ASSESSMENT OF THE POLYTANK FOR FUMIGATION AND STORAGE OF COWPEA

FRANCIS ADEMANG KORLETEY
(Dip. Postharvest Tech., BSc. Agriculture, PGD. Grain Storage Management)

A Thesis submitted to the Department of Agricultural Engineering,
Kwame Nkrumah University of Science and Technology,
in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE IN FOOD AND POSTHARVEST ENGINEERING

Faculty of Mechanical and Agricultural Engineering
College of Engineering

JUNE, 2009

DECLARATION

I hereby declare that this work presented to the Department of Agricultural Engineering, is the outcome of my own research work and that no such work has ever been presented anywhere else. Works by other authors, which served as sources of information, have been duly acknowledged by references to the authors.

Francis Ademang Korletey (PG 7624604)	……..……	..…….
(Student's Name and ID)	Signature	Date

Certified by:

Dr. Joseph O. Darko	……..	……..
(Supervisor)		
Dr. Ahmad Addo	.....	.....
(Supervisor)		

Certified by:

Dr. Emmanuel H. Y. Bobobee	…….	…….
(Head of Department)	Signature	Date

DEDICATION

To my late father,

DANIEL KORLETEY ADEMANG

ABSTRACT

Insect infestation of cowpea (*Vigna unguiculata*) in storage is identified as a major constraint facing cowpea farmers in Ghana. The major insect pest causing losses to stored cowpea in West Africa is the cowpea weevil (*Callosobruchus maculatus*). Fumigation is the most effective control method against cowpea weevil considering its mode of infestation. The jute sack lined with a plastic film bag commonly used by farmers for fumigation and storage is very delicate to handle, not sufficiently airtight for fumigation and easily attacked by rodents. The objectives of the project were to (1) assess the polytank for fumigation and storage of cowpea, and (2) compare the storage qualities of stored cowpea using the polytank and jute sack lined with a plastic film bag. The cowpea was fumigated using aluminium phosphide tablets for a period of 7 days and stored for six mouths. Data was collected, analysed and compared between the two storage containers on seed germination, seed vigour, grain moisture content, insect infestation, percentage usable proportion by number and by weight before, mid-storage and after the trial. The levels of phosphine gas concentration in the polytank and the jute sack were assessed daily for 7 days. The results showed no significant differences (1% probability) between the two storage containers in their performance as storage containers in terms of grain moisture content, seed germination, seed vigour, insect infestation, percentage usable proportion by number and by weight. There was also significant difference (5%) in phosphine gas concentration between the two storage containers in their performance as fumigation containers except on day one. However, it was found that fumigation and storage using the polytank had a greater advantage over the jute sack lined with plastic film bag in terms of air tightness, handling and resistance to rodent attacks.

ACKNOWLEDGEMENT

I sincerely thank Dr. J. O. Darko for supervising this work with great patience. I also appreciate the overwhelming support and encouragement that I received particularly from Mr. Joseph Oppong Akowuah and Dr. Ahmad Addo of the Department of Agricultural Engineering and Mr Isaac Ayim, of Kwadaso Agricultural College who helped in the type-setting of the work. I do also acknowledge the moral support of Miss Joyce Mumuni gave to me. Above all, I am sincerely grateful to the Almighty God for being with me throughout this academic journey.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1.0 INTRODUCTION

Cowpea (*Vigna unguiculata*) is the most important food legume grown in the tropical savanna zones of Africa (Langyintuo *et al*., 2003). Although indigenous to south-eastern Africa, cowpea has spread worldwide and is extensively cultivated and consumed in regions of Asia, South and Central America, the Caribbean, the United States, the Middle East and southern Europe (Bingen *et al*., 1988).

Cowpea is a preferred staple food in many regions of Africa. Its desirability reflects the fact that the leaves, immature pods, fresh seeds and dry grain can be eaten or marketed. Also, some varieties have a short cycle and mature early and thus are able to provide food during the "hunger period", the period at the end of the wet season when food can become extremely scarce in semi-arid regions of Sub-Saharan Africa (Langyintuo *et al.,* 2003).

The dry grain is also commonly milled and consumed in numerous traditional dishes in Africa as porridge and bread fed to young children as weaning foods, and eaten as processed snack foods. Cowpea grains, as well as the vegetative parts, make major nutritional contributions to diets. The mature grain contains 23-25% protein, 50-67% starch, B vitamins such as folic acid which is important in preventing birth defects, and essential micronutrients such as iron, calcium, and zinc (Omueti and Singh, 1987).

Cowpea plays a critical subsistence role in the diets of many households, in Africa, Latin America and Asia, providing nutrients that are deficient in cereals. An added advantage of cowpea is that the plants can be harvested as fodder for livestock. In certain regions of West and Central Africa the fodder is highly valued. During the height of the dry season stored cowpea fodder becomes an important feed for livestock.

From an agronomic perspective, cowpea is well suited to the agro-climatic, technological and socioeconomic situations in sub-Saharan Africa. The traits that distinguish cowpea from many other crops currently grown in Africa include substantial adaptation to drought, high potential to biologically fix nitrogen in marginal soils with low organic matter (less than 0.2%), high sand content (more than 85%), and a broad range of pH (4.5 – 9.0), tolerance to high temperatures during the vegetative stage, tolerance to shade, rapid vegetative growth and tri-purpose utilization, producing vegetable leaves and pods, dry grain and forage (Thiaw *et al*., 1993).

Despite this importance of cowpea in food security, trade and therefore poverty reduction, increased cowpea production, storage and marketing face many constraints that need attention from research and development. Although cowpea represents an economical source of protein, calories and B-vitamins, its consumption in the seventies and eighties implied poverty and was associated with low-income groups to the extent that it was regarded as “the poor man’s meat”. The major factor that militated against increased consumption of cowpea was consumer aversion to infested cowpeas, since

acceptability of any food hinges critically on the aesthetics, irrespective of how nutritious the food product is perceived to be (Nielsen *et al*., 1993).

Until recently, most grain fumigation in developing countries has been at large-scale, centralized storage level by marketing boards and cooperatives. However, with increasing agricultural market liberalization and decentralization, many of these grain marketing and storage systems are breaking down resulting in more grain being stored for longer periods by the farmer and trader. The need to fumigate grain at the small-scale level is therefore becoming more important. Given that much of the research into fumigation techniques has concentrated upon large-scale storage systems, there is now a very real need to develop methods and techniques which will be appropriate for much smaller scale, on-farm storage structures.

On-farm storage of dry cowpea for domestic use or local marketing is a major problem in the tropics (Murdock *et al*., 2003). The cowpea weevil (*Callosobruchus maculates)* is a well-known problem during storage of cowpea and there have been attempts to assess the levels of damage that farmers routinely experience and improve on the storage. It is well established that fumigation is the most effective control method against the cowpea weevil and its eggs and larvae inside the seed and does not have any residual effects. Although fumigation with phosphine is a simple technique, results in terms of insect mortality, are often unsatisfactory. This is because, availability of low-cost containers, that are sufficiently airtight, is a problem (Wohlgemuth and Harnisch, 1986). Plastic sacks, which can serve this purpose, are particularly prone to penetration by bruchid

adults emerging from infested seeds in contact with the plastic. This can cause the phosphine gas concentration not to be maintained for a sufficient length of time to completely control the insects (Harris, 1986).

According to Price and Mills (1984) there has been an increase in the incidence of stored product insect populations exhibiting resistance to phosphine. This gives cause for serious concern because the only alternative fumigant currently in general use is methyl bromide, and fumigation carried out with this material requires more equipment and skill than those needed for phosphine if it is to be used successfully. Particular equipment in phosphine fumigations which has often proved difficult to meet is that of maintaining lethal concentrations for the seven days or more needed to kill all insects present. Resistance is developed when successive generations of insects are subjected to such sub-lethal doses of an insecticide. This also results in prompt release of gas to the surrounding environment, which is highly toxic to humans. It is against these backgrounds that the project focused on the assessment of the polytank for fumigation and storage of cowpea, to control the cowpea weevil.

1.1 Significance of the study

Ghana cannot achieve its planned economic growth and poverty reduction without a significant improvement in the performance of the agricultural sector. Storage of food therefore enhances food security through continuous supply of food for processing and distribution. Inadequate, inappropriate, as well as expensive storage facilities are constraints to agricultural production. They contribute to high postharvest losses and low

returns for farmers and processors. Minimising postharvest losses and maintaining high quality of produce are crucial for sustainable and profitable agriculture. The nature of storage structures and the type of storage management practices leave much to be desired. The contribution of cowpea to food and poverty reduction can be substantial in Ghana if both biological and socioeconomic constraints such as storage and marketing are addressed. The demand for cowpea is increasing because of high population growth mainly from the urban areas and also because of poverty and demand for low-cost food (Langyintuo *et al.*, 2003).

While attention has been given to genetics, agronomy and pre-harvest pest control, such economic issues as storage which enhances shelf life, marketing quality and consumer preferences are neglected in cowpea research. Cowpea suffers heavily from insects, both in the field as well as when the grain is stored after harvest. Yield reduction caused by insects can reach as high as 95 percent depending upon the location, year and cultivar (Murdock *et al.*, 2003). Most cowpea farmers in sub-Saharan Africa including Ghana are confronted with storage problems. Cowpea has to be sold soon after harvest in many semi-arid areas of Africa because they cannot prevent losses due to storage insect pest damage. Selling early in the season results in a loss of income because prices rise over time as grain legumes become increasingly scarce. However, deterioration in cowpea quality is not just a problem faced by farmers. Traders at all levels within the system also suffer storage losses as a result of increased pest damage. Damage and weight loss to stored cowpea are caused by the larvae, which develop inside the grain and consume the seed. Often, farm storage for six months is accompanied by about 30% loss in weight

with up to 70% of seeds being infested and virtually unfit for consumption (Murdock *et al.,* 2003). The damage incurred is highly significant as poor quality cowpea commands much reduced market prices.

In an attempt to control the cowpea weevil, farmers have adopted the use of locally available plant parts and other minerals in large quantities as repellents for cowpea storage. Such methods are not universally accepted, however, because of the problem of adulteration of the grain. This causes chemical residual and toxicological effects on consumers. Similarly, it is now well established that vegetable oils such as palm oil and groundnut oil are very effective in controlling certain species of bruchids on pulses by their ovicidal effect (Golob and Webley, 1980). Some of these cheaply available oils in the locality will be effective but may impart some rancid or off-flavour to the product which will be unacceptable to consumers (Schoonhoven, 1978).

1.2 Objectives of the project

The general objective of this project was to conduct evaluation studies and compare the effectiveness of the polytank for fumigation and storage of cowpea to the existing technology using jute sack lined with plastic film bag.

The specific objectives of the project were to:

1. assess the polytank for fumigation and storage of cowpea, and
2. compare the storage qualities of stored cowpea using polytank and jute sack lined with plastic film bag.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The crop

Cowpea (*Vigna unguiculata)* is a legume that is extensively grown throughout sub-Saharan Africa. It is a subsistence crop, often intercropped with sorghum, maize and pearl millet. The grain provides valuable protein and the leaves are used as a nutritious vegetable. Cowpea is an indigenous crop that has evolved from the native wild types and its genetic diversity is greater than that of any crop in the dry African savannah (IFAD, 2000). It is an annual herb with a strong principal root and many spreading lateral roots in surface soil.

The root system has large nodules containing bacteria (*rhizobia*). The *rhizobia* possess a nitrogenase complex, an enzyme capable of reducing atmospheric nitrogen into compounds assimilable by the host plant. Effective cowpea rhizobium symbiosis fixes more than 150 kg N/ha and supplies 80-90 of the host plant nitrogen requirement (Aveling, 1999*). Badyrhizobiuim sp* are the specific symbiotic nodular bacteria.

Growth forms vary and may be erect, trailing, climbing or bushy, usually indeterminate under favourable conditions. Leaves are alternate and trifoliate usually dark green. The first pair of them is simple and opposite. Stems are striate, smooth or slightly hairy, sometimes tinged with purple (Aveling, 1999).

There are usually 8-20 seeds per pod that vary in size, shape, colour and texture. They are usually brown when ripe but may also be brown or purple in colour. They may be erect, crescent-shaped, or coiled. They are relatively large, 2-12 mm long and weigh 5-30g/100 seeds. The testa may be smooth or wrinkled, white, green, red, brown, black, speckled, blotched, eyed (the hilum central line is white surrounded by a dark ring) or mottled in colour (Porter *et al.,* 1974).

2.1.1 Geographical distribution of cowpea

Its geographical range is wide. It grows best in hot areas and can produce a yield of one tonne seed and five tonnes hay per hectare with as little as 300mm of rainfall. A long tap root and mechanisms such as turning the leaves upwards to prevent them from becoming too hot and closing the stomata give to cowpea an excellent drought tolerance (Van Rij, 1999). This makes it the crop of choice for the Sahelian zone and the dry savannahs, though cultivars that flourish in the moist savannah are available as well The length of the growing season varies with type; 100 days in the determinate type, 110 days in the semi-determinate, 120 days in the ranking type. The climate will also have an effect on the length of the growing season; the hotter the weather, the shorter the maturity period (Van Rij, 1999).

2.1.2 Nutritional properties

The protein in cowpea seed is rich in amino acids, lysine and tryptophan in comparison with cereal grains as indicated in Table 1. However, it is deficient in methionine and cystine in animal protein.

Table 1: Chemical composition of cowpea

Component	Seeds (%)	Hay (%)	Leaves (%)
Carbohydrate	56-66	-	8
Protein	22-24	-	4.7
Water	11	18	85
Crude fibre	5.9-7.3	9.6	2
Ash	3.4-3.9	23.3	-
Fat	1.3-1.5	11.3	0.3
Phosphorous	0.146	2.6	0.063
Calcium	0.104-0.076	-	0.256
Iron	0.005	-	0.005

Source: Quinn (1999)

2.1.3 Diversity and origin of cultivated cowpea

Cultivated species are usually variable because of artificial selection under diverse environments, and cowpea is no exception. *Unguiculata* is the most diverse of the cultivated subspecies *unguiculata* and has the widest distribution. It is commonly called cowpea and is widely grown in Africa, India and Brazil. Varieties are prostrate, semi-erect, erect or climbing, and pods are coiled, round, crescent or linear.

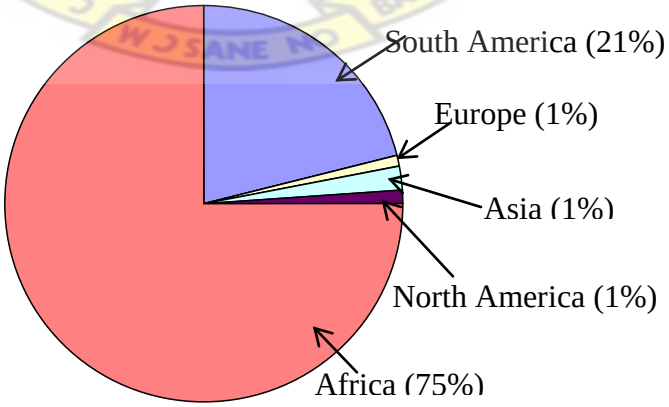
Peduncles are from less than 5cm to more than 50cm long. The number of days from sowing to pod maturity of different cultivars varies from 53 days to more than 120 days when grown in Ibadan during the second growing season (Porter *et al*., 1974)

2.1.4 Cowpea cropping system

In West Africa, including Ghana, cowpea is grown mostly in subsistence farming systems and on a small scale in the lowland dry savanna and Sahelian region. Traditionally, cowpea is grown in association or in relay cropping with cereals such as sorghum, millet and maize mainly in Sahelian regions. However, cowpea cropping systems are moving towards monocropping as the crop's economic importance increases (Coulibaly, 1987). Increase in cowpea production is linked to the use of improved technologies including high yielding varieties and improved crop protection and production practices. A key issue behind the wide use of the improved cowpea technologies is their profitability.

2.1.5 Cowpea production

World cowpea production as shown in Figure 1 was estimated at 3,319,375 MT and 75% of that production is from Africa (FAOSTAT, 2000). West Africa is the key cowpea producing zone, mainly in the dry savanna and semi-arid agro ecological zones. The principal cowpea producing countries are Nigeria, Niger, Senegal, Ghana, Mali and Burkina Faso (Langyintuo *et al*., 2003).



Source: FAOSTAT (2000)

Figure 1: World cowpea production

According to Lowenberg-DeBoer (2000), Ghana is one of the major producers of cowpeas in the world but in addition, it imports about 10,000 MT annually, about 30 percent of the Ghanaian imports are from Burkina Faso and the rest from Niger as shown in Table 2. In Accra, the large, rough coated Niger cowpea sells for a premium, but it needs to be marketed quickly because it does not store well in the humid coastal climate. Table 3 shows the domestic food supply and demand position of some food crops grown in Ghana.

Table 2: Official imports of cowpea into Ghana, (1992 -1998)

Year	Total imports (MT)	Imports from Burkina Faso (MT)	Imports from Burkina Faso (% of total)	Imports from Niger (MT)	Imports from Niger (% of total)
1992	2055.34	592.00	28.80	14.63	71.20
1993	2640.80	637.92	24.36	2002.88	75.84
1994	11798.98	2898.95	24.57	8900.03	75.43
1995	13086.29	3295.95	25.19	9790.34	74.81
1996	6816.80	3077.79	45.15	3739.01	54.85
1997	NA	NA	NA	NA	NA
1998	10167.18	3050.15	30.00	7117.03	70.00

Source: Langyintuo (1999)

Table 3: Domestic Food Supply and Demand Position (2004)

Crop	Total Domestic Production ('000 Mt)	Production Available for Human Consumption ('000 Mt)	Per Capita Consumption (kg/Annum)	Estimated National Consumption ('000 Mt)	Deficit/Surplus ('000 Mt)
Maize	1,158	810	42.5	894	-84
Rice (milled)	145	116	14.5	305	-189
Millet	144	101	9.0	189	-88
Sorghum	287	201	14.8	311	-110
Cassava	9,739	6,817	151.4	3,186	3,632
Yam	3,892	3,114	42.3	890	2,224
Plantain	2,381	2,024	84.0	1,767	257
Cocoyam	1,716	1,373	56.0	1,178	195
Groundnut	390	332	20.0	421	-89
Cowpea	141	120	0.9	19	101
Total	19,993	15,008	435.4	9,160	5,849

Source: SRID, MOFA (2004)

2.2 Pest management

2.2.1 Field Pest Control

It has been shown in most of the cowpea producing countries in West Africa that field pest problems are substantial, and insects such as flower thrips are highly implicated in production losses (Jackai and Adalla, 1997). Without chemical treatment at flowering, for instance, there can be total crop failure. Results from insecticide treatment on improved

varieties have shown a substantial yield increase from 30 to 100 percent compared to non-treated cowpea (Salifu, 2000). Most of the pest management research on cowpea in West Africa has focused on developing and testing field and storage pest control technologies. Among these technologies are improved genetic material (pest and disease resistant and tolerant varieties), insecticide treatment and plant extract.

2.2.2 Storage pest control

2.2.2.1 Low temperature

A serious postharvest pest of storage cowpea grain is cowpea weevil. . Loss of methyl bromide and possible restriction of phosphine in some countries, in addition to rising popularity of organic produce lines has created interest in non-chemical disinfestation treatments. In developed countries, one alternative is the use of cold storage. Johnson and Valero (2000) found that exposures to – 8^{o}C during 6 to 24 hours reduced pest numbers by more than 99 percent.

2.2.2.2 Solarisation

Solar disinfestation technology is an effective, low cost, non-toxic pest control process, which does not alter the physical, cooking, nutritive, and other desirable properties of the cowpea grain (Nyankori, 2002). Exposing threshed cowpea to solar radiation on a simple solar heater developed at Purdue (USA) and tested in Cameroon can kill within minutes, resident infestation of cowpea weevils in grain. This technique has already undergone testing and extension in Cameroon and in many West African countries, namely, Burkina Faso, Mali, Nigeria, Chad, Benin and Ghana (Ntoukam *et al.,* 2000).

2.2.2.3 Metal Drums, Plastic Sheets and Plastic Bags

In 1998, the Cowpea Collaborative Research Support Program (CRSP) carried out studies on feasibility of metal drum storage, especially with botanicals, steam treatment and other storage technologies for rural and urban use. Results have indicated that, like the solar heater and triple bagging, drum storage has the greatest economic advantage for long storage period, more than 3 months. Metal drum storage has a lower labour requirement than solar treatment or insecticides because the grain is handled only to fill and empty the drum. In Senegal, drum storage is economical because of the large supply and hence modest cost of steel drums. Over 80% of stored cowpea is stored in the metal drum (Faye and Lowenberg-DeBoer, 1999).

2.2.2.4 Plastic Bucket, Solarisation and Kim-Kim Solution

On-farm trial in farmers' stores, to test the most promising treatments for protecting grain pulses identified in station trials, revealed that hermetic storage in plastic buckets is very effective. Unfortunately it was also the most expensive form of protection tested and is therefore unlikely to be adopted by farmers (Murdock *et al.*, 2000). Thermal disinfestation (seed laid out in the midday sun for 3 hours) proved to be very valuable followed by treatment with "kim-kim" (*Synedrella nodiflora*) solution or admixture with "shea" nut butter. Farmers have more recently commented that it discolours cowpea, which deters consumers and reduces the market value (Lowenberg-DeBoer, 2000).

2.2.2.5 Contact chemicals

The commonest use of insecticides in this manner is admixture with raw grain. The treatments, when timed and applied efficiently, are generally highly effective, reasonably inexpensive and safe in practice. The main limitations in effectiveness arise from misuse, which may create hazards and accelerate the development of pests resistance or from logistical or formulation problems which may lead to the marketing of poor quality product (Arthur, 1996). In Benin, for example, more than 294,000 farmers use banned insecticides such as organochlorides or organophosphates on cowpea. Death and poisoning were reported from 16 villages in seven out of 12 districts in Benin, as a result of cotton insecticides, which are very often diverted onto cowpea. If poisoning occurred at the same rate throughout all cotton growing areas, at least 70 people might have died as a result of endosulfan (organochloride) use in just one cotton producing district in Benin (Langyintuo, 2000).

Cotton insecticides are virtually the only pesticides available in the rural areas of northern Benin and the only ones delivered on a credit basis. This may account for some of the hazardous uses of the insecticides, such as on food crops or in storage. Such inappropriate uses of cotton pesticides in West Africa are well know to cotton research institutes and should have been considered when selecting insecticides for large-scale application. In Cameroon, a survey in the Western mid-altitude region showed that various chemicals are used for pest control in the field and in storage by farmers and traders (Lowenberg-DeBoer, 1994). Synthetic chemical products are reported to be used by 46 percent of traders and 12 percent of farmers to protect cowpea in storage whereas 17 percent of the

traders and 40 percent of the farmers reported using traditional methods of treatment (no chemicals). Among the traders using chemical control in storage 57 percent reported using Actellic or Actellic super (Primiphos methyl, or primiphos methyl plus permethrin), and methyl-parafene (22%). Other unidentified chemicals are used by 24 percent of chemical users for storage of cowpea. Malathion and prohibited DDT are also fairly often used and are easily obtainable from local dealers (Murdock *et al.*, 2003).

Among farmers using chemicals in storage, 65 percent reported the use of methyl parafene. Ease of use (tablet or dust formulations) and effectiveness in controlling weevils were cited as the major reasons for wide use of chemicals in storing cowpea. Insecticide admixtures, if correctly applied, will disinfest the treated commodity. In Ghana grains are treated with Actellic 25EC or Actellic 2% dust or Actellic super EC (pirimiphos-methyl plus cypermethrin) before storage at the rates of 1kg of Actellic 2% dust to 20 bags of threshed cowpea and 5ml of Actellic 25EC diluted with 195ml of water to treat 100kg of threshed cowpea (FCDP, 2005). The admixture of pesticides will always produce a residue in the commodity which will be more or less persistent depending upon the chemical nature of the pesticide used. So long as it persists relatively unchanged, the residue has positive value in providing protection against reinfestation. However, it may also create a potential hazard or, at least, a source of possible anxiety to the user of the commodity (Murdock *et al.*, 2003)

2.2.2.6 The use of other additives

Traditional grain protectants including wood ash, vegetable oils and abrasive powders such as diatomite, are of considerable value in on-farm storage, but they are generally much less effective than the synthetic grain protectants (Golob and Webley, 1980). They are mostly chemically inert materials which may be abrasive, absorbent or obstructive. They act as insecticides by damaging the surfaces of an insect's body, so that it dies by loss of moisture or by impeding an insect's movements in the commodity. The use of such materials, especially wood ash or locally available mineral dust or sand, appears to be widespread. Amongst rural communities in the tropical countries they may be considerable value even when not completely effective.

More recently, in addition to the traditional materials, some very effective synthetic compounds such as silica aerogels with non-chemical insecticidal action have been developed as grain protectants or proposed for use as insecticide carriers (Shawir *et al.,* 1986). These are less likely to be suitable for rural use despite their effectiveness, because they would be more costly. The use of inert silica dust has been usefully reviewed by Ebeling (1971). In India, activated kaolins and vegetable oils are recommended for control of bruchid beetles. Shawir *et al.,* (1986) have recommended that, use of levilite (amorphous aluminium pentasilicate) for protecting beans with rates of application up to 0.4%. The action of silica dusts and ashes of materials like rice husk, which contain at least 90% silica, is abrasive. Their effectiveness for insect control is consequently influenced by the grain moisture content and the ambient relative humidity. The drier the conditions, the more likely it is that a high level of control will be achieved. Silica

aerogels are non-abrasive powders that damage the insect by absorbing surface waxes and moisture. They also absorb other oily substances and are therefore less effective when used on commodities of high oil content.

In Ghana vegetable oils such as palm oil and groundnut oil are particularly effective as protectants against bruchid beetles. Adult beetles are little affected by the presence of oil admixed at 5ml/kg, but egg mortality is increased. The oil may inhibit oviposition or it may obstruct the entry of oxygen into the egg and it may also enter the egg and prevent development (Singh *et al*., 1978). The effect of sand as a stored grain protectant may be largely obstructive. Sand is sometimes used to cover completely the exposed surface of grain in a storage vessel, thus reducing access by insects. Where it is admixed throughout the grain, so that the intergranular space is filled, the movements of the insects amongst the grains are impeded and this may reduce or prevent both feeding and breeding. The effectiveness of inert materials as grain protectants, particularly the abrasive materials depend greatly upon the conditions of use. Relatively high application rates are needed (Golob and Webley, 1980).

2.2.2.7 The use of plant extracts

A number of other naturally occurring materials which have been used or suggested as grain protectants and may also be particularly useful in rural storage are more correctly described as chemical protectants (Golob and Webley, 1980). These include plant materials that are aromatic and may be repellant to insects, such as the dried fruit of *Capsicum species*, the powdered roots of *Derris elliptica* (“derris dust”) and the leaves

and seeds of the neem tree, *Azadirachta indica*. Derris dust contains the toxin rotenone while azadirachtin, in neem, has antifeedant properties (Schmutterer, 1990). In Ghana, Togo, Benin and other African countries in the eighties, GTZ extended a stored cowpea protection method based on the use of neem oil. This method offered the following advantages in small-scale farming. It was easy to apply, it required locally available resources, raw materials were free and it posed no risk to users and consumers (Forster and Moser, 2000).

Given the considerable losses caused by bruchids and the advantages mentioned, there is no doubt that the recommendations responded to a real and serious problem, and that the proposed technology had all that was required to attract the interest of the rural target groups. In fact, farmers found that neem oil was very difficult to extract and also it was very bitter. In spite of all the effort at extending it, the adoption rate for the preservation of cowpea with neem oil remained generally low. Informal investigations carried out in the framework of the extension programme in Benin revealed that the collection of grains, and most especially the cottage industry production of oil were considered too energy and time consuming. Furthermore, the bitter taste of neem oil discouraged many farmers from applying it on beans meant for consumption (Murdock *et al.,* 2003). The extracts of *Bascia senegalensis*, a common plant in the Sahel, is shown to cause 75 to 100% mortality among cowpea bruchids at very low concentration (0.67g/l), in Senegal (Murdock *et al*., 2003).

It is often assumed that natural plant extracts are safer than synthetic chemicals, but this is not always true. Plant fragments or extracts should not be recommended for admixtures with stored foodstuffs until appropriate tests had proved them to be safe (Golob and Webley, 1980).

2.3 Principles of fumigation

Fumigation is a very specific operation in which a gas is held in an air-tight enclosure for a set period of time. When applied correctly, fumigation will kill all insects, mites and rodents within the gas-tight enclosure. However, this treatment confers no lasting protection; as soon as grain is no longer in the gas-tight enclosure it may become re-infested (Price, 1985). For this reason, fumigation cannot be used as the only means of pest control, it needs to be linked to the wider pest management strategy that limits the opportunity for reinfestation. Fumigation is a very convenient pest control technique as grain can be treated without undue disturbance. Grain can be fumigated wherever it is stored, provided that it can be sealed to give sufficient gas tightness, for example, in warehouses, silos, rail-cars, containers, ships or barges (Heseltine, 1973). For fumigation to be successful, recommended dosage rates and exposure periods must be followed.

2.3.1 Basic properties of fumigants

2.3.1.1 Physical properties

Fumigants are able to exist in the gaseous state at ambient temperatures and pressures. They also diffuse very readily in air and through granular commodities (Price, 1985).

2.3.1.2 Biological properties

All fumigants act as respiratory poisons and are potentially lethal to all stages of insect and mite development, provided that adequate concentrations of gas are maintained for a sufficient time period (Wohlgemuth and Harnisch, 1986).

2.3.1.3 Environmental properties

Fumigants are generally non-persistent and are only present in treated materials for a relatively short period of time. However, treatment at a high dosage (rate) or repeated treatments can cause the accumulation of significant residue, particularly when the fumigant reacts chemically with constituent of the treated commodities (Price, 1985).

2.3.2 Fumigation with Phosphine

The insecticide properties of phosphine were first demonstrated by Freyburg in 1935 using aluminium phosphide powder in packets, but it was not until the mid 1950s, and after considerable research, that this simple and convenient method of fumigation gained world-wide popularity. In 1973, Heseltine published "A guide to phosphine fumigation in the tropics" (Heseltine, 1973), but more recently there has been an increase in the incidence of stored product insects populations exhibiting resistance to phosphine. This gives cause for serious concern because the only alternative fumigant currently in general use is methyl bromide and fumigation carried out with this material require more equipment and skill than those needed for phosphine if it is to be used successfully.

2.3.2.1 Properties of Phosphine

It has a density similar to air so its distribution in, for example a bag stack, is far less of a problem than for methyl bromide. It penetrates a stack or bulk of grain easily and does not leave any residue (Scudamore and Goodship, 1986). Pure phosphine is colourless and odourless, however, impurities result in a garlic-like smell. It is slightly soluble in water and explosive at a concentration above 1.7 % in air. It combusts spontaneously at temperature above 100 ^{o}C and at reduced pressures.

2.3.2.2 Phosphine dosages and exposure periods

The minimum temperature for the use of phosphine is about 15^{o}C and at temperatures below 20^{o}C long exposure periods of up to 16 days are recommended. Below 15^{o}C, insect activity is so slow that exceedingly long and therefore impractical, exposure period would be required before total control could be guaranteed (Harris, 1986). Fumigation dosage is calculated on the volume of the sheeted stack or the tonnage of the commodity to be fumigated. The former is preferred because the total volume has to be treated and it may be more than that occupied by the commodity, for example, in a part-filled silo. However, if the stack is irregular in shape it may be more convenient to calculate the dosage on tonnage.

Under a sheeted stack the available airspace is approximately 50 % of the total volume, the remainder being occupied by the commodity and its packaging. In theory this would double the phosphine concentration, but in practice this does not occur because some of the phophine is lost owing to leakages through damaged sheet and floors and inadequate

sealing of sheets to floors, the permeability of sheets and floors to phosphine, absorption on to sheets, commodities and packaging and chemical breakdown of phosphine. The most serious losses are attributable to leakages, and a successful fumigation with a single application of fumigant requires still air conditions, the proportion of fumigant lost will increase with extended exposure periods. Table 4 presents the dosage rates of phosphine for effective fumigation.

Table 4: Recommended dosage rates of phosphine for effective fumigation.

Type of fumigation	Recommended dosage g PH_3 per tonne	g PH_3 per m^3
Bulk fumigation gas-tight silos	2 to 4	1.5 to 3.0
Bagged commodities under gas proof sheets	3 to 5	2 to 3.5
In-bag fumigations	0.2 per bag	
Space fumigation, e.g. empty store	0	0

Source: NRI Training Manual (2000)

2.3.2.3 Criteria for a successful phosphine fumigation

For a phosphine fumigation to be a success, the gas concentration must not fall below a minimum value during the required exposure period. Table 5 presents minimum duration of fumigation with phosphine. Current recommendations state that the concentration must not fall either below 150 (ppm) before the end of the seventh day (NRI, 2000).

Table 5: Minimum duration required for fumigation with phosphine

Temperature (^{o}C)	Duration of fumigation (days after application of the fumigant)
Below 15	Do not use phosphine
15 to 25	10
Above 25	7

Source: NRI Training Manual (2000)

2.3.2.4 Detection of phosphine and the monitoring of concentrations

Although it is often suggested that the smell (due to impurities within the gas) can be used as a warning to people of its presence, the smell is only generated at concentrations in excess of that which should be encountered (Webley *et al*., 1981). This argument is further strengthened by Taylor (1989) in that the amount of smell present (for a given gas concentration) is presumably dependant on the gas purity (which could vary between sources), and that people's sensitivity to smells will vary from one person to another. Concentrations should therefore be determined using a suitable monitoring device. On occasion it is necessary to monitor phosphine concentrations during fumigations, for example where an application technique is not giving satisfactory results, and for field research purposes. Gas-detector tubes have been commonly used for this purpose, but they are expensive and relatively inaccurate up to $\pm$15%. Webley *et al.*, (1981), described the successful use of a portable infra-red gas analyer in Mali, but very expensive.

A less expensive field meter known as the "bubbler" was developed by Taylor (1989). This instrument indicates the phosphine concentration by comparing colour changes with

a Lovibond Disc Comparator, and is accurate within 10 % but can not be used to measure concentrations below 0.2 g/m^3. A conductimetric method was developed at ODNRI by Harris (1986) using a cell connected to a meter which gives a digital read-out in (ppm). This equipment has been field-tested in several countries, is accurate to $\pm$ 15% and less expensive. Although there are several methods of determining concentrations of phosphine in air, the two most common methods are Gas Detector Tubes and Electronic meters. Electronic meters, fitted with electrochemical sensors, such as the Bedfont EC 80 phosphine Monitor which measures phosphine concentrations in the range 0 to 2000 ppm. Samples may be drawn directly into the meter using an aspirator bulb, or by syringe injection.

2.3.2.5 Factors that influence gas loss

Once the sources of gas loss are recognized, it is important to consider the various factors that will influence the rate of gas loss from various structures including those in which a high level of gas tightness has been achieved. In this context, studies in Australia have indicated the significance of temperature, wind, velocity, and barometric pressure. Because the temperature in most commodities is relatively stable, ambient temperatures, particularly diurnal changes, will create pressure gradients within the fumigated structure due to the relative density of the atmosphere (Champ and Dyte, 1976). Hence, during the heat of the day, leakage from the bottom of the structure will occur, while at night leakage will occur from the top. This is the so-called “chimney effect” and is most pronounced in vertical silos. Where the atmosphere of the structure is heated and cooled with diurnal changes, for example in freight containers, the resultant expansion and

contraction of the internal atmosphere will produce pressure gradients. Hence gas will leak out during the day as the temperature rises and will be diluted by incoming air during the cooling phase at night. Wind is also an important factor affecting gas loss. Wind blowing around and over a structure will create pressure gradient across the surface of the structure and this will increase rates of gas loss (Harris, 1986).

Qasim-Chaudhry *et al.,* (1989) clearly illustrated that the rate of gas loss from a fumigated structure was increased when exposed to "puffs of wind". This appears to be especially important when using thin polyethylene structures since they are particularly prone to wind-induced gas loss. This wind-induced gas loss is due to the "chimney effect", and is proportional to the difference in gaseous densities inside and outside of the structure (Banks and Annis, 1984). Gas loss due to chimney effect is also induced by changes in external temperatures, for example, throughout the day. Therefore careful selection of the location of stores where they are protected against both wind and extremes of temperature should assist in inducing the rate of gas loss from storage structures. Changes in barometric pressure during fumigation will also influence loss by creating pressure gradients between the inside and outside of structures. A fall in barometric pressure will cause a simple gas loss, but a rise in atmospheric pressure will result in dilution of the gas within a structure, that is lowering of the concentration.

Sorption is the retention of gas by any solid or liquid material with which it is in contact. The degree of absorption of the fumigant by commodity varies between fumigants and commodities (Worhlgemuth and Harnisch, 1986). Generally absorption is less of a

problem with phosphine when compared with methyl bromide, and so recommended dosage rates of phosphine are usually quoted irrespective of the commodity being fumigated. It should be noted, however, that significant quantities of phosphine are absorbed by paddy, brown rice, grain legume in-shell, and some varieties of wheat so it is recommended that the dosage should be increased to 4 grams per tonne in these cases. (Scudamore and Goodship, 1986). Cotton seed and linseed and therefore oily seeds are very high sorptive commodities, and large quantities of phosphine must be added to compensate for the quantity of gas lost due to absorption and long aeration periods will be required to allow this absorbed gas to be released.

2.3.2.6 Uptake of phosphine by insects and its mode of action

Oxygen appears to be essential for the absorption of phosphine by insects as it does not occur to any appreciable extent under anoxic conditions (Price, 1985). Opening and closing of spiracles had little effect on absorption, possibly because phosphine diffuses readily through the insect integument. It was observed that after cockroaches had been exposed to phosphine, they continued to exhibit muscular spasms until exhausted. The extent of the injuries sustained appeared to be related to the concentration of phosphine to which the insects had been exposed, and this condition was irreversible (Price and Mills, 1984). The rate at which phosphine is absorbed varies with different insect species, *Tribolium confusum* rapidly becomes saturated during a 5 hour exposure to 5 mg/l of phosphine, whereas *Sitophilus granarius* absorbed phosphine more slowly over a 24 hour period. It was suggested that the reaction of phosphine with copper and copper

compounds indicates a possible reaction with cytochrome oxidase, and that phosphine may have a direct effect on the biochemical components of the respiratory system.

The insecticidal properties of phosphine have been reviewed by Price (1985) who stated that it was the inhibition of the enzyme catalase, rather than cytochrome oxidase, which caused mortality in insects. Catalyse lowers the level of energy required to reduce hydrogen peroxide to oxygen and water. In addition to variation in the rate of phosphine uptake exhibited by different insect species, Webley *et al.* (1981) reported that the adult and juvenile phases within a single species exhibit different tolerance levels to phosphine, in four species of stored product moths eggs and pupae were generally more tolerant than larvae and adults. Furthermore, young eggs were less susceptible than older ones and to a lesser extent the same applied to pupae. Variations also occurred between strains within a single insect species as to their susceptibility to phosphine.

Using radio-active phosphine Price, (1985) carried out experiments which indicated that a resistant strain of *Rhizopertha dominica* actively excluded phosphine absorbing less than a susceptible strain. Non-absorption was enhanced by increase in both temperature and carbon dioxide content, and metabolic detoxification did not appear to contribute to resistance. Live and dead adult insects from susceptible strains were used in the experiment and it was observed that, live susceptible insects absorbed phosphine rapidly for the first two hours of exposure and then the rate declined. Live resistant insects absorbed phosphine slowly for the first 5 hours after which there was a slight increase and dead susceptible and resistant insects absorbed phosphine at approximately the same

rate, but more slowly than live susceptibles. Only dead insects desorbed phosphine. Live resistant adults absorbed phosphine at a slower rate than dead insects and exhibit negative exclusion for the first 5 hours (Price and Mills, 1984).

From the above, it can be seen that the precise way in which phosphine kills insects is not known. However it is clear that there is considerable variation in both the minimum lethal concentration and exposure period to obtain 100% mortality for the different insect species, strains within a single species and the adults and juveniles which may be present in any given infestation. For this reason recommendations are based on dosage rates and exposure periods to kill the most tolerant insects (Price and Mills, 1984).

In any given field situation these recommendations may have to be adjusted upwards where more tolerant insect pest complexes commonly occur. Because of variation in the rate of phosphine uptake within a mixed insect population, higher dosage rates will not compensate for reduced exposure period (Scudamore and Goodship, 1986).

2.4 Relative status of the major cowpea pest

Common Name: Cowpea weevil

Scientific Name: *Callosobruchus maculatus* (Fabricius)

Order: Coleoptera

Family: Bruchidae

Distribution

Callosobruchus maculatus originated in Africa, where it is still the dominant species of *Callosobruchus*. It is now distributed throughout the tropics and subtropics (Southgate, 1978).

Recognition and identification

In common with other species of *Callosobuchus*, *Callosobruchus maculatus* has a pair of distinct ridges (inner and outer) on the ventral side of each hind femur, and each ridge bears a tooth near the apical end. The inner tooth is triangular, and equal to or slightly longer than the outer tooth. The antennae of both sexes are slightly serrate. Females often have strong markings on the elytra consisting of two large lateral dark patches mid-way along the elytra and smaller patches at the anterior and posterior ends, leaving a paler brown cross-shape area covering the rest. The males are much less distinctly marked (Haines, 1991). The larvae and pupae are normally only found in cells bored within the seeds of pulses.

Life history and behaviour

Callosobrachus maculatus is a major primary pest of *Vigna unguiculata* (cowpeas), *Lens* culinaris (lentils) and *Vigna radiata* (green gram).

The adult beetles, which do not feed on stored products, are very short-lived usually not more than 12 days under optimum conditions and during this time the females lay many eggs up to 115, although oviposition may be depressed in the presence of previously infested seeds (Southgate, 1979). The optimum temperature for oviposition is 30 to 35^{o}C. As the eggs are laid, they are firmly glued to the surface of the host seeds, smooth-seeded

varieties being more suitable for oviposition than rough-seeded varieties (Southgate, 1978). The eggs are domed structures with oval, flat bases. When newly laid they are small, grey and inconspicuous. Upon hatching, the larva bites through the base of the egg, through the testa of the seed and into the cotyledons. Detritus produced during this period is packed into the egg as the insect hatches, turning the egg white and making it clearly visible to the naked eye (Southgate and McFarlane, 1976).

The developing larva feeds entirely within a single seed, excavating a chamber within the cotyledons as it grows. The optimum development conditions are around 32^{o}C and 90% relative humidity and minimum development period is short (21 days). At 25^{o}C and 70% relative humidity, the total development period of cowpea weevil breeding on seeds of *Vigna unguiculata* is about 36 days pupation taking place within the seed 26 days after oviposition (Southgate, 1978). Infestation can begin in the field, where eggs are laid on maturing pods. As the pods dry, the pest ability to infest them decreases. Thus, dry peas stored in pods are quite resistant to attacks, whereas threshed peas are susceptible to attack throughout storage (Allotey, 1991).

2.5 Features of the Polytank

Polytanks have replaced tanks of most other materials especially metal tanks over the last decade. Polytanks are made of high quality polyethylene and are originally used for holding drinking water and food. The size ranges from 10,000 litres to 30,000 litres, with a wall thickness of 10 cm. Polytanks are relatively air-tight when the lid is tightly sealed against the tank, especially with the use of adhesive cello-tape. The advantages polytank

have over storage tanks made from most materials are its lighter weight, easy to transport, handling and positioning.

2.6 Seed germination

Although seed dormancy is common among species in a wide range of plant families, it has largely been overcome, with some notable exceptions, in most important commercial crops (Villiers, 1972). In the absence of dormancy, the basic germination requirements for crop species are simple: adequate temperature, water, and a favourable gaseous environment (Hegarty, 1984). When any of these basic requirements become limiting in seedbed, seeds may fail to germinate. Seed quality determines the ability of seed to cope with these sub-optimal conditions and to compete with soil micro-organisms for resources (Tekrony and Egli, 1991). Thus, germination is defined by the International Seed Testing Association (ISTA, 1985) as the emergence and development of the seedling to a stage where the aspects of it essential structure indicate whether or not it is able to develop further into a satisfactory plant under favourable conditions in the soil.

2.6.1 The relevance of germination test

The ultimate objective of testing for germination is to gain information with respect to the field planting value of the seed (ISTA, 1985). Field emergence ability is the major aspect of seed quality of concern to growers (Pieta-Filho and Ellis, 1991). The second objective of germination test is to provide results which can be used to compare the values of different seed lots (ISTA, 1985). Germination test result in conjunction with the analytical purity result provides the principal data upon which the seed traders buys

markets and sells seeds nationally and internationally (Hampton and Coolbear, 1990). The third objective of germination test pertains to storage. The initial quality of seed determines its potential longevity under storage conditions (Roberts and Ellis, 1989). Germination testing and seed moisture content is traditionally used to provide the data upon which storage decision is based. Thus, a seed store manager would correctly conclude that a seed lot with germination of 95% should be able to be stored longer under the same conditions of temperature and humidity than a seed lot of the same species and cultivar with a germination of 75% (Hampton, 1990).

2.6.2 Seed vigour

Seed vigour refers to both the ability and strength of seed to germinate successfully and establish into a normal seedling (Delouche, 1973). Seed vigour used to be referred to as driving force" or "shooting strength" (Perry, 1981). Seed vigour as defined by the Association of Official Seed Analysts (AOSA, 1983) refers to those seed properties which determine the potential for rapid, uniform emergence and the development of normal seedlings under a wide range of field conditions. Since soil conditions during planting are often not optimal, growers require seeds with good germination ability and vigour. In recent years considerable effort has been focused on the measurement of these vigour levels to both stand establishment in the field and yield. To ensure the highest possible vigour of a seed lot, then, effort must focus on creating a positive growth environment so that vigorous seeds can develop and be harvested as soon as possible after physiological maturity, and handling and storing the seed in such a way as to minimize damage and slow the deterioration process (Oplinger and Philbrook, 1992).

CHAPTER THREE

3.0 MATERIALS AND METHODS

The study was conducted at the Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi (KNUST) for 6 months. The study involved storage laboratory analysis of seed germination, seed vigour, grain moisture content, percentage usable proportion by weight and by numbers before and after the trial. The study also involved the determination of phosphine gas concentration (ppm) daily for the first 7 days, determination of level of insect infestation (dead or alive) before the trial, after 7 days, and monthly to the end of the six months period of the trial.

3.1 MATERIALS

The following materials were used to conduct the research:

- Chemically untreated white smooth black eye cowpea. This variety was chosen because it is much cultivated by farmers and is highly susceptible to attack by the cowpea weevil.
- Three 50 kg capacity polytanks and jute sacks respectively for storage and fumigation of cowpea
- Plastic film bags for lining the jute sacks
- Bedfront EC80 phosphine meter for measuring phosphine gas concentration
- Sampling spear and sampling bags for sampling
- Moisture meter for moisture content determination of cowpea
- Seed pans and river sand for germination test
- Sieves for insect collection

- Aluminium phosphine tablet as fumigant
- Thermometer for temperature measurement
- Tally counter for counting grains for analysis
- Stereo microscope to identify live and dead insects
- Electronic weighing scale for weighing samples
- Cello-tape to provide air-tightness of polytank and jute sack

3.2 METHODS

3.2.1 Experimental design

The completely randomised design (CRD) was used for the experiment. The experiment was to compare a new technology to an existing technology. It involved phosphine fumigation and storage of cowpea in a polytank (capacity approximately 40kg) and a jute sack lined with plastic film. The polytank and the jute sack constituted the treatments. The treatments were replicated 3 times in a completely randomised design

3.2.2 Baseline information

Before the trial, values of moisture content, germination and seed vigour test, percentage usable proportion by number and by weight and level of insect infestation were determined as baseline information against which changing parameters were compared, 3 months and 6 months after the trial had began.

3.2.3 Moisture content determination

The untreated cowpea was evenly sun dried to a safe moisture content of 8% and 20 kilograms were measured into the three polytanks and the three jute sacks lined with plastic film. To ensure uniform moisture content of 8% in cowpea samples in each of the storage containers, the double tube sampling spear was used to randomly sample 100 g of grain at 3 different depths from each of the polytanks and jute sacks to determine the moisture content using a Dole moisture tester model 500. Average and standard deviation values were recorded.

3.2.4 Germination test

For each storage container, 100 seeds were sampled randomly at different depths using a double tube sampling spear. The seeds were planted in a seed pan filled with moist sieved river sand and replicated thrice. The germination test as indicated in Figure 2 and Figure 3 was conducted before the trial and repeated 3 months and 6 months to ascertain any consistency in the trend in germination percentage.

Figure 2: Germination test for seeds from jute sack

Figure 3: Germination test for seeds from polytank

A total of 18 seed pans were used in each of the germination tests. The first count was taken 3 days after planting. Germination count was carried out daily after first germination. The results for each sample were averaged and the standard deviation determined and recorded.

$$\text{Germination \%} = \frac{Ng}{Np} \times 100 \qquad \text{.....(1)}$$

where Ng = Number of seeds germinated

Np = Number of seeds planted.

3.2.5 Seed vigour test

Vigour test was carried out using the seedling growth rate method (i.e. speed of germination). The seed vigour test was incorporated into the standard germination test. An index was computed for each sample by dividing the number of normal seedlings removed each day by the day after planting on which they were removed (Agrawal, 1986).

$$\text{The vigour index} = \frac{Nr}{Dap} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where Nr = Number of seedlings removed daily

Dap = Day after planting

3.2.6 Determination of percentage usable proportion (by weight and number)

One thousand (1000) seeds were counted using a tally counter from randomly sampled grains for each storage container, using the double tube sampling spear. The damaged grains were separated from the undamaged. The quality test was carried out using the International Grain Procurement Manual (1984), guidelines, procedure and rules. The percentage usable proportion by number was calculated as follows:

$$\text{Percentage usable proportion (by numbers)} = \frac{\text{Number of undamaged grains}}{1000} \times 100 \quad \ldots(3)$$

To determine the percentage usable proportion by weight the number of damaged and undamaged grains separated were weighed using an electronic weighing scale. The weights of undamaged grain were divided by the sum of weight of undamaged grain and the weight of the damaged grain expressed as:

$$\text{Percentage Usable proportion (by weight)} = \frac{\text{Weight of undamaged grain}}{\text{Sum of weight of undamaged and damaged grain}} \times 100 \quad \ldots. (4)$$

The results for each sample were averaged and the standard deviation determined.

3.2.7 Determination of insect infestation level before the trial

For each storage container, 2 kg grains were sampled randomly from different depths using a double tube sampling spear. The samples for each storage containers were sieved using 4mm sieve size on to a white paper. The inert materials were separated from the insects with the help of a spike. The insects were subjected to two types of test. The first test was by visual inspection using the naked eye and then thoroughly examined under a different magnification of a stereo microscope.

Identification of cowpea weevil (*maculatus*) was based on the morphological features of the body, compared to the identification keys used commonly for identifying organisms. The insects were counted for each storage container. The results for each sample were averaged and the standard deviation determined and recorded. This was done to determine the level of insect infestation before the trial.

3.2.8 Phosphine fumigation

The phosphine fumigation trial involved the comparison of the phosphine gas concentration (ppm) for each storage container, for the first seven days after inserting the aluminium phosphide tablet (fumigant). 1.5 g of aluminium phosphide tablets were wrapped in an empty envelope and placed on the surface of the grain in each of the storage containers. Polyethylene sheets were sandwiched between the lid and the tank and cut around the lid and sealed to the lid and the tank with adhesive cello-tape (5 cm x 7 m). In the case of the jute sack, the top of the plastic liner was folded tight and the

folded portion bend over twice and then tied with a 7 metre long piece of string. The jute sacks were later folded tight and tied to protect the plastic liner.

3.2.9 Monitoring of the phosphine gas concentration (ppm)

Two metres long plastic tubes were inserted into the centre of each storage container through a small hole drilled at the top side of each of the storage containers. The holes drilled through which the plastic tubes were inserted and connected into the storage containers were sealed around the tubes to the container making it air tight and also firmly held the tubes in place. The inserted plastic tubes were meant for drawing the phosphine gas from the storage containers into the phosphine meter with the aid of a syringe for daily monitoring of the gas concentration in the storage containers. 100 ml of phosphine gas was drawn from each of the storage containers through the inserted plastic tubes using a 100 ml, syringe and then drawn directly into a Bedfront EC80 phosphine monitor for reading. 3 readings were successively taken daily from each of the storage containers for the first 7 days after the fumigation. The readings for each sample were averaged and standard deviation determined and recorded. The ambient temperatures during the period of the fumigation varied from 28 to 33ºC.

The fumigation was terminated on the seventh day and the storage containers were opened. The envelopes containing the powered residue of the fumigant were removed and buried. Phosphine gas concentration (ppm) was measured in the polytanks and the jute sacks for 7 days, after the fumigation trial.

3.2.10 Quality assessment of the fumigation

Quality assessment of the fumigation was done by immediate monitoring for live and dead insects in each of the tanks and the jute sacks after the fumigation was terminated. There was also monthly monitoring for live and dead insects after the fumigation for the 6 months storage period. The assessment was done by randomly sampling 1 kg of grain at different depths from each of the storage containers. The sampled grains were sieved with a 4mm sieve on to a table covered with white paper for easy identification of the insects. Live and dead insects were separated from other inert materials and counted. The insects were thoroughly examined under different magnification of a stereo microscope to determine live and dead insects.

CHAPTER FOUR

4.0 RESULTS

4.1 Observations

It was observed that the cowpea storage weevil or bruchid *(maculatus)* infestation starts in the field. There was weevil damage of some of the grains, with distinctive round holes in the freshly processed grain with a significant number of live cowpea weevils. However, some were effective as seed, since most of them germinated.

In the germination test conducted and evaluated, none of the samples in the containers, the polytank and the jute sacks fell below 60 %. At certain stages of the trial, there was rodent attack on the jute sacks as the fibre jute sacks did not give protection against rodents.

It was also observed that, unlike other grains, cowpea takes fewer days to dry to the safe moisture content of 8% and 3 days to start germination. The polytank, like the jute sack, had no effect on the colour of the grain after the trial.

4.1.1 Moisture content before, mid storage and after storage

The untreated cowpea samples stored in each of the storage container was evenly sun dried to a safe moisture content of 8% before the trail. There were no significant differences in the moisture content of the grain between the polytank and the jute sack after the trial (P> 0.05) (Figure 4).

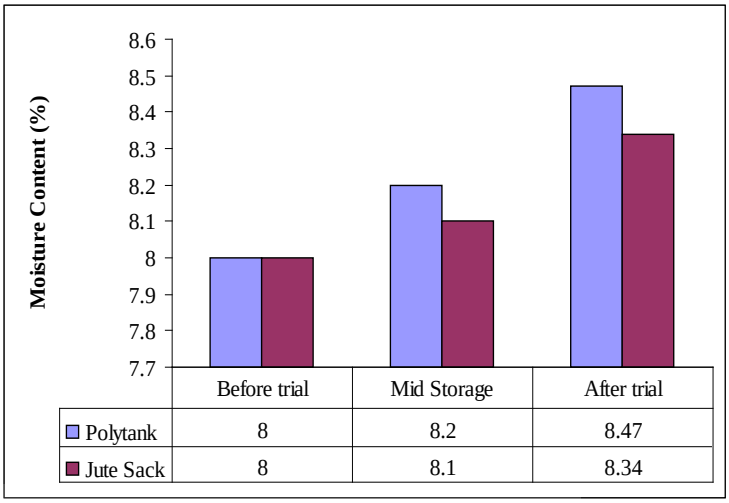


Figure 4: Moisture content of cowpea at different storage periods

4.1.2 Germinability during experiment

Germinability and vigour tests were conducted on cowpea stored using cowpea samples from the polytank and the jute sack at different stages of the trial to assess germinability and vigour.

4.1.2.1 Germinability test before trial

There was no significant difference (P>0.05) in the germinability of cowpea stored in the polytank and the jute sack (Figure 5).

4.1.2.2 Germinability test at 3 months

There was no significant difference (P>0.05) in the germinability of cowpea stored in the polytank and the jute sack (Figure 5).

4.1.2.3 Germinability test after the trial

Again, there was no significant difference (P>0.05) in the germinability of cowpea stored in the polytank and the jute sack after the trial (Figure 5).

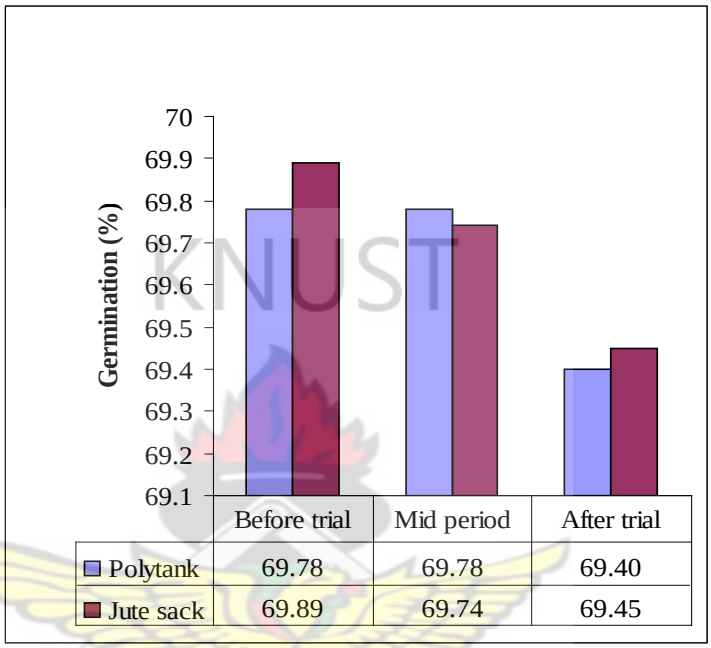


Figure 5: Germination test at different storage periods

4.1.3 Vigour test during experiment

4.1.3.1 Vigour test before trial

There was no significant difference (P>0.05) between the vigour index of cowpea stored in the polytank and the jute sack (Figure 6).

4.1.3.2 Vigour test at 3 months

There was also no significant difference (P>0.05) between the vigour index of cowpea stored in the polytank and the jute sack at three months as shown in Figure 6.

4.1.3.3 Vigour test after trial

Again, there was no significant difference (P>0.05) between the vigour index of cowpea stored in the polytank and the jute sack after the trial (Figure 6).

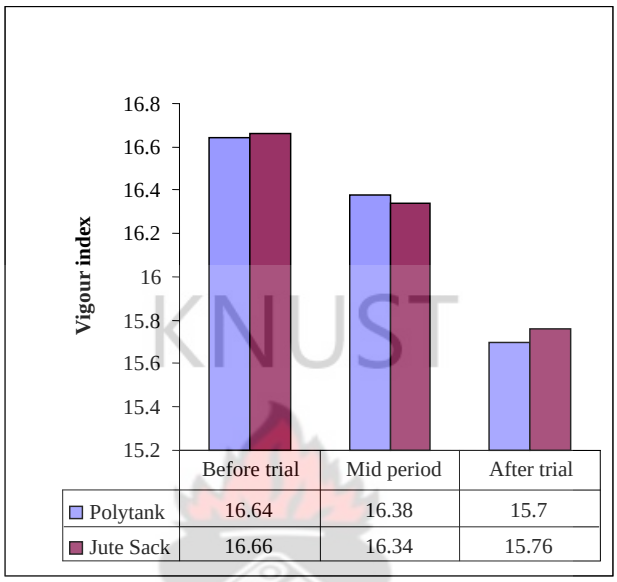


Figure 6: Vigour test of cowpea at different storage periods

4.1.4 Usable proportion by number and weight (%)

Quality test was conducted before, 3 months and after the trial to ascertain the effects of the polytank and the jute sack on the quality of stored cowpea within the test period.

4.1.4.1 Usable proportion (by number) before trial

There was no significant difference (P>0.05) between the usable proportion by number of cowpea stored in the polytank and the jute sack lined with plastic film bag before the trial (Figure 7).

4.1.4.2 Usable proportion (by number) at mid storage

There was on significant difference (P>0.05) between the usable proportion by number of cowpea stored in the polytank and the jute sack (Figure 7).

4.1.4.3 Usable proportion (by number) after trial

There was also no significant difference (P>0.05) between the usable proportion by number of cowpea stored in the polytank and the jute sack after the trial (Figure 7).

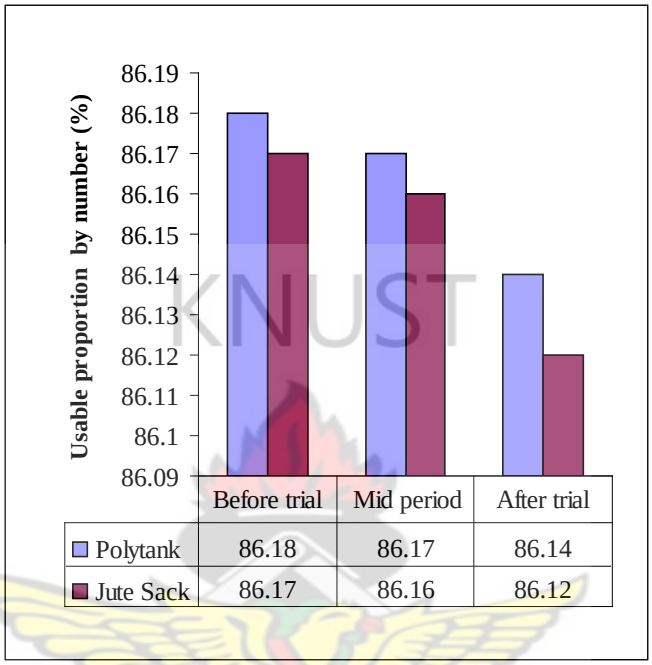


Figure 7: Usable proportion by numbers at different storage periods

4.1.5 Usable proportion (weight) before trial

There was no significant difference (P>0.05) between the usable proportion by weight of cowpea stored in the polytank and the jute sack before the trial (Figure 8).

4.1.5.1 Usable proportion (by weight) at mid storage

There was no significant difference (P>0.05) between the usable proportion by weight of the cowpea stored in the polytank and the jute sack (Figure 8).

4.1.5.2 Usable proportion (weight) after trial

There was also no significant difference (P>0.05) between the usable proportion by weight of cowpea stored in the polytank and the jute sack after the trial (Figure 8).

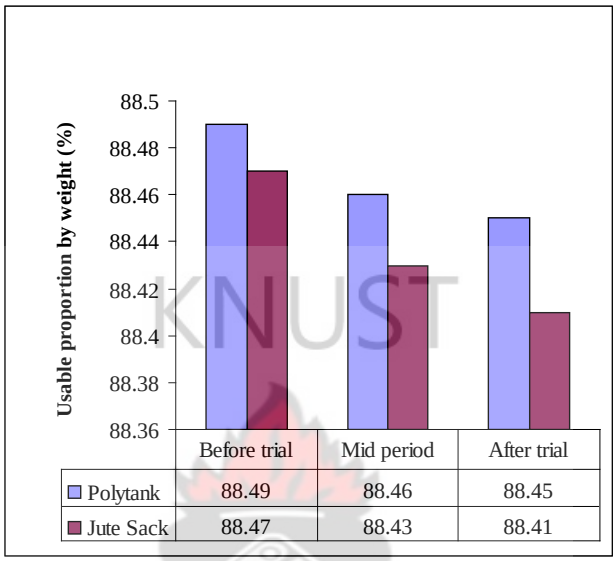


Figure 8: Usable proportion by weight at different storage periods

4.1.6 Phosphine gas concentration during fumigation trial

Phosphine gas concentration in each of the storage container was measured for the first 7 days during the fumigation trial to assess the air-tightness of the polytank and the jute sack lined with plastic film bag. The results are shown in (Figure 9).

4.1.6.1 Phosphine gas concentration (ppm) on day 1

There was no significant difference (P>0.05) between the phosphine gas concentration (ppm) in the polytank and the jute sack lined with plastic film bag. The polytank recorded a initial phosphine gas build up concentration of 500 (ppm) while the jute sack had 483 (ppm) (Figure 9). Ambient temperature at mid-day during the trial was 30^{o}C.

4.1.6.2 Phosphine gas concentration (ppm) on day 2

There was a significant difference (P<0.05) between the phosphine gas concentration (ppm) in the polytank and jute sack lined with plastic film bag as shown in (Figure 9). The highest phosphine gas concentration of 1000 (ppm) was recorded in the polytank, while the jute sack had 783 (ppm). The ambient temperature at mid-day during the trial was 29 ^{o}C.

4.1.6.3 Phosphine Gas Concentration (ppm) no day 3

There was a significant difference (P<0.05) between the phosphine gas concentration (ppm) in the polytank and jute sack lined with plastic film bag as shown in (Figure 9). The highest phosphine gas concentration of 1300 (ppm) was recorded in the polytank, while the jute sack lined with plastic film bag had 883 (ppm) .The ambient temperature at mid-day was 30 ^{o}C.

4.1.6.4 Phosphine Gas Concentration (ppm) on day 4

There was a significant difference (P<0.05) between the phosphine gas concentration (ppm) in the polytank and jute sack lined with plastic film bag as shown in (Figure 9). The highest phosphine gas concentration of 1416 (ppm) was recorded on the fourth day in the polytank which was also the highest value for the 7 days fumigation trial. The jute sack lined with plastic film bag had gas concentration of 1012 (ppm) which is also the highest in the jute sack lined with plastic film bag. The ambient temperature at mid-day was 31^{o}C

4.1.6.5 Phosphine Gas Concentration (ppm) on day 5

There was a significant difference ($P<0.05$) between the phosphine gas concentration (ppm) in the polytank and the jute sack lined with plastic film bag, as shown in (Figure 9). The highest gas concentration was recorded in the polytank with gas concentration of 1415 (ppm) while the jute sack lined with plastic film bag had 883 (ppm). However, the gas concentration in both storage containers had declined in gas concentration. This is shown in (Figure 9). The ambient temperature at mid-day was 29^{o}C.

4.1.6.6 Phosphine Gas Concentration (ppm) on day 6

There was a significant difference ($P<0.05$) between the phosphine gas concentration (ppm) in the polytank and the jute sack lined with plastic film bag, as shown in (Figure 9). The highest gas concentration was recorded in the polytank with a gas concentration of 1214 (ppm) while the jute sack lined with plastic film bag had the lowest gas concentration of 600 (ppm). However the increasing gas concentration was at a reducing rate in both storage containers. This is shown in (Figure 9). The ambient temperature at mid-day was 30^{o}C.

4.1.6.7 Phosphine Gas Concentration (ppm) on day 7

There was significant difference ($P<0.05$) in the phosphine gas concentration (ppm) in the polytank and the jute sack lined with plastic film bag, as shown in (Figure 9). The highest gas concentration was recorded in the polytank with gas concentration of 817 (ppm) while the jute sack had the lowest gas concentration of 233 (ppm). However the

gas concentration had declined in both storage containers. This is shown in (Figure 9). The ambient temperature at mid-day was 31^{o}C.

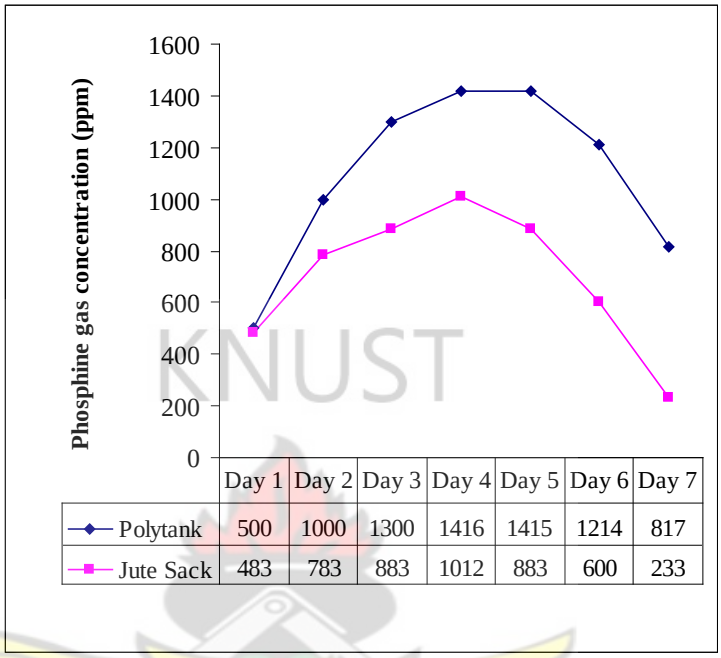


Figure 9: Phosphine gas concentration during the fumigation trial

4.1.7 Monitoring for insects

4.1.7.1 Determination of insect infestation before trial

There was no significant difference (P>0.05) in the insect infestation level before the trial between the cowpea stored in the polytank and the jute sack lined with plastic film bag as shown in (Figure 10).

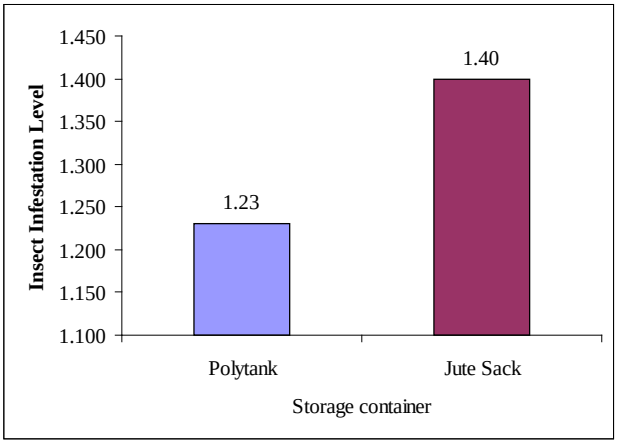
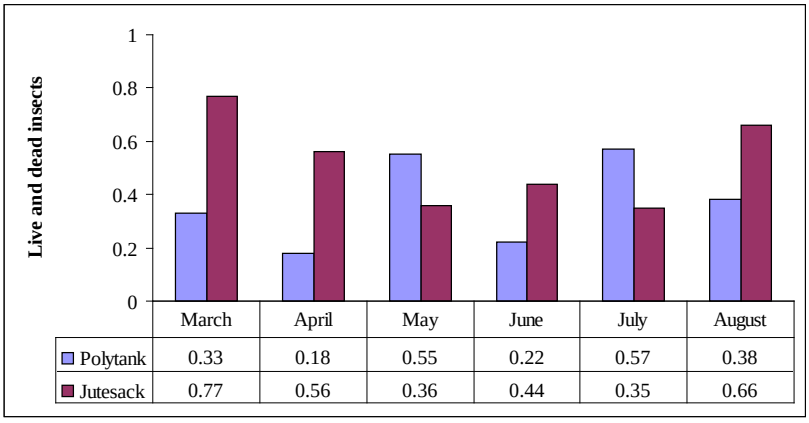


Figure 10: Insect infestation before trial

4.1.7.2 Monthly monitoring for live and dead insects after fumigation trial

There was a quality assessment of the fumigation trial on the effect of the phosphine gas concentration on the cowpea weevil through monthly sampling for live and dead insects (*maculatus*) from each of the storage container throughout the 6 months storage period. No live cowpea weevil was discovered in the grains sampled from each of the storage containers. However dead insects were observed throughout the six months monitoring period from each of the storage containers, but there was no significant difference (P>0.05) in the number of dead cowpea weevils sampled from the polytank and the jute sack lined with plastic film bag, as shown in (Figure 11).



	March	April	May	June	July	August
Polytank	0.33	0.18	0.55	0.22	0.57	0.38
Jutesack	0.77	0.56	0.36	0.44	0.35	0.66

Figure 11: Six months monitoring of mortality rate

CHAPTER FIVE

5.0 DISCUSSION

5.1 Post harvest characteristics of cowpea

Low yields of cowpea constitute a significant attribute to heavy biotic pressures particularly from insects and other pests, which often affect the plant throughout its life cycle and the seed in storage. The primary insect pest causing losses to stored cowpea in West Africa is the cowpea weevil. The cowpea used in this trial was the local white smooth seeded variety. This variety was selected from the other varieties due to the fact that it is very popular to farmers and consumers. The variety is also highly susceptible to cowpea weevil attack, because of its prolonged podding and the smooth nature of the seed.

According to Southgate (1978) smooth-seeded varieties are more suitable for oviposition than rough seeded varieties. Haines (1991) also noted that the smooth seeded varieties are more suitable for eggs laid to be firmly glued to the surface of the grain than rough seeded varieties.

5.2 Condition of cowpea before the trial

It was observed that some of the grains from the freshly harvested processed cowpea were damaged with distinctive round holes. There was a significant number of cowpea weevils present. This actually supported the claim by Haines (1991) that the primary insect pests causing losses to stored cowpea, the cowpea weevil starts in the field at a low level, and when the crop is placed in storage, the insect population continues to grow

until there is an obvious severe infestation. Laurie (1999) also indicated that the cowpea weevil is the principal storage pest of cowpea and infestation starts in the field on the pods but population growth accelerates following threshing, when eggs can be laid directly on the seed. The factors noted above could possibly be responsible for the high infestation rate of cowpea weevils on stored cowpea.

Laurie (1999) again stated that the bruchid larvae feed and develop inside the seed and emerge as adults after three to four weeks. The adults mate and give rise to another generation in the stored seed. The mode of breeding noted above could possibly be responsible for the distinctive round holes associated with infested cowpea which some consumers have a strong aversion to. The optimum temperature for oviposition of the cowpea weevil is 30-35^{o}C and relative humidity of 70-90%. The female lay many eggs up to about 115 and are hatched within 5-20 days. Six or seven generations, may occur per year (Southage, 1979). These factors could possibly be responsible for rapid infestation of stored cowpea and also the significantly high post harvest losses in stored cowpea in the tropics.

5.3 Moisture content of cowpea before, mid storage and the after trial

Moisture contained in the grain is an indicator of its quality and the key to safe storage. The initial moisture content of the grain was 8% before the trial; this agrees with the recommendation made by Laurie (1999) that for a long-term storage of cowpea, the moisture content should be 8 – 9 %. The polytank and the jute sack recorded moisture contents of 8.2% and 8.1 respectfully after the 3 months storage period. The polytank recorded moisture content of 8.47 % while the jute sack lined with plastic film bag had a

moisture content of 8.34 % after the trial, as shown in Table 1 in Appendix 1. However, there was no significant difference between the moisture uptake of the cowpea samples from each of the storage containers after trial. There was also no significant difference between the final moisture content and the initial moisture content of each of the storage containers. The slight difference in moisture uptake between the two storage containers could be due to the difference in air tightness of the two containers as it was indicated in the fumigation trial shown in Table 6 in Appendix 4. The low moisture uptake of the grain in both storage containers could also be due to the low initial moisture content of the grain before the trial coupled with absence of live insects and low temperature variation inside and outside of the storage containers.

5.4 Germination and Vigour test

The most vital attribute of good quality seed is viability (Basu, 1990). In many parts of the world especially those with hot and humid climates, maintenance of seed viability and vigour poses serious problems due to poor storage structures. In the experiment, each of the storage containers evaluated exhibited high germination percentage and vigour index value of stored cowpea, as shown in Table 2 and 3 in Appendix 1 and 2. The new technology under trial, which is the polytank has no effect on germination as compared to the existing technology, which is the jute sack lined with plastic film bag. There was no significant difference in germination percentage and vigour index value between the jute sack lined with plastic film bag and the polytank after the trial. There was also no significant difference in germination percentage and vigour index value between the initial test and the final test of each of the storage containers. The slight difference in

germination percentage and the vigour index value of the jute sack lined with plastic film bag over the polytank after the trial is normal in any germination test, and these could be due to differences in the nursery management.

Perry (1978) noted that even, when a good quality seed has been produced and harvested, faulty storage techniques may prove detrimental to the maintenance of vigour and viability. Jelle (2003) also indicated that some fumigants, particularly methybromide and ethylenedibromide are harmful to seed viability, when moisture content is high. However, photoxin is harmless to seed. These factors noted above could possibly be responsible for the good germination percentage and vigour index value of the stored cowpea.

5.5 Usable Proportion by Weight and Number

Usable proportion by number and weight was evaluated before, 3 months and after the trial to determine the effect of the polytank compared to the jute sack lined with plastic film bag on quality of stored cowpea. There was no significant difference in quality of stored cowpea of each of the storage containers after the trial, as shown in Table 4 and 5 in Appendix 2 and 3.There was a slight difference in usable proportion in number of the cowpea in the polytank compared to the jute sack lined with plastic film bag. This was reflected in the weight of samples in the polytank over the jute sack lined with plastic film bag.

However there was no significant difference in the initial and the final quality of the grain, in each of the storage containers. Mathur and Joergensen (1992) noted that the spore of A*spergillus* and *Penicillium* species are usually present in large numbers in the

air and on surface in seed storage areas and can thus infect seeds easily. This might be responsible for the insignificant difference between the initial quality of the grain and the final quality of grain in both storage containers, because the stored grain are enclosed and free from the spores of *Aspergillus* and *Penicillium* spacies which cause unwholsome grains. It was also an indication of successful fumigation since the phosphine gas concentration in each of the storage container on day 7 was above the recommended value of 150 (ppm) hence the absence of live cowpea weevils that might have caused damage to the grain.

5.6 Phosphine gas concentration during the fumigation trial

Although the same dosage of the aluminium phosphine was applied under the same condition, the rate of decrease in phosphine gas concentration varied considerably between the polytank and the jute sack lined with plastic film bag. There was significant differences between the polytank and the jute sack for the 7-days exposure period, except day one where there was no significant difference between the polytank and the jute sack lined with plastic film bag. This indicated that the initial pattern of gas generation was similar in both cases but changed as the gas concentration built up.

The high phosphine gas concentration in the polytank from day 2 to the exposure period of 7 days was due to the better air tightness of the polytank as a result of the use of adhesive cellotape to seal the lid tightly to the body of the tank. This was confirmed by Qasim-Chaudhry *et al.,* (1989) when they examined the phosphine gas tightness of a plastic water tank sealed with plastic tape with exposure period in excess of eight days in

Pakistan. The high gas concentration of the polytank as compared to the jute sack lined with plastic film bag might be due to the thickness of the polytank which prevented the wind effect of gas loss as indicated by Champ and Dyte (1976) that wind blowing around and over a structure will create pressure gradient across the surface of the structure and increase the rate of gas loss. This observation is supported by Qasim-Chaudbry *et al.,* (1989) who clearly illustrated that the rate of gas loss from a fumigated structure increased when exposed to puffs of wind. This appears to be especially important when using thin polythene structure since they are particularly prone to wind-induced gas loss hence the low gas concentration in the jute sack lined with the plastic film bag.

Champ and Dyte (1976) held the view that where the atmosphere of the structure is heated and cooled with diurnal changes, the resultant expansion and contraction of the internal atmosphere will produce pressure gradients which cause leakage of phosphine gas. The polytank made of high-density polyethylene is not a good thermal conductor. This physical factor might have reduced the diurnal changes between internal and external pressure of the polytank, hence the high phosphine gas concentration throughout the exposure period of 7 days.

Worhlgemuth and Hamisch (1986) demonstrated that, the degree of absorption of the fumigant depended on the commodities and the structure it comes into contact with. The concentrations of the phosphine measured over the 7 days proved to be more satisfactory in the polytank than the jute sack lined with plastic film bag. Phosphine gas concentration of 817 (ppm) was recorded on day 7 in the polytank which was far above the

recommended value of 150 (ppm) while the jute sack lined with plastic film bag had 233 (ppm). Even though the phosphine gas concentration values in each of the storage container were above the recommended value of 150 ppm, there was significant difference in the phosphine gas concentration as shown in Table 6 in Appendix 4. The highest gas concentration was attained on day 4. This could be explained by the very low relative humidity of the air inside the containers due to the low moisture content of the grain, which reduced the initial rate of gas release by the phosphine tablets. Prompt release of phosphine gas during fumigation is always associated with moisture in the product.

Apart from the highest concentration on day 4, the rate of decrease in concentration was reduced towards day 7. The phosphine gas concentration in the polytank at the recommended exposure period of 7 days was above the recommended phosphine gas concentration value of 150 (ppm) and therefore the concentration was enough to kill all the developmental stages of cowpea weevils and their eggs, larvae and pupae present in the grain. The high gas concentration in the polytank was an indication that the polytank seal with the cellotape was gas-tight and therefore prevented leakage of phosphine gas into the immediate environment with its associated risks of exposure to human and livestock.

5.7 Determination of insect infestation of cowpea before trial

A considerable number of cowpea weevils were found in the grain of the freshly harvested grain in both containers before the trial. However, there was no significant

difference in the number of insects sampled from the two storage containers as shown in Table 7 in Appendix 5. This confirms the claim by Haine (1991) and Laurie (1999) that the cowpea weevil causing losses to stored cowpea starts infection from the field to the store.

5.8 Monthly sampling for live and dead insects after the fumigation trial

Even though there was significant difference in phosphine gas concentration between the polytank and the jute sack lined with plastic film bag, no live cowpea weevils were discovered in both storage containers throughout the period monitored. The absence of live insects in both containers is an indication of the fact that the gas concentration was maintained above the recommended phosphine gas concentration of 150 (ppm) at the recommended exposure period of 7 days. It also confirms the claim by Brice and Golob (2000) that at an exposure period of 7 days, phosphine gas concentration at 150 (ppm) kills cowpea weevils and their eggs, larvae and the pupae.

There was difference in number of dead insects sampled from each of the storage container at each month up to the end of the storage period after the fumigation trial as shown in Table 8 in Appendix 5. The difference could be due to the fact that stored product pests were not evenly distributed in stored grain. This may account for the increase in metabolism of insects at a particular spot inside stored grain associated with increase in temperature and heat resulting in locally heat grain called “hot spots”.

CHAPTER SIX

6.0 CONCLUSION

The following conclusions were drawn:

a. The polytank performed better as a fumigation container and exceeded the recommended gas concentration value of 150 (ppm) at the end of the 7 days exposure period and had no effect on the storage qualities of the stored cowpea.

b. It was relatively safe, in terms of leakage of phosphine gas into the immediate environment with the associated risks of exposure to the farm family and livestock.

c. It was economical; no need to purchase fumigation sheets or seasonal purchase of plastic film bag as in the case of the jute sack method.

d. With different sizes of the polytank, various quantities of cowpea can be fumigated at once while in the case of the jute sack method several bags have to be handled, that is the polytank has a lower labour requirement than the jute sack lined with plastic film bag method.

e. The thick plastic walls of the polytank serve as a physical barrier against rodent attack as compared to the jute sack lined with plastic film bag.

f. In contrast, the jute sack method is delicate to handle because the plastic film bag enclosed in the jute sack can easily be burst without being known by the user which will result in leakage of the gas.

g. The result also revealed no significant differences in the storage qualities of the stored cowpea, such as germination, vigour, usable proportion by number and weight, and moisture content. Even though, the polytank performed better as a

fumigation container than the jute sack lined with the plastic film bag, there was no comparative advantage of the two storage containers over each other since both containers exceeded the recommended gas concentration value of 150 (ppm) at the end of the 7 days exposure period.

h. The highest phosphine gas concentration of 1416 (ppm) was recorded in the polytank on day 4 while the jute sack had phosphine gas concentration of 1012 (ppm). At the last exposure period on day 7 the polytank had the highest gas concentration of 817 (ppm) while the jute sack lined with plastic film bag had the lowest gas concentration of 233 (ppm).

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APPENDICES

Appendix 1

Table 1: Determination of moisture content before, mid-storage and after trial (%)

	Moisture content trial before		Moisture content mid-storage		Moisture content after trial	
	Polytank	Jute sack	Polytank	Jute sack	Polytank	Jute sack
Mean	8	8	8.2	8.1333	8.47	8.34
Variance	0	0	0.010	0.023	0.025793	0.0403
Standard Error	0.00000	0.00000	0.05774	0.08819	0.092723	0.115902
Median	8.00	8.00	8.30	8.30	8.4	8.36
Observation	3	3	3	3	3	3
t- stat	0.655351		0.555		0.673971	
P(T<=t)	0.101264		0.10000		0.284894	
t Critical	2.131846		2.919986		2.919986	

Table 2: Germination test before, mid-storage and after trial (%)

	Germination test before trial		Germination test mid-storage		Germination test after trial	
	Polytank	Jute sack	Polytank	Jute sack	Polytank	Jute sack
Mean	69.87667	69.89467	69.78333	69.74333	69.40	69.45333
Variance	1.378533	0.479633	0.929633	1.4389	1.4389	0.259633
Standard Error	0.677872	0.399847	0.556667	0.692556	0.692556	0.294184
Median	70	70	70.33	69.66	69.66	69.33
Observation	3	3	3	3	3	3
t- test	0.103689		0.282051		-0.114883	
P(T<=t)	0.463439		0.402206		0.459516	
t critical	2.919986		2.919986		2.919986	

APPENDIX 2

Table 3: Vigour test before, mid- storage and after the trial

	Vigour test before trial		Vigour test mid-storage		Vigour test after trial	
	Polytank	Jute sack	Polytank	Jute sack	Polytank	Jute sack
Mean	16.64333	16.655333	16.38333	16.34333	15.7	15.76333
Variance	0.574533	0.186533	0.371233	0.273233	0.39	0.317233
Standard Error	0.43762	0.24935	0.351773	0.301791	0.360555	0.325184
Median	16.6	16.7	16.7	16.06	15.9	15.56
Observation	3	3	3	3	3	3
t-stat	-0.294963		0.311475		-0.09472	
P(T<=t)	0.397912		0.392454		0.466586	
t critical	2.919986		2.919986		2.919986	

Table 4: Usable proportion by number before, mid-storage and after trial (%)

	Usable proportion (numbers) before trial		Usable proportion (numbers) mid-storage		Usable proportion (numbers) after trial	
	Polytank	Jute sack	Polytank	Jute sack	Polytank	Jute sack
Mean	86.18067	86.17	86.16667	86.15667	86.14	86.12
Variance	0.001633	0.0219	0.173333	0.048633	0.01732	
Standard Error	0.023333	0.08544	0.24037	0.127323	0.01155	.00577
Median	86.13	86.5	86	86.23	86.12	86.11
Observation	3	3	3	3	3	3
t-stat	-5.192291		-2.088717		1.549193	
P(T<=t)	0.017574		0.085974		0.098130	
t critical	2.919986		2.919986		2.919986	

APPENDIX 3

Table 5: Usable proportion by weight before, mid-storage and after trial (%)

	Usable proportion (weight) before trial		Usable proportion (weight) Mid-storage		Usable proportion (weight) after trial	
	Polytank	Jute sack	Polytank	Jute sack	Polytank	Jute sack
Mean	88.49	88.47333	88.46	88.43267	88.44666	88.41
Variance	0.0061	0.127633	0.0967	0.099633	0.014533	0.01732
Standard error	0.045092	0.206263	0.179536	0.182239	0.00882	0.0057
Median	88.53	89.41	88.2	88.9	88.43	88.40
Observation	3	3	3	3	3	3
t-stat	-4.857143		-3.106321		3.478505	
P(T<=t)	0.019935		0.019517		0.012693	
T critical	2.919986		2.919986		2.131846	

APPENDIX 4

Table 6: Concentration of phosphine (ppm) gas during the fumigation trial for 7 days

	Day 1		Day 2		Day 3		Day 4	
	Polytank	Jute sack	Polytank	Jute sack	Polytank	Jute sack	Polytank	Jute sack
Mean	500	483.3333	1000	783.3333	1300	883.3333	1415.667	1011.667
Variance	0	833.3333	0	833.3333	0	883.3333	833.3333	833.3333
Standard Error	0	16.66667	0	16.66667	0	16.66667	16.66667	16.66667
Median	500	500	1000	800	1300	900	900	1100
Observation	3	3	3	3	3	3	3	3
t-stat	1		13		25		13.85641	
P(T<=t)	0.211325		0.002933		0.000798		0.002584	
t critical	2.919986		2.919986		2.919986		2.919986	

	Day 5		Day 6		Day 7	
	Polytank	Jute sack	Polytank	Jute sack	Polytank	Jute sack
Mean	1414.667	883.3333	1213.667	600	816.6667	233.3333
Variance	833.3333	5833.333	833.3333	2500	833.3333	10833.33
Standard Error	16.66667	44.09586	16.66667	28.86751	16.66667	60.09252
Median	1400	900	1200	600	800	200
Observation	3	3	3	3	3	3
t-stat	8.875203		8.029551		8.029551	
P(T<=t)	0.006229		0.007579		0.007579	
t critical	2.919986		2.919986		2.919986	

APPENDIX 5

Table 7: Determination of insect infestation before trial

	Polytank	Jute sack
Mean	1.23	1.40
Variance	0.149633	0.1089
Standard Error	0.223333	0.190526
Median	1	1.33
Observation	3	3
t-stat	-1.383862	
P(T<=t)	0.15302	
t critical	2.919986	

Table 8: Six months monitoring for live and dead insects after the fumigation

	March		April		May	
	Polytank	Jute sack	Polytank	Jute sack	Polytank	Jute sack
Mean	0.33	0.773333	0.183333	0.56333	0.55	0.36
Variance	0.1089	0.038533	0.028233	0.258533	0.0363	0.1089
Standard Error	0.190526	0.113333	0.097011	0.293561	0.11	0.19052
Median	0.33	0.66	0.22	0.66	0.66	0.33
Observation	3	3	3	3	3	3
t-stat	-1.506991		-1.882438		2.919986	
P(T<=t)	0.135402		0.100243		0.091752	
t critical	2.919986		2.919986		2.919986	

	June		July		August	
	Polytank	Jute sack	Polytank	Jute sack	Polytank	Jute sack
Mean	0.22	0.44	0.57	0.35	0.38	0.66
Variance	0.0363	0.0363	0.363	0.1089	0.1089	0
Standard Error	0.11	0.11	0.11	0.190526	0.190526	0
Median	0.33	0.33	0.66	0.33	0.33	0.66
Observation	3	3	3	3	3	3
t-stat	0.755929		0.755929		-1.732051	
P(T<=t)	0.264298		0.264298		0.112702	
t critical	2.919986		2.919986		2.919986	