caterpillars in Zaire, (mostly Saturniidae), were found to average 457 kcal (~1919 kJ)/100g dry weight, ranging from 397 to 543 kcal (1667 to 2281 kJ) (Malaisse and Parent, 1980). High caloric values can be hypothesized as the fat content in the respective species of insects as it was observed in Odontotermes sp. and A. nepalensis in which considerable amount of fat was detected compared to other insects in the present study. Additionally, the calorific value of the tested insects was higher than that reported calorific values for rice (345 kcal), wheat (345 kcal), whole grams (335 kcal), and egg (173 kcal) (cf. Srilakshmi, 2012). The recommended dietary allowances (RDA) of energy i.e. the average daily requirements corresponding to daily average energy expenditure for Indian man and woman doing heavy work are 3490 kcal and 2850 kcal per day, whereas, the requirement increases for pregnant and lactating woman by 350 and 600 kcal more per day respectively (ICMR, 2009). Therefore, consumption of 100g tested insect species can meet up the RDA to 17.69% in case of Odontotermes sp., in which the calorific content was found be highest and 10.70% in case of C. rosea where the calorific content was the lowest. However, the calorific values for most of these insects seem to be considerable since these insects
are mostly taken as a side dish and not as their staple food. So at least the termite
(Odontotermes sp.) the stink bug (A. nepalensis) and rhinoceros beetle (X. gideon) are
better source of energy compared to other insects species in this study.

Edible insects as source of fiber:

Fibers affect lipid absorption by adsorbing fatty acids, cholesterol and/or bile
acids within the digestive tract. Fatty acid and cholesterol that are bound to fiber
cannot form micelles, thus not absorbed in the small intestine and pass into the large
intestine where they are to be excreted or degraded by intestinal bacteria. Thus, high
fiber in the diet reduces cholesterol, and prevents coronary heart disease. Fiber is also
important as it prevent constipation and has protective role against colon cancer
(Srilakshmi, 2012).

The indigestible part of the insect or the non structural carbohydrates,
expressed as crude fiber and it differed from each other accounting for about 1.27% to
33.47%. Crude fiber content in the edible insects under study was 33.47% for bug (A.
nepalensis), 19.84% for ant (O. smaragdina), 12.38% for short horned grasshopper
(C. rosea), 10.92% for locust (Schistocerca sp.), 8.75% for bush cricket (B.
orientalis), 7.73% for scarab beetle (Anomala sp.), 6.30% for termite (Odontotermes
sp.) and comparatively very low 1.27% in rhinoceros beetle (X. gideon). These values
are appreciably high and could be attributed to amount of chitin found normally in
insects. Chen and Feng (1999) and He et al. (1999) reported that the body and skin of
edible insects are rich in chitin; different insects have different chitin content 5-15%.
Oduor et al. (2008) have reported that chitin and chitosan yield differ with species.
Bhaulaidok et al. (2010) reported the fiber content of 25.4% and 26.4% for
Polyrhachis vicina (hymenoptera) from two different geographical region of China.
Ramos-Elorduy et al. (1997) has reported the lowest value of fiber in the social
insects from 1 to 6%, in bee and stingless bee *M. beeckei* and the highest values in adult beetle *Callipogon barbatus* (22.7%), the avocado tree hopper, *Holophorion monogramma* (19.4%) the bugs *Euschistus eglestoni* (13.5%) *Acanthocephala decilvis* (18.4%) and *Edessa petersii* (18.0%) the beetle larvae of *Aplagiognathus spinosus* (15.0%) and the tree hopper *Umbonia reclinata* (13.3%). Blasquez et al. (2012) reported 10 to 12% in some orthopteran species while Ekop et al. (2010) reported 3.30 for cricket, 3.0, 2.20 and 2.5 for yam beetle, palm weevil, and grasshopper respectively. Banjo et al., (2006) and Igwe et al. (2011) reported 2.70% for *Macrotermes bellicosus*, 2.20% for *M. notalensis* and 5.71% for *M. nigeriensis*. It was noted that the fiber contents of the insects in the present study except *A. nepalensis* fall in the range reported for fiber values within and between insect taxa (cf. Fig. 2f). Crude fiber content of the insects in the present study was comparable to the dietary fiber content (g/100g) of rice (4.1), wheat (12.5), whole Bengal gram (28.3), lentil (15.8), cabbage (2.8), green colacasia (6.6), yam (4.2) (Gopalan et al., 2004).

RDA for dietary fiber has not been prescribed so far for most of the countries including India. However, Current recommendation for dietary fiber intake are related to age, gender and energy intake, the general recommendation for adequate intake is 14g/1000 kcal (IOM, 2005). The physiological role of crude fiber in the body is to maintain an internal distention for proper peristaltic movement of the intestinal tract (Oduor et al., 2008). Food having high fiber content has nutritional advantage as it assists in reducing constipation and other attendant problems. Moreover, diet with high fiber content have been used for weight control and fat reduction as they give a sense of satiety even when small quantity of food is eaten. High fiber content in the studied insects may contribute all these physiological advantage when they are being consumed.
Edible insects as source of NFE as Carbohydrate:

Carbohydrates are important nutritive component in the human body. Besides providing C, H and O, carbohydrates are the main heat source, can combine with protein and fat and in turn their compounds have important physiological functions (Jin, 1987). Recent research has revealed that insects have considerable amount of polysaccharide that can enhance the immunity function of the human body (Sun et al., 2007).

Five insects in the present study contained 12 to 20% crude carbohydrate as Nitrogen free extract (NFE) others contained lesser amount of carbohydrate but still it was about 6 to 7%. NFE content (%) of orthopteran species like grasshoppers and cricket, C. rosea (6.69%), B. orientalis (15.19%) and Schistocerca sp. (20.63%) can be compared favourably with range 0.19 to 22.64 given for some orthopterans by Blasquez et al. (2012). Ekop et al. (2010) reported NFE content in other orthopteran species: 13.08% for Gymnogryllus lucens, 24.94% for Zonoceros variegates. While NFE content of bug, A. nepalensis (15.3%) was much higher than Aspogobus viduatus (7%) and Agonoscelis pubescens (4.4%) reported by (Mariod et al., 2011). In the termite, Odonototermes sp. NFE content (6.09%) was lower than other reported termite species. Macrotermes nigeriensis (20.74%) (Igwe et al., 2011). NFE content of coleopteran species, X. gideon and Anomala sp. 12.78% and 19.60% respectively which was comparable to coleopteran species e.g. Oryctes monoceros larvae (15.05), Heteroligus meles larvae (21.707%), Rhynchophorus phoenicis larva (22.759%) (Idolo and Henry, 2011; Ekop et al., 2010). Carbohydrate content of a novel food, under most often received very little attention than protein or fat received. Though, under most circumstances there is no absolute need for carbohydrate as amino acids, glycerol component of fat, and some organic acids can be converted to carbohydrate.
However, in the absence of dietary carbohydrates lipolysis of stored triglycerides and the oxidation of fatty acids increases and ketone bodies accumulate (Manninen, 2004; Recommended Dietary Allowances, 1989). A carbohydrate free diet is also generally associated with an accelerated breakdown of dietary and tissue protein, loss of cations especially sodium and results in dehydration. Calloway (1971) suggested that the effects produced by low carbohydrate diets can be prevented by daily ingestion of 50 to 100g of carbohydrates. In general, the insects in the present study contained significant amount of NFE, especially *B. orientalis*, *Schistocerca* sp., *X. gideon*, *Anomala* sp. and *A. nepalensis* which indicate that these insects have the potential to complement diet and assists in complete utilization of protein, thereby enhancing nutritional value of insects as food. Among the eight studied insects, the ratio of crude fiber to carbohydrate (2:1) for *A. nepalensis*, *C. rosea*, and *O. smaragdina* whereas, reverse is true for *B. orientalis*, *Schistocerca* sp., and *Anomala* sp. i.e. the ratio of crude fiber to carbohydrate is 1:2. Srilakshmi (2012) proposed that, the proportion of soluble to insoluble fiber should be 1:2 and the intake is preferred through diet made up of various sources of conventional food. However, for such type of non-conventional food like insects this ratio is yet to be worked out. Nonetheless, high carbohydrate content of these insect makes it a good quality food.

**Edible insects as source of protein and amino acids:**

**Protein:** Protein is the basis of many important components such as enzymes, hormones and haemoglobin. It is an important component of antibodies as it bolsters the immunity function of the body. It is the only material to produce nitrogen for maintaining acid and alkali balance, transforming genetic information and transporting important materials in the human body. As a nutritive element that produces heat, protein can supply energy. According to reports and analysis (Ramos-
Elorduy and Pino, 1989; Mitsuhashi, 1992; DeFoliart, 1992; Yang, 1998; Banjo et al., 2006) many edible insects are rich in protein ranging from 20 to 70%.

This study revealed that, all the edible insects, in general, are rich in protein, though these values vary among them. It was noted that the protein contents of the insects in the present study except A. nepalensis fall in the range reported for protein values within and between insect taxa (cf. Fig. 2b). It is worth mentioning that protein values varied from a low of about 6.25% to 27% to a high of about 65.62% to 81.69% for already reported insects species from hemiptera, orthoptera, hymenoptera, isopteran and coleoptera respectively reported from different parts of the world (de Conconi et al., 1984; Banjo et al., 2006; Bhuaidok et al., 2010; Blasquez et al., 2012). These variations may partly be due to differences in feed, seasons, insect stages and their geographical location. Bhuaidok et al. (2010) reported a significant difference in protein content of same species of black ant from two different localities. Protein content of Zonoceros variegates adult was reported 26.8% (Banjo et al., 2006) whereas Adedire and Aiyebami (1999) reported the value 50.39% for larvae and 53.1% for adult.

The protein content, with the values 65 to 73.9 % in, Anomala sp.; B. orientalis, C. rosea, X. gideon were higher than the amount reported for grasshopper, termites, bugs and ants (de Conconi et al., 1984; Banjo et al., 2006) and comparable to many grasshopper and cricket species (Blasquez et al., 2012). Similarly respective values 55.27% and 53.07% in O. smaragdina and Schistocerca sp. were higher than that reported for other ant species like Atta sexdens, A. cephalotes, Liometopum apiculatum, adult and reproductive forms of L. lucensim (Dufour, 1987; de Conconi et al., 1984; cf. Rastogi, 2011) and some coleopteran species like Rhynchophorus phoenicis larvae, Oryctes rhinoceros, june beetle (Ekpo et al., 2009; Ramos-Elorduy, 85
The crude protein content of *A. nepalensis* and *Odontotermes* sp. were 10.62 and 33.67% respectively, were less than the amount reported for witiuti grub (Meyer-Rochow, 1976) or most species mentioned in Bukkens (2005) and thirteen species tested by Banjo et al. (2006), but in these two species protein content was still higher than that of the protein content in cow's milk (whole 3.22g/100g) or soy milk (3.27g/100g) (USDA).

Based on dry weight, protein values, 75.3%, 75.3%, 77.13%, 77.13% and 77.13%, respectively, were reported for orthopteran species *Melanoplus femurrubrum*. Red legged locusts. *Melanoplus mexicanus*, *Boopedon flaviventris* and *Sphenarium* sp. (de Conconi et al., 1984; Ramos-Elorduy, 1998). *Brachytrupes* sp., *Brachytrupes membranaceus*, *Cynacanthus aeruginosus unicolor*, *Zonocerus variegates*, *Sphenarium histrio* contained 6.25%, 35.06%, 12.1%, 26.8% for adult and 50.39% for larvae, and 52.13% respectively (Banjo et al., 2006; Agbidye et al., 2009; de Conconi et al., 1984; Adedire and Aiyesanmi, 1999; Banjo et al., 2006). A study by Ekop et al. (2010) showed that *Heteroligus meles* (yam beetle), *Rhynchophorus phoenicis* (palm weevil), *Zonoceros variegates* (grasshopper) contained 37.62%, 49.87% and 44.62% protein respectively. Banjo et al. (2006) reported the respective value of caterpillar *Anaphes* sp., *A. venata* and *Cirina forda* 18.9, 25.7 and 20.2%; termite *Macrotermes bellicosus* and *M. notalensis* 20.4 and 22.1%; honey bee *Apis mellifera* 21% for crude protein. Compared to conventional food of animal and plant origin, grasshopper (*C. rosea*), locust (*Schistocerca* sp.), cricket (*B. orientalis*) beetles (*X. gideon & Anomala* sp.) possessed higher protein content than chicken beef, pork egg, bamboo shoot soybean and mung beans etc. (cf. Fig. 2c). Though, the bug (*A. nepalensis*) and the termite (*Odontotermes* sp.) contained lesser protein but still higher than the protein content of cow’s milk (whole 3.22g/100g) or soy milk (3.27g/100g).
(USDA). The recommended dietary allowances (RDA) of protein for Indian man and woman are 60g and 55g per day. For pregnant and lactating woman are 82.2g and 77.9g per day respectively. For growing boys and girls in the age group of 16-17 years, protein requirements are 61.5g and 55.5g per day. (ICMR. 2009). Therefore, Daily consumption of 100g of the tested edible insects can satisfy to if not full (17.7% of RDA for A. nepalensis, 56.12% RDA for Odontotermes sp., 88.46% of RDA for Schistocerca sp., 92.13% of RDA for O. smaragdina, 108.37% of RDA for Anomala sp., 109.57% of RDA for B. orientalis, 114.81% of RDA for C. rosea and 123.17% of RDA for X. gideon) protein requirements for man.

Amino acid: Protein is composed of more than 20 types of amino acids. Protein quality, as related to human nutrition, is dependent upon the amino acid composition of the source. A cell can synthesize non-essential amino acids when they are unavailable from food, but essential amino acids can only be obtained from foods (Sizer and Whitney, 2000). In this regards, having high protein content in the studied edible insects, the information about the amino acid profile is of great value from a nutritional standpoint.

About 18 amino acids could be detected in these insects in the present study and the most predominant ones were Glu, Ala, and Asp as non-EAA and Leu, Lys and Ile as EAA. The amino acid composition varied among the species in the present study which may be attributable to differences in amino acid content in the feed of these insects. Nevertheless, the total EAA of Odontotermes sp., C. rosea, B. orientalis, A. nepalensis, O. smaragdina were 40.86%, 37.31%, 36.23%, 35.78%, 35.21% respectively (cf. Fig. 3a). Most of the amino acids are obtained from diet and it maintains nitrogen balance in the body.
Among the EAA the branched-chain amino acids, Ile, Leu, and Val help in minimizing muscle wasting under conditions of increased protein breakdown, which is particularly beneficial for athletes. Leu is solely a ketogenic amino acid, giving rise to acetyl CoA or acetoacetate, neither of which can bring about net glucose production. In the present study, Leu, a predominant EAA ranged between 8.96% for O. smaragdina to 7.61% for A. nepalensis. This findings were in agreement with the leu content for other edible insects like Boopedon flavivenris (Orthoptera), Hapliphorion monograma (Homoptera), Parachartogus apicalis (Hymenoptera), Brachygastra azteca (Hymenoptera) Ortyes rhinoceros larva (Coleoptera), Rhynchophorus phoenicus larvae (Coleoptera), Bombyx mori (Lepidoptera), etc. (de Guevara et al., 1995; Okaraonye and Ikewuchi, 2009; Ekpo and Onigbinde, 2005; Tomotake et al., 2010; Idolo and Henry, 2011; Ghaly and Alkoai, 2010) except a few like Ascalapha odorata (Lepidoptera) in which Phe was found to be dominant (de Guevara et al., 1995) and Busseola fusca (Lepidoptera) (Ghaly and Alkoai, 2010) in which His was dominant one. The next predominant amino acid found was Val. Val, a glucogenic amino acid, influences brain to uptake other precursors for neurotransmitter like Trp, Phe and Tyr. The proportion of Val ranged between 7.30% in A. nepalensis to 5.83% in O. smaragdina. Val content of tested insect was higher than that of other reported edible insects like Busseola fusca, Heliothis armerigera, Boopedon flavivenris, Rhynchophorus phoenicus larva etc (Ghaly and Alkoai, 2010; de Guevara et al., 1995; Ekpo, 2010). Lys, another entirely ketogenic amino acid, has received attention as it is a limiting amino acid in cereals, especially wheat, rice, cassava and maize based diets which are prevalent in the developing world including India (Hill, 1970; Ozimek et al., 1985). Lys synthesizes carnitine which is required for transportation of medium and long chain fatty acids into mitochondria for
β- oxidation. Except *A. nepalensis*, all the studied insects contained considerable amount of Lys. Yet, Lys content in *A. nepalensis* could meet recommended values as proposed by FAO/WHO/UNU (2007) upto 83.87%. Thr is known to be the second rate limiting amino acid in the maintenance requirement for the body (Said and Hegsted, 1970; Hegsted, 1973; Fuller *et al.*, 1989). Considerable amount of Lys and Thr are present in these insects ranged within 3.77% to 5.34% for Lys and 4.18% to 4.94% for Thr. Ile, Thr and Phe are both glucogenic and ketogenic amino acid. His is a precursor of histamine, carnosine and arserine. Histamine, releases from the cells as a part of allergic reaction and also takes part in dilation and contraction of certain blood vessels. Among the amino acids in this study, though His content was comparatively lower, yet, it was 2.73 to 2.94% in *O. smaragdina*, *C. rosea* and *B. orientalis*; and in *A. nepalensis* and *Odontotermes* sp. it was 3.51 and 4.25% respectively. However, the contents of all these EAA in these insects were much closer to the values for conventional meat like beef, pork chicken and conventional protein sources of plant origin like chickpeas, beans, lentils, soybean etc. (*cf.* Fig. 3b). Moreover, it was also noted that, in these five insects, values for Val, Leu, Ile, Lys (except for *A. nepalensis*), Phe, His, Thr surpassed (>100%) the values recommended by FAO/WHO/UNU (2007) for "chemical score" of amino acid as an index of assessing the protein quality (*cf.* Fig. 3c; Table 3c). However, Met content in these insects was comparatively lower even lower than the conventional meat but remained at detection level (*cf.* Fig. 3b), and in *O. smaragdina* it was devoid of it. But among these insects, *A. nepalensis* contained relatively good amount of Met but not as good as Met content in conventional protein sources; it could meet about 93.75% of chemical score (FAO/WHO/UNU, 2007). It implies that the protein needs to be fortified with Met to fulfill its requirement, if needed.
In addition to the presence of these EAA, effective utilization of the dietary protein requires an appropriate balance between the EAA and non-EAA and other nitrogen containing compounds. Among the non-EAA, the most predominant one is Gln+Glu. It was 12.06% in B. orientalis, 12.72% in O. smaragdina, 11.46% in C. rosea and 11.12% in Odontotermes sp. and 10.18% in A. nepalensis. These values fall within the range as reported for other edible insects (Okaraonye and Ikewuchi, 2009; Ekpo, 2010; Idolo and Henry, 2011). The principle activity of Gln is to transport free ammonia, which is toxic to human body. Glu is a component of glutathione and a precursor of γ-amino butyric acid (GABA), a neurotransmitter and precursor for Pro and ornithine. Next to Gln+Glu, Ala is the next predominant non-EAA for these insects. Ala helps to convert blood glucose to energy and plays a role in muscle health and reduces muscle fatigue (Culbertson et al., 2010). Ala content of tested insects was comparatively higher than the Ala content reported for many insects like Oryctes rhinoceros, Rhynchophorus phoenicis, Oryctes monoceros, Bombyx mori (Okaraonye and Ikewuchi, 2009; Ekpo, 2010; Idolo and Henry, 2011; Tomotake et al., 2010). Besides Ala, Asn is important for proper functioning and chemical balance in various tissues including human brain (Gropper and Smith, 2013). With the values of 7.85 to 10.08% Asp+Asn content in these five insects were much closer to the values reported for other insects (Okaraonye and Ikewuchi, 2009; Ekpo, 2010; Idolo and Henry, 2011; Tomotake et al., 2010). Similarly, Arg, one of the important components of enzyme of urea cycle, ranged between 5.28% for A. nepalensis to 7.81% for Odontotermes sp. Arg is synthesized by mammalian tissues, but the rate is insufficient to meet the need of it during growth. It is essential for growing children but not essential in adults because Arg can be synthesized from Met and ornithine in them. In addition to all these amino acids, substantial amount of both Ser and Gly
were also present in these insects. In the body, Ser is converted reversibly to gly in a reaction that requires pyridoxal phosphate and tetrahydrofolate and Gly is the precursor of glyoxalate, which can be transaminated back to glycine or oxidized to oxalate. Gly is one of two major inhibitory neurotransmitters that balance the excitation in the brain. Therefore, these insects can also serve as a source of non-EAA as and when it is required.

Studies on amino acid profile of these insects indicate that these insects are the sources of good quality protein or “complete protein” from a nutritional point of view and can supplement protein supply by complementing other animal protein sources.

**Edible insects as source of fat and fatty acids:**

**Fat:** The importance of fat for the body is not unknown; it is one of the main constituents of cell membrane, helps in transportation and absorption of fat soluble vitamins and other nutrients, provides energy to the body etc. Nevertheless, fats are unpopular and avoidable for consumers, being considered as unhealthy. However, to meet the calorific deficiency, there is need of fat to combat malnutrition in developing countries. In general fats are commonly found in different food sources in varying proportions and their databases can be available from varied sources. However, until recent time, exploitation of insects as an alternative source of food in general and fat in particular has received little attention despite being in abundance and widely used by 3000 ethnic communities of 113 countries around the world (MacEvilly, 2000; Mitsuhashi, 2008).

Energy is necessary for all biological processes and heterotrophic organisms obtain it through their food. Compare to other macronutrients, fat supplies the highest amount of energy. Edible insects vary widely in fat, and, thus, energy content. They
are natural renewable resource used as food by people around the world (Ramos-Elorduy and Conconi, 1994) and the quantity and quality of nutrients that insects contribute to human diets may be considerable as proposed by Dufour (1987). Besides supplying energy, fats play important roles in formation of cerebrosides, phospholipids, cephalins, and sphingomyelins as well as in the elaboration of steroids. Fat is also precursors of prostaglandins, thromboxins and prostacyclins and involved in the formation of cholesterol (Krause and Mahan, 1984). Regarding malnutrition in developing countries, the problem of calorific deficiency reflects mainly the need of fat.

The fat content of edible insects varies widely. Not all edible species of insects contain high amount of fat. Ramos-Elorduy et al. (1997) reported in seventy eight species of insects and found it ranged from 4.0 to 77.2%. In the present study, fat content of Odontotermes sp. was considerably higher than many reported insects (Ukhun and Osasena, 1985; Adeduntan, 2005; Agbidye et al., 2009; Banjo et al., 2006; Omotoso, 2006; Ekpo and Onigbinde, 2007; Ekpo et al., 2009; Okaraonye and Ikewuchi, 2009) and lesser than that reported for Rhyhchophorus phoenicis larvae (coleoptera). Brachytrupes membranaceus (orthoptera) and winged termite (isoptera) (Ekpo et al., 2009; Adeduntan, 2005). Adeduntan (2005) and Leung (1972) reported fat content of winged termite and termite 53.063% and 55.24% dry weight basis respectively. Fat content of A. nepalensis was higher than most of the reported edible insects belonging to orders coleoptera, orthoptera, lepidoptera, hymenoptera except few like winged termites and Australian wignjiti grab (39.8% of the dry weight basis) (Adeduntan, 2005; Banjo et al., 2006; Fast, 1970; Meyer-Rochow, 1982; Meyer-Rochow, 1976). Fat content of O. smaragdina was little higher than that reported for worker caste of O. smaragdina (about 13%) and lesser than that reported for queen
caste of the species (about 37%). *Atta sexdens. A. cephalotes* (cf. Rastogi. 2011: 
Raksakantong *et al.*. 2010; Dufoir. 1987). In another study, Young-Aree and
Viwatpanich (2005) reported fat content of young *O. smaragdina* 12.5% though the
condition of dry/ wet weight basis was unspecified. Fat content of *C. rosea* was found
higher than that reported for grasshopper, cricket. *Brachytrupes* sp., *Cytacanthacris
aeruginosus unicolor, Zonocerus variegatus* and lesser than that reported for cricket,
*Brachytrupes membranaceus* among orthopteran insects (Adeduntan, 2005; Banjo *et
al.*, 2006; Leung, 1972; Agbidye *et al.*, 2009). Fat content of *B. orientalis* was higher
than that reported for *Brachytrupes* sp. (2.34%) (Banjo *et al.*, 2006). however,
Agbidye *et al.* (2009) reported considerably lesser value for *Brachytrupes
membranaceus* (53.05%). It was noted that the fat contents of the insects in the
present study fall in the range reported for protein values within and between insect
taxa (cf. Fig. 2d).

High fat content is particularly relevant in the developing countries as much of
energy is expended in doing works manually in contrast to developed countries where
the work is done through machine. *DeFoliart* (1992) pointed out that calorific
deficiency as that of protein deficiency is one of the reasons behind malnutrition in
developing countries. Food containing high amount of fat is thus expected to play
significant role to avoid malnutrition. In this regards, the termite *Odontotermes* sp. the
bug *A. nepalensis* and to a lesser extent the ant *O. smaragdina* in the present study,
can contribute to the fat requirement of the people who eats them. The intake of at
least 50g dried *Odontotermes* sp. can provide 25g fat, which is near to the value of
RDA as suggested by (RDA 2009 by ICMR). The recommended dietary allowance
(RDA) of visible fat for Indian man and woman varies and depends on the nature of
work a person used to perform. RDA for the Indian man and woman under heavy
work category are 40g and 30g per day respectively. The requirement remains same for pregnant and lactating woman. For growing boys and girls in the age group of 16-17 years visible fat requirements are 50g and 35g per day respectively, higher than RDA for man and woman (ICMR, 2009). Daily consumption of 100 g of tested insects can serve to provide 13.52% of RDA for Anomala sp., 15.82% of RDA for B. orientalis, 19.71% of RDA for C. rosea, 22.86% of RDA for Schistocerca sp., 25.12% of RDA for X. gideon, 37.48% of RDA for O. smaragdina, and 127.33% of RDA for Odontotermes sp. of fat for Indian man.

**Fatty acid:** Fat is a source of essential fatty acids. Fatty acid compositions determine the quality of fat. Fatty acids can be categorized into saturated fatty acid (SFA) and unsaturated fatty acids (UFA) and in turn UFA can be sub categorized into mono unsaturated fatty acids (MUFA) and poly unsaturated fatty acids (PUFA). The consumption of proper quality and quantity of SAF, MUFA and PUFA in diets may benefit human health. Foods containing low levels of saturated fatty acids and/or high proportions of unsaturated fatty acids are considered the most suitable. There are two series of essential fatty acids which cannot be synthesized by mammals- (a) ω-6 series linoleic acid derivatives and (b) ω-3 series from α-linolenic acid and therefore must be supplied in the diet. Insects represent an alternative source of essential fatty acids polyunsaturated fatty acids that cannot be synthesized *de novo* in animals like minerals and vitamins (DeFoliart, 1989; Bukkens, 2005).

The most abundant SFA in all the five species of edible insects was palmitic acid (16:0), which was similar in many edible insects, such as mole cricket, ground cricket, spur-throated grasshopper, giant water bug, true water beetle, water scavenger beetle, and winged reproductive of termite (Yang et al., 2006; Ekpo and Onigbinde, 2005; Bophimai and Siri, 2010). However, high concentrations of 18:1 oleic acid
were detected in all species, which was also reported in some insects belonging to the order Coleoptera (Ghioni et al., 1996; Bophimai and Siri, 2010), silkworm (Lepidoptera) (Priyadarshini and Revanasiddaiah, 2013). Among the detected MUFAs, oleic acid (18:1 ω-9) was the most abundant one. Low concentrations of eicosenoic acid (20:1) were also detected in three species, C. rosea, O. smaragdina and A. nepalensis. Among detected PUFAs, linoleic acid (18:2) was the most abundant in all the five species. Besides linoleic acid, 18:3 ω-3 linolenic acid was detected in three species C. rosea, O. smaragdina and Odontotermes sp., ranged from 0.03 g/100g in O. smaragdina to 0.07 g/100g in Odontotermes sp. 18:3 ω-6 linolenic acid as PUFAs were detected in all the species except O. smaragdina. Long-chain fatty acids 20:4 ω-6 arachidonic acid was detected only in O. smaragdina. The content of PUFAs in all these insects was very low compared to the content of SFA (35.25 to 85.57% of total fatty acids) and MUFAs (11.4 to 56.10% of total fatty acids).

SFA was higher than UFA in Odontotermes sp. and B. orientalis. Bophimai and Siri. (2010) and Raksakantong et al. (2010) also reported higher SFA in edible Helicopris bucephalus (Coleoptera) and Meimuna opalifera (Hemiptera). From a nutritional point of view, the SFA is important, since cholesterol is synthesized in the liver from saturated fats. Yet, too high an amount of saturated fats, as has been widely publicized, can result in excessively high levels of blood cholesterol and thereby increase the risk of cardiovascular disease from atherosclerosis. Moreover, high blood cholesterol is widely accepted to depress the immune system. In this context, it is important to mention that saturated fats in the liver do not all have the same effect on cholesterol synthesis. Only saturated fats of long chain lengths; e.g., 12, 14, and 16 (lauric, myristic, and palmitic acids) have been shown to elevate blood cholesterol. Of
these, myristic acid elevates cholesterol the most (Mensink, 1993). Lauric acid level was either very low as in case of C. rosea, O. smaragdina and Odontotermes sp. or remained below the detection level in A. nepalensis and B. orientalis. Myristic acid content of these insects' oils was low and even found lower than that reported for lamb, veal and beef except chicken (cf. Fig. 4f). But, Stearic acid (18 carbons, saturated) which was found in moderate amount, has been shown to lower cholesterol by 21% which is even more than the reported ability of oleic acid (18 carbons, monounsaturated) to lower low-density lipoprotein (LDL) by 15% (Bonanome and Grundy, 1988). Therefore, in spite of having predominant level of palmitic acid (16:0) and stearic acid (18:0) as SFA in all the species in general and B. orientalis in particular in which SFA was highest (85.57% of total fatty acids) along with very low level of myristic acid (2.55% of total fatty acids) and comparatively high level of stearic acid (32.06% of total fatty acids) may not pose any health problem. Moreover, the fat content of B. orientalis was low (6.33%), the lowest among the insects in this study, with this quantity of fat in it, the contribution of SFA for cholesterol enhancement can also be expected to be meager when it is consumed. On the contrary, Odontotermes sp. with its high fat content (50.93%) and higher SFA (52.89% of total fatty acids) than UFA may be expected to exert the ill effect of SFA. However, the difference between SFA and UFA was found to be much lower, it was about 1:1.123. Moreover, Odontotermes sp. contained high concentrations of oleic acid (20.27g/100g) as MUFA and considerable amount of both 18:2 linoleic (1.02g/100g), 18:3 ω-3 linolenic acid (0.07g/100g) as PUFA. Therefore, in spite of having high fat in Odontotermes sp. it may be not considered as unsafe, rather it can exert health benefit through UFA and can be recommended as good source of fat. However, further study need to be done before coming to any such conclusion.
UFA was higher in C. rosea, A. nepalensis, O. smaragdina than SFA. Similar trend was also reported for other edible insects (Womens et al., 2009; Raksakanong et al., 2010; Ekpo et al., 2009; Bophimahi and Siri, 2010; Yang et al., 2006; Okaraonye and Ikewuchi, 2009; Due et al., 2009; Fontaneto et al., 2011; Wang et al., 2006; Bukkens, 2005; Paoletti et al., 2003; Oyarzun et al., 1996). Unsaturated fat is safe for consumption by individuals predisposed to dyslipidemia, diabetes mellitus and cardiovascular disease. Reduction in the consumption of saturated fats and an increase in unsaturated fatty acid intake are likely to prevent (or at least reduce) the negative effects of lipid metabolism (Holub and Holub, 2004) because UFAs were shown to lower the serum cholesterol and triglyceride levels (Holub and Holub, 2004). This effect is increased when a part of the unsaturated fatty acids in question consists of the essential linoleic acid (Mainamne et al., 1999). The UFAs: eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) is known for their health benefit (Nair, et al., 1997; Simopoulos, 1999). Alpha linolenic acid is converted into eicosapentaenoic acid (EPA) and in turn docosahexaenoic acid (DHA) (Emken et al., 1994). DHA is particularly important in infant nutrition (Oski, 1997).

MUFA was predominant followed by SFA and PUFA in A. nepalensis and O. smaragdina. Among MUFAs, oleic acid (18:1) was the predominant one. Oleic acid is one of the necessary components in diet. Oleic acid is considered to be responsible for lowering levels of the low-density lipoprotein (LDL) cholesterol (Grundy, 1989). Current theory suggests that higher levels of LDL (the bad cholesterol) promote health problems and cardiovascular diseases as opposed to high-density lipoprotein (HDL), which are often called good cholesterol or healthy cholesterol (Peskin et al., 2008). However, it is to be noticed that, the desirable intake of monounsaturated fatty acid is more difficult to define. Some investigators suggest that higher intake of
MUFA is desirable whereas others suggest lower intake of MUFA is favorable in case of higher consumption of carbohydrate (Grundy, 1997). A reduction in the consumption of saturated fatty acids prevents and/or reduces the impact of the lipid metabolism when some of the unsaturated fatty acid in question is represented by essential fatty acid, linoleic acid (Maimance et al., 1999).

*A. nepalensis*, with considerably high fat content (38.36%) where, the palmitic (32.31% of total fatty acid) as SFA and oleic acids (46.41% of total fatty acid) as MUFA were the two major fatty acids in the insect oil. Similar is the case with *O. smaragdina* where crude fat content was moderate, palmitic (22.29% of total fatty acids) and oleic acids (49.96% of total fatty acids) were the two major fatty acids in it. In this regards, palm oil contains even a higher amount of palmitic acid (as % of total fat) than *A. nepalensis* and *O. smaragdina* but other commonly used edible oils contain lesser amounts of palmitic acid than *A. nepalensis* and *O. smaragdina* (cf. Fig. 4f). Like other common edible oils, *A. nepalensis* and *O. smaragdina* oil also contained a moderate amount of stearic acid (cf. Fig. 4f). The proportion of MUFA was relatively high for both the species (51.5 to 56.1%). Oleic acid was rather less abundant than in olive oil and canola oils but other commonly used edible oils contain lesser amounts of oleic acid than *A. nepalensis* (cf. Fig. 4f). Having more MUFA than SFA and PUFA the oils of both the species are of similar nutritive value. However, *O. smaragdina* remained in better position compared to *A. nepalensis* as it contained ω-3 fatty acids and it is available throughout the year where as availability of *A. nepalensis* is seasonal for their consumption, though it contained 2.5 times more of crude fat and in turn their fatty acid than *O. smaragdina*. However, one can avail the full nutritional potential of *A. nepalensis* through innovation culture system development for *A. nepalensis* and fortified with ω-3 fatty acid. From nutritional point
of view, both the species *O. smaragdina* and *A. nepalensis* have the potential for their recommendation as good source of fat.

In *C. rosea*, PUFA was predominant (41.61% of total fatty acids) followed by SFA and MUFA. The proportion of PUFA of *C. rosea* was higher than that reported for egg, veal, beef, chicken, pork and most of the conventional oil sources except wheat germ oil, even higher than other four studied insects in this study (cf. Fig. 4e). For other four insects, proportion of PUFA was comparable if not higher than that of coconut oil, cocoa butter, palm oil, veal, beef (cf. Fig. 4e). Among the PUFAs linoleic acid was 16.46% of total fatty acids and linolenic acid (both alpha 0.62% and gamma 24.53%) were the two major fatty acids in *C. rosea*. PUFA have beneficial effects for both maintenance of normal health and prevention of chronic diseases by regulating lipid levels (Lauritzen et al., 2000; Mori et al., 2000), cardiovascular (Kris-Etherton et al., 2002) and immuno functions (Hwang, 2002). Animal studies suggest that α-linolenic acid-rich food has ability to prevent atherosclerosis and chemical-induced cancer, improves immune and mental function, decreased postprandial plasma lipids in male Sprague-dawley rats (Kurowska et al., 2003; Kim and Choi, 2005). ω-3 fatty acid α-linolenic acid (C18:3) cannot be produced within the body and therefore, must be acquired from outside sources. α-linolenic acid is a precursor of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The adequate intake of α-linolenic acid is 1.6g and 1.1g for adult male and female respectively. The recommended requirement for pregnant and lactating women is 1.4g and 1.3g respectively. In addition to ω-3 fatty acid α-linolenic; ω-6 linoleic acid (C18:2) was also detected in *C. rosea* (16.46% of total fatty acids). This value is more than the foods of animal origin like lamb, veal and beef (cf. Fig. 4f). It is an essential fatty acid as it is known that mammals cannot convert oleate into linoleate or α-linolenate and is therefore
required to be present in the diet. The adequate intake of linoleic acid is 17g and 12g
per day for adult male and female (31 to 50 years) respectively, for the pregnant and
lactating women, the requirement is 13g per day and the requirement is little less in
the more aged condition (IOM, 2005). However, studies indicate that a high intake of
ω-6 fatty acids shifts the physiologic state to one that is prothrombotic and
proaggregatory, characterized by increases in blood viscosity, vasospasm, and
vasoconstriction and decreases in bleeding time (Simopoulos, 1999). However role of
linoleic acid is conflicting. Today, more than 85% of the total dietary polyunsaturated
fatty acid in developed country is ω-6 polyunsaturated fatty acid, mainly linoleic acid,
a precursor of arachidonic acid, whereas the consumption of ω-3 polyunsaturated fatty
acid has declined (Simopoulos, 2002). Since the consumption of ω-6 has been
associated with childhood obesity, concerns have been raised (Ailhaud et al., 2006).
However, animal studies have yielded conflicting results, with some studies
demonstrating that a diet enriched in ω-6 polyunsaturated fatty acid decreases adipose
tissue mass (Matsuo et al., 2002; Okuno et al., 1997) whereas others have showed that
consumption of ω-6 polyunsaturated fatty acid is associated with an increased
propensity for obesity (Cleary et al., 1999; Massiera et al., 2003). FAO/WHO (1994)
recommended that the ratio of linoleic acid to α-linolenic acid or ω-6/ω-3 in the diet
should be between 5:1 and 10:1. Excessive amounts of ω-6 polyenoic acid and very
high ω-6/ω-3 ratio promote the pathogenesis of many diseases, including
cardiovascular disease, cancer and inflammatory and autoimmune diseases
(Okuyama, 2001; Simopoulos, 2002; Griffin, 2008). The ratio of ω-6/ω-3 fatty acids
were found for C. rosea 66.11, for O. smaragdina 31 and for Odontotermes sp. 17.5
which is much higher. However, several studies indicated that the optimal ratio may
vary with the disease under consideration (Simopoulos, 2002). Except C. rosea, ratio
of ω-6/ω-3 of *O. smaragdina* and *Odontotermes* sp. was comparable to insects reported for *Agonoscelis pubescens* (27.5), *Onitis* sp. (17.9), *Onthophagus mouhoti* (21.0) (Mariod *et al.*, 2011; Bophimai and Siri, 2010) but higher than many other insects (Bhulaidok *et al.*, 2010; Fontaneto *et al.*, 2011). This result implies that there is a scope to fortify the insect oils with ω-3 fatty acid in order to fulfill the recommendation of FAO/WHO (1994). Diet with excessive amounts of ω-6 PUFA and a very high ω-6/ω-3 ratio, has been reported to promote the pathogenesis of many diseases, but, in *C. rosea*, in which fat content is very low (7.8%) and in turn ω-6 linoleic acid therefore, to substantiate recommended amount, e.g. 17g Linoleic acid, about 1.3kg of *C. rosea* is required. However, *C. rosea* and all the other edible insects are not the staple food for the ethnic people who eat them rather they take them as side dish. Therefore, the intake of *C. rosea* may not pose any health problem rather it may be considered as fat of good quality.

Elaidic acid (MUFA) which is a trans fatty acid (TFA) was found in *O. smaragdina*, *C. rosea* and *Odontotermes* sp. and it varies from 0.31% in *C. rosea*, 0.33% in *O. smaragdina* and 0.45% in *Odontotermes* sp. TFA potentially increases coronary heart diseases (CHD) risk factors and CHD events by raising cholesterol concentration (Uauy *et al.*, 2009). Elaidic acid increases cholesteryl ester transfer protein (CETP) activity, which in turn raises VLDL and lower HDL cholesterol (Abbey and Nestel, 1994). However, the TFA content of these insects occurs within the range of recommended intake of TFA which is 1% of total energy intake (FAO/WHO, 2008). Elaidic acid occurs in small amount in caprine and bovine milk (0.1% of the fatty acids) (Alonso *et al.*, 1999).

The study revealed that the most abundant SFA is Palmitic acid representing the range from 50.32% for *B. orientalis* to 17.24% for *C. rosea*. Palmitic acid content
of the insect's oil was found higher than most commonly used edible oil like safflower oil (4.86%), sunflower oil (5.40%), walnut oil (7.60%) etc. (USDA). These insect oils may be used as a source of palmitic acid, industrially needed for margarine production, production of hard soap. In these insects oils palmitic acid was followed by stearic acid and the proportion of stearic acid is also found higher than that reported for most of the commonly used oil (cf. Fig. 4f). As insect fats contain substantial saturated fatty acid, they may be used in the paint industry as truly suggested by Due et al. (2009).

Therefore, fatty acid compositions of five edible insects in general and Odontotermes sp., A. nepalensis and O. smaragdina in particular, reinforce the utilization of these insects as promising sources of fat from nutritional point of view as well as have their industrial implication too.

**Edible insects as a source of ash and minerals:**

**Ash:** Ash content of the studied insects ranged 1.99 to 6.23%. Among the insects, orthopteran species possessed higher level (4.16% to 6.23%) of ash followed by termite (3.01%). Ash content of coleopteran and hymenopteran species was more or less similar to termite. These values of ash were also comparable to the ash content of larvae and adult beetle of *Lachnosterna* sp. with values of 2.0% and 1.6% respectively (Davis, 1918), lepidopteran *Popillia japonica*, 1.5% (Flemming, 1968), *Anaphe venata*, 3.21% (Ashiru, 1988), *Bombyx mori*, 3.8% (Leung, 1972) and reported by Banjo et al. (2006) for other insects species like *Analeptes trifasciata* (4.21%), *Macrotermes bellicosus* (2.90%), *Cystanthis aruginosa unicolor* (2.1%), *Brachytrupex* sp. (1.82%), *Zonoceros variegates* (1.20%) as well as 0.34 to 5.05% for orthopteran species (Blasquez et al., 2012). *Imbrasia belina* (Lepidoptera) (6.2%)
(Onigbinde and Adamolekun, 1998). *Rhynchophorus phoenicis* larva (Coleoptera) (5.7%) (Ukpoko, 2010). Higher values were also reported for *Hermetia illucens* 14.6% (Newton et al., 1977). *Macrotermes bellicosus* 10.2% (Ukhun and Osasona, 1985). *Cirina forda* larva 10.26% (Omotoso, 2006). *Arphia fula*, *Sphenarium histrio* and *S. purpurascens* (16.5% each) (Blasquez et al., 2012). There is a consensus among researchers that ash content of a given sample correlates the mineral contents of the sample. It indicates that the eight insects studied here can give a fair source of mineral elements as earlier suggested by Ene (1963).

**Minerals:** Micromutrients play an important role in nutrition, which is why mineral contents were analyzed. The insect in general is phytophagous, so, its mineral composition would be greatly influenced by the mineral composition of its host plant. This is analogous to the observation that the trace element content of plants vary widely and is dependent on the composition of the soil on which the plant grew (Nye and Tinker, 1977; Bremner and Mills, 1981; Tinker, 1981; West, 1981). To evaluate the status of mineral content of the insects in the present study with that of other edible insects it is observed that:

At value 340mg/100g DM, **calcium** content of *C. rosea* was found higher than that reported for 25 orthopteran species of Mexico (50-120mg/100g). *Zonoceros variegatus* (orthoptera) (42.16mg/100g), *Analeptes trisfaciata* larva (Coleoptera) (61.28mg/100g), *Oryctes hoas* larva (coleoptera) (45.68mg/100g), *Rhynchophorus phoenicis* larva (coleoptera) (39.58mg/100g) etc. (Blasquez et al., 2012; Banjo et al., 2006; Adeduntan, 2005; Sirimungkararat et al., 2010). Ca content (68.35 to 120mg/100g DM) of other four species in the present study i.e. *Odontotermes* sp., *O. snaragdina*, *B. orientalis*, *A. nepalensis* were considerably higher than reported for *Brachytrupes* sp. (orthoptera) (9.21mg/100g). *Cirina forda* larva (lepidoptera)
(33.16mg/100g). *Anaeridium melanorhodon* (orthoptera) (19.23mg/100g and 19.41mg/100g for boiled and fried) *Macrotermes bellicosus* (21mg/100g) and *Macrotermes natalensis* (18mg/100g) (Banjo et al., 2006; Omotoso, 2006; Hassan et al., 2008) and lower than that reported for *Aspogobus viduatus* (hemiptera) (1021.21mg/100g) and *Agonoscelis pubescens* (hemiptera) (759.51mg/100g) (Mariod et al., 2011 Banjo et al., 2006).

*A. nepalensis* contained the highest amount of magnesium 160mg/100g DM followed by *C. rosea* 120mg/100g DM, among the tested insects as well as higher than reported values for many edible insects like *Anaeridium melanorhodon* (orthoptera) (0.83mg/100g and 0.56mg/100g for boiled and fried), *Cirina fordi* larva (lepidoptera) (62.31mg/100g), *Polyrhachis vicina* (hemiptera) (65.3 and 67.6mg/100g for two different location) (Hassan et al., 2008; Omotoso, 2006; Bhulaidok et al., 2010) and lower than that reported for *Busseola fusca* larva (lepidoptera) (470mg/100g), *Heliothis armigera* larva (lepidoptera) (450mg/100g); *Gonimbrassia belina* larva (lepidoptera) (410mg/100g); *Oryctes monoceros* larva (coleoptera) (175mg/100g), *Aspogobus viduatus* (hemiptera) (301.10mg/100g), *Agonoscelis pubescens* (hemiptera) (309.2mg/100g) (Ghaly and Alkoai, 2010; Ghaly, 2009; Mariod et al., 2011). Mg content of *B. orientalis* (87.21mg/100g DM) was found considerably higher than that reported for *Brachytrupes* sp. (0.13mg/100g), *Cycancia africana* (0.09mg/100g), *Zonoceros variegates* (orthoptera) (8.21mg/100g) (Banjo et al., 2006). However, Mg content of these orthopteran species was lower than the range of 350-940mg/100g reported for edible orthopteran species (Blasquez et al., 2012). Mg content of *Odontotermes* sp. (47.71mg/100g DM) was comparatively much higher than that reported for isopteran species like *Macrotermes bellicosus* (0.15mg/100g) and *Macrotermes natalensis*.
(0.26mg/100g) (Banjo et al., 2006). Mg content of *O. smaragdina* was also higher than the reported values for black ant *Polyrhachis vicina* (65.3 and 67.6mg/100g for two different locations) (Bhulaidok et al., 2010).

With regard to sodium content, the bug *A. nepalensis* contained 1020mg/100g DM, which was much higher than the other four insects studied here and other bug species. *Aspangobius viduatus* (Hemiptera) (401.10mg/100g). *Agonoscelis pubescens* (Hemiptera) (340.41mg/100g) and many other insects other than bug. the hemipteran species (Mariod et al. 2011; Ekpo. 2010; Ghaly and Alkoaiik. 2010; Idolo and Henry. 2011). Though some lepidopteran larvae contains higher amount of Na e.g. *Anthoera zambezia* larva (3370mg/100g) and *Gonimbrasia belina* larva (3330mg/100g) (Ghaly. 2009). With the value for Na, ranged 92.74 to 150mg/100g DM in *Odontotermes* sp., *B. orientalis* and *O. smaragdina* was higher than lepidopteran species. *Heliothis armigera* larva (70mg/100g), *Cirina forda* larva (45.26mg/100g) and orthopteran species. *Anacridium melanorrhodon* (6.32 and 3.43mg/100g for boiled and fried) (Ghaly and Alkoaiik, 2010; Omotoso, 2006; Hassan et al., 2008). Though *C. rosea* had the least amount of Na among the studied insects in this study as well as other orthopteran species reported by Blasquez et al., (2012) however, this value was much higher than *Anacridium melanorrhodon* (Orthoptera) (6.32 and 3.43mg/100g for boiled and fried) (Hassan et al., 2008).

Potassium content, 1130mg/100g DM, in orthopteran species, *C. rosea* was higher than that reported values i.e. for other orthopteran species 40 to 570mg/100g (Blasquez et al., 2012) for several orthopteran species. However, K content in lepidopteran species were reported to be much higher e.g. *Busseola fusca* larva (5760mg/100g), *Heliothis armigera* larva (3520mg/100g), *Anthoera zambezia* larva (5760mg/100g).
(5250mg/100g) and Gonimbrasia belina larva (3520mg/100g) (Ghalay and Alkoaik, 2010; Ghalay, 2009). At value 412.28 mg/100g DM, K content of cricket B. orientalis species contained about 2.5 times lesser than the potassium content of C. rosea, but its value was very similar to K content of other orthopteran species (Blasquez et al., 2012). For hemipteran bug, A. nepalensis had higher K content than that reported for Asponogobus viduatus (Hemiptera) (200.08mg/100g) and lower than that reported for Agonoscelis pubescens (412.52mg/100g) as reported by Mariod et al., (2011). In case of O. smaragdina, a hymenopteran species and Odontotermes sp., an isopteran species, K content were higher than Rhynchophorus phoenicis larva (Coleoptera) (26.65mg/100g); Oryctes monoceros larva (Coleoptera) (38.40mg/100g), Cirina forda larva (Lepidoptera) (64.02mg/100g) (Ekpo, 2010; Idolo and Henry, 2011, Omotoso, 2006).

With the value 3.62 mg/100g DM, copper content of C. rosea was higher than Polyrhachis vicina (hymenoptera) (1.9 and 2.4mg/100g in two different geographical location), Rhynchophorus phoenicis larva (coleoptera) (1.26mg/100g), Oryctes monoceros larva (coleoptera) (1mg/100g) (Bhulaidok et al., 2010; Ekpo, 2010; Idolo and Henry, 2011). Similarly, Cu content of A. nepalensis, Odontotermes sp. and B. orientalis was comparable with the reported value of other edible insects. However, the value for O. smaragdina was lower than that reported for other edible insects (Bhulaidok et al., 2010; Ekpo, 2010; Idolo and Henry, 2011).

At the value 20mg/100g DM, iron content of A. nepalensis was found higher than that reported for Cirina forda larva (Lepidoptera) (5.34mg/100g), Anacridium melanorhodon (orthoptera) (12.31 and 12.20mg/100g for boiled and fried), Sphenarium histrio, S. purpurascens, Melanoplus ferrubrum (orthoptera) (16mg/100g) (Omotoso, 2006; Hassan et al., 2008; Blasquez et al., 2012). Similarly,
with the value 18.66mg/100g. Fe content of *B. orientalis* fell within the range of 10-40mg/100g determined for several orthopteran species by Blasquez *et al.* (2012). However, Fe content of *C. rosea* was lower than reported range for orthopteran species (Blasquez *et al.*, 2012). In general, Fe content of the insects of present study was relatively lower than that reported for *Polyrhachis vicina* (hymenoptera) (53.7 and 118mg/100g in two different geographical region), *Rhyynchophorus phoenicis* larva (coleoptera) (65.23mg/100g). *Busseola fuscata* (lepidoptera) (280mg/100g), *Heliothis armigera* (lepidoptera) (170mg/100g) and *Oryctes monoceros* larva (coleoptera) (85 mg/100g) (Bhulaidok *et al.*, 2010; Ekpo, 2010; Ghaly and Alkoaik, 2010; Idolo and Henry, 2011).

At the value 18.97 and 12.24mg/100g DM, zinc content of *O. smaragdina* and *Odontotermes* sp. respectively were higher than *Rhyynchophorus phoenicis* larva (coleoptera) (10.57mg/100g). *Busseola fuscata* larva (lepidoptera) (10mg/100g), *Anacridium melanorhodon* (orthoptera) (2.80 and 2.95mg/100g for boiled and fried), *Oryctes monoceros* larva (Coleoptera) (7mg/100g) and *Cirina forda* larva (3.81mg/100g) and lower than *Anthoeca zambezina* larva (lepidoptera) (250mg/100g). *Gonimbrasia belina* (lepidoptera) (190mg/100g) and many orthopteran species (Ekpo, 2010; Ghaly and Alkoaik, 2010; Hassan *et al.*, 2008; Idolo and Henry, 2011; Omotoso, 2006; Ghaly, 2009; Blasquez *et al.*, 2012). Zn content of *O. smaragdian* was comparable to black ant (7.6mg/100g) *Polyrhachis vicina* of Zhejiang of China as reported by Bhulaidok *et al.*, (2010). Zn content of *C. rosea* was within the range of 10-80 mg/100g reported for twenty five orthopteran species of Mexico while with 8.50 mg/100g DM, Zn content in *B. orientalis* was found below the range (Blasquez *et al.*, 2012). High values of Zn are usually obtained from high-protein foodstuff, whereas low levels are obtained from food rich in carbohydrates.
Except for *A. nepalensis*, manganese content of all insects of the present study was higher than that reported for *Rynchophorus phoenicis* larva (coleoptera) (1.16mg/100g), *Oryctes monoceros* larva (coleoptera) (1.21mg/100g), *Cirina forda* larva (lepidoptera) (1.14mg/100g) (Ekpo, 2010; Idolo and Henry, 2011; Omotoso, 2006) and for all studied insects, Mn content was found lower than *Anthoaea zambezina* larva (lepidoptera) (60mg/100g) and *Gonimbrasia belina* larva (lepidoptera) (40mg/100g) (Ghaly, 2009).

Therefore, based on these minerals contents, *A. nepalensis* and *B. orientalis* stand for Fe: *C. rosea* for Ca, K and Cu; *O. smaragdina* for Zn and Mn; *A. nepalensis* for Mg, Na; and *Odontotermes* sp. also stands good, if moderate amount of all these minerals are required. However, based on the RDA requirements for the minerals, *B. orientalis* is good for Fe, Cu and to some extent for Zn; *C. rosea* for Cu and Zn; *O. smaragdina* for Fe and Zn; *A. nepalensis* for Fe and Cu; *Odontotermes* sp. for Zn.

Mineral content in the studied insects were compared with mineral content of bamboo shoot, cabbage, cauliflower, mung beans, cassava, soybean and conventional meats like pork, beef, veal, chicken (common and highly preferred food) (Fig. 5a to 5h). In general, Cu, Fe, Zn and Mn contents in all the studied insects were comparable to or higher than foods of plant and animal origin. But, Mn content in *A. nepalensis* was higher than food of animal origin not the plant origin. Ca content in *C. rosea* and Na content in *A. nepalensis* was higher than the food of plant and animal origin considered in this study. K content in *C. rosea* and *O. smaragdina* was higher than the foods of animal origin but comparable in case of *Odontotermes* sp. While comparing with bamboo shoot, one of the most preferred local food, it was revealed that: Ca content in *C. rosea*; Na and Mg content in all studied insects (except *C. rosea* for Na);
Fe content in all the studied insects: Zn in *O. smaragdina* and Cu in *C. rosea*. Mn content in *O. smaragdina* and *B. orientalis* was higher than the bamboo shoot.

*C. rosea* may be one of the good sources of Ca, Mg, K and Cu. Consumption of 100g of *C. rosea* meets 56.67% of RDA for Ca, 35.29% of RDA (for male) for Mg, and 30.13% of RDA (for male) for K, the highest among five studied insects. Similarly, Mg, Na and Fe were predominant in *A. nepalensis* and satisfy 47.06% of RDA (for male) for Mg, 48.76% of RDA (for male) for Na which was the highest among the studied insects. As far as micro-minerals (Fe, Zn, Cu) are concern, assuming good bioavailability of Fe from insects, recommended dietary allowance can be met by consumption of 100g each of *B. orientalis* (109.79% of RDA) and *A. nepalensis* (117.65% of RDA) for man; other studied insects in the present study also fulfill RDA (92.12% to 45.94%) for man. However, requirement of Fe is much higher for women, but consumption of 100g of *A. nepalensis* can meet 95.24% of RDA for women. Similarly, eating 100g of *C. rosea* which contains least amount of Fe, even then, this species can fulfill 37.19% of RDA for women. Likewise, consumption of 100g each of *C. rosea*, *B. orientalis*, *A. nepalensis* and *Odontotermes* sp. satisfy fully even more than 100% of RDA for Cu. In case of Zn, 100g each of *O. smaragdina* and *Odontotermes* sp. meet 100% RDA for man and for women. It implies that all the tested insects are good source of minerals. These minerals are nutritionally important as, they are used in formation of soft tissue (Carnes, 1971; Doisy, 1974; Underwood, 1977; Underwood, 1981), formation of rigid body structure (Bearn, 1972; Davis, 1972; Evans et al., 1973; Hambidge and Silverman, 1973; Henkin, 1978) and as component of body fluids (Wacker, 1978; Burton, 1979).

The richest dietary source of Ca among conventional food of animal origin is milk and dairy products. Skim milk powder and whole milk powder contain 1370mg
and 950mg calcium per 100g. Buffalo milk contains 210mg Ca/100g (cf. Srilakshmi, 2012). However, it is often inaccessible to a large population because of poverty. Ca is an essential nutrient, playing vital roles (to name but a few) by virtue of its phosphate salts in neuromuscular function, in many enzyme-mediated processes and blood clotting, and in bone and tooth formation. Compared with other minerals, Ca is economically relatively inefficient. Following most intakes, only about 25 – 30% of dietary Ca is effectively absorbed and obligatory Ca losses are relatively large. On the other hand Na administration raises Ca excretion, presumably because Na competes with Ca for reabsorption in the renal tubules. C. rosea and A. nepalensis specimen contains 3400μg g⁻¹ and 1200μg g⁻¹ respectively of calcium on a dry weight basis. This amount is higher than that found in conventional meats (cf. Fig. 5a). Manganese activates numerous enzymes such as hydrolases, transferases, kinases, and dehydropolymerases and is a constituent of some enzymes like pyruvate carboxylase, arginase and superoxide dismutase (SOD) (Scrutton et al., 1966). Mn activates enzymes associated with fatty acid metabolism and protein synthesis and is also involved in neurological functions (Wilson et al., 1979). Mn contents in all the studied insects except A. nepalensis were comparable to or higher than foods of both plant and animal origin. But, Mn content in A. nepalensis was higher than food of animal origin not the plant origin. Dietary deficiency of magnesium of a severity sufficient to provoke pathological change is rare. Mg is widely distributed in plant and animal foods. Most green vegetables, legume seeds, beans, and nuts are rich in Mg, as are some shellfish, spices, and soy flour, all of which usually contain more than 500 mg/kg fresh weight. By comparison, magnesium content of C. rosea, O. smaragdina, B. orientalis, Odontotermes sp. and A. nepalensis were 1200mg/kg, 931.4mg/kg, 872.1mg/kg, 477.0mg/kg and 1600mg/kg respectively.
Zn is an essential component of a large number (>300) of enzymes participating in the synthesis and degradation of carbohydrates, lipids, proteins, and nucleic acids as well as in the metabolism of other micronutrients. Furthermore, it has an essential role in polynucleotide transcription and thus in the process of genetic expression (Sandstrom, 1989). Lean red meat, whole grain cereals, pulses, and legumes provide the highest concentration of Zn in the range of 25 – 50mg/kg (380 – 760μmol/kg) raw weight. Processed cereals with low extraction rates, polished rice, chicken, pork, or meat with high fat content contain moderate amounts of zinc, typically between 10 – 25mg/kg (150 – 380μmol/kg). Fish, roots and tubers, green leafy vegetables, and fruits are only modest sources of zinc, having concentrations of <10mg/kg (<150 μmol/kg); and saturated fats and oils, sugar, and alcoholic beverages have very low Zn content (Sandstrom, 1989). Zn content in O. smaragdina (18.97mg/100g), B. orientalis (8.5mg/100g), Odontotermes sp. (12.24mg/100g), C. rosea (10.83mg/100g) and A. nepalensis (7mg/100g), are higher than the amounts present in most conventional food sources.

The sections of a population most at risk for Fe deficiency are infants, children, adolescents, and women of childbearing age, especially when pregnant. The situation with regard to Fe supplies is much less critical in developed countries compared with developing countries. In the latter there are still many groups, especially infants in the weaning stage, who do not obtain sufficient Fe from their diet. The Fe content of A. nepalensis B. orientalis, O. smaragdina, Odontotermes sp. and C. rosea showed that they are as high as that of conventional meats (cf. Fig. 5f). However, a bioavailability study to examine the nutritional potential of the Fe content in these insects, in order to avoid iron deficiency symptoms in the local population is still to be carried out. Finally, all these insects also contained moderate amount of Na,
K and Cu. Cereal based diet provide only meager amount of these essential trace elements. The small amounts of these micronutrients are found in the aleurone layer cells associated with bran and germ which are removed during milling, therefore cereal-based foods tend to be deficient in trace elements (Salunkhe and Deshpande, 1991). The possible inclusion of these insects in their diet will take care of such needs.

**Anti-nutrient components:**

Based on the results on nutritional composition of the insects included in this study it can be said that these insects occupy an important place in human nutrition as in many countries they are one of the staple food. All the edible insects in the present study have unique nutritive value. Besides being a cheap source of valuable protein, and several micronutrients including minerals, they are rich source of fiber and good fat. They can contribute many beneficial physiological effects as some of the nutrient components may allow to prevent common metabolic diseases like coronary heart disease (CHD). However, a positive nutritional component in a food material does not indicate the nutritional value of that food. There is a wide distribution of biologically active constituent in food that elicits toxic responses. They are mainly categorized as anti-nutritional factors. A balance between the nutritional composition and anti-nutritional factors in food give the nutritional value of food.

Anti nutritional factors are compounds which reduce the nutrient utilization. The factors that determine the nutritive value of foods are very complex. All available information, both qualitative and quantitative aspects of nutrition must be used in making judgments about the food value of particular food material. Suitability or satisfactoriness of a particular food is only an indication of acceptability. Much
emphasis is usually put on the analysis of crude protein, fiber, minerals, amino acid and fatty acid. However, more importance should be given to the presence of secondary compounds such as tannin hydrolysable phenolics, which may interfere with the level of protein, fiber and mineral contents which are used as indicator of high nutritional value.

Most of the edible insects are phytophagous. It is known that plants generally contain anti-nutrients acquired from fertilizers and pesticides and several naturally occurring chemicals (Igile, 1996). They include tannin, phytic acid, alkaloids, oxalates, flavonoids etc. The list is inexhaustible. Some of these chemicals are known as secondary metabolites. These secondary metabolites may reach up to human through food chain who consumes insects. Some of these plant chemicals have shown to be deleterious to health or evidently advantageous to human health if consumed at appropriate amounts. Many insect species maintain conditions in their midgut, such as high pH (Berenbaum, 1980); the presence of surfactants (Martin and Martin, 1984); or a specific redox potential (Appel, 1993; Appel and Maines, 1995) that ameliorate or negate the precipitation of tannin-protein complex in insects. The present study focused mainly on tannin and phytic acid present in the eight edible insects considered here.

At 1783.33mg/100g, tannin content of Schistocerca sp. was higher than the tannin content of almost all reported insects. Tannin content of Odontotermes sp. (615mg/100g) was comparatively higher than the values reported for winged termite (250mg/100g) and lower than that reported for termite (948.33mg/100g) (Adeduntan, 2005). Tannin content of X. gideon (675mg/100g) and Anomala sp. (629.17 mg/100g) was considerably higher than that reported for coleopteran species like Heteroligus meles (yam beetle) (0.0379mg/100g). Rhynchophorus pheonicis (palm weevil)
(0.0405mg/100g). *Oryctes monoceros* larva (14.3mg/100g) and *Rhyynchophorus pheonicis* larva (1.04mg/100g) (Ekop et al., 2010; Idolo and Henry, 2011; Ekpo, 2010). Tannin content of *C. rosea* (781.67mg/100g) and *B. orientalis* (600mg/100g) was found lower than that reported for grasshopper (1050mg/100g), cricket (900mg/100g) (Adeduntan, 2005) and considerably higher than *Gymnogryllus lucens* (cricket) (0.0329mg/100g) and *Zonocerus variegates* (grasshopper) (0.0430mg/100g) (Ekop et al., 2010). Tannin content of *O. smaragdina* (496.67mg/100g) was also higher than that reported for ant (400mg/100g) (Adeduntan, 2005). Tannin content of *A. nepalensis* (478.333mg/100g) was found lower than that reported for tree hopper (1000mg/100g) and meal bug (1150mg/100g) (Adeduntan, 2005).

Phytic acid content of *X. gideon* (427.51mg/100g) was considerably higher than that reported for other coleopteran species like *Rhyynchophorus pheonicis* larva (1.35mg/100g), *Heteroligus meles* (yam beetle) (0.0280mg/100g) (Ekpo, 2010; Ekop et al., 2010) whereas phytic acid content of *Anomala* sp. (56.99mg/100g) was lower than the values reported for *Oryctes monoceros* larva (178mg/100g) (Idolo and Henry, 2011) and *B. orientalis* (303.1mg/100g) was lower than the phytic acid content of cricket (3159.017mg/100g) (Adeduntan, 2005) but considerably higher than *Gymnogryllus lucens* (cricket) (0.0283mg/100g) (Ekop et al., 2010). Likewise phytic acid content of *C. rosea* (71.25mg/100g) and *Schistocerca* sp. (95.23mg/100g) was comparatively lower than that reported for grasshopper (1100.146mg/100g) (Adeduntan, 2005) and considerably higher than *Zonocerus variegates* (grasshopper) (0.0281mg/100g) (Ekop et al., 2010). Phytic acid content of *Odontotermes* sp. (141.23mg/100g) was also much lower than that reported for winged termite (1128.227mg/100g) and termite (2482.084mg/100g) (Adeduntan, 2005). Likewise phytic acid content of *O. smaragdina* (171mg/100g) and *A. nepalensis*
(70.55mg/100g) was lower than that reported for ant (2030.797mg/100g) and meal bug (2256.437mg/100g) respectively (Adeduntan, 2005).

Phytic acid binds to mineral elements such as Ca, Zn, Mn, Fe and Mg to form complexes that are indigestible, thereby decrease bioavailability of these elements for absorption (Erdman, 1979). Phytic acid has also been implicated in the removal of phosphorus and causing indigestion and flatulence in human system (Ndubuakaku et al., 1989). Similarly, tannins are known to interact with proteins forming complexes which, in turn, decrease the solubility of proteins and make protein complexes less susceptible to proteolytic attack than the same proteins when they are present alone (Reddy et al., 1985; Carbonaro et al., 1996). However, tannin is also receiving growing interest due to their potential role as protective factors against free radical mediated pathologies, such as cancer and atherosclerosis, in humans (Kehrer, 1993). Likewise, beneficial properties of phytate have been observed as antioxidant (Graf et al., 1987) and for anticancer activities (Shamsuddin, 1995). Inhibition of calcium salt crystallisation and prevention of renal stone formation through dietary phytate were described by Grases and Costa-Bauza (1999).

Nevertheless, considering their anti-nutritional property, there are reports that the impact of phytic acid and tannin can be reduced/eliminated through the thermal processing in plant based diet (Alonso et al., 2000; Habiba, 2001). However, the present study mainly focused, not on the traditionally processed insects but on the fresh insect’s samples. Therefore, the high value of tannin and phytic acid is not unexpected. In this regards, we can speculate that the ill effect of these anti-nutrients can prevail in diets containing marginal amount of protein and minerals. Therefore, having considerably high protein and mineral content in most of these insects than plant based diet, can balance the protein loss or other nutrient (mineral) loss through
phytic acid and tannin. Further study in this regards is required to be carried out to come to such conclusion. It is noteworthy that the ethnic people consume the insect either by roasting, frying or by boiling that might help in reducing or keeping at a safe level for both tannin and phytic acid in those insects that are taken as food. Though taking the insects as raw (by preparing chutney mixing with other spicy ingredients and salt) are not uncommon. In such situation, the ethnic people need to be informed about the ill effects of these anti-nutritional components in insects when they are taken as raw. However, some of the conventional food like brown rice, wheat, maize, millet, rye also contains tannin about 400mg/100g. and oats, sorghum contain 1100 and 1600mg/100g tannin respectively (cf. Fig. 6). These value of phytic acid were much lower than the phytic acid content of most of the so far reported species of insects as well as conventional food (cereals and rice) (Table 6b).

B. NUTRACEUTICAL PERSPECTIVE OF FOOD INSECTS

The basic challenge to improve food security by introducing novel ways of feeding world’s human population is to secure adequate nutrition. The nutritional value of food largely depends on the quality of protein and thus, amino acid composition it contains. Also sufficient energy in diet is necessary in order to assimilate protein. Fat supplies the highest amount of energy. Calorific deficiency such as protein deficiency is one of the reasons behind malnutrition in developing countries and often called as protein-energy malnutrition (PEM). Eradicating and averting hunger is not enough to assure good health. The lack of key micronutrients like minerals is also important cause of poor health. Moreover, diseases such as obesity, cardiovascular disease, type II diabetes, cancer are often associated with lack of nutrition. Beside addressing basic functions, nutrition science needs to expand in order to support of the state of well being and health, and minimizing the risk of diet-
related diseases associated with either excess or deficiency of some nutrients. Krupa (2008) rightly showed the evolution of the concept of functional food. The “functional food” concept was developed in Japan at the early 1980s and as “food for specified health use (FOSHU)” was established in 1991 (Diplock et al., 1999). Functional food, defined as “any food or ingredient that has a positive impact on an individual’s health, physical performance, or state of mind, in addition to its nutritive value” (Goldberg, 1994), must satisfy the following conditions: should be naturally occurring, can be consumed as part of the daily diet, and when ingested should enhance or regulate a particular biological process or mechanism to prevent or control specific diseases. Soon, the term “functional food” was accompanied by numerous related expressions such as “nutraceuticals”, “pharmafood”, “medifood”, “vitafood” etc. Although all these terms, derived from a field of nutrition science, emphasize the beneficial effects of food components and their interactions with body functions and/or pathological processes, though they are intrinsically dissimilar in meaning, besides they are often misused for nutrients or nutrient-enriched food that can prevent or treat diseases. The term “nutraceutical” was defined by the Foundation for Innovation in Medicine (Pszczola, 1992) as “substances considered a food or part of a food, that provide medical and/or health benefits, including the prevention and treatment of diseases”. Nutraceuticals are clearly not drugs, which are pharmacologically active substances, but surely are components that not only maintain, support, and normalize any physiological or metabolic function, but can also potentiate, antagonize, or otherwise modify physiological or metabolic functions (Hardy, 2000).

Insects occupy an important place in human nutrition as in many countries as well as in the state of Arunachal Pradesh. Besides being a cheap source of valuable proteins, minerals, some of them are known as rich in fibre and contain good quality
fat as it was evident from the present study. The contribution of insects in the daily diet may have beneficial physiological effects. In this part, the nutraceutical potential of the studied insects has been discussed with reference to different disease condition.

Protein energy malnutrition and edible insects:

Protein energy malnutrition (PEM) occurs when inadequate protein and/or calories are ingested to meet an individual’s nutritional requirements. DeFoliart (1992) pointed out calorific deficiency as one of protein deficiency, as one of the reasons behind the malnutrition in developing countries. Nutritionally, significant amount of fat and protein of the tested insects could be useful in attempts to mitigate the risk of PEM. Infants and children are the most affected section of population at risk for PEM. The average energy deficit in Indian children is 300 kcal per day (Srilakshmi, 2012). Moreover, these sections of population are predisposed to under-nutrition particularly in the context of developing countries including India and often it is because of maternal malnutrition prior to and/or during pregnancy and diets with low concentration of protein and energy like diluted milk or bulky vegetable foods with low nutrient density. The nutritional value of edible insects demonstrates that insects can fill dietary gaps in places where malnutrition especially under-nutrition is an issue. Consumption of 100g dried Odontotermes sp. can provide 617.406 kcal energy which is the highest followed by A. nepalensis among the tested 8 insects. This knowledge can, in turn, be used to control local nutritional deficiencies or else where who consume insects.

Coronary heart disease (CHD) and fatty acids of edible insects:

The issue of nutraceutical benefits of fatty acids is complex. As it has already been discussed earlier that a high level of saturated fatty acids in foods might be
undesirable because of the linkage of SFA and atherosclerotic disorder; the desirable intake of MUFA is subject to different contextual discussion and beyond the scope of this thesis. The uniqueness of MUFA as a major nutrient in the Mediterranean region’s food supply was first identified by Ancel Keys and his colleagues in the landmark 7 countries study (Keys, 1970). Certain Mediterranean populations in that study had a low prevalence of CHD and low plasma cholesterol levels despite consumption of diet high in total fat and low in SFA. The typical diet of populations living in Mediterranean countries (Spain, Italy and Greece) includes olive oil, which is high in MUFA. A regression analysis of data from the nurses’ health study of 80,082 women followed up for >14 years showed that intake of MUFA was protective against CHD (Hu et al., 1997). To answer debatable question ‘substitute of SFA’, two similar kind of study were conducted by Grundy (1986) and Mensink and Katan (1987) it is found that high fat diet rich in MUFA and low in SFA is having advantage over a low fat/ carbohydrate rich diet. Although both diets lower the total and Low density lipoprotein (LDL) cholesterol, the MUFA diet does not lower high density lipoprotein (HDL) or increases triglyceride, as low fat/ carbohydrate diet does. Among the tested insects A. nepalensis and O. smaragdina were found to contain higher MUFA proportion in their fat and it implies that these insect foods may have advantages over a low fat/ carbohydrate rich diet.

The PUFA/SFA ratio is one of the major parameters currently used to assess the nutritional quality of the fat fraction of foods. Nutritional guidelines recommended for PUFA/SFA ratio is above 0.4 (FAO/WHO, 2003). Among the studied insects, only in case of Chondacris rosea, PUFA/SFA was found 1.180 which was above the recommended value 0.4(FAO/WHO, 2003). PUFA/(SFA-stearic acid) showed a better trend where the values were higher than their respective PUFA/SFA value. However,
the ratio PUFA/SFA is not a very suitable measure of the atherogenicity or thrombogenicity because only three of SFAs are in fact hypercholesteremic (Ulbricht and Southgate, 1991). Consequently, lipid quality indicators that depend on the relative contents of particular groups of fatty acids are Atherogenic Index (AI) and Thrombogenic Index (TI), which indicate the global dietetic quality of fat, therefore, their potential effect on development of coronary heart disease (CHD) (Ulbricht and Southgate, 1991, Jankowska et al., 2010).

In addition to PUFA/SFA ratio for determination of quality of fat, the indices like AI and TI has also been recommended for assessing the quality of fat. Ulbricht and Southgate (1991) proposed Atherogenicity Index (AI) and Thrombogenicity Index (TI). In general it is known that lesser the value of AI and TI better is the quality of fat but there is no such recommended value for AI and TI for any particular type of food containing fat.

The term atherogenic is used for substances or processes that cause atherosclerosis which is a hardening of an artery specifically due to an atheromatous plaque. Atheroma is an accumulation and swelling in artery walls made up of (mostly) macrophage cells, or debris, and containing lipids (cholesterol and fatty acids), calcium and a variable amount of fibrous connective tissue. In context of heart or artery matters atheromata are commonly referred to as atheromatous plaques. AI indicates the relationship between the sum of the main saturated fatty acids and that of the main classes of unsaturated, the former being considered pro-atherogenic (favoring the adhesion of the lipids to cells of the immunological and circulatory system), and the later anti-atherogenic (inhibiting the aggregation of plaque and diminishing the levels of esterified fatty acids, cholesterol and phospholipid, thereby preventing the appearance of micro and macro coronary diseases. Only saturated fatty
acids with chain lengths of 12, 14 and 16 are atherogenic and myristic acid (chain lengths 14) is considered to be four times more atherogenic than the other two. However, all unsaturated fatty acids regardless of their number of double bond, position and configuration are effective in decreasing atherogenicity.

Except for B. orientalis, A1 in all the studied insects were 0.336 to 0.913 whereas some food components like cocoa butter, vegetable oils and meat fats also have the A1 value to be 0.7, <0.5, 0.5-1 respectively. Qualitatively as far as atherogenicity is concern, the fat of all the studied insects were seems to be superior to coconut oil (A1 value 13-20), palm kernel oil (7) (Bobe et al., 2004).

On the other hand, Thrombogenic index (TI) indicates the tendency to form clots in the blood vessels. This is defined as the relationship between prothrombogenic (saturated) anti-thrombogenic fatty acids (MUFA, PUFA n-6 and PUFA n-3). With high TI value, (11.755), in B. orientalis consumption of the same indicate the potential risk for CHD compared to other four studied insects (TI: 0.922 to 2.178). TI values of C. rosea (0.922), O. smaragdina (1.080), and A. nepalensis (1.199) can be compared with reported values for Lithuanian wattle pig (1.23), wild boar (0.95) but higher beaver (0.35) (Razmaite et al., 2011), roach fish (0.41 to 0.54) and conventional meats like lamb, beef, pork, rabbit and chicken (Stanek et al., 2012). It implies that the fat fraction of the insect may be fortified with PUFA of different categories like ω-3 and ω-6.

**Brain related disorders and oleic acid of edible insects:**

Oleic acid was proposed to have a potential role in decreasing brain related disorders such as dementia and Alzheimer’s disease (Park et al., 2006). Park et al., (2006) also reported that, among unsaturated fatty acids, oleic acid had the highest in
vitro inhibition of propyl endopeptidase (PEP), an enzyme that is believed to have a role in amyloid formation in brain.

In this regards considerable proportion of oleic acid in *O. smaragdina*, *A. nepalensis* and *Odontotermes* sp. may be useful in the management of brain related disorders like dementia. Alzheimer's disease; however, further research is needed to come to any such conclusion. Further, proportion of oleic acid was comparable to if not higher than that reported for common foods of animal origin like cow milk (26.6), beef (43.14), chicken (37.52), veal (37.84), and lamb (39.83) (USDA). Therefore, eating such insects can be recommended to the people who eats them and as when the need arises.

**Minerals deficiency and edible insects:**

**Calcium deficiency conditions:** Sixty million people in India are affected by osteoporosis (Srilakshmi, 2012). According to the studies conducted at National Institute of Nutrition (NIN), women in low socio-economic group have thinner bones due to poor nutritional status and poor reproductive health. Osteoporosis is associated with development of soft bones due to reduced plasma levels of calcium and increased bone resorption (loss of calcium from the bones to compensate for low plasma levels). Postmenopausal women are especially susceptible to osteoporosis due to reduced estrogen production because the hormone is believed to improve calcium utilization and bone development. For lactating women calcium loss is due to milk production, maternal urinary and maternal skin calcium loss.

In a cohort study conducted by American Cancer Society (cancer prevention study II nutrition), on more than 120000 men and women showed that, highest intake of calcium through both their diet and supplement modestly reduced the risk of colorectal cancer compared with those who had the lowest calcium intake.
(McCullough et al., 2003). Similar results were reflected in another study on 61000 Swedish women, where, the risk of colorectal cancer was approximately 28% lower among individuals who had the highest Ca intakes (approximately 800-1000 mg per day) compared to those with the lowest calcium intakes (approximately 400-500 mg per day) (Terry et al., 2002). Although, the mechanism by which calcium helps to reduce the risk of colorectal cancer is unclear. Though there are some propositions regarding this: at the biochemical level, calcium binds to bile acids and fatty acids in the gastrointestinal tract to form insoluble complexes known as calcium soaps which reduces the ability of the acids (or their metabolites) to damage cells in the lining of the colon and stimulate cell proliferation to repair the damage. Calcium may also act directly to reduce cell proliferation in the lining of the colon or cause proliferating colon cells to undergo differentiation which in turn, leads to a reduction in cell proliferation (Milner et al., 2001; Lamprecht and Lipkin, 2001). Calcium also improves signalling within cells and cause cancer cells to differentiate and/or die as proposed by Milner et al., (2001). Consumption of 100 g of *C. rosea* meets 56.667% of RDA for calcium which is much higher than conventional meat sources veal, chicken, beef and pork (cf. Fig. 5a).

**Iron and Zinc deficiency conditions:** Iron deficiency is probably the most common nutritional deficiency disorder in the world. Though it was quite old estimate based on WHO criteria which indicated that around 600-700 million people worldwide have marked iron deficiency anaemia (De Maeyer and Adiels-Tegman, 1985). Populations most at risk for iron deficiency are infants, children, adolescents and women of childbearing age, especially pregnant women. Though, iron deficiency has markedly been improved in most developed countries. However, in developing countries, the iron situation is still very critical. Assuming good bioavailability of iron from insects,
recommended daily allowance can be met by consumption of 100g each of *B. orientalis* and *A. nepalensis* for man. Other studied insects also fulfill RDA (92.118% to 45.941%) for man. However, requirement of iron is much higher for woman, but consumption of 100g of *A. nepalensis* can meet 95.238% of RDA for women. Similarly, eating 100g of *C. rosea*, which contains least amount of iron, even then this species can fulfill 37.19% of RDA for woman. Similarly, the central role of zinc in cell division, protein synthesis, and growth is especially important for infants, children, adolescent, and pregnant women; these groups suffer most from an inadequate zinc intake. 100g each of *O. smaragdina* and *Odontoctermes* sp. meet complete RDA for man and to a little lesser extent for women.

**Tannin and health benefits:** Polyphenolic compounds are commonly found in virtually all types of food plants and constitute an important component of human diet. In the present study, all the tested insects were found to contain varying amount of tannin ranging from 478.33mg/100g DM for *A. nepalensis* to 1783.33mg/100g DM for *Schistocerca* sp. Tannin is considered as antinutrient, prevent absorption of nutrients when taken in excess amount there by reduces the food value. However, the recent trend of research identified certain food polyphenols as being potential of health promoting agent because of their ability to act as anti-oxidants and free radical scavengers. The inhibitory effect of green tea on cancer formation has been well studied. Tea contains 3700mg/100g tannin (Savolainen, 1992). Tannin from green tea has shown anticarcinogenic activity in esophageal, colon, duodenum, lung, small intestine, pancreas and skin tumors (Huang and Ferraro, 1992; Conney et al., 1992). Polyphenol-rich blackberry extract exhibited protective effects against oxidative stress in carbon tetrachloride (CCL4) treated rats by reducing lipid peroxidation in the
liver through increased activities of antioxidant enzymes like catalase, glutathione peroxidase and superoxide dismutase (Aluko, 2012).

Higher tannin content in the insects of present study indicate their further possibility of exploration regarding the beneficial effect of tannin, though excessive intake is to be avoided before being experimented to establish a concrete outcome.

Therefore to summarise the nutraceutical potential of edible insects in the present study: for protein energy malnutrition (PEM), Odontotermes sp. may be recommended as it contains much amount of fat (50.93%) and moderate amount of protein (33.67%). As fat content of the species is high, it provides high calorific value. At the same time the quality of fat is a matter of concern and it is found that in Odontotermes sp. proportion of saturated and unsaturated fatty acids is almost similar (SFA/UFA=1.123). Whereas, fat/oil of C. rosea and A. nepalensis are superior to other three edible insects in the present study and comparatively better than conventional meat source or oil sources. However, there is a scope to fortify these insects’ oil with ω-3 fatty acids in order to fulfill the recommendation of FAO/WHO (1994). Since oleic acid content in O. smaragdina, A. nepalensis and Odontotermes sp. are comparatively higher; these insects may prevent brain related disorder. Odontotermes sp. and A. nepalensis may be recommended for the commercial exploitation as edible oil source. As far as the minerals content are concern, assuming good bioavailability consumption of 100g B. orientalis and A. nepalensis satisfy daily iron requirement, consumption of O. smaragdina and Odontotermes sp. satisfy daily zinc requirement. These insect species may be recommended for the iron and/or zinc deficiency. C. rosea can be recommended for the calcium deficiency condition like osteoporosis.
Conclusion: The results of this study confirm the fact that the insects in this study are not just a traditional food but contain reasonable levels of protein, fat, fiber and calorific value. The results also indicate that these insects are rich in essential amino acids like lysine, threonine, valine, leucine, and may well meet the criteria to satisfy protein criteria (FAO/WHO/UNU, 2007). This is particularly important as there is a need for novel protein sources owing to the increasing cost of conventional sources of protein in the third world. In addition, the cereal-based diets common in developing countries could receive a boost with the inclusion of these insects in their diet. The fat contents in these are of good quality having reasonable level of essential saturated and unsaturated fatty acid to substantiate high energy requirement in their physical work and at various physiological situation where need arises for quality saturated fatty acids and unsaturated fatty acids. As far as mineral contents are concerned, they are also good source of zinc, iron, calcium, copper and magnesium. However, further research is needed to understand the bioavailability of nutrients and minerals through edible insects. Though anti-nutrients, like tannin and phytic acid were present in considerable amount in these insects they may not indicate a bar on their food value as far as the food safety is concerned till further study is done on the absorption mechanism of these anti-nutrients for evaluation of their beneficial effects.

Therefore, their continued consumption is advocated and encouraged in solving the problem of malnutrition among the less privileged in parts of Arunachal Pradesh and world at large where need arises. However, the insect food will become better known when both the private and public sectors provide long term promotional support. Food processing sector should take up projects to develop high valued product from insects as there are several scopes to fortify them with lacking nutrients. Insect food should be quickly and widely promoted through consumer publicity
campaigns. In this way, the potential of these food insects can be realized to support government food security policies and broaden the availability of edible insects as commodities in Arunachal Pradesh. Protection and sustainable utilization must be considered in the exploitation of these insects.

Culture system should be developed in order to avail nutritional benefits of edible insects. Food security can be enhanced, where necessity arises, by development and implementation of the protocol for sustainable production system of insects. As livestock in most cases are integrated part of inclusive agriculture growth and also augment income for farmers, likewise edible insect production system may be a good source of income for the ethnic people of the state. Beside the indigenous eaters, edible insects may occupy the attraction as ethnic/exotic food for foreign tourists, as occurs in Thailand and Laos. To encourage the use of insects as food it is reasonable to develop policies to include insects as part of livestock production system. It will also help to reduce adverse environmental effect of animal protein production.

The decline in entomophagy in the ethnic communities is a real cause for concern and has to be taken seriously. Scientific documentation or database preparation of the edible insects and its associated knowledge is required before complete disappearance of the traditional knowledge. The revival of entomophagy may help the tribal communities of Arunachal Pradesh and India as whole.