SCREENING OF SOME RICEBEAN [*Vigna umbellata* (Thunb.) Ohwi & Ohashi] CULTIVARS AGAINST PULSE BEETLE [*Callosobruchus chinensis* (L.)] AND ITS MANAGEMENT WITH BOTANICALS

Thesis

submitted to

NAGALAND UNIVERSITY

in partial fulfillment of requirements for the Degree

of

Doctor of Philosophy

in

ENTOMOLOGY

by

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Nagaland

2022

Dedicated

to

My Parents and

My Respected Supervisor

DECLARATION

I, Khrieketou Kuotsu, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis had not been submitted by me for any research degree in any other university/institute.

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CERTIFICATE – I

This is to certify that the thesis entitled **"Screening of some ricebean [*Vigna umbellata* (Thunb.) Ohwi & Ohashi] cultivars against pulse beetle [*Callosobruchus chinensis* (L.)] and its management with botanicals"** submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Entomology is the record of research work carried out by Mr. KHRIEKETOU KUOTSU Registration No. Ph.D./ENT/00043 under my personal supervision and guidance.

The result of the investigation reported in the thesis have not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

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CERTIFICATE – II

VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN ENTOMOLOGY

This is to certify that the thesis entitled **"Screening of some ricebean [*Vigna umbellata* (Thunb.) Ohwi & Ohashi] cultivars against pulse beetle [*Callosobruchus chinensis* (L.)] and its management with botanicals"** submitted by KHRIEKETOU KUOTSU, Admission No. Ph-205/16 Registration No. Ph.D./ENT/00043 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Entomology has been examined by the Advisory Board and External examiner on …………………….

The performance of the student has been found **Satisfactory/Unsatisfactory.**

Member	Signature
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Dated :

Place: Medziphema, Nagaland *(Khrieketou Kuotsu)*

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LIST OF ABBREVIATIONS

%	Per cent
@	at the rate
°C	Degree Celsius
etc.	*et cetera*
et al.	*Et alli* (and other)
viz.	videlicet (namely)
ha	Hectare
mt	Metric Tonnes
g	Gram
mg	Mili gram
ml	millilitre
BOD	Biological Oxygen Demand
GAE	Gallic acid equivalent
TAE	Tannic acid equivalent
Fig.	Figure
SEm	Standard error of mean
CRD	Completely Randomized Design
ANOVA	Analysis of Variance
DMRT	Duncan's Multiple Range Test
A.O.A.C.	Association of Official Analytical Chemists
ACT	At controlled temperature
ART	At room temperature
HAT	Hours after treatment
W/W	Weight by weight

CONTENTS

ABSTRACT

Ricebean, [*Vigna umbellata* (Thunb.) Ohwi and Ohashi] is an important pulse crop in Nagaland with many landraces under cultivation. Like any other pulse crop, ricebean is also attacked by insects both in the field and storage conditions. Among the insect pest, pulse beetle, *C. chinensis* is one of the most important pest that causes considerable damage in storage. A laboratory experiment was conducted during 2017-2020 in the laboratory of the Department of Entomology, School of Agricultural Sciences and Rural Development, Nagaland University, Medziphema Campus to screen some local ricebean cultivars against pulse beetle, *C. chinensis* and to study the effect of storage structure on the incidence of pulse beetle and also to evaluate the efficacy of botanicals as grain protectants. The experiment was conducted in a Completely Randomized Design (CRD). Sixteen local ricebean cultivars *viz*., *Akixi Anila*, *Rhüjo, Ashei Nyakla*, *Kurhi Süre, Pinchong Wethroi*, *Kerhü, Mügo Rhi*, *Rhüse*, *Hera Ragei*, *Hera Rahau*, *Rhüdi*, *Manyhü Rhi*, *Kurhi Rhide*, *Khueishuei Shumei*, *Rhüluo* and *Sipheghonu* were used for screening against pulse beetle at controlled temperature of 28 ± 2ºC in a B.O.D. incubator and at room temperature of the laboratory in a no-choice test.

The highest oviposition (131.33 and 121.67 eggs/25 seeds), adult emergence (73.60 and 72.33%), infestation (63.67 and 60.85%) and weight loss (11.07 and 10.33%) were observed in cultivar *Sipheghonu* at both temperatures. While the least oviposition was found in *Manyü Rhi* (32.67 eggs/25 seeds) at controlled temperature and in *Rhüjo* (21.67 eggs/25 seeds) at normal room temperature. The least adult emergence (58.00 and 56.92%), infestation (7.10 and 7.01%) and weight loss (3.73 and 3.41 %) were found in *Rhüjo*.

The physical characteristics *viz.*, seed size and seed index and biochemical contents *viz.*, protein and starch were positively correlated with the biological parameters of the pest *viz.*, oviposition, adult emergence, growth index, per cent infestation and weight loss, while phenol and tannin contents were negatively correlated. The seed coat thickness and fat content were not found to be significantly correlated with the biological parameters of the pest.

Four storage structures *viz.,* plastic jar, bamboo basket, jute bag and cloth bag were evaluated for their effect on the incidence of *C. chinensis.* Among the different storage structures, the highest infestation and weight loss were found in cloth bag (90.54 and 25.08%) and the lowest was found in plastic jar (76.65 and 16.20%) after 6 months of storage. The grain moisture content increased with the increase in the storage period.

Among the different botanicals tested, the order of toxicity was found in the following order: *P. nigrum* > Jatropha oil > *L. citrata* > *A. indica* > *E. globules* > *O. tenuiflorum* > *P. pinnata* > *A. sativum*. The seeds treated with Jatropha oil @ 3% concentration showed the highest reduction in oviposition (82.30%). Among the plant powders, the highest was found in *L. citrata* (38.38%) followed by *A. indica* (24.73%) and *P. nigrum* (19.03%) @ 5% w/w. Similarly, in the plant extracts the highest was found in *L. citrata* (35.82%) @ 3% followed by *P. nigrum* (22.18%) @ 2%. *L. citrata* seed powder and extract provided effective protection up to 2 months of storage with an infestation of 16.12 and 17.61% and weight loss of 2.40 and 4.10%, respectively followed by *P. nigrum* seed powder and extract with an infestation of 31.67 and 26.18% and weight loss of 6.93 and 5.60%, respectively. Among all the treatments, Jatropha oil was the most effective with minimum seed infestation (1.40, 2.11 and 4.65%) and weight loss (2.36, 2.91 and 3.23%) at 2, 4 and 6 months of storage. The result of Jatropha oil was at par with the standard check Malathion 50EC up to 4 months of storage. The treatments did not show any adverse effect on the seed germinability.

Keywords: Ricebean, Pulse beetle, Biological parameters, Correlation, Storage structures, Botanicals.

CHAPTER I

INTRODUCTION

INTRODUCTION

Pulses are important food crops for a substantial proportion of the world's population, especially in developing nations where they provide the nutritional needs of diverse human diets. It is estimated that humans have been cultivating and eating pulses for more than 11,000 years. Pulses have a rich and colourful history of nourishing cultures all over the world. They are a good source of proteins, carbohydrates, vitamins, minerals and certain essential amino acids. Pulses are also called "Poor man's meat" and "rich man's vegetable" because of their high protein content ranging from 20 to 40 per cent (Das *et al*., 2005). In India, a variety of pulse crops are cultivated across a wide range of agro-climatic conditions which are utilized as a fodder crop and contribute to soil health, in addition to being consumed for their protein content. Pulses are the highest source of protein for vegetarians therefore it plays an essential role in the Indian diet since a major portion of Indians are vegetarian (Singh *et al*., 2010). Pulses contribute about 10 per cent of the protein consumed among rural Indians (Roy *et al*., 2017). India is the world's largest producer and consumer of pulses with about 29% in the global area and 19% in the global production (Singh *et al*., 2015).

Among various pulse crops, ricebean [*Vigna umbellata* (Thunb.) Ohwi and Ohashi] is an important food legume cultivated in many developing countries. It is also known as climbing mountain bean, mambi bean, oriental bean and red bean. Ricebean like other *Vigna* species is a versatile crop mostly grown as a dry pulse and also used as a fodder and green manure. Ricebean is one of the underutilized grain legumes regarded as a minor food (Joshi *et al*., 2007) has great potential to solve the food and nutritional problem. The ricebean seeds are rich sources of carbohydrates, proteins, minerals and vitamins. They are mostly cultivated in the non irrigated and uncultivated land that otherwise goes to waste which helps in utilizing uncultivated land and also contributes to food and nutritional security (Bhardwaj and Thakur, 2017). In India cultivation of ricebean is mainly confined to the tribal areas of Eastern and Northern India and to some extent in Orissa and Bihar. In North Eastern Region it is cultivated mainly as a rainfed crop in mixed cropping system, shifting cultivation or in the kitchen garden. It is also cultivated along rice bunds and terrace-margins in the midhills particularly in Assam, Meghalaya, Manipur, Mizoram, Arunachal Pradesh and Nagaland (Shitiri *et al*., 2019). Ricebean has emerged as a viable alternative to other legumes such as black gram and green gram which do not thrive in this region due to their sensitivity to cold weather (Bhardwaj *et al*., 2021).

Ricebean is an important pulse in Nagaland and is popularly known as '*Naga Dal*'. It is known by different local names in different parts of the state, such as *Kerhü* (Angami), *Akixi* (Sema), *Shumai* (Chang), *Orho* (Lotha), *Pheang* (Konyak) *etc*. In Nagaland, ricebean is a traditional and native crop, which has been cultivated for centuries and is considered a minor legume. There are many landraces of ricebean under cultivation in Nagaland which constitutes a rich source of biodiversity. However, its cultivation and production are limited and confined to small and marginal areas. Being a native species it has high local adaptability and can grow well without much efforts and inputs. All cultivated varieties of ricebean in Nagaland are landraces that have disseminated from one village to another and from generation to generation (Shitiri *et al*., 2019). In Nagaland, during 2020-21 the total production was 5,730 MT from an area of 4,970 ha (Statistical Handbook of Nagaland, 2021).

However, the full yield potential of ricebean has not been realized due to a number of constraints. Insect pests of both field and stored products are one of the major constraints encountered during the production, storage and marketing of pulses. Moreover, the climatic condition of the North East region supports a rich biodiversity of flora and fauna which is highly favorable for the reproduction and development of insects. Among the insect pest, *Callosobruchus chinensis* (L.) is the most important bruchid that causes considerable damage to *Vigna* seeds. In general, the bruchid infestation begins in the field, where the insect feeds through the pod and remains hidden in the seeds. When such seeds are harvested and stored, it results in secondary infestation in storage causing complete destruction in about six months of storage (Srinivasan *et al*., 2010). It is estimated that pulses infestation by *C. chinenesis* causes about 55 to 60% loss in seed weight and 45.50 to 66.30% loss in protein content (Kutbay *et al*., 2011). The damage due to this pest affects seed viability as well as the nutritive value of the seed (Pradhan *et al*., 2020). So far in Nagaland, there is almost no relevant information on the extent of damage cause by *C. chinensis* on ricebean seeds in storage.

Several studies had concluded that there is a substantial difference in host suitability and preference by the pulse beetle on different varieties. Therefore, it is imminent to screen out cultivars and determine the factors influencing differential preference by the pest so that the information generated can be explored in resistance breeding. The use of bruchid-resistant cultivars has considerable potential for minimizing the losses in storage (Dongre *et al*., 1996). The physical characters of seed and biochemical constituents are known to confer resistance to bruchids. Various physical factors such as colour, shape, texture, size, *etc.* and bio-chemical composition such as protein, phenols, flavonoid, tannin, starch, fats, *etc.* influencing feeding and ovipositional responses have already been studied by various workers (Bhattacharya & Banerjee, 2001; Umarao & Verma, 2003; Lattanzio *et al*., 2005; Chandel & Bhadauria, 2015a). In India, so far for the management of bruchids, conventional treatments methods have been in use. However, keeping the environmental aspects in mind the need for ecologically sound methods such as resistant varieties for pest management is required in an integrated approach and exploitation of host plant resistance is one of the promising methods (Pradhan *et al*., 2020).

With the increasing demand for more food production, the need for increasing productivity and reducing post harvest loss is of outmost importance. Insect pests cause substantial losses due to secondary infestation in storage. In India, farmers usually store seed in plastic containers, gunny bags, metal containers, polythene bags, *etc*. with little consideration for insect pest attacks throughout storage periods (Kumar *et al*., 2016a). The storage containers play a critical role in the population build-up of bruchid and also in decreasing the extent of damage in storage conditions (Roja *et al*., 2021). Therefore appropriate storage structure plays an important role in reducing post harvest losses. Generally, synthetic insecticides are used for the management of pest. However, there are many limitations and undesirable side effects associated with the use of synthetic insecticides. The indiscriminate use of synthetic insecticides has led to the development of insect resistance, resurgence, toxic residues on food, *etc*. Therefore, there has been an increased need to explore suitable alternative methods of pest management. Various plant extracts have been found to have insecticidal, oviposition deterrent, and ovicidal properties against bruchids and other insect pests (Siskos *et al*., 2008 and Nymador *et al*., 2010). The use of plant products is one such alternative as they are cheap, easily available, and safe for the environment and human beings.

The demand for pulses is fast increasing, both in developed and developing countries, where they meet the minimum protein requirements of an increasing population turning to a vegetarian diet. Their productivity can be doubled by improved cultivars, modern production technologies and the adoption of proper crop protection measures. Among the different pulses, ricebean is an important pulse in Nagaland with many landraces cultivated by the farmers where the seeds are mainly used for consumption. Ricebean which has been considered a minor and an underutilized pulse has a wide range of uses and has gained importance in recent times due to its high nutritive value (Balmiki *et al*., 2021). However, like any other pulse ricebean seeds are also prone to attack by bruchids in storage condition and pulse beetle, *C. chinensis* is one of the important pests. Although many researchers have conducted several studies on pulse beetle, *C. chinensis* on various stored pulses and their management but no such work has been attempted on ricebean cultivars in Nagaland. The information on ricebean cultivation, economic loss due to the infestation of stored grain pests and their eco-friendly management is very limited. Therefore, keeping these aspects in view, the present study entitled "Screening of some ricebean [*Vigna umbellata* (Thunb.) Ohwi & Ohashi] cultivars against pulse beetle [*Callosobruchus chinensis* (L.)] and its management with botanicals" is proposed with the following objectives:

1. To screen some ricebean cultivars against *C. chinensis* (L.)
2. To study the effect of storage structures on the incidence of *C. chinensis* (L.)
3. To study the efficacy of some botanicals as grain protectants

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The pulse crops are attack by several insect pests both in field and storage condition. Among these, the pulse beetle, *Callosobruchus chinensis* (L.) is a serious pest of pulse crops causing considerable damage to the grains in storage. Almost all pulse crops have been reported to be infested by this beetle all over the world (Singh *et al*., 1980).

Therefore, considering the importance of the pest in the present study an attempt has been made in this chapter to review available literatures which are relevant to the objectives of the present study.

2.1 Status of ricebean, *Vigna umbellata*

Pulses play an important role in diverse human diet. They are rich in protein, minerals and essential amino acids. Among various pulse crops, ricebean, *Vigna umbellata* (Thunb) Ohwi and Ohashi is an important crop cultivated in many developing countries due to their higher nutritional quality and multipurpose uses as food, fodder and green manure. Ricebean belongs to the family *Leguminosae* and sub family *Papilionacae.*

Ricebean is a native of South and South East Asia from the Himalayas to South China and Indonesia (Chandel & Pant, 1982). The major ricebean cultivating countries are India, Nepal, Myanmar, Thailand, Laos and Southern China. In India, they are mainly cultivated in the North Eastern Region (Assam, Meghalaya, Manipur, Mizoram, Arunachal Pradesh and Nagaland). Ricebean is grown predominantly under rainfed condition in mixed cropping system, shifting cultivation or in the kitchen garden (Shitiri *et al*., 2019).

Ricebean is one of the underutilized grain legumes regarded as a minor food (Joshi *et al*., 2007). However, in the recent time it has emerged as a viable alternative to other legumes such as black gram and green gram which do not thrive in the North East Region due to their sensitivity to cold weather

(Bhardwaj *et al*., 2021). Ricebean has a wide range of uses and has gained importance in recent times due to its high nutritive value (Balmiki *et al*., 2021).

2.2 Screening against pulse beetle, *C. chinensis*

Insect pests are a serious limitation in the production of pulses, causing significant losses both in the field and in storage. In general synthetic chemical pesticides are routinely used to manage storage insect pests, but they have a number of downsides, including high costs, pollution and food safety concerns. Therefore, development of suitable control measures is essential. Identification of new sources of resistance by screening methods can help in developing resistant cultivars. So far various studies have been conducted on host preference and screening of cultivars to identify resistant traits.

Edward and Gunathilagaraj (1994) screened 26 accessions of chickpea for their resistance against pulse beetle and reported that resistance was due to antibiosis as reflected in lower survival, prolonged development period and adults with reduced longevity.

Sison *et al*. (1996) screened several mungbean varieties for resistance to *C. chinensis* under both choice and no choice tests and reported that TC 1966 was highly resistant, while pag-aga (1, 3, 5 and 7) was susceptible.

Liu-xuming *et al*. (1998) conducted a study for identification of resistance source of mung bean by using both artificial and natural infestation of *C. chinensis*. Among the tested germplasms, 17 lines from Asian Vegetable Research and Development Center (AVRDC) showed moderate resistance to immunity, while only three land races from Gangxi showed moderate resistance.

Riaz *et al*. (2000) conducted a study to evaluate seven strains of chickpea namely, NCS 96002, NCS 950004, NCS 950012, 92CC-076, 92CC-079, NCS 950183 and NCS 960003 under laboratory conditions. Three tests (confinement, free choice and antixenosis) were conducted in laboratory condition.The strains of chickpea NCS-96003, NCS-950012 and 92CC-079 were found to be partially resistant, whereas NCS-96002 was registered as partially susceptible.

Singh and Sharma (2001) evaluated thirteen varieties of chickpea for oviposition preference and subsequent larval development of *C. chinensis.* PG-5 was found to be the most resistant variety with minimum growth index of 1.358 and longest grub development period of 28.33 days.

Divya *et al*. (2012) investigated 50 horsegram accessions for resistance to pulse beetle, *C. chinensis* and observed significant variation among the accessions with respect to preference for oviposition (0.00 to 82.00), adult emergence (0.0 to 35.7), per cent damage (0.00 to 52.7) and per cent weight loss (0.00 to 49.3). Three accessions *viz.*, Palem-1, AK-21 and NSB-27 were found to be resistant against *C. chinensis* with no adult emergence and no per cent insect infestation.

Ponnusamy *et al*. (2014) conducted an experiment for the identification of new sources of resistance in 475 accessions of two *Vigna* species against *C. chinensis* using ‘free choice’ and ‘no-choice’ techniques. Four green gram accessions (LM 131, V 1123, LM 371 and STY 2633) were found moderately resistant and in black gram, three accessions (UH 82-5, IC 8219 and SPS 143) were found moderately resistant.

Chakraborty *et al.* (2015) conducted a study on the life history, ovipositional preference and nature of damage caused by *C. chinensis* on five different pulses. Among the pulses, Kidney bean was preferred most for oviposition followed by cowpea, black gram, small pea and green gram, but adult survival rate was low in kidney bean. The degree of infestation was found to be different among the pulses. The order of susceptibility as per susceptible index was cowpea > green gram > small pea > black gram, whereas kindey bean was found to be resistant.

Sarkar and Bhattacharyya (2015) conducted a feeding assay in laboratory condition to screened some wild *Vigna radiata* germplasm namely

Sub2, Sub9, Sub2/7/2, Sub2/3/4, *setulosa* and Sub14, and four popular cultivars of green gram namely B1, NP28, PS16 and Kopergaon against *C. chinensis*. The various development stages of the insect was observed and evaluated from which wild green gram *V. radiata* var. *sublobata* namely Sub2 was found to be resistance to the bruchid.

Tripathi *et al*. (2015) screened 52 accessions of cowpea including two checks (Pusa Komal and Local variety) for resistance to pulse beetle, *C. chinensis* in a no choice test. They found significant differences among the accessions in terms of number of eggs laid, development period, adult emergence, number of emergence holes, weight loss and growth index of *C. chinensis* on cowpea. Two accessions *viz*., Pusa Komal and IC328859 were found to be resistant, while IC106033 and Local variety were most susceptible to *C. chinensis* based on growth parameters. The growth index and adult emergence were found to be positively correlated. Adult emergence and weight loss were also found to be positively correlated.

Ahmad *et al*. (2016) investigated 11 chickpea varieties for host preference of *C. chinensis* based on growth and development of the bruchid. The study revealed significant difference in oviposition preference. Maximum oviposition was observed on PKG 1 (81.00 eggs/100 seeds) and minimum on PBG 1 (59.00 eggs/100 seeds). They also observed significant difference in the development period and growth index on various varieties. Among the varieties tested, the variety PKG1 was found to be the most susceptible against pulse beetle.

Singh *et al.* (2016) evaluated ten germplasm of chickpea namely NDG97-1, NDGK98-8, NDG11-5, NDG12-1, BG50-28, BG-362, IPC2004-5, BG-256, DCP92-3 and NDG93-1 for their resistance against pulse beetle, *C. chinensis* under laboratory conditions. Based on per cent infestation the germplasm DCP 92-3 was found to be significantly tolerant and BG-256 least tolerant followed by NDG11-5, NDGK 98-8, NDG 93-1, NDG 97-1, IPC

2004-52, BG-362, BG 50-28 and NDG 12-1 was significantly susceptible. They also found positive correlation between per cent infestation and per cent moisture content, protein content and fat content.

Bharathi *et al*. (2017) studied the developmental response of pulse beetles (*C. chinensis* and *C. maculatus)* on different pulses and reported that among the pulses studied, green gram and Bengal gram were most preferred hosts based on both development and damage, while soybean and pea were least preferred.

Kavitha *et al*. (2018) conducted a screening test on 12 greengram genotypes for resistance to pulse bruchid, *Callosobruchus chinensis,* under no-choice artificial infestation conditions. The study revealed five genotypes *viz.*, PM-5, LGG-610, LGG-607, GGG-1 and LGG-595 to be resistant. Among the genotypes the highest number of eggs laid (73.17 / 100 seed), adult emergence (63.20%), seed weight loss (29.21%), growth index (2.83) and shorter mean development period (25.81 days) were recorded in WGG-42. They also observed that with the increase in storage period the development and infestation of the bruchid also increases.

Gopi and Singh (2020) studied the varietal preference of pulse beetle on six green gram varieties *viz.,* Pant M-6, PUSA 0672, KM 2241, DGGS 4, IPM 2-3 and IPM 02-14. Based on seed damage and weight loss, maximum damage and weight loss was observed in variety KM 2241. High degree of resistance was observed in variety DGGS 4 with minimum damage and weight loss.

Sathish *et al*. (2020) investigated promising genotypes of chickpea seeds for host plant resistance in storage against *C. chinensis*. Among the genotype tested, the genotype PI 599066 was found to be completely resistant in both free choice and no choice test. No seed damage was observed in the study. They concluded that the genotype can be used in breeding programmes for resistance development.

Meena *et al*. (2021) reported differences in host preference of pulse beetle, *C. chinensis* at different growth stages of the insect on various pulses. The study reported that for incubation period green gram, cowpea and lentil were most preferred, for larval-pupal period and fecundity cowpea was most preferred, green gram was most preferred in terms of pre-oviposition period and total life cycle (42.67 for male, 44.00 for female), kabuli gram was recorded as most preferred for oviposition period and chickpea was found preferred for post-oviposition period.

Jatav *et al*. (2022) investigated several green gram varieties *viz*. Virat, Shikha, Pusa Ratna, Pusa Vishal, Pusa 1431, TJM 3, PDM 139, IPM 99-125, IPM 2-14, IPM 2-3 and MH 421 for host preference against the pulse beetle. Observations were made on oviposition, adult emergence, grain damage, weight loss and per cent germination at 90 days of storage. Among the varieties, Pusa Vishal and TJM 3 was most preferred host for egg laying. The maximum mean adult emergence, seed damage (68.33%) and weight loss (27.03 %) was observed in Pusa Vishal. The variety MH 421 was found least preferred against *C. chinensis*.

2.3 Physical and biochemical basis of resistance against Pulse beetles, *C. chinensis*

The physical characters of seed and biochemical constituents are known to confer resistance to pulse beetle, *C. chinensis*. The resistance mechanisms include morphological, physiological and biochemical strategies that can range from merely reducing the impact of an insect attack to negatively impacting the insects' cellular processes, growth and development (Singh *et al*., 2001). Several studies had concluded that there is a substantial difference in host suitability and preference by the pulse beetle based on physical characters and biochemical contents.

2.3.1 Physical basis for bruchid resistance

Seed characteristics like size, colour, lustre, *etc*. are known to affect resistance or preference of bruchids. Singh *et al*. (1974) have attributed grain resistance to differences in grain size (mass) and asserted that the larger grains supply more food and space for insect growth and then the smaller grains or grains with less mass offer more resistance to pests attack than the larger grains. Nwanze and Horber (1976) reported that cowpea weevil prefers smooth coated seeds to wrinkled seeds for oviposition, and more first instar larvae successfully penetrate the seed coat in smooth than in rough seeds. Ahmed *et al*. (1993) reported that cultivars with hard seed coat showed non preference by pulse beetle. Rathore and Chaturvedi (1997) reported that larger seeds of chickpea were more preferred for oviposition than smaller seeds.

Srinivasan and Durairaj (2007) reported that biophysical factors like seed weight and hardness had a highly significant and negative relationship with that of suitability index of *C. maculatus.*

Erler *et al*. (2009) reported that rough (wrinkled) and thick seed coat of chickpea might be responsible for resistance to pulse beetle, *C. maculatus.*

Neog and Singh (2011) observed that the seed characters such as 100 seed weight, seed coat thickness, colour and texture of seed coat were not related with the ovipositional preference and host suitability of the pest to different pulse seeds.

Muhammad (2012) investigated 12 chickpea genotypes for resistance to *C. maculatus* attack and reported that the seeds with hard and wrinkled seed coat, dark brown colour and small size grain were tolerant and showed significant harmful effect to pest and grain damage. The genotypes with soft and smooth seed coat, white seed colour and bigger grain size were susceptible.

Lephale *et al*. (2012) reported that the cultivars with small mass were infested with large number of bruchids while that with larger mass recorded very small insect numbers.

Tripathi *et al*. (2013) reported that growth index of *C. chinensis* had no significant relation with seed hardness and seed coat hardness, while it showed positive relationship with length width ratio of seed and 100 seed weight.

Ponnusamy *et al.* (2014) registered less numbers of eggs and lower percentage of emergence in small (62.6 per 50 seeds and 78.4% emergence) and shiny seeds (69.9 per 50 seeds and 74.3% emergence) in green gram as compared to the large (85.0 eggs and 90.4% emergence) and dull (75.3 eggs and 80.7% emergence) seeds. They concluded that preference of female for egg laying in large and dull seeds could be possibly due to the ease for settling of adults for ovipoistion.

Kamble *et al.* (2016) conducted a varietal screening of chickpea cultivars to study the oviposition preference of pulse beetle and found that minimum number of eggs (17.75 eggs/30 seeds) was laid on the variety with wrinkled seed coat, rough, yellowish colour and medium sized seed characteristics as compared to bold seeded white to brown colour variety where maximum eggs (31.33 eggs/30 seeds) was laid.

Prajapati *et al*. (2018) studied the effect of seed size and seed coat colour on oviposition, development and orientation of pulse beetle. The study revealed that seeds of dark brown in colour were less preferred for orientation and oviposition, followed by brown colour, whereas light yellow seeded varieties were most preferred by the beetle. Significant differences were not observed in seed size. Eker *et al*. (2018) also reported lower numbers of eggs on hairy, wrinkled/reticulated and dark seed. They observed that the physical characters of seeds influence the host preference of the bruchid for host selection and oviposition.

Jaiswal *et al*. (2019) conducted an experiment to study the ovipositional preference of pulse beetle *C. chinensis* on different pulses *viz.*, cowpea, green gram, black gram, red gram and chickpea. They found that the adults on pulse beetle preferred smooth, well-filled seeds for oviposition.

Pawara *et al*. (2019a) reported significant differences in terms of preference for oviposition, development period, adult emergence, seed infestation, weight loss and growth index of *C. chinensis* on 21 interspecific progenies of mungbean. They found that cultivars with small, rough, wrinkled, hard and thick seed coat were more resistant compared to those having smooth, soft and thin seed coat.

Falke *et al.* (2021) studied host preference of *C. chinensis* on different pulses and concluded that softer the seed, the attack of *C. chinensis* results in more seed damage and weight loss.

Paikaray *et al*. (2021a) investigated 10 interspecific progenies of mungbean against pulse beetle. In the study they found that the physical characters of the seeds influence the host preference of the bruchid. The seeds with small, rough, wrinkled, hard and thick seed coat were found to be more resistant compared to those having smooth, soft and thin seed coat.

Senthilraja and Patel (2021) reported minimum oviposition on seeds having a rough testa texture and greater number of eggs were found on smooth texture seeds. They concluded that irrespective of shape and colour of seeds, smooth textured seeds were favored for oviposition by pulse beetle.

2.3.2 Biochemical basis of bruchid resistance

Marconi *et al*. (1997) analyzed the seeds of eight wild species of *Vigna* for their chemical contents and observed significant positive correlations between seed resistance to bruchids and trypsin inhibitor, tannin and starch contents.

Venugopal *et al*. (2000) conducted a study to bruchid resistance in wild and cultivar legume varities. The primary metabolites (protein, carbohydrate, lipids and amino acids) and secondary metabolites (phenol, ortho-dihydroxy phenols and tannin) of seeds were correlated with the developmental parameters of the bruchid. Greater amount of resistance was observed in the wild varieties where the secondary metabolites content were higher compared to the cultivar varieties. They concluded that the secondary metabolites are crucial in conferring resistance in seeds.

Umarao and Verma (2003) studied the protein composition of 20 pea genotypes to estimate their protein composition for preference of *C. chinensis*. It was found that low protein content genotypes were least susceptible, while high protein content genotypes were highly susceptible to pulse beetle.

Lattanzio *et al*. (2005) reported that during bruchid infestation in stored cowpea seeds, seed coat tannins are effectively involved in the biochemical defence mechanisms, which can deter, poison or starve bruchid larvae that feed on cowpea seeds.

Misal *et al.* (2008) evaluated green gram, black gram and ricebean for resistance to *C. chinensis* and found that α amylase inhibitor, trypsin inhibitor, total phenols and tannic acid had a positive correlation with resistance to pest.

Somta *et al.* (2008) reported that the biochemical contents in cotyledons of green gram varieties were responsible for the resistance to bruchids.

Tripathi *et al*. (2013) conducted a laboratory study on 52 accessions of cowpea to determine the physical and biochemical basis of resistance against pulse beetle. In the study they observed variable response of *C. chinensis* to cowpea accessions and they concluded that the resistance observed in different accessions might be due to biochemical factors rather than the physical parameters of the seed. Phenol and tannin content of seeds were found to be negatively correlated with the growth index of pulse beetle.

Chakraborty and Mondal (2016) studied the host preference of pulse beetle on five different species of pulses. The interaction of physico-chemical characters on the degree of infestation by assessing the number of eggs laid, adult emergence and developmental period on different pulses were studied and positive correlation was found between phenol content, OD phenol content and protein content with oviposition and developmental period, while negative correlation with adult emergence percentage was observed.

Holay *et al*. (2018) reported that protein, carbohydrate and fat content of pigeonpea had a positive correlation with the growth and development of *C. maculatus*.The pigeonpea genotypes with high protein, carbohydrate and fat exhibited higher per cent grain damage and per cent weight loss. The ash content was found to be negatively correlated.

Deepika *et al*. (2020) evaluated the biochemical content (protein, total soluble sugar, starch, trypsin inhibitor and protease inhibitor) of 15 chickpea genotypes and studied their effect on per cent weight loss and damage. They reported negative correlation between seed damage, weight loss and trypsin inhibitor activity, protease inhibitor activity. Whereas significant positive correlation was observed between seed damage, weight loss and protein content, starch content and total soluble sugars.

Pradhan *et al*. (2020) observed positive significant correlation between per cent seed damage, per cent weight loss and biochemical parameters like protein content, total soluble sugar (TSS) content and starch content, whereas parameters like trypsin inhibitor activity and protease inhibitor activity were negatively correlated. 15 genotypes of chickpea were studied and maximum seed damage and weight loss was observed in the genotype HC-10 (47.92 and 64.00%, respectively), while in genotype Digvijay minimum seed damage and weight loss (33.92 and 37.99%, respectively) was observed. The maximum protein content was recorded in genotype Annegiri (23.67%) and minimum content was recorded in Digvijay (14.20%). The maximum total soluble sugar content was observed in the genotype HC-10 (8.55 mg/g) and minimum in genotype CSJD-884 (4.19 mg/g). Maximum starch content was recorded in genotype HC-10 (50.82 mg/g) and minimum in the genotype Digvijay (41.36

mg/g). The highest activity of trypsin inhibitor was seen in Digvijay (34.80 TIU/mg protein) and lowest in the genotype HC-10 (7.20 TIU/mg protein). The maximum protease inhibitor activity was observed in Digvijay (31.50%).

Kavitha *et al*. (2021) reported positive correlation between biological parameters (*i.e*., number of eggs, adult emergence and growth index) and biochemical parameters (*i.e*., protein content, sugar content and moisture content) and negative correlation with phenol content. In the study 12 genotypes were investigated to know the influence of biochemical parameters on development of the pulse bruchid in green gram. The study revealed that genotypes having low sugar and protein contents and high phenol content were resistant to pulse bruchid.

2.4 Storage structures

The storage structures play a critical in maintaining the quality and quantity of grains in storage. Grains in India, is stored at farmers, traders and industrial levels. Ramesh (1999) reported that the lack of proper storage facility at farm level results in high wastage and value loss.

In India, around 60-70% of pulses produced were stored at home level (Kanwar and Sharma, 2003). The amount of time pulses can be safely stored depends on the condition in which they were harvested and the storage mechanisms used. The insect pest infestation in storage varies with different storage structures (Meena and Bhargavam, 2003). Farmers use locally available raw materials to develop traditional structures differing in design, shape, size and functions. Earthen pots and bamboo baskets are the most commonly used storage device, which is available with almost every household mainly for short-term storage, known by different vernacular names like Paanai and Urai in Tamil, Kulhi and Chabri/Peru in Himachal Pradesh (Sharon *et al*., 2014).

Bhargava and Choudhary (2007) conducted a survey in all of Rajasthan's districts. They found that *Callosobruchus* spp. caused the most grain damage in loose storage. Among the storage containers, they found that grains stored in metal containers were least damaged by *Callosobruchus* spp.

Regmi and Dhoj (2011) reported that the storage structures of Aluminium sheet bin and jute bag with plastic lining in combination with botanical pesticides can be used as eco-friendly measures for the management of bruchid in chickpea and other related pulses.

Pareek *et al*. (2013) studied different packing materials and storage containers against pulse beetle, *C. chinensis* and reported minimum damage in the metal bin (4.00-11.67 %). They concluded that the metal bin could provide effective protection up to 90 days. The different containers they evaluated were cloth bag, gunny bag, polythene bag, urea bag, *Matka* bin, metal bin and *Kuthla* bin.

Kumar *et al*. (2016a) conducted a survey in Munger, Bihar on the storage containers used by the farmers. They found that the most common containers were polythene bag, metal container and jute bag. For storage of green gram polythene bag was most common and for chickpea it was metal container.

Nehra *et al*. (2021) reported that the use of silica (2%) in different packaging materials (polythene bags, gunny bags, cloth bags and jute bags) effectively minimize the storage losses by the infestation of pulse beetle (*C. chinensis*) during storage. Among the materials, polythene bags with silica (2%) were observed to be most effective with minimum oviposition (21.33), seed damage (3.33%) and weight loss (7.93%).

Roja *et al*. (2021) reported that triple layered polyethylene bag and plastic bin with 3 cm sand layer above the grain were effective in reducing the weight loss (5.43 and 9.89%, respectively) at 90 days after infestation. In a laboratory experiment, they evaluated several storage containers *viz*., earthen pot, metal bin, plastic bin, plastic bin with 3 cm sand layer above the grain, polypropylene bag, double layered poly ethylene bag, triple layered polyethylene bag and polyethylene lined gunny bag for management of pulse beetle. Gunny bag was used as control. In the study they found maximum oviposition on metal bin (27.33 eggs/female on 500 seeds) followed by earthen pot (27.00 eggs/female on 500 seeds) and plastic bin (24.33 eggs/female on 500 seeds) and lowest oviposition was found on triple layered polyethylene bag (6.33 eggs/female on 500 seeds) followed by Plastic bin with 3 cm sand layer above the grain (14.00 eggs/female on 500 seeds).

Rolania *et al*. (2021) conducted a survey in Southern Haryana to assess the losses caused by pulse beetle (*Callosobruchus* spp.) of chickpea grains during storage in different storage structures. It was found that traditional storage structures (earthen pots, earthen pots + sand, jute bags) were used by the farmers. Among the storage structures, they found that there was no infestion of pulse beetle in grains stored in earthen pot along with sand.

Ganiger *et al*. (2022) conducted a study on seed solarization and vaccum packaging of green gram seeds and reported that solarization of fresh seeds for 4h for 8 days and stored in vaccum packed bag effectively preserve the seed quality and zero seed infestation during storage.

2.5 Plant products as grain protectants against pulse beetle

Plant products as grain protectants have a long history and many plants are currently in use as grain protectant against damage caused by insect infestation. The key benefits of employing botanicals as a grain protectant are that they are environment friendly, easily biodegradable and locally available. To avoid insect pests damage during storage, many components of plants have been evaluated. Diverse studies have been conducted on the usage of various botanicals during the storage of food grains.

Yadav (1973) reported complete protection from pulse beetles (*C. maculatus* and *C. chinensis*) in gram and pigeon pea up to 12 months of storage when treated with 2.0g of neem kernel powder per 100 g of seeds.

Negasi and Abage (1992) reported that seed powder of neem (*A. indica*), pepper (*Piper longum* L.) and persian lilac (*Melia azederach*) effectively protect bean seeds from bruchid infestation up to 120 days.

Paneru and Shivakoti (2001) studied the effect of sweet flag (*Acorus calamus*), goat weed (*Ageratum conyzoids*), lantana (*Lantana camara),* Indian privet (*Vitex negundo*), mug-wort (*Artimisia vulgaris*), chinaberry (*Melia azederach*), rice husk ash, mustard (*Brassica* spp.) oil and neem oil (*Azadirechta indica*) against pulse beetle (*C. maculatus*). @ 0.5, 1 and 2% w/w or v/w. The powder of sweet flag, rice husk ash and mustard oil showed a significant effect in killing the pulse beetle within a week. Neem oil was found very effective with 100% mortality of the beetle within two days.

Juneja and Patel (2002) reported that seed of green gram treated with 1% of powdered black pepper seeds protected the seeds from pulse beetle up to 5 months.

Khalequzzaman and Sultana (2006) studied the insecticidal activity of the seed extracts of custard apple, *Annona squamosa* in petroleum spirit, ethyl acetate, acetone and methanol against Raj, CR 1, FSS II and CTC-12 strains of the red flour beetle, *Tribolium castaneum.* The highest toxicity was recorded for petroleum spirit extract (LD50= 0.03μg cm-2) in Raj strain and the lowest toxicity was for methanol extract (LD50=15.697μg cm-2) in FSS II strain. In case of adults, petroleum spirit extract offered highest toxicity (LD50= 58.697μg cm-2) in CTC 12 strain and the lowest toxicity (LD50=22004.710μg cm-2) was for acetone extract in CR 1 strain.

Kumar *et al*. (2006) studied the insecticidal property of Karanj (*Pongamia pinnata*) leaf, bark and seed oil on *Spodoptera litura*, *Trogoderma granarium* and *Tribolium castaneum* and reported that the methanolic extracts of crude seed oil showed the maximum growth reduction and antifeedancy against the larvae of *S. litura* and was also most toxic to *T. granarium*, whereas karanj leaves exhibited toxicity against *T. castaneum*. The crude seed oil showed the maximum repellency against *T. granarium*.

Rahman and Talukder (2006) studied the bioefficacies of plant derivatives against pulse beetle development and observed that the plant oils were effective as grain protectants. Among the treatments, the powdered leaves and extracts of nishinda, eucalyptus and bankalmi @3% mixture showed effective results in reducing oviposition adult emergence and grain infestation. The treatments did not affect germination up to 3 months of storage.

Khalequzzaman *et al*. (2007) tested seven vegetable oils *viz*., sunflower, mustard, groundnut, sesame, soybean, olive and oil palm @0.5, 0.75 and 1% v/w concentrations as grain protectants of pigeonpea against the pulse beetle (*C. chinensis*) and found that groundnut oil at 1% was the most effective up to 66 days after treatment.

Lakshmi and Venugopal (2007) reported that the seed powder of *Annona squamosa* and rhizome powder of *Acorus calamus* @ 3% against *C. maculatus* resulted in minimum egg hatching and grain weight loss.

Shukla *et al*. (2007) studied the efficacy of six plant powders *viz*. *Syzygium cumini*, *Aegle marmelos*, *Eupatorium cannabinum*, *Murraya koenigii*, *Ammomum subulatum* and *Citrus medica* against pulse beetle in both free choice and no choice test. Among the plant powders they reported *M. koenigii* and *E. cannabinum* to be the most effective in reducing the orientation, oviposition and causing the mortality of bruchids at dose of 2% (w/w).

Sathyaseelan *et al*. (2008) tested indigenous plants against pulse beetle in green gram and reported that leaf extract of *Vitex* sp. at 5% concentration was the most effective in inhibiting oviposition.

Yankanchi and Lendi (2009) reported 100% ovicidal activity of plant leaf powders of *Tridax procumbens, Withania somnifera, Pongamia pinnata* and *Gliricidia maculate* against pulse beetle in stored green gram seeds. The leaf powders of *T. procumbens* and *W. somnifera* showed significant mortality, oviposition deterrence and F1 adult deterrence of *C. chinensis* at low concentrations @ 5 mg/g seed.

Rajapakse and Ratnasekera (2010) conducted a bioassay study on 20 plant species for its insecticidal property against *C. chinensis* and *C. maculatus*. They observed 41 to 100% egg mortality from six plant oil extracts *viz*., black pepper, lemon grass, clove seeds, neem, custard apple and sacred basil.

The efficacy of seven botanicals (neem leaf, chilli, NSK, tulsi leaf, nerium leaf, lantana leaf, tobacco leaf) at 4.0 and 8.0 % w/w/100 grams of mungbean on mortality of *C. chinensis* was studied by Varma and Anandhi (2010). From the study they found neem leaf (8 gm) to be more effective with 38.33 % mortality, whereas nerium leaf (4 gm) was least effective with 5.70 % mortality.

Singh (2011) evaluated six plant extracts *viz.*, kaner leaf extract (*Nerium indicum*), khejri leaf extract (*Prosopis cineraria*), neem leaf extract (*Azadirachta indica*), safeda leaf extract(*Eucalyptus globulus*), tomato leaf extract (*Lycopersicum esculentum*) and mustard seed extract (*Brassica compestris*) and four plant powders *viz.*, black pepper powder (*Piper nigrum*), garlic clove powder (*Allium sativum*), tulsi leaf powder (*Ocimum sanctum*) and turmeric rhizome powder (*Curcuma longa*) for their oviposition deterrence properties against *C. maculatus*. Three doses (0.5, 0.75 & 1.0ml/100gm or gm/100gm) of each plant product were tested and the maximum oviposition deterrence (55.86%) was recorded with neem leaf extract at the highest dose level (1.0ml/100gm) and minimum (36.98%) with garlic clove powder at lowest dose level (0.5gm/100gm).

Ahad *et al*. (2012) tested N-hexane solvent extracts of 13 local plants for their insecticidal activity against pulse beetle, *C. chinensis*. They observed that all plants extracts demonstrated insecticidal activity in mortality, inhibition of F_1 adult emergence, reduced seed damage and fecundity or repellency. However, 100% mortality within 72 hours was found in extracts of *Emblica officinalis* and *Annona reticulate.*

Neog and Singh (2012) reported that the seed powder of *Piper nigrum* and *Litsea citrata* @ 5% w/w was effective against pulse beetle infesting stored green gram which reduced oviposition by 62.18 to 70.32% and adult emergence by 53.20 to 58.24%.

Ratnasekera and Rajapakse (2012) reported high bioactivity of three plant extracts, *Azadirachta indica* (Neem), *Anona reticulata* (Anona) and *Ocimum sanctum* (Maduruthala/sacred bail) against *Callosobruchus* spp. The seeds were treated at concentration of 0.5, 1.5 and 3.0 µL/50 seeds. The crude plant extracts were extracted by using ethanol as solvent. Complete inhibition of oviposition and adult emergence was reported in *O. sanctum* at 1.5 µL and *A. reticulata* at 3.0 µL concentration.

Tesfu and Emana (2013) investigated the insecticidal properties of different parts of *Parthenium hysterophorus* powder against *C. chinensis* at 0.5, 1.0, 1.5 and 2.0 g per 50 g of seeds. Among the treatments, inflorescence powder exhibited the highest mortality followed by leaf powder and the least was stem powder.

Thakur and Pathania (2013) reported 100% mortality of *C. chinensis* after 7 days of exposure caused by black pepper powder@ 5% w/w, neem oil and mustard oil @ 7.5 ml/kg grains.

Hossain *et al*. (2014) reported the effectiveness of tobacco leaf powder (TLP) on reducing oviposition and adult emergence, seed infestation, and weight loss by *C. chinensis*. Complete protection of chickpea seeds was achieved when the seeds were treated with TLP @20.0 g/kg seeds. 100% oviposition inhibition was also reported.

Radha and Susheela (2014a) reported complete oviposition inhibition of pulse beetle at 0.75 g/l concentration of extracts of *Murraya koenigii* and neem.

Ahad *et al*. (2015) reported 35 to 69% reduction in oviposition and 33 to 63% reduction in adult emergence and 13 to 49% grain protection of mung beans with n-hexane extracts of *Mimosa pudica*, *Argemone mexicana*, *Leucus aspara*, *Polygonum hydropiper* and *Blumea lacera* weeds against pulse beetle, *C. chinensis*. They also observed increase in grain protection activity with increase in concentration of the extracts.

Khan *et al.* (2015) evaluated some promising botanicals *viz*., dried leaf powder of neem, bishkatali, marigold, dholkolmi @ 2.5 g/kg mung bean grains and chopped garlic bulb @ 1 g/kg mung bean grains along with control against *C. chinensis*. They reported that dried leaf powder of neem @ 2.5 g/kg was the most effective control measure among the treatments. The neem leaf powder treatment showed significant reduction in grain infestation (43.12%) and weight loss (41.72%).

Kosar and Srivastava (2016) evaluated different formulations of plants *Euphorbia hirta*, *Phyllanthus amarus* and *Jatropha gossypiifolia* in the form of crude extract, aqueous suspension, aqueous extract, ethanol extract and diethyl ether extract (DEE) against *C. chinensis*. The treatments were made using different dose concentrations *viz*., 1, 5, 10 and 25%. The number of eggs laid by the pest was recorded and ovipositional deterrence was worked out. The lowest oviposition by *C. chinensis* was observed in seeds treated with 25 % DEE extract of *J. gossypiifolia.*

Kumar *et al*. (2016b) evaluated the efficacy of 6 essentials oils of camphor, wild marigold, cone-bearing sage, eucalypts, lemongrass and sweet flag at 2.5ml/kg, 1.25ml/kg, 0.60ml/kg and 0.30ml/kg (v/w basis) against *C. chinensis* infesting pea seeds. Among the six essentials oils, sweet flag was the most effective resulting in 78.33 % and 96.67 % (2.5ml/kg and 1.25ml/kg doses) mortality in 1 and 3 days after treatment.

Neupane *et al*. (2016) studied on the effect of plant dusts, oils and indigenous materials against pulse beetle (*Callosobruchus chinensis* L.) on mungbean seeds. They observed that the botanicals camphor (*Cinnamomum camphora)* and tobacco (*Nicotiana tabacum*) dust @ 2 g/kg of seed and plant oils of neem, sesamum and soybean @ 5 ml/kg of seed were effective for management of pulse beetle.

Singh and Pandey (2016) conducted a study on eco-friendly management of pulse beetle in stored chickpea under laboratory conditions with nine plant based protectants *viz*. dhatura seed powder, tobacco leaf powder, bhaitt leaf powder, lemon leaf powder, ginger rhizome powder, bitter gourd seed powder, asafoetida latex, gunghchi seed powder and alocasia leaves powder. The per cent moisture contents, per cent infestation and per cent germination were evaluated at 3 to 6 months of storage. Among the treatments, asafetida latex was found to be most effective with maximum germination and minimum infestation.

Choudhary *et al*. (2017) reported adult mortality (>57%) of *C.chinensis* during 6 months of storage of cowpea seeds treated with castor, neem and pongam oil @ 1% (v/w) as seed protectants.

Adhe *et al.* (2018) conducted an experiment to study the effect of botanicals on the mortality of pulse beetle @ 10 gm/kg seed and found significant mortality of 70% in *Acorus calamus* rhizome powder, 63.33 % in black pepper seed powder and 30% in turmeric powder in the first month of storage.

Zafar *et al*. (2018) conducted a study to investigate the efficacy of 6 different botanicals (Neem, Bakain, Dharek, Turmeric, Tumha and AK), each at six different concentrations (0.5, 1.0, 1.5, 2.0, 2.5 and 3%) for the management of *C. chinensis*. They reported Neem and Turmeric powders to be comparatively more effective in controlling progeny production of *C. chinensis* than the other tested plant powders.

Afrin *et al*. (2019) reported that black cumin oil and mustard oil when applied on seeds as protectant @ 10% concentration resulted in reduction of adult emergence, seed infestation and seed weight loss. The adult emergence was reduced by 95.86 and 91.05 %, respectively.

Pawara *et al*. (2019b) assessed different plant products *viz.,* Neem seed kernel powder, cow dung cake ash, custard leaf powder, tobacco leaf powder, castor oil, karanj oil and sesamum oil for their efficacy against pulse beetle (*C. chinensis*) and found that the seeds treated with castor oil @ 5 ml/kg was more effective against pulse beetle for ovipositional preference, adult emergence, seed infestation and weight loss followed by karanj oil and sesamum oil @ 5 ml/kg seed.

Ahmad *et al.* (2020) conducted a laboratory experiment to study the contact and ovicidal toxicity of the nine plant essential oils, *viz*. *Cinnamonum camphora*, *Cymbopogon citrates*, *Cymbopogon flexuosus*, *Mentha longifolia*, *Lavender agustifolia*, *Ocimum basilicum*, *Polargonium graveolens*, *Elethia cardmomum* and *Foeniculum vulgare* on *C. chinensis* adults. Residual film bioassay was used for contact and ovicidal studies. Highest contact toxicity and hatching inhibition rate was found in lavender oil at 24, 48, 72 and 96 h after exposure.

Ahmed *et al.* (2020) evaluated the bioefficacy of neem, custard apple and eucalyptus extracts against pulse beetle, *C chinensis* where neem exhibited the highest mortality (36.78%) and eucalyptus showed the lowest mortality (22.75%). Acetone and methanol were used as solvent for extraction and the acetone solvent extracts showed the highest toxicity.

The study conducted by Chakravarty *et al*. (2020) to evaluate the efficacy of eight plant oils *viz.*, Neem oil, sesame oil, clove oil, castor oil, mahua oil, Coconut oil, Mustard oil and Karanj oil at 0.25, 0.50, and 1.0 per cent concentrations against pulse beetle, *Callosobruchus chinensis* L. in chickpea reported maximum adult mortality (63.89 and 61.89%), minimum oviposition (10.00 and 22.44 eggs/20g seed) and F1 adult emergence (12.20 and 15.43%), and delayed developmental period (67.67 and 48.84 days) from seeds treated with mahua and neem oils, respectively. All the oils were found to provide protection to chickpea seeds up to 3 months of storage. The results also revealed that the efficacy of oils was directly proportional to the concentration.

Getachew *et al*. (2020) in their study on the effectiveness of fennel seed and koseret leaf powders on the mortality of pulse beetle, *C. chinensis* adult reported significant mortality rate (60%) in koseret leaf powders treatments.

Islam *et al*. (2020) evaluated the efficacy of plant products on oviposition, adult emergence, seed infestation and weight loss caused by pulse beetle and found sesame oil @ 2 % provided the most effective protection against pulse beetle.

Jahan *et al*. (2020) reported the effectiveness of datura (*Datura stramonium*) against pulse beetle in an experiment conducted to evaluate pesticidal efficacy of botanical powders (neem, datura, marigold and garlic) at three different rates (0.5, 1.0 and 1.50 g powder/kg of chickpea seeds). They reported the highest adult mortality in the seeds treated with datura leaf powder at 1.50 g/kg.

Mahmoud *et al*. (2020) studied the effect of aqueous and acetone leaf extracts of castor, datura, jatropha and neem on antifeedant property, oviposition inhibition and adult emergence of *C. chinensis* and found that the neem leaf extracts were more effective than the other plant extracts. The acetone extracts were more effective than those of aqueous extracts.

Nair *et al.* (2020) evaluated five locally available plant products *viz.*, Neem powder, turmeric powder, mustard oil, coconut oil and cow dung ash against *C. maculatus* on three different pulse seeds *viz.*, Field pea (*Pisum* *sativum*), chick pea (*Cicer arietinum*) and pigeon pea (*Cajanus cajan).* Out of the five treatments, mustard oil and coconut oil provided protection up to three months of storage.

Pathania and Thakur (2020) studied the effect of plant products *viz*., neem (*Azadirachta indica*) leaf powder, black pepper (*Piper nigrum*) fruit powder, aonla (*Emblica officinalis*) fruit powder, chaste tree (*Vitex negundo*) leaf powder, curry (*Murraya koenigii*) leaf powder, mustard (*Brassica juncea*) oil and neem (*A. indica*) seed kernel oil on oviposition, adult emergence and weight loss by pulse beetle on stored black gram seeds. They reported that both the oils treatment @7.5 and 10 ml/kg were more effective than the powder treatments. Among the plant powders, black pepper @ 3 and 5 g/kg was found to be effective up to 150 days of storage.

Yoriyo *et al.* (2020) studied the effectiveness of five oils (coconut oil, cotton seed oil, groundnut oil, palm oil and sesame oil) as grain protectant against cowpea weevil and reported that cotton seed oil, groundnut oil and sesame oil at @8 to 12 ml/kg can effectively protect the grains for up to 90 days of storage.

Hasan *et al*. (2021) conducted an experiment to study the efficacy of some biorational insecticides on pulse beetle, *C. chinensis* and reported highest mortality in neem oil treatment (89%) followed by mahogany oil (78%) and karanja oil (62%).

Paikaray *et al.* (2021b) evaluated the efficacy of seven botanicals against pulse beetle in stored green gram. Tulsi leaf powder, neem leaf powder, black pepper seed powder, sweet flag (*Acorus calamus*) rhizome powder, dry chilli powder, *Lantana camara* leaf powder and tobacco leaf powder @ 5g/kg seed were used against adult pulse beetle. Among all the plant products, they reported neem leaf powder to be the most effective with 35.63 % mortality, whereas black pepper powder was found least effective with 10.25 % mortality.

CHAPTER III

MATERIALS AND METHODS

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The present study entitled "Screening of some ricebean [*Vigna umbellata* (Thunb.) Ohwi & Ohashi] cultivars against pulse beetle [*Callosobruchus chinensis* (L.)] and its management with botanicals" was conducted in the laboratory of the Department of Entomology, School of Agricultural Sciences and Rural Development, Nagaland University, Medziphema Campus during 2017-2020. The experimental site is located at Medziphema (25° 45′ 43″ N latitude and 93° 53′ 04″ E longitude), Nagaland at an altitude of 304.8m above mean sea level. The climate is subtropical and the temperature varies from 21℃ to 32℃ in summer and in winter it varies from 10℃ to 15℃.

The details of materials and methodologies used in this study are described below:

3.1 Description of the test insect: Pulse beetle, *Callosobruchus chinensis* (L.)

The insect used in the study was the bruchid pulse beetle, *C. chinensis*. The adult beetles are 3-4mm long brown in colour and covered in black and grey spots. The distinguishing character between males and females is the antennae, males have pectinate antennae and females have serrate antennae. The females are slightly bigger than males and the abdomen to some extent is longer than the elytra. Adults mate within an hour of emergence and the fecundity of the females varies between 34-113 eggs. Eggs are laid on the seed which hatches in 4-6 days. The young larva remains hidden and feeds inside the seed and emerges out as fully developed adults.

3.2 Insect culture

Stock cultures of *C. chinensis* were raised with susceptible ricebean seeds in a plastic container. For a continuous supply of insects for the

a.) *C. chinensis* (Male with pectinate antennae)

b.) *C. chinensis* (Female with serrate antennae)

c.) Eggs laid on ricebean seed

Plate 1: Test insect: Pulse beetle, *Callosobruchus chinensis* (L.)

Plate 2: Culture of *C. chinensis*

experiment, the population of pulse beetle was maintained at regular intervals by adding fresh seeds for egg laying. The adults were differentiated as male (♂) and female (♀) using key described by Arora, 1977. Adults were collected and released in fresh containers with ricebean seeds for egg laying and subsequently removed for obtaining adults of uniform age. The containers were observed regularly for adult emergence and were collected for use in the experiment.

3.3 Source of seed

The seeds of local ricebean cultivars were collected from different parts of Nagaland during December 2017-January 2018. To ensure that there is no hidden infestation before carrying out the experiment; the seeds were disinfested of mites or insects by heating the seeds in the hot air oven at 50 °C for one hour. Since there are many local cultivars available in Nagaland known by different names, the cultivars were collected by observing the variations in physical characters of the seeds such as colour, shape and size and were marked accordingly. From the collection, a total of 16 cultivars were used for screening against pulse beetle, *C. chinensis.* Collection details are presented in Table 3.1.

3.4 Screening of local ricebean cultivars against pulse beetle, *C. chinensis*

For screening the local ricebean cultivars against *C. chinensis* 'no choice test' (Ponnusamy *et al.,* 2014) was done. The experiment was carried out in a Completely Randomized Design (CRD) with 3 replications. The experiment was conducted under both controlled temperature of 28±2°C in BOD incubator and normal room temperature in the laboratory.

In the 'no-choice' test, 25 seeds of each cultivar were weighed and kept separately in a container closed with perforated lid. Four pairs of well characterized and freshly emerged male and female adults of pulse beetle were

Plate 3: Different local ricebean cultivars used in the investigation

released in the container and observations on various parameters were recorded.

Table 3.1 Collection details of local ricebean cultivars

Sl.no.	Cultivar (Local name)	Place of collection	Month of collection
1.	*Akixi Anila*	Zunheboto	December 2017
2.	*Rhüjo*	Phek	December 2017
3.	*Ashei Nyakla*	Longleng	January 2018
4.	*Kurhi Süre*	Phek	December 2017
5.	*Pinchong Wethroi*	Mon	January 2018
6.	*Kerhü*	Kohima	December 2017
7.	*Mügo Rhi*	Phek	December 2017
8.	*Rhüse*	Dimapur	December 2017
9.	*Hera Ragei*	Peren	December 2017
10.	*Hera Rahau*	Peren	December 2017
11.	*Rhüdi*	Dimapur	January 2018
12.	*Manyhü Rhi*	Phek	December 2017
13.	*Kurhi Rhide*	Phek	December 2017
14.	*Khueishuei Shumei*	Tuensang	January 2018
15.	*Rhüluo*	Kohima	January 2018
16.	*Sipheghonu*	Kiphire	January 2018

3.4.1 Oviposition

After the freshly emerged pulse beetles were released, the insects were allowed to remain in the containers for the purpose of oviposition for 10 days and were subsequently removed. The numbers of eggs laid were counted by visual observation and also with the help of a magnifying glass.

3.4.2 Adult emergence

After counting the eggs, the containers were kept undisturbed and regular observation was done for the emergence of adults. As adult emergence initiates, observations were recorded and adults were removed at a regular interval of 24 hours until no further emergence occurred for 5 consecutive days. The per cent adult emergence was calculated by using the formula:

$$\text{Per cent adult emergence} = \frac{\text{Number of adult emerged}}{\text{Number of eggs laid}} \text{ x}100$$

3.4.3 Development Period

Observations were made on the time taken from the day of releasing the insects up to the day of the first emergence and the number of adults emerged were recorded. The observations were recorded up to the day of the last emergence. The average developmental period from egg to adult was calculated as follows:

$$\text{Development Period} = \frac{D1A1+D2A2+D3A3+\cdots..DnAn}{\text{Total number of adults emerged}}$$

Where,

D-Day at which the adults started emerging

A-Number of adults emerged on Dth day

3.4.4 Growth index

To determine the susceptibility of various cultivars to *C. chinensis* the growth index of the insect on these hosts was determined by using the formula as suggested by Howe, 1971.

Growth Index= Log S/T

Where S = Per cent adult emergence

T = Average developmental period (days)

The cultivars were categorized based on the growth index as follows:

Category	**Growth index**
Resistant	< 0.05
Moderately resistant	0.051-0.060
Moderately susceptible	0.061-0.070
Susceptible	0.071-0.080
Highly susceptible	>0.081

3.4.5 Per cent infestation and per cent weight loss

100g seeds of each cultivar were taken separately in a container closed with a perforated lid. Four pairs of well characterised and freshly emerged male and female adult *C. chinensis* were released into each container. After the release of the freshly emerged pulse beetle, the insects were allowed to remain in the container for the purpose of oviposition for 10 days and were subsequently removed. The containers were kept undisturbed and observed regularly for adult emergence i.e. for one generation.

From the infested containers, seeds were examined and the numbers of seeds with emergence holes were counted. The average data taken from 3 replicates were used for calculating the per cent infestation. The following formula was used for the determination of per cent infestation of seeds.

$$\text{Per cent infestation} = \frac{\text{Number of holed seeds}}{\text{Total number of seeds}} \text{ x } 100$$

To determine the per cent weight loss, the insects and frass from each container were removed and the weight of seeds was taken separately and measured with an electronic weighing balance from each replicate. The per cent weight loss was calculated by the following formula:

$$\text{Per cent weight loss} = \frac{\text{Initial weight of grains} - \text{Final weight of grains}}{\text{Final weight of grains}} \text{x} 100$$

3.4.6 Evaluation of physico-chemical parameters of seed

The various physical and biochemical characters of the seeds were analysed by following standard methods.

3.4.6.1 Determination of physical characters of seeds

The seed index was determined by taking the weight of 100 seeds of each cultivar with the help of an electronic balance. The seed size and seed coat thickness were measured with the help of a micrometer screw gauge. The seed coat was peeled out carefully with the help of a scalpel and the thickness

a.) BOD

b.) Oven

c.) Soxhlet Extractor

d.) Electronic weighing balance

e.) Electronic Moisture meter

f.) Electric grinder

g.) Digital micrometer

Plate 4: Equipments used in the experiment

was measured. The shape of the seeds, colour and texture were also recorded based on visual observation.

3.4.6.2 Determination of bio-chemical characters of seeds

For this 100g seeds of each cultivar were oven dried at 40°C to attain a constant weight. The seeds were ground with the help of a grinder and were used for bio-chemical analysis. The bio-chemical contents *viz*., protein, phenols, tannin, starch, and fat contents were determined. The determination of phenol was done by outsourcing at Indian Institute of Food Processing Technology (IIFPT), Thanjavur, Tamil Nadu.

3.4.6.2.1 Protein

The protein content of the ricebean cultivars was estimated by Kjeldahl method as described by A.O.A.C. (1970).

For the estimation of protein content, 2 g of sample was taken in a Kjeldahl flask and 2 g of catalyst was added. 20 ml of concentrated sulphuric acid was added and mixed thoroughly with the sample and catalyst. Digestion was done by heating at 200 - 300°C until the solution turn clear. The digest was diluted with distilled water and the volume was made up to 100 ml in a volumetric flask. 10 ml of the diluted sample was added into the distillation flask and 50 ml of 40% sodium hydroxide was added and volume was up to 100 ml by adding distilled water. Distillation was done by heating at 150-200°C. The distillate was collected in a conical flask with 30 ml of 4% boric acid placed into the distillation unit. Few drops of methyl red indicator were added into the distillate and titrated against 0.1 N hydrochloric acid (HCl). The nitrogen content (%) was calculated and from the nitrogen content, the protein content (%) was determined.

$$\text{Nitrogen content (\%)} = \frac{(\text{V1} - \text{V2})\text{x normality of HCl x Mwn x 100}}{\text{Ws x 1000}}$$

Where,

V1 = Volume of standard acid (HCl) required for blank

V2 = Volume of standard acid (HCl) required for sample

Mwn = Molecular weight of nitrogen

Ws = Sample weight (g)

Protein content (%) = Nitrogen content (%) x 6.25

3.4.6.2.2 Tannin

The tannin content was estimated by Folin-Denis method as described by Schanderi, 1970.

For the estimation of tannin content, 0.5 g of sample was taken in a 250 ml conical flask and 75 ml of water was added. The sample was gently heated and boiled for 30 minutes. Then it was centrifuged at 2000 rpm for 20 minutes and the supernatant was collected. 1 ml of sample extract was taken in a 100 ml conical flask along with 75 ml water. 5 ml of Folin-Denis reagent, 10 ml of sodium carbonate was added and volume was made up to 100 ml with water and allowed to stand for colour development. The absorbance of the reaction mixture was measured at 700 nm in spectrophotometer. Tannic acid was used as standard and tannin content was calculated from the graph as tannic acid equivalent (TAE) in mg/100g.

3.4.6.2.3 Starch

The estimation of starch was done by anthrone reagent method as described by Hodge and Hofreiter, 1962.

For the estimation of starch content, 0.5 g of sample was treated with hot 80% alcohol to remove sugar which was centrifuge and the residue was retained. 5 ml of water and 6.25 ml of 52% perchloric acid was added into the residue. Extraction was done at 0°C for 20 minutes. The extract was centrifuged and the supernatant was taken and the volume was made up to 100 ml by adding distilled water. 0.2 ml of the supernatant was taken and volume was made up to 1ml with distilled water. The standards were made by taking

0.2, 0.4, 0.6, 0.8 and 1 ml in each tube and the volume was made up to 1 ml in each tube with distilled water. 4 ml of anthrone reagent was added into each tube and heated for 8 minutes in a boiling water bath which was cooled rapidly and the intensity was read at 630 nm in spectrophotometer. The glucose content in the sample was determined from the standard graph and the starch content was estimated by multiplying the value by a factor 0.9.

3.4.6.2.4 Fat

The fat content of the ricebean cultivars was estimated by using Soxhlet extraction method as described by A.O.A.C. (1970) with modifications using an automated Soxhlet extractor (SOCS PLUS SCS04 AS DLS).

For the estimation of starch content, 2 g of sample was transferred into thimbles and placed in beakers and 80 ml of solvent (acetone) was added. Then the beakers were loaded in the extractor and boiled at 80°C for 1 hour. After that, the temperature was increased to recovery temperature at 160°C and boiled for 30 minutes. The thimbles were rinsed 2 to 3 times. The beakers were taken out from the extractor and the thimbles were removed. The beakers were placed in a hot air oven at 100°C for 20 to 30 minutes to remove the leftover acetone. The beakers were then removed and placed in a desicator and cooled at room temperature. The fat content was determined by using the formula:

$$\text{Fat (\%)} = \frac{\text{W2} - \text{W1}}{\text{SW}} \text{ x } 100$$

Where,

W2 = Final weight of beaker

W1= Initial weight beaker

SW= Sample weight

Data obtained were statistically analysed. Mean, standard error of mean were worked out using analysis of variance (ANOVA). Means were compared by Duncan Multiple Range Test (DMRT) at 5% level of significance.

Correlation between different growth parameters of *C. chinensis*, per cent infestation, per cent weight loss and physico-chemical contents recorded in different ricebean cultivars were worked out.

3.5 Effect of storage structures on the incidence of *C. chinensis*

The experiment was carried out in normal laboratory conditions in a Complete Randomized Design (CRD) with 5 replications. Four types of storage structures *viz*., cloth bag, plastic jar, jute bag and bamboo basket were evaluated against *C. chinensis* on the most susceptible cultivar of ricebean.

For this experiment the seeds were disinfested by heating in a hot air oven at 50°C for one hour. In each storage container, 500g of seed was kept and 10 pairs of freshly emerged *C*. c*hinensis* were released. The mouths of the bags were tightened with the help of thread. Observations on per cent infestation and per cent weight loss were recorded at monthly intervals up to 6 months of storage. Moisture content was recorded before and after 6 months of storage.

3.5.1 Per cent infestation

Per cent infestation was calculated using the formula as described in 3.4.5

3.5.2 Per cent weight loss

Per cent weight loss was calculated using the formula as described in 3.4.5

3.5.3 Per cent grain moisture

Grain moisture content was determined by randomly selecting 100 grains in each bag and was estimated with help of an Electronic Moisture Meter.

The data on different observations were transformed into suitable values, analysed statistically and the means were compared by DMRT.

a.) Cloth bag

b.) Jute bag

c.) Plastic jar

d.) Bamboo basket

Plate 5: Storage structures used in the experiment

3.6 To study the efficacy of botanicals against pulse beetle, *C. chinensis*

The study was carried out in normal laboratory conditions using CRD with 3 replications. A total of 7 plant materials and jatropha oil was tested for their efficacy against *C. chinensis*. The fresh plant material *i.e*. leaves and seeds were collected from Medziphema area and were washed and shade dried. The dried plant materials were ground by using an electric grinder, sieved and made into fine powders and used for extraction and treatments. Standard Jatropha oil was collected from the Department of Entomology, AAU, Jorhat. Both powder and extract of the plant materials along with Jatropha oil was used for the study. Malathion 50 EC and Malathion 5% dust was used as a standard check and one untreated control was taken for comparison. The seed of the most susceptible cultivar was used for this experiment. The parameters observed were reduction in oviposition, per cent adult emergence, per cent infestation, per cent weight loss and seed germination.

3.6.1 Description of plant materials

The plants used in the study are described as follows:

3.6.1.1 *Azadirachta indica* A. Juss

A. indica commonly known as neem belongs to the Meliaceae family. It is a rapidly growing evergreen tree that can attain a height of up to 15-20m. The bark is somewhat thick and scaly with brown greyish colour. The leaves are alternate consisting of 5-15 serrated leaflets. The flowers are white in colour arranged in a panicle and the fruit is a drupe, oblong to ovoid in shape with a shell and a kernel. For the experiment, the leaves were used.

3.6.1.2 *Piper nigrum* L.

It is a perennial woody vine commonly known as black pepper belongs to the Piperaceae family. It can grow up to 4 meters in height on supporting trees or poles. The plants have heart shape alternate leaves with prominent palmate veins. The flowers are small, produced on pendulous spikes at the leaf nodes. The length of spikes goes up to 7-15 cm. The fruits are small called a drupe. The seeds were used in the experiment.

3.6.1.3 *Ocimum tenuiflorum*

It is an aromatic plant also called holy basil or tulsi, belongs to the Lamiaceae family. The plant is a shrub with many branches and the stems are hairy. The leaves are green to purplish in colour with long hairs on both sides. The flowers are purplish in colour arranged in closed whorls on elongate racemes and the fruits are in the form of nutlets. The leaves were used in the experiment.

3.6.1.4 *Eucalyptus globules*

E. globules is a tall aromatic evergreen tree of the Myrtaceae family. The leaves are elongated and sickle-shaped covered in a blue-grey waxy bloom. The bark sheds frequently in long strips. White colour single flowers are formed on the leaf axils which produces a strong flavored aroma. The fruits are hardy with numerous small seeds. The leaves were used in the experiment.

3.6.1.5 *Allium sativum*

Garlic, *A. sativum* is an aromatic bulb with perennial flowering from the Amaryllidaceae family. The bulb is round, made up of smaller bulblets known as cloves. The bulbs and cloves are enclosed by a white-pinkish papery coat. Leaves are sword-shaped attached to an underground stem. The plant has a tall flowering stem that produces greenish-white to pinkish flowers. The bulb/cloves were used in the experiment.

3.6.1.6 *Pongamia pinnata*

It is an evergreen fast-growing, medium to large tree commonly known as karanj and belongs to the Fabaceae family. The leaves are imparipinnate, glossy with 5-9 leaflets which are ovate to oblong. The flowers are creamy-white or pink and form into clusters. The pods are hard, obliquely-oblong,

a.) *A. indica*

b.) *P.nigrum*

c.) *O. tenuiflorum*

d.) *E. globules*

e.) *A. sativum*

f.) *P. pinnata*

g.) *L. citrata*

Plate 6: Botanicals used in the study

flattened and elliptical with a small curved. The pods bear one or two bean-like seeds. The leaves were used for the experiment.

3.6.1.7 *Litsea citrata* Bl.

It is a deciduous tree belonging to the Lauraceae family. Leaves are somehow equilateral, dark green in colour. It bears greenish-white to greenish-yellow flowers. The fruits are placed in a small calyx tube, copular and enlarged. The tree barks are green, thin, warty and a bit mucilaginous. The seeds were used for the experiment.

3.6.2 Preparation of plant extracts

The extracts of the plant materials were prepared according to Singh (2011) with modifications using an automated Soxhlet extractor (SOCS PLUS SCS04 AS DLS). Acetone was used as the solvent.

For extraction, 20 g of plant powder was weighed and transferred into thimbles and placed in beakers. 80 ml of solvent (acetone) was added to the beakers. Then the beakers were loaded in the extractor and boiled at 80°C for 1 hour. After that, the temperature was increased to recovery temperature at 160°C and boiled for 30 minutes. The thimbles were rinsed 2 to 3 times. The beakers were taken out from the extractor and the thimbles were removed. After that the beakers were placed in a hot air oven at 100°C for 20 to 30 minutes to remove the leftover acetone. The beakers were then removed and placed in a desicator and cooled at room temperature. After extraction, the final extract was kept as a stock solution (100%) in glass bottles for experimental study.

3.6.3 Bioassay on the toxicity of plant extracts on adult *C. chinensis* by dipping method

The plant extracts and Jatropha oil emulsions of required concentrations were made by dilution with water and 1ml of triton X (0.1%). The plant extracts along with Jatropha oil were diluted to make 2, 4, 6, 8, and 10%

a.) Plant extracts

b.) Jatropha oil

c.) Malathion 50 EC

d.) Malathion 5 % Dust

Plate 7: Plants extracts, Jatropha oil and chemical pesticides used in the experiment

solutions. For comparison Malathion 50 EC @ 0.03, 0.04, 0.05, 0.06 and 0.07% was used. Five pairs of adult insects (2–3 days old) were enclosed in a filter paper and dipped in diluted solution for 35 seconds (Rahman and Talukder, 2006). After that, the insects were removed, air-dried and kept for observation in Petri dishes containing 5 gm of ricebean seeds. Four replications were made for each dose. Mortality was recorded at 24, 48, and 72 hours after treatment. Insects were observed regularly and those that did not move or react to mild touch were counted as dead. Insect mortality data was corrected by Abbott's formula (Abbott, 1925). The concentration mortality line was calculated using probit analysis (Finney, 1971) in SPSS software with a log10 transformation of the concentrations. The results were expressed as concentration (%) per insect.

3.6.4 Treatment of susceptible ricebean cultivar with plant powders and extracts

All the plant products were mixed with susceptible ricebean cultivar seeds @ 5% w/w for powder and Malathion 5% dust @ 1% w/w. The concentration of the plant extracts, Jatropha oil and Malathion were determined by the bioassay test as mentioned in 3.6.3 and the lowest LC50 concentration obtained from the probit analysis was used. The seeds were treated with chemical Malathion as standard check. The treated seeds were used to determine the efficacy of plant products against *C. chinensis*. Treatment details are given in Table 3.2.

3.6.4.1 Effect of treatment on oviposition and adult emergence

For the evaluation of oviposition deterrent effects of the plant products, a sample of 25 seeds of susceptible cultivar was taken and four pairs of newly emerged *C. chinensis* male and female were introduced in each container. Untreated seeds were used as control. The study was conducted using CRD with 3 replications. After 10 days, the number of eggs laid on treated and

Table 3.2 Treatment details

Sl. No.	Treatments	Parts used	Dosage
1.	*Azadirachta indica*	Leaf	Extract-8%
2.	*A. indica*	Leaf	Powder-5% w/w
3.	*Piper nigrum*	Seeds	Extract-2%
4.	*P. nigrum*	Seeds	Powder-5% w/w
5.	*Ocimum tenuiflorum*	Leaf	Extract-10%
6.	*O. tenuiflorum*	Leaf	Powder-5% w/w
7.	*Eucalyptus globules*	Leaf	Extract-10%
8.	*E. globules*	Leaf	Powder-5% w/w
9.	*Allium sativum*	Bulb	Extract-15%
10.	*A. sativum*	Bulb	Powder-5% w/w
11.	*Pongamia pinnata*	Leaf	Extract-10%
12.	*P. pinnata*	Leaf	Powder-5% w/w
13.	*Litsea citrata*	Seeds	Extract-3%
14.	*L. citrata*	Seeds	Powder-5% w/w
15.	Jatropha oil		3%
16.	Malathion 5% Dust		1%w/w
17.	Malathion 50EC		0.04%
18.	Untreated control		

control seeds were recorded and the percentage reduction in oviposition was calculated by using the formula:

$$\text{Reduction in oviposition (\%)} = \frac{\text{No.of eggs laid in control} - \text{No.of eggs laid in treated seeds}}{\text{No.of eggs laid in control}} \text{x}100$$

After the eggs were counted, the containers were kept undisturbed and regular observation was done for the emergence of adults. As adult emergence initiates, observations were recorded and adults were removed at a regular interval of 24 hrs until no further emergence occurred for 5 consecutive days. The per cent adult emergence was calculated by using the formula:

$$\text{Per cent adult emergence} = \frac{\text{Number of adult emerged}}{\text{Number of eggs laid}} \text{x } 100$$

3.6.4.2 Effect of treatment on infestation and weight loss

To study the effect of treatment on infestation and weight loss 100gm each of treated as well as untreated seeds were taken and kept in a container closed with a perforated lid. Four pairs of freshly emerged male and female adults of *C. chinensis* were released into each container. The observations on per cent infestation and weight loss were recorded after 2, 4 and 6 months of storage.

The per cent infestation and weight loss was calculated using the formula as described in 3.4.5.

3.6.4.3 Effect of treatment on seed germination

The treated, as well as untreated seeds (100g) were kept in separate air-tight containers. After 6 months of storage, a germination test was conducted. 25 healthy seeds samples were taken at random from all the treatments and were placed in Petri dishes with moistened filter paper (Whatman No. 1). Healthy untreated seeds were used as control. After 7 days, the number of germinated seeds from each Petri dish were counted and recorded. The per cent germination was calculated by using the formula as follows:

$$\text{Per cent seed viability} = \frac{\text{No.of seeds germinated}}{\text{Total no.of seeds in each petri dish}} \text{ x } 100$$

The percentage data on different observations were transformed into suitable values and were statistically analysed. The means were compared by DMRT.

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The results and discussion of the present investigation entitled, "Screening of some ricebean [*Vigna umbellata* (Thunb.) Ohwi & Ohashi] cultivars against pulse beetle [*Callosobruchus chinensis* (L.)] and its management with botanicals" are presented in this chapter under the following heads.

4.1 Screening of local ricebean cultivars against pulse beetle, *C. chinensis*

The screening was carried out in a Completely Randomized Design (CRD) with 3 replications. The experiment was conducted under both controlled temperature of 28±2°C in a BOD incubator and normal room temperature in the laboratory. The results obtained under the various parameters of the study are presented under the following subheads.

4.1.1 Oviposition

The results showed a significant difference in the oviposition preference of *C. chinensis* on the different local cultivars of ricebean in no-choice test, both in controlled temperature (28±2°C) and normal room condition (Table 4.1, Fig 4.1).

In controlled temperature, the number of eggs laid per 25 ricebean seeds ranged from 32.67 to 131.33. The cultivars *Manyhü Rhi* (32.67), *Rhüjo* (33.33), *Kerhü* (36.33) and *Pinchong Wethroi* (38.67) were at par with each other and significantly least preferred for oviposition than the other cultivars. On the other hand, the highest number of eggs laid was observed in cultivar *Sipheghonu* (131.33) followed by *Kurhi Rhide* (118.33) which were significantly different from the other cultivars *Rhüdi* (74.67), *Mügo Rhi* (70.67), *Rhüluo* (63.67), *Kurhi Süre* (60.33), *Akixi Anila* (55.33), *Ashei Nyakla* (48.67), *Hera Rahau* (47.67), *Hera Ragei* (43.67), *Rhüse* (41.33) and *Khueishuei Shumei* (40.33).

Table 4.1 Oviposition of *C. chinensis* on different local ricebean cultivars

Cultivars	*No. of eggs laid on 25 seeds		*Fecundity per female	
	At controlled temperature (28±2°C)	At room temperature	At controlled temperature (28±2°C)	At room temperature
Akixi Anila	55.33^{e} (7.47)	38.67^{gh} (6.26)	13.83^{e} (3.79)	9.67^{gh} (3.19)
Rhüjo	33.33^{j} (5.82)	21.67^{i} (4.71)	8.33^{j} (2.97)	5.42^{i} (2.43)
Ashei Nyakla	48.67^{f} (7.01)	44.67^{fg} (6.72)	12.17^{f} (3.56)	11.17^{fg} (3.42)
Kurhi Süre	60.33^{de} (7.80)	53.67^{e} (7.36)	15.08^{de} (3.95)	13.42^{e} (3.73)
Pinchong Wethroi	38.67^{hij} (6.26)	39.33^{gh} (6.31)	9.67^{hij} (3.19)	9.83^{gh} (3.21)
Kerhü	36.33^{ij} (6.07)	33.67^{h} (5.85)	9.08^{ij} (3.10)	8.42^{h} (2.99)
Mügo Rhi	70.67^{c} (8.44)	71.67^{c} (8.50)	17.67^{c} (4.26)	17.92^{c} (4.29)
Rhüse	41.33^{ghi} (6.47)	39.33^{gh} (6.31)	10.33^{ghi} (3.29)	9.83^{gh} (3.21)
Hera Ragei	43.67^{fgh} (6.65)	34.67^{h} (5.93)	10.92^{fgh} (3.38)	8.67^{h} (3.03)
Hera Rahau	47.67^{fg} (6.94)	40.33^{gh} (6.39)	11.92^{fg} (3.52)	10.08^{gh} (3.25)
Rhüdi	74.67^{c} (8.67)	62.67^{d} (7.95)	18.67^{c} (4.38)	15.67^{d} (4.02)
Manyhü Rhi	32.67^{j} (5.76)	23.67^{i} (4.92)	8.17^{j} (2.94)	5.92^{i} (2.53)
Kurhi Rhide	118.33^{b} (10.90)	97.67^{b} (9.91)	29.58^{b} (5.48)	24.42^{b} (4.99)
Khueishuei Shumei	40.33^{hi} (6.39)	34.33^{h} (5.90)	10.08^{hi} (3.25)	8.58^{h} (3.01)
Rhüluo	63.67^{d} (8.01)	51.67^{ef} (7.22)	15.92^{d} (4.05)	12.92^{ef} (3.66)
Sipheghonu	131.33^{a} (11.48)	121.67^{a} (11.05)	32.83^{a} (5.77)	30.42^{a} (5.56)
SEm±	0.55	0.64	0.14	0.16

*Figures in the table are mean values
Figures in the parentheses are square root transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

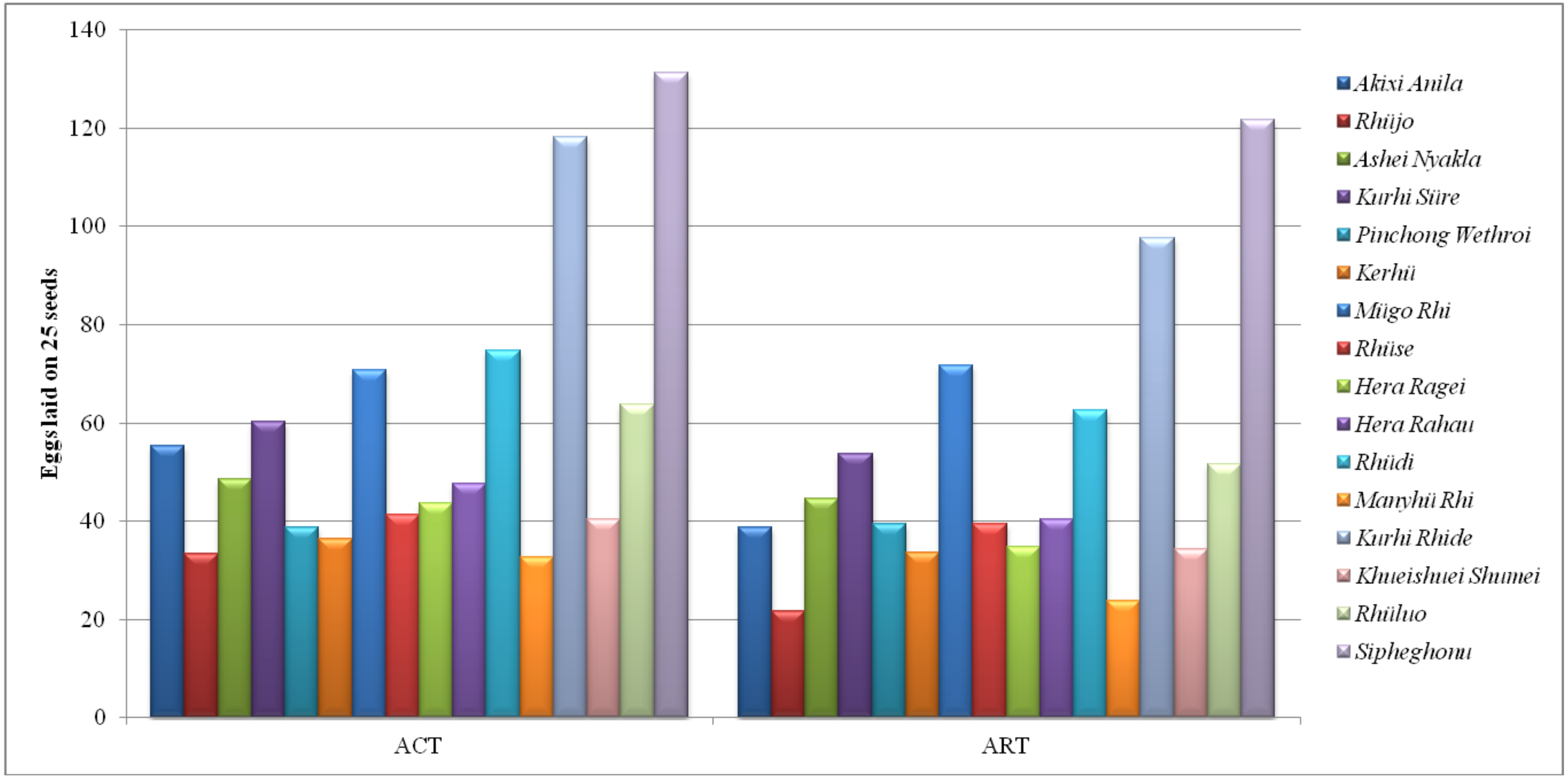

Fig 4.1 Oviposition of *C. chinensis* on different local ricebean cultivars

Based on oviposition the order of preference was *Sipheghonu* > *Kurhi Rhide* > *Rhüdi* > *Mügo Rhi* > *Rhüluo* > *Kurhi Süre* > *Akixi Anila* > *Ashei Nyakla* > *Hera Rahau* > *Hera Ragei* > *Rhüse* > *Khueishuei Shumei* > *Pinchong Wethroi* > *Kerhü* > *Rhüjo* > *Manyhü Rhi*.

In the normal room temperature condition, similar results were obtained. The number of eggs laid ranged from 21.67 to 121.67. However, the least number of eggs laid was observed in cultivar *Rhüjo* (21.67) followed by *Manyhü Rhi* (23.67) with no significant difference between the two cultivars. The highest number of eggs was laid on the cultivar *Sipheghonu* (121.67) followed by *Kurhi Rhide* (97.67). The number of eggs laid in room temperature condition was comparatively lower than the controlled temperature which may be due to the fluctuations of temperature in the normal room condition.

The present investigation showed variation in oviposition preference of *C. chinensis* on different ricebean cultivars. The differences in the numbers of eggs laid in different cultivars ranged from 32.67 to 131.33 in controlled temperature and 21.67 to 121.67 in normal room temperature. The results are in similarity with Chakraborty *et al*. (2015) who reported a difference in oviposition preference by *C. chinensis* on five pulses with the number of eggs laid ranging from 79.25 to 160.25. Divya *et al*. (2012) also reported a significant difference in ovipositional preference in 51 horsegram accessions which varied from 0.00 to 82.00. Similar results of variation in oviposition preference were also reported by various workers (Arpitha & Sagar, 2011; Shivanna *et al*., 2011; Kumari *et al.*, 2020). The variation in preference for oviposition of *C. chinensis* might be due to some physical characters of the seeds as well as biochemical constituents. Senthilraja and Patel (2021) reported that the smooth textured seeds were favored for oviposition by pulse beetle. Similarly, the seeds with small, rough, wrinkled, hard and thick seed coats were found to be more resistant (Paikaray *et al*., 2021a). Kavitha *et al*. (2021)

reported that genotypes having low sugar and protein contents and high phenol content were resistant to pulse bruchid.

4.1.2 Adult emergence

The results of *C. chinensis* adult emergence from different ricebean cultivars are presented in Table 4.2 and illustrated in Fig 4.2.

At controlled temperature, the adult emergence was highest in the cultivar *Sipheghonu* (73.60%), *Kurhi Rhide* (72.39%) and *Mugo Rhi* (71.70%). The adult emergence in these three cultivars was significantly more than the other cultivars. The least was in cultivar *Rhijo* (58.00%). The per cent adult emergence in 16 local ricebean are arranged in decreasing order as follows: *Sipheghonu* > *Kurhi Rhide* >*Mugo Rhi* > *Rhüdi* > *Kurhi Süre* > *Hera Rahau* > *Khueishuei Shumei* > *Hera Ragei* > *Rhüse* > *Ashei Nyakla* > *Kerhü* > *Akixi Anila* > *Rhüluo* > *Pinchong Wethroi* > *Manyhü Rhi* > *Rhüjo.*

Similarly, at normal room temperature, the results were in trend with the controlled temperature. The highest adult emergence was in *Sipheghonu* (72.33%) followed by *Kurhi Rhide*(70.99%) with a significant difference between them. The least adult emergence was in *Rhüjo* (56.92%).

In the present investigation, the cultivar *Rhüjo* was least preferred for adult emergence at both controlled temperature and normal condition, while the cultivar *Sipheghonu* exhibited the highest adult emergence. The less number of adult emergence could be due to non-preference of cultivar for oviposition by *C. chinensis*. The results are in conformity with the findings of Arpitha and Sagar (2011), who also reported significant differences in adult emergence on different varieties of pea. In their study, they found that the *C. chinensis* emergence varied from 20.7 to 86.5% among the pea varieties. Kavitha *et al*. (2018) reported variation among greengram genotypes in adult emergence of *C. chinensis.* Among the genotypes tested, the variety WGG reported the highest adult emergence (63.20%), while the least was observed in variety PM-5 (17.44%). The differences in per cent adult emergence on

Table 4.2 Adult emergence of *C. chinensis* on different local ricebean cultivars

Cultivars	*Adult emergence (%)	
	At controlled temperature (28±2°C)	At room temperature
Akixi Anila	63.25^{ab} (52.69)	61.21^{a} (51.48)
Rhüjo	58.00^{b} (49.60)	56.92^{a} (48.98)
Ashei Nyakla	65.07^{ab} (53.77)	64.93^{a} (53.68)
Kurhi Süre	69.61^{ab} (56.55)	69.57^{a} (56.52)
Pinchong Wethroi	60.34^{ab} (50.97)	60.17^{a} (50.87)
Kerhü	64.22^{ab} (53.26)	64.36^{a} (53.34)
Mügo Rhi	71.70^{a} (57.86)	71.63^{a} (57.82)
Rhüse	66.13^{ab} (54.41)	63.56^{a} (52.87)
Hera Ragei	67.18^{ab} (55.05)	64.42^{a} (53.38)
Hera Rahau	67.83^{ab} (55.45)	66.12^{a} (54.40)
Rhüdi	70.54^{ab} (57.12)	68.09^{a} (55.60)
Manyhü Rhi	60.20^{ab} (50.89)	59.15^{a} (50.28)
Kurhi Rhide	72.39^{a} (53.80)	70.99^{a} (57.41)
Khueishuei Shumei	67.77^{ab} (55.41)	66.02^{a} (54.34)
Rhüluo	61.26^{ab} (51.51)	59.35^{a} (50.39)
Sipheghonu	73.60^{a} (59.08)	72.33^{a} (58.26)
SEm±	0.99	1.19

*Figures in the table are mean values
Figures in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

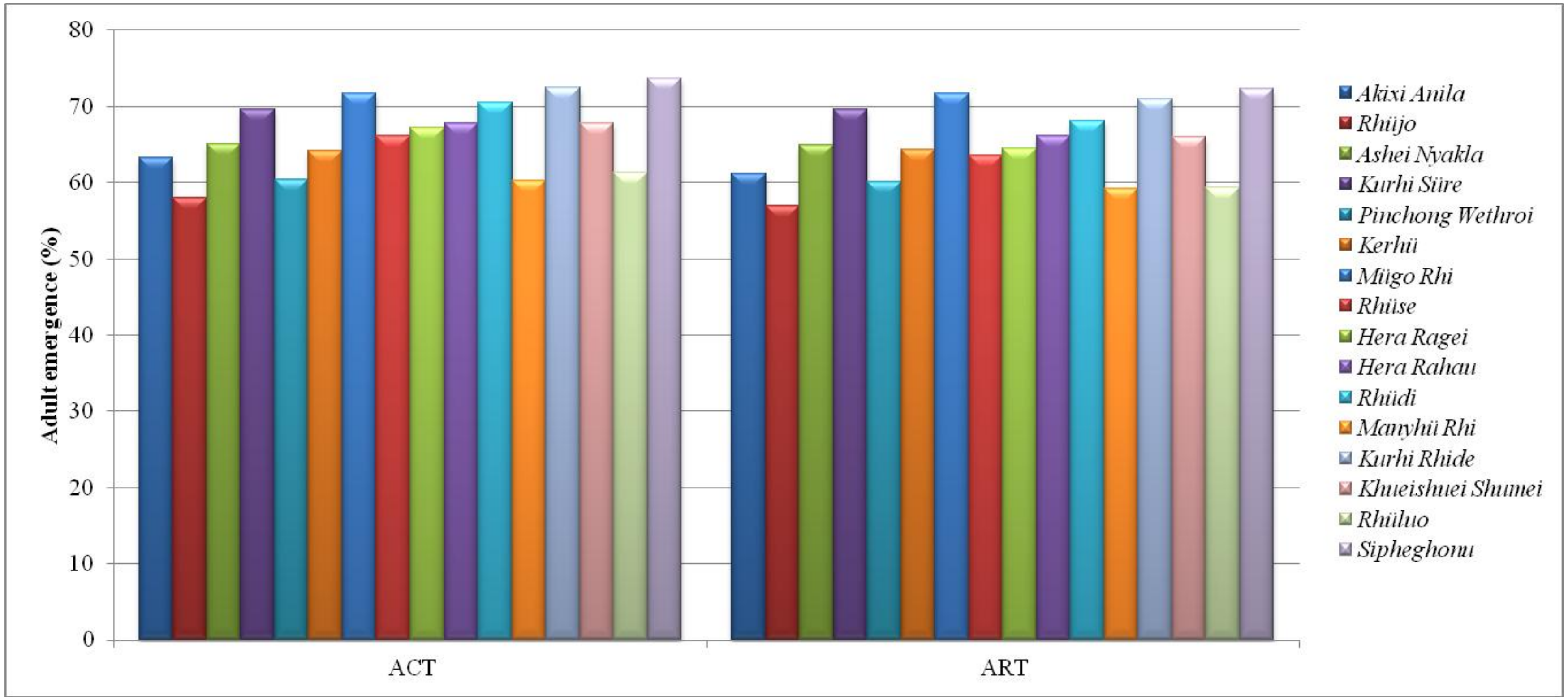

Fig 4.2 Adult emergence of *C. chinensis* on different local ricebean cultivars

different pulses were also reported by Obadofin (2014) and Radha and Susheela (2014b).

4.1.3 Development Period

At controlled temperature, the mean development period of *C. chinensis* ranged from 21.60 to 33.10 days. The details of the results are presented in Table 4.3 and illustrated in Fig 4.3. Among the ricebean cultivars, the minimum development period of 21.60 days was found in cultivar *Kurhi Rhide* followed by *Sipheghonu* (22.75 days) and *Khueishuei Shumei* (23.92 days) with no significant difference among them. The maximum of 33.10 days for the development of the pulse beetle were found in *Mügo Rhi.* The development period in the remaining cultivars ranged from 25.48 to 31.11 days. The order of development period among the cultivars in decreasing order was found as *Mügo Rhi* > *Rhüjo* > *Akixi Anila* > *Manhyü Rhi* > *Hera Ragei* > *Ashei Nyakla* > *Hera Rahau* > *Rhüluo* > *Pinchong Wethroi* > *Rhüse* > *Kerhü* > *Kurhi Süre* > *Rhüdi* > *Khueishuei Shumei* > *Sipheghonu* > *Kurhi Rhide*.

Similar results were also observed at room temperature with the number of days for the development of the pest varying from 20.28 to 30.58 days. However, in room temperature, the least number of days for development was observed in *Sipheghonu* (20.28 days) followed by *Khueishuei Shumei* (21.66 days) and *Kurhi Rhide* (22.33 days) with no significant difference among them. The maximum days was found in *Rhüjo* (30.58 days).

The present investigation revealed that among the ricebean cultivars there is variation in the development period of the pest which could be due to some physico-chemicals characters of the seed. Similar findings were reported by Chakraborty *et al*. (2015) in different pulses ranging from 26.75 to 32.25 days. The shortest development period of 26.75 days was found in cowpea and the longest of 32.25 days was found in kidney bean. Pawara *et al.* (2019a) also reported a mean development period ranging from 23.72 to 26.33 days in different mung bean cultivars. In another investigation of pulse beetle on

Table 4.3 Development period of *C. chinensis* on different local ricebean cultivars

Cultivars	*Development period (days)	
	At controlled temperature (28±2°C)	At room temperature
Akixi Anila	30.82[ab] (5.60)	29.67[ab] (5.49)
Rhüjo	31.11[ab] (5.62)	30.58[a] (5.57)
Ashei Nyakla	26.78[ab] (5.22)	24.73[c] (5.02)
Kurhi Süre	25.72[ab] (5.12)	24.99[c] (5.05)
Pinchong Wethroi	26.38[ab] (5.18)	25.27[c] (5.08)
Kerhü	26.25[ab] (5.17)	23.89[cd] (4.94)
Mügo Rhi	33.10[a] (5.80)	23.59[cd] (4.91)
Rhüse	26.26[ab] (5.17)	23.96[cd] (4.95)
Hera Ragei	27.07[ab] (5.25)	24.67[c] (5.02)
Hera Rahau	26.74[ab] (5.22)	24.78[c] (5.03)
Rhüdi	25.48[ab] (5.10)	22.98[cd] (4.85)
Manyhü Rhi	30.50[ab] (5.57)	27.99[b] (5.34)
Kurhi Rhide	21.60[b] (4.70)	22.33[de] (4.78)
Khueishuei Shumei	23.92[ab] (4.94)	21.66[de] (4.71)
Rhüluo	26.50[ab] (5.20)	23.25[cd] (4.87)
Sipheghonu	22.75[ab] (4.82)	20.28[e] (4.56)
SEm±	0.76	0.18

*Figures in the table are mean values
Figures in the parentheses are square root transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

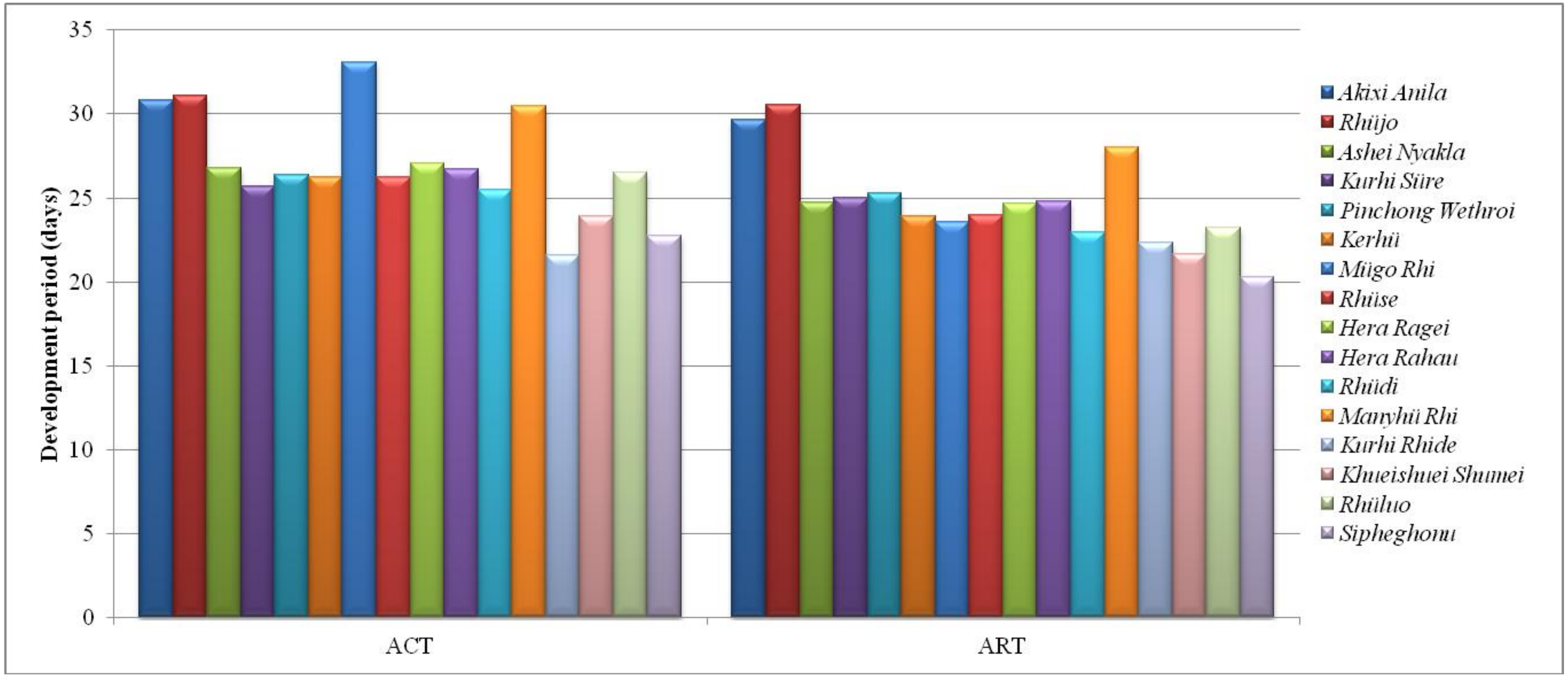

Fig 4.3 Development period of *C. chinensis* on different local ricebean cultivars

different pulses, Bharathi *et al*. (2017) found differences in the developmental period ranging from 28.47 days (greengram) to 41.65 days (soybean). The present findings are also in conformity with various authors (Ponnusamy *et al*., 2014; Ahmad *et al*., 2016; Kavitha *et al*., 2018).

The cultivars such as *Rhüjo* and *Manyhü Rhi* which were not preferred for oviposition showed longer period for development (31.11 and 30.50 days, respectively), whereas the cultivars such as *Sipheghonu* and *Kurhi Rhide* which were most preferred for oviposition showed a preference for development with the least number of days (22.75 and 21.60 days, respectively). This shows that the cultivar which was preferred for oviposition took lesser time for its development. Similar finding was reported by Khokhar and Singh (1987) in pigeonpea variety ICPL-289 which was more preferred for oviposition took less time to complete its development. This will lead to a shorter life cycle of the pest resulting in more generations which will increase per cent infestation and damage.

The biochemical contents such as protein could be influencing the development of the pest due to their nutritional properties. The cultivars with higher protein such as *Sipheghonu* (21.12%) and *Kurhi rhide* (21.04%) showed less development period (22.75 and 21.60 days, respectively) compared to other cultivars. The cultivar with higher protein content was more preferred for development with less number of days. Umarao and Verma (2003) reported that cultivars with high protein content were highly susceptible to pulse beetle. Pradhan *et al*. (2020) also observed a positive significant correlation between per cent seed damage, per cent weight loss and biochemical parameters like protein content.

4.1.4 Growth index

At controlled temperature, the highest growth index was found in cultivar *Kurhi Rhide* (0.086) followed by *Mugo Rhi* (0.084) and *Sipheghonu* (0.082). The least was found in *Rhüjo* (0.057) followed by *Akixi Anila*(0.058)

Table 4.4 Growth index of *C. chinensis* on different local ricebean cultivars

Cultivars	Growth index	
	At controlled temperature (28±2°C)	At room temperature
Akixi Anila	0.058[c]	0.060[ef]
Rhüjo	0.057[c]	0.057[f]
Ashei Nyakla	0.068[bc]	0.063[cde]
Kurhi Süre	0.072[abc]	0.071[bcd]
Pinchong Wethroi	0.067[bc]	0.068[de]
Kerhü	0.069[bc]	0.063[bcd]
Mügo Rhi	0.084[bc]	0.076[bcd]
Rhüse	0.069[bc]	0.062[de]
Hera Ragei	0.067[bc]	0.066[cd]
Hera Rahau	0.068[bc]	0.068[cd]
Rhüdi	0.073[abc]	0.073[bcd]
Manyhü Rhi	0.058[c]	0.058[ef]
Kurhi Rhide	0.086[a]	0.083[ab]
Khueishuei Shumei	0.077[ab]	0.075[abc]
Rhüluo	0.067[bc]	0.068[bcd]
Sipheghonu	0.082[ab]	0.090[a]
SEm±	0.001	0.001

Figures in the table are mean values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

and *Manyhü Rhi* (0.058). Among the 16 cultivars, the growth index ranged from 0.057 to 0.086. The details are presented in Table 4.4. Based on the susceptibility index (Howe, 1971) the cultivars were categorized and presented in Table 4.5. The cultivars *Rhüjo, Akixi Anila* and *Manyhü Rhi* were moderately resistant; *Pinchong Wethroi, Hera Ragei, Rhüluo, Ashei Nyakla, Hera Rahau, Kerhü*, and *Rhüse* were moderately susceptible; *Kürhi Süre, Rhüdi* and *Khueishuei Shumei* were susceptible and the highly susceptible cultivars were *Sipheghonu, Mügo Rhi* and *Kurhi Rhide.* Resistant was not found in the ricebean cultivars.

At normal room temperature, the highest growth index was found in cultivar *Siphegonu* (0.090) followed by *Kurhi Rhide* (0.083) and the least was found in *Rhüjo* (0.057). The growth index of cultivar *Mügo Rhi* reduced from 0.084 (highly susceptible) in controlled temperature to 0.076 (susceptible) in room temperature, while the remaining cultivars showed a similar trend with controlled temperature.

In the present study, the ricebean cultivars were grouped into 4 categories based on the growth index. Among the 16 cultivars, 3 cultivars were moderately resistant, 7 moderately susceptible, 3 were susceptible (4 at room temperature) and 3 (2 at room temperature) were highly susceptible (Table 4.5). Similar results were reported by Ponnusamy *et al*. (2014) who studied the growth index of pulse beetle on green gram and black gram varieties. Four green gram accessions (LM 131, V 1123, LM 371 and STY 2633) were found moderately resistant and in black gram, three accessions (UH 82-5, IC 8219 and SPS 143) were found moderately resistant. The results of the present investigation are in conformity with Singh and Sharma (2003), Tripathi *et al.* (2015) and Kavitha *et al*. (2018) who categorized pulses into resistant and susceptible varieties based on the growth index of pulse beetle.

Table 4.5 Categorization of different local ricebean cultivars based on growth index

Category	Growth index	Cultivars	
		At controlled temperature (28±2°C)	At room temperature
Resistant	< 0.05	-	-
Moderately resistant	0.051-0.060	*Rhüjo, Akixi Anila, Manyhü Rhi*	*Rhüjo, Manyhü Rhi, Akixi Anila.*
Moderately susceptible	0.061-0.070	*Pinchong Wethroi, Hera Ragei, Rhüluo, Ashei Nyakla, Hera Rahau, Kerhü, Rhüse.*	*Rhüse, Ashei Nyakla, Kerhü, Hera Ragei, Pinchong Wethroi, Hera Rahau, Rhüluo*
Susceptible	0.071-0.080	*Kürhi Süre, Rhüdi, Khueishuei Shumei*	*Kürhi Süre, Rhüdi, Khueishuei Shumei, Mügo Rhi*
Highly susceptible	>0.081	*Sipheghonu, Mügo Rhi, Kurhi Rhide.*	*Kurhi Rhide, Sipheghonu*

4.1.5 Per cent infestation and per cent weight loss

The per cent infestation by *C. chinensis* on different local ricebean cultivars at controlled temperature varied from 7.10 to 63.67. The details of the results are presented in Table 4.6 and illustrated in Fig 4.4. Among the ricebean cultivars, the maximum infestation was observed in *Sipheghonu* with 63.67% followed by *Kurhi Rhide* (49.43%), *Mügo Rhi* (36.24%), *Rhüdi* (25.10%), *Kurhi Süre* (23.01%) and *Ashei* Nyakla (18.74%) having a significant difference among them. The minimum infestation was found in *Rhüjo* with 7.10%. The per cent infestation of the remaining cultivars ranged from 9.27 to 16.03. Similar results were also found at room temperature condition with the per cent infestation varied from 7.01 (*Rhüjo*) to 60.85 (*Sipheghonu*).

The results of weight loss due to infestation by *C. chinensis* on different local ricebean cultivars are presented in Table 4.7 and illustrated in Fig 4.5. At controlled temperature, the per cent weight loss varied from 3.73 to 11.07. The weight loss in cultivar *Sipheghonu* was highest with 11.07% followed by *Kurhi Rhide* (10.25%) *and Rhüdi* (9.49%) with no significant difference among the three cultivars. The minimum weight loss was observed in cultivar *Rhüjo* with 3.73% followed by *Rhüse* (5.37%) *and Manyhü Rhi* (5.45%) with no significant difference among them. The per cent weight loss of the remaining cultivars ranges from 5.82 to 8.85. The per cent weight loss in decreasing order was: *Sipheghonu* > *Kurhi Rhide* > *Rhüdi* > *Mügo Rhi* > *Ashei Nyakla* > *Kurhi Süre* > *Rhüluo* > *Kerhü* > *Khueishuei Shumei* > *Hera Ragei* > *Akixi Anila* > *Hera Rahau* > *Pinchong Wethroi* > *Manyhü Rhi* > *Rhüse* > *Rhüjo.* Similar results were also obtained at room temperature condition with per cent weight loss ranging from 3.41 (*Rhüjo*) to 10.33 (*Sipheghonu*).

As per the present investigation, there was significant variation in per cent infestation among the ricebean cultivars. The findings are in similarity with Khokhar and Singh (1987) who reported variation in per cent infestation

Table 4.6 Infestation of *C. chinensis* on different local ricebean cultivars

Cultivars	*Infestation (%)	
	At controlled temperature (28±2°C)	At room temperature
Akixi Anila	9.27^{l} (17.73)	9.11^{hi} (17.57)
Rhüjo	7.10^{m} (15.45)	7.01^{i} (15.36)
Ashei Nyakla	18.74^{f} (25.65)	16.03^{f} (23.60)
Kurhi Süre	23.01^{e} (28.67)	23.44^{d} (28.96)
Pinchong Wethroi	13.25^{hij} (21.34)	13.49^{fg} (21.54)
Kerhü	15.07^{gh} (22.84)	14.44^{f} (22.33)
Mügo Rhi	36.24^{c} (37.01)	35.50^{c} (36.57)
Rhüse	11.44^{jk} (19.77)	11.04^{gh} (19.40)
Hera Ragei	13.80^{hi} (21.81)	13.55^{fg} (21.60)
Hera Rahau	12.62^{ij} (20.81)	12.96^{fg} (21.10)
Rhüdi	25.10^{d} (30.06)	22.72^{de} (28.47)
Manyhü Rhi	9.86^{kl} (18.30)	9.26^{hi} (17.71)
Kurhi Rhide	49.43^{b} (44.67)	46.32^{b} (42.89)
Khueishuei Shumei	22.86^{e} (28.56)	20.17^{e} (26.69)
Rhüluo	16.03^{g} (23.60)	15.01^{f} (22.80)
Sipheghonu	63.67^{a} (52.93)	60.85^{a} (51.27)
SEm±	0.16	0.25

*Figures in the table are mean values
Figures in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

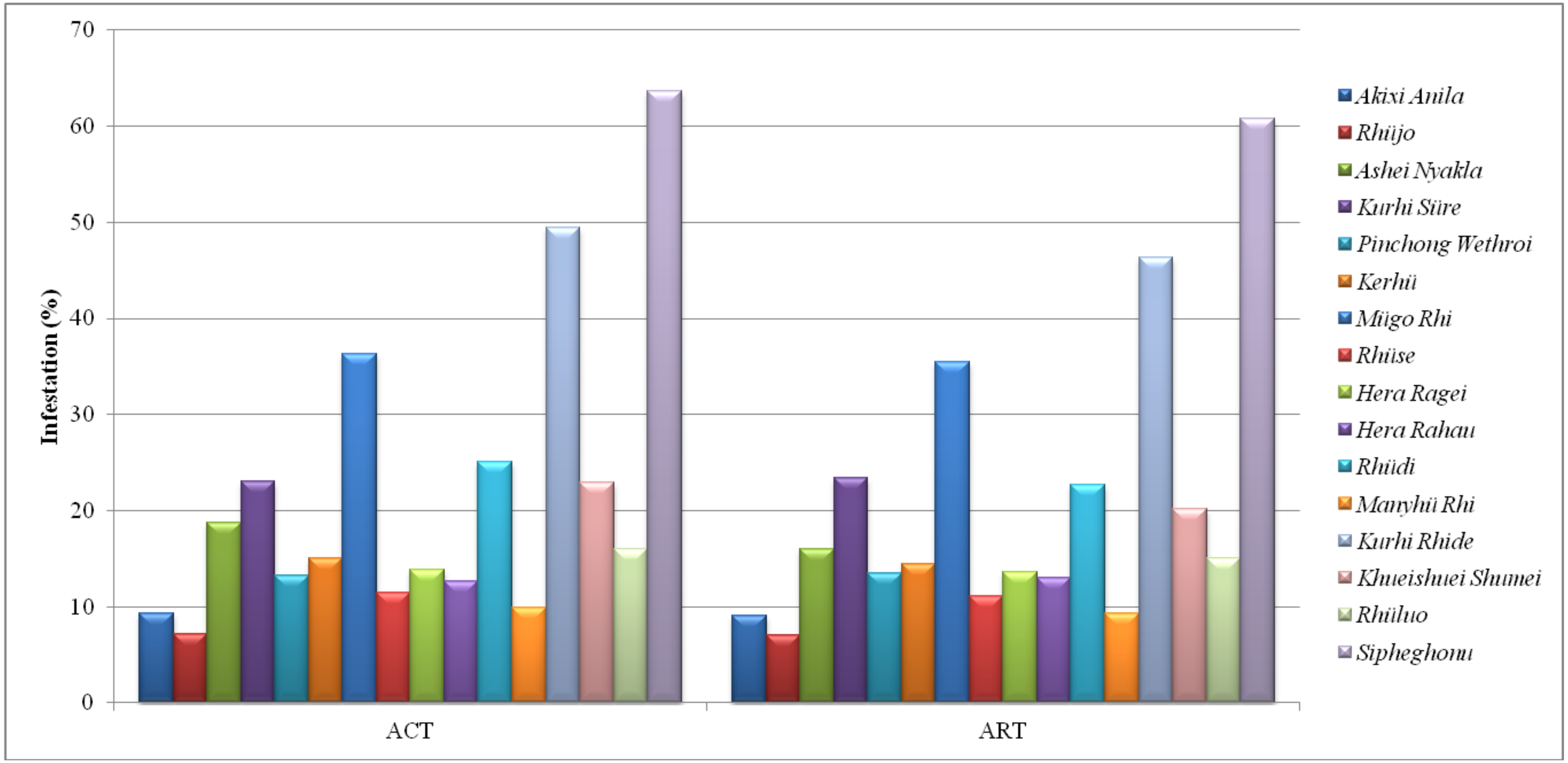

Fig 4.4 Infestation of *C. chinensis* on different local ricebean cultivars

Table 4.7 Weight loss due to infestation of *C. chinensis* on different local ricebean cultivars

Cultivars	*Weight loss (%)	
	At controlled temperature (28±2°C)	At room temperature
Akixi Anila	6.42[fg] (14.68)	6.23[defgh] (14.46)
Rhüjo	3.73[h] (11.14)	3.41[i] (10.65)
Ashei Nyakla	8.38[cde] (16.83)	6.65[cdefg] (14.94)
Kurhi Süre	7.45[def] (15.84)	7.68[bcde] (16.09)
Pinchong Wethroi	5.82[fg] (13.96)	6.01[efgh] (14.19)
Kerhü	7.14[defg] (15.50)	6.80[cdefg] (15.12)
Mügo Rhi	8.85[bcd] (17.31)	8.23[bc] (16.67)
Rhüse	5.37 [g] (13.40)	5.34[gh] (13.36)
Hera Ragei	6.72[efg] (15.03)	6.46[defgh] (14.72)
Hera Rahau	6.01[fg] (14.19)	6.31[defgh] (14.55)
Rhüdi	9.49[abc] (17.94)	7.91[bcd] (16.34)
Manyhü Rhi	5.45[g] (13.50)	4.82[h] (12.68)
Kurhi Rhide	10.25[ab] (18.68)	8.50[b] (16.95)
Khueishuei Shumei	6.72[efg] (15.03)	5.75[efgh] (13.87)
Rhüluo	7.37[def] (15.76)	7.18[bcdef] (15.54)
Sipheghonu	11.07[a] (19.43)	10.33[a] (18.75)
SEm±	0.14	0.13

*Figures in the table are mean values
Figures in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

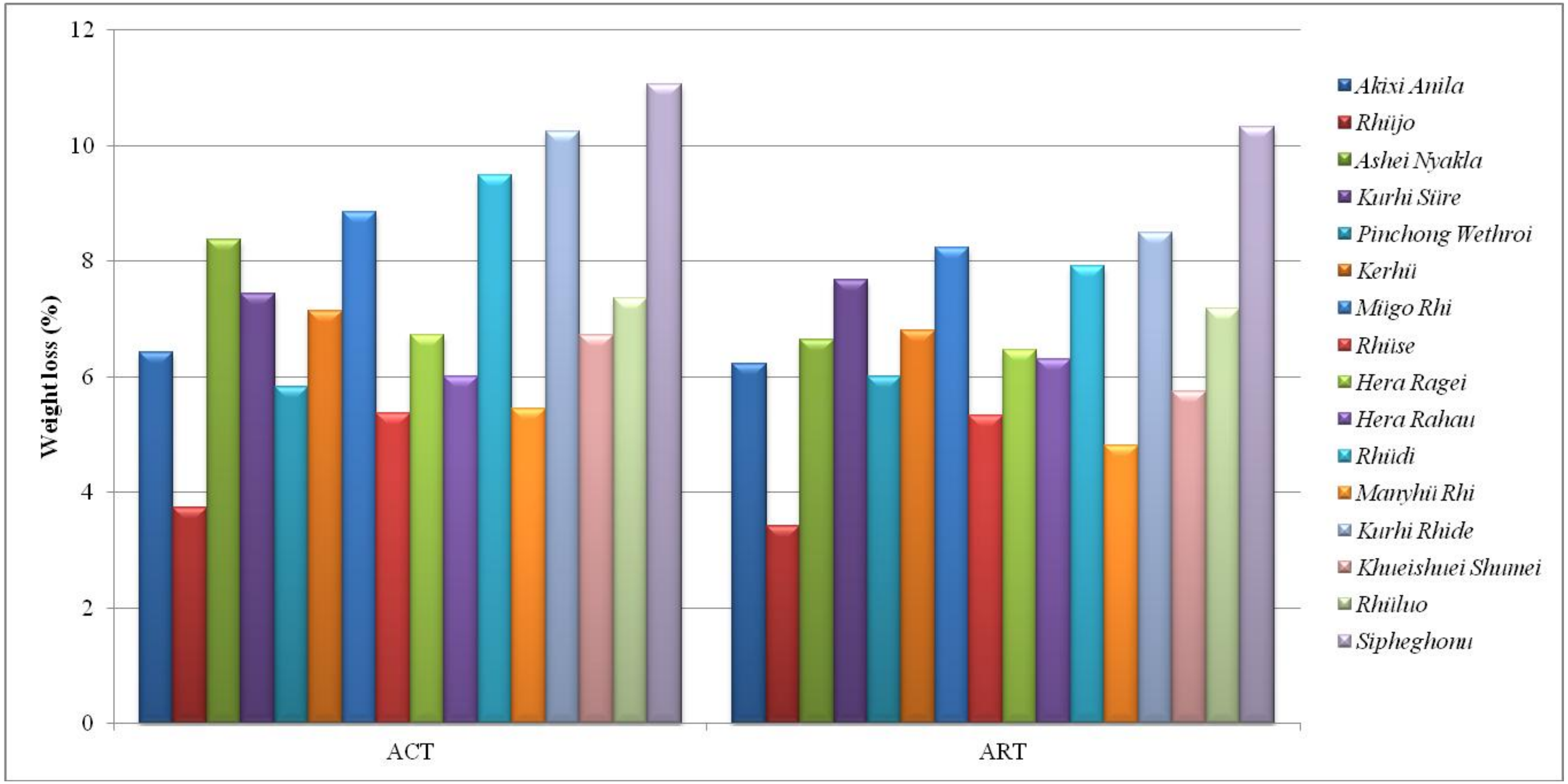

Fig 4.5 Weight loss due to *C. chinensis* infestation on different local ricebean cultivars

by pulse beetle in pigeonpea varieties ranging from 5.2 to 88.7. Divya *et al*. (2012) also reported a variation in per cent infestation by the bruchid on different horsegram accessions ranging from 0.00 to 52.7. Sathish *et al.* (2020) screened 15 chickpea cultivars against pulse beetle and found maximum infestation on ICCV 2 with 77.41% and minimum on IG 72953 with 8.33%.

In the present study the least per cent infestation was observed in cultivar *Rhüjo* both in controlled and room temperature may be due to non preference by the pest. The cultivar was found to be least preferred for oviposition, adult emergence and delayed development period (days) compared to the other cultivars. Likewise, the cultivar with the highest per cent infestation was found to be the most preferred for oviposition, adult emergence and less development period (days) compared to the other cultivars (Table 4.1; Table 4.2; Table 4.3).

The per cent weight loss among the cultivars due to pulse beetle infestation also showed significant variation ranging from 3.73 to 11.07 in controlled temperature and 3.41 to 10.33 in normal room temperature. The result in weight loss may be due to feeding of the seed by the developing larva inside the seed. Similar reports on variation in per cent weight loss due to *C. chinensis* infestation was reported by Jatav *et al*. (2022) in green gram varieties ranging from 12.90 to 27.03 (MH 421 and Pusa Vishal respectively). The results of the present investigation are comparable with the findings of Khokhar and Singh (1987), Bharathi *et al*. (2017) and Pawara *et al*. (2019a).

From the results, it is evident that the per cent infestation directly influences the per cent weight loss in the cultivars. The correlation studies (Table 4.10; Table 4.11) showed that the per cent infestation have a significant positive correlation with per cent weight loss. Likewise, the biological parameters of the pest *viz.,* oviposition, adult emergence and growth index also showed significant positive correlation with per cent infestation and weight loss, while the development period was found to be negatively correlated with per cent weight loss and per cent infestation.

4.1.6 Evaluation of physico-chemical parameters of seed

The physical and biochemical parameters of the local ricebean cultivars are presented in Table 4.8 and Table 4.9, respectively.

4.1.6.1 Physical characters of seeds

In the present study, the physical characteristics of 16 ricebean cultivars were analysed. The physical character *viz.,* colour, texture, shape, seed coat thickness, seed size and seed index (100 seed weight) were recorded. The details are presented in Table 4.8. The colour, texture and shape were recorded based on visual observation. Among the 16 local ricebean cultivars the colour varied from green, light green, yellowish-green, dark blue, creamy white, light yellow, light yellow with black spots, brown, light brown and light brown with black spots. The seed texture was smooth in all the cultivars. The shape varied from nearly round to oblong. Out of 16 cultivars, two cultivars were found to be nearly round and the remaining cultivars were oblong.

The seed coat thickness of the cultivars varied from 0.057±0.004mm to 0.103±0.011mm. The maximum seed coat thickness was found in *Pinchong Wethroi* (0.103±0.011mm) followed by *Ashei Nyakla* (0.096±0.007) and *Mügo Rhi* (0.093±0.004mm). The minimum seed coat thickness was reported in *Hera Rahau* (0.057±0.004mm) followed by *Kerhü* (0.061±0.004mm). In the remaining cultivars it ranged from 0.066±0.003mm to 0.091±0.011mm.

The seed size varied from 118.54±2.36mm^2 to 19.46±0.71 mm^2. There was significant difference in the seed size. The largest seed size was found in *Sipheghonu* (118.54±2.36mm^2) and the smallest was in *Hera Rahau* (19.46±0.71 mm^2). Based on seed size, the 16 cultivars were found in the following order: *Sipheghonu* > *Kurhi Rhide* > *Mügo Rhi*> *Kurhi Süre* > *Khueishuei Shumei* > *Ashei Nyakla* > *Akixi Anila* > *Rhüdi* > *Pinchong*

Wethroi > Rhüluo >Manyhü Rhi > Rhüjo > Hera Ragei >Rhüse >Kerhü > Hera Rahau.

The seed index (100 seed weight) varied from 47.84±0.014g to 5.28±0.008g. Significant differences were observed in the seed index. The highest seed index was found in *Sipheghonu* (47.84±0.014g) followed by *Kurhü Rhide* (46.18±0.012g) and the least was in *Rhüjo* (5.28±0.008g) followed by *Rhüse* (5.33±0.012g), *Hera Rahau* (5.41±0.012g) and *Hera Ragei* (5.43±0.015) which were at par with each other.

4.1.6.2 Biochemical characters of seeds

The biochemical contents *viz.,* protein, fat, phenol, tannin and starch were determined (Table 4.9) to study their influence on the biochemical basis of resistance in pulse beetle.

The protein content among the cultivars at a range of 17.20 % (*Pinchong Wethroi*) to 21.12 %.(*Sipheghonu*). The protein content did not show much variation in different cultivars. They were at par with each other. The cultivar *Sipheghonu* with the highest protein content (21.12%) reported the highest ovipositional preference, adult emergence, infestation and weight loss which indicate that this cultivar was most preferred by pulse beetle.

The fat content of the cultivars varied from 0.51 (*Kurhi Rhide*) to 1.23% (*Kurhi Süre*). On the remaining cultivars, it varied from 0.57 to 0.99% which were at par with each other.

Phenol content showed significant variation among the cultivars. It varied from 80.06 to 747.19 mgGAE/100g. The highest content was found in *Ashei Nyakla* (747.19 mgGAE/100g) followed by *Kurhi Süre* (700.37 mg GAE/100g) and *Rhüse* (655.89 mgGAE/100g). Minimum phenol content was found in *Sipheghonu* (80.06 mgGAE/100g), while in the remaining cultivars it ranged from 194.76 to 571.63 mgGAE/100g. The cultivar *Sipheghonu* with minimum phenol content was found to be most preferred by pulse beetle.

Table 4.8 Physical characters of seeds of local ricebean cultivars

Cultivar	Colour	Texture	Shape	Seed coat thickness (mm)	Seed size (mm^2)	Seed index (g) (100 seed weight)
Akixi Anila	Green	Smooth	Oblong	0.070±0.002	53.11±1.43	11.97±0.016
Rhüjo	Green	Smooth	Oblong	0.091±0.011	22.87±0.96	5.28±0.008
Ashei Nyakla	Dark blue	Smooth	Nearly round	0.096±0.007	61.85±3.78	17.16±0.039
Kurhi Süre	Creamy white	Smooth	Oblong	0.068±0.002	69.50±1.44	25.06±0.020
Pinchong Wethroi	Light yellow	Smooth	Nearly round	0.103±0.011	46.17±0.61	10.86±0.019
Kerhü	Light brown	Smooth	Oblong	0.061±0.004	20.66±0.11	9.58±0.010
Mügo Rhi	Light Brown with black spots	Smooth	Oblong	0.093±0.004	72.91±1.53	24.73±0.022
Rhüse	Yellowish green	Smooth	Oblong	0.086±0.006	21.34±1.02	5.33±0.012
Hera Ragei	Brown	Smooth	Oblong	0.087±0.004	22.51±1.29	5.43±0.015
Hera Rahau	Light yellow with black spots	Smooth	Oblong	0.057±0.004	19.46±0.71	5.41±0.012
Rhüdi	Light yellow with black spots	Smooth	Oblong	0.086±0.006	51.95±1.83	16.59±0.007
Manyhü Rhi	Light yellow with black spots	Smooth	Oblong	0.079±0.006	27.85±0.60	8.22±0.008
Kurhi Rhide	Brown	Smooth	Oblong	0.068±0.003	84.69±2.16	46.18±0.012
Khueishuei Shumei	Light green	Smooth	Oblong	0.073±0.006	65.29±2.34	26.45±0.012
Rhüluo	Light brown	Smooth	Oblong	0.066±0.003	40.31±0.43	10.55±0.015
Sipheghonu	Creamy white	Smooth	Oblong	0.068±0.002	118.54±2.36	47.84±0.014
SEm±				0.002	0.468	0.005

Table 4.9 Bio-chemical contents of seeds of local ricebean cultivars

Cultivars	Protein (%)	Fat (%)	Phenol (mg GAE/100g)	Tannin (mg TAE/100g)	Starch (%)
Akixi Anila	17.86^{i}	0.57^{gh}	382.02^{h}	1178.33^{b}	51.54^{ef}
Rhüjo	18.01^{hi}	0.93^{bc}	477.99^{e}	1181.67^{a}	51.11^{f}
Ashei Nyakla	17.85^{i}	0.87^{cd}	747.19^{a}	1086.23^{f}	54.89^{abcd}
Kurhi Süre	18.21^{h}	1.23^{a}	700.37^{b}	997.55^{i}	56.23^{abc}
Pinchong Wethroi	17.20^{j}	0.83^{de}	316.48^{l}	1103.21^{d}	53.23^{cdef}
Kerhü	18.55^{g}	0.99^{b}	323.50^{k}	1080.56^{g}	54.11^{bcdef}
Mügo Rhi	20.76^{b}	0.77^{ef}	288.39^{n}	944.21^{j}	56.78^{ab}
Rhüse	19.03^{f}	0.71^{f}	655.89^{c}	1160.54^{c}	52.33^{def}
Hera Ragei	18.64^{g}	0.77^{ef}	314.14^{m}	1090.38^{e}	53.87^{bcdef}
Hera Rahau	19.57^{d}	0.73^{f}	571.63^{d}	1161.23^{c}	52.56^{def}
Rhüdi	20.02^{c}	0.78^{ef}	412.45^{g}	1002.11^{h}	56.67^{ab}
Manyhü Rhi	18.22^{h}	0.74^{f}	377.34^{i}	1176.03^{b}	52.14^{def}
Kurhi Rhide	21.04^{a}	0.51^{h}	194.76^{o}	840.54^{k}	56.98^{ab}
Khueishuei Shumei	19.33^{e}	0.61^{g}	440.54^{f}	998.63^{i}	55.10^{abcd}
Rhüluo	19.01^{f}	0.99^{b}	363.29^{j}	1087.21^{f}	54.46^{bcde}
Sipheghonu	21.12^{a}	0.60^{g}	80.06^{p}	808.57^{l}	57.89^{a}
SEm±	0.02	0.008	0.008	0.008	0.218

Figures in the table are mean values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

Tanin content varied from 800.57 to 1181.67 mgTAE/100g. The highest content was found in *Rhüjo* (1181.67 mgTAE/100g) followed by *Akixi Anila* (1178.33 mgTAE/100g), *Manyhü Rhi* (1176.03 mgTAE/100g),*Hera Rahau* (1161.23 mgTAE/100g) and *Rhüse* (1160.54 mgTAE/100g). Minimum tannin content was found in *Sipheghonu* (808.57 mgTAE/100g). On the remaining cultivars, it ranged from 840.54 to 1103.21 mgTAE/100g. The cultivar *Rhüjo* with the highest tannin content (1181.67 mgTAE/100g) reported low oviposition, adult emergence, per cent infestation and weight loss which indicates that the cultivar was not preferred by *C. chinensis.*

Starch content varied from 51.11 (*Rhüjo*) to 57.89% (*Sipheghonu*). Among the cultivars, the starch content did not show much variation. The cultivars such as *Sipheghonu*, *Kurhi Rhide* and *Mügo Rhi* with high starch content (57.89, 56.98 and 56.78%, respectively) reported more infestation and damage compared to cultivars *Rhüjo* and *Akixi Anila* with low starch content (51.11 and 51.54%, respectively) which indicates the preference of pulse beetle to cultivars with high starch content which may be due to nutritional quality of starch for growth and development of the pest.

4.1.7 Correlation studies between biological parameters of *C. chinensis* and physico-chemical parameters of ricebean cultivars

The results of the correlation studies between biological parameters of *C. chinensis* both at controlled (28±2°C) and room temperature and the physico-chemical parameters are presented in Table 4.10, Table 4.11, Table 4.12 and Table 4.13.

According to the correlation study, the correlation between the biological parameters of *C. chinensis* both at controlled temperature and room temperature showed that oviposition was significantly correlated with adult emergence (r = 0.735** and 0.779**), growth index (r = 0.728** and 0.908**), infestation (r = 0.934** and 0.967**), weight loss (r = 0.872** and

0.905**) and development period (r = -0.666** and -0.846**). This indicates that with increase in oviposition, the adult emergence also increases resulting in more infestation and damage.

4.1.7.1 Physical parameters

The physical characters of ricebean seeds *viz.*, seed coat thickness, seed size and seed index (100 seed weight) were correlated with the biological parameters of *C. chinensis* both in controlled and room temperature condition.

In the present investigation, the correlation of seed coat thickness with biological parameters did not show any significant correlation. The result is in similarity with Neog and Singh (2011) and Divija *et al*. (2020) who also reported no significant correlation of seed coat thickness with the suitability of pulse beetle, *C. chinensis.*

However the seed size showed positive significant relationship with oviposition (r = 0.831** and 0.857**), adult emergence (r = 0.667** and 0.710**), growth index (r = 0.716** and 0.839**), infestation (r = 0.889** and 0.884**), weight loss (r = 0.808** and 0.781**) and negative significant relationship with development period (r = -0.653** and -0.804**).

The seed index also showed positive significant relationship with oviposition (r = 0.879** and 0.884**), adult emergence (r = 0.731** and 0.766**), growth index (r = 0.813** and 0.893**), infestation (r = 0.945** and 0.938**), weight loss (r = 0.820** and 0.770**) and negative significant relationship was found with development period (r = -0.747** and -0.844**).

The present study revealed that the seed size and seed index influence the biological parameters of pulse beetle. The increase in physical parameters such as seed size and seed index increases the suitability of the pest. The largest seed size and seed index were observed in cultivar *Sipheghonu* where oviposition was also found highest both in controlled and room temperature condition. The result indicates that larger the seed area more is the oviposition which results in more adult emergence leading to increased infestation and

Table 4.10 Correlation of physical parameters of ricebean cultivars and biological parameters of *C. chinensis* at controlled temperature (28±2°C)

Parameters	Oviposition (no. of eggs)	Adult Emergence (%)	Development Period (days)	Growth index	Infestation (%)	Weight loss (%)	Seed coat thickness (mm)	Seed size (mm^2)	100 seed weight (g)
Oviposition (no. of eggs)	1	0.735**	-0.666**	0.728**	0.934**	0.872**	-0.281	0.831**	0.879**
Adult Emergence (%)	0.735**	1	-0.821**	0.869**	0.795**	0.811**	-0.257	.0667**	0.731**
Development Period (days)	-0.666**	-0.821**	1	-0.987**	-0.801**	-0.767**	0.116	-0.653**	-0.747**
Growth index	0.728**	0.869**	-0.987**	1	0.856**	0.802**	-0.132	0.716**	0.813**
Infestion (%)	0.934**	0.795**	-0.801**	0.856**	1	0.880**	-0.193	0.889**	0.945**
Weight loss (%)	0.872**	0.811**	-0.767**	0.802**	0.880**	1	-0.189	0.808**	0.820**
Seed coat thickness (mm)	-0.281	-0.257	0.116	-0.132	-0.193	-0.189	1	-0.077	-0.228
Seed size (mm^2)	0.831**	0.667**	-0.653**	0.716**	0.889**	0.808**	-0.077	1	0.939**
100 seed weight (g)	0.879**	0.731**	-0.747**	0.813**	0.945**	0.820**	-0.228	0.939**	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 4.11 Correlations of physical parameters of ricebean cultivars and biological parameters of *C. chinensis* at room temperature

Parameters	Oviposition (no. of eggs)	Adult Emergence (%)	Development Period (days)	Growth index	Infestation (%)	Weight loss (%)	Seed coat thickness (mm)	Seed size (mm^2)	100 seed weight (g)
Oviposition (no. of eggs)	1	0.779**	-0.846**	0.908**	0.967**	0.905**	-0.21	0.857**	0.884**
Adult Emergence (%)	0.779**	1	-0.781**	0.829**	0.820**	0.835**	-0.229	0.710**	0.766**
Development Period (days)	-0.846**	-0.781**	1	-0.986**	-0.877**	-0.824**	0.209	-0.804**	-0.844**
Growth index	0.908**	0.829**	-0.986**	1	0.939**	0.858**	-0.236	0.839**	0.893**
Infestion (%)	0.967**	0.820**	-0.877**	0.939**	1	0.864**	-0.2	0.884**	0.938**
Weight loss (%)	0.905**	0.835**	-0.824**	0.858**	0.864**	1	-0.295	0.781**	0.770**
Seed coat thickness (mm)	-0.21	-0.229	0.209	-0.236	-0.2	-0.295	1	-0.077	-0.228
Seed size (mm^2)	0.857**	0.710**	-0.804**	0.839**	0.884**	0.781**	-0.077	1	0.939**
100 seed weight (g)	0.884**	0.766**	-0.844**	0.893**	0.938**	0.770**	-0.228	0.939**	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 4.12 Correlation of biochemical parameters of ricebean cultivars and biological parameters of *C. chinensis* at controlled temperature (28±2°C)

Parameters	Oviposition (no. of eggs)	Adult Emergence (%)	Development Period (days)	Growth index	Infestation (%)	Weight loss (%)	Protein (%)	Fat (%)	Phenol (mgGAE/100g)	Tannin (mg TAE/100g)	Starch (%)
Oviposition (no. of eggs)	1	0.735**	-0.666**	0.728**	0.934**	0.872**	0.789**	-0.389	-0.554*	-0.870**	0.765**
Adult Emergence (%)	0.735**	1	-0.821**	0.869**	0.795**	0.811**	0.818**	-0.313	-0.23	-0.816**	0.827**
Development Period (days)	-0.666**	-0.821**	1	-0.987**	-0.801**	-0.767**	-0.774**	0.221	0.346	0.871**	-0.866**
Growth index	0.728**	0.869**	-0.987**	1	0.856**	0.802**	0.826**	-0.283	-0.376	-0.912**	0.884**
Infestion (%)	0.934**	0.795**	-0.801**	0.856**	1	0.880**	0.819**	-0.368	-0.567*	-0.961**	0.858**
Weight loss (%)	0.872**	0.811**	-0.767**	0.802**	0.880**	1	0.731**	-0.258	-0.438	-0.889**	0.920**
Protein (%)	0.789**	0.818**	-0.774**	0.826**	0.819**	0.731**	1	-0.469	-0.501*	-0.776**	0.708**
Fat (%)	-0.389	-0.313	0.221	-0.283	-0.368	-0.258	-0.469	1	0.469	0.247	-0.045
Phenol (mg GAE/100g)	-0.554*	-0.23	0.346	-0.376	-0.567*	-0.438	-0.501*	0.469	1	0.526*	-0.342
Tanin (mg TAE/100g)	-0.870**	-0.816**	0.871**	-0.912**	-0.961**	-0.889**	-0.776**	0.247	0.526*	1	-0.938**
Starch (%)	0.765**	0.827**	-0.866**	0.884**	0.858**	0.920**	0.708**	-0.045	-0.342	-0.938**	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 4.13 Correlation of biochemical parameters of ricebean cultivars and biological parameters of *C. chinensis* at room temperature

Parameters	Oviposition (no. of eggs)	Adult Emergence (%)	Development Period (days)	Growth index	Infestation (%)	Weight loss (%)	Protein (%)	Fat (%)	Phenol (mgGAE/100g)	Tannin (mg TAE/100g)	Starch (%)
Oviposition (no. of eggs)	1	0.779**	-0.846**	0.908**	0.967**	0.905**	0.799**	-0.341	-0.536*	-0.903**	0.819**
Adult Emergence (%)	0.779**	1	-0.781**	0.829**	0.820**	0.835**	0.772**	-0.214	-0.215	-0.844**	0.864**
Development Period (days)	-0.846**	-0.781**	1	-0.986**	-0.877**	-0.824**	-0.770**	0.302	0.519*	0.921**	-0.869**
Growth index	0.908**	0.829**	-0.986**	1	0.939**	0.858**	0.815**	-0.348	-0.539*	-0.950**	0.876**
Infestion (%)	0.967**	0.820**	-0.877**	0.939**	1	0.864**	0.815**	-0.348	-0.573*	-0.956**	0.850**
Weight loss (%)	0.905**	0.835**	-0.824**	0.858**	0.864**	1	0.703**	-0.151	-0.46	-0.859**	0.888**
Protein (%)	0.799**	0.772**	-0.770**	0.815**	0.815**	0.703**	1	-0.469	-0.501*	-0.776**	0.708**
Fat (%)	-0.341	-0.214	0.302	-0.348	-0.348	-0.151	-0.469	1	0.469	0.247	-0.045
Phenol (mgGAE/100g)	-0.536*	-0.215	0.519*	-0.539*	-0.573*	-0.46	-0.501*	0.469	1	0.526*	-0.342
Tanin (mg TAE/100g)	-0.903**	-0.844**	0.921**	-0.950**	-0.956**	-0.859**	-0.776**	0.247	0.526*	1	-0.938**
Starch (%)	0.819**	0.864**	-0.869**	0.876**	0.850**	0.888**	0.708**	-0.045	-0.342	-0.938**	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

weight loss. The cultivar with a smaller seed size and seed index were less preferred by the pest. Preference for larger seeds may be due to the availability of more space for oviposition, growth and development. Similar results were reported by Rathore and Chaturvedi (1997) who reported that larger seeds of chickpea were more preferred for oviposition than smaller seeds. Muhammad (2012) reported that bigger grain sizes of chickpea was more susceptible to pulse beetle. Tripathi *et al*. (2013) reported that the growth index of *C. chinensis* showed a positive relationship with length-width ratio of seed and 100 seed weight. Ponnusamy *et al.* (2014) reported fewer numbers of eggs and a lower percentage of emergence in small seeds compared to the large and dull seeds of green gram. They concluded that the preference of females for egg laying in large and dull seeds could be possibly due to the ease for settling of adults for ovipoistion. The findings are also in conformity with Cope and Fox (2003) and Chakraborty and Mondal (2016).

However on the contrary, Neog and Singh (2011) reported that the physical characters of seed *viz.,* 100 seed weight, seed coat thickness, colour and texture of seed coat were not related with the ovipositional preference and host suitability of pulse beetle. Prajapati *et al*. (2018) also reported no significant relationship between seed size and oviposition preference of *C. chinensis* on chickpea varieties.

4.1.7.2 Biochemical parameters

The biochemical parameters of ricebean seeds *viz.*, protein, fat, phenol, tannin and starch were correlated with the biological parameters of *C. chinensis* both in controlled temperature and room temperature.

Protein content showed positive significant correlation with oviposition (r = 0.789** and 0.799**), adult emergence (r = 0.818** and 0.772**), growth index (r = 0.826** and 0.815**), infestation (r = 0.819** and 0.815**), weight loss (r = 0.731** and 0.703**) and negative significant correlation with development period (r = -0.774** and -0.770**).

Fat content did not show any significant correlation with the biological parameters of *C. chinensis*.

Phenol content showed negative significant correlation with oviposition (r = -0.554* and -0.536*), growth index (r = -0.539* at room temperature), per cent infestation(r = -0.567* and 0.573*) and positive significant correlation with development period (r = 0.519* at room temperature). The adult emergence was found to be non significant with phenol content.

Tannin content showed negative significant correlation with oviposition (r = -0.870** and -0.903**), adult emergence (r = -0.816** and -0.844**), growth index (r = -0.912** and -0.950**), infestation (r = -0.961** and -0.956**), weight loss (r = -0.889** and -0.859**) and positive significant correlation with development period (r = 0.871** and 0.921**).

Starch content showed positive significant correlation with oviposition (r = 0.765** and 0.819**), adult emergence (r = 0.827** and 0.864**), growth index (r = 0.884** and 0.876**), infestation (r = 0.858** and 0.850**), weight loss (r = 0.920** and 0.888**) and negative significant correlation with development period (r = -0.866** and -0.869**).

The present study revealed that the biochemical content of seed influences the growth and development of pulse beetle. Biochemical content such as protein and starch showed a positive significant correlation with the biological parameters (*viz.,* oviposition, adult emergence, growth index, per cent infestation and per cent weight loss) and a negative significant correlation with the development period of *C. chinensis.*

There was no significant correlation between fat content and biological parameters of *C.chinensis* which indicates that the fat content does not influence the growth and development of pulse beetle.

The result of the present study revealed significant differences in biochemical parameters of the cultivars. The cultivars with higher protein and starch content were highly preferred by the pest for growth and development and were highly susceptible. However, cultivars having higher phenol and tannin content were less preferred by the pest and they exhibited resistance against *C. chinensis.*

The findings are in conformity with Tripathi *et al*. (2013) who reported that the resistance observed in different cowpea accessions is due to biochemical factors such as protein and tannin. Deepika *et al.* (2020) observed significant positive relation of protein and starch content of chickpea cultivars with the infestation of pulse beetle. Kavitha *et al*. (2021) reported a positive correlation of biological parameters with protein, sugar and moisture content and a negative correlation with phenol content. The study revealed that cultivars with high protein and sugar contents were more susceptible to pulse beetle and cultivars with high phenol content showed resistance. Comparable results were also reported by different workers (Saxena & Saxena, 2011; Chandel & Bhadauria, 2015b; Vishwamithra *et al.*, 2015; Holay *et al*., 2018; Usha *et al*., 2020).

4.2 Effect of storage structures on the incidence of *C. chinensis*

The experiment was carried out in normal laboratory conditions in a Complete Randomized Design (CRD) with 5 replications. Four types of storage structures *viz*., cloth bag, plastic jar, jute bag, and bamboo basket were evaluated against *C. chinensis* on the most susceptible cultivar of ricebean (*Sipheghonu*). The results of the study are presented and discussed below:

4.2.1 Effect of storage structures on per cent infestation and per cent weight loss

The observations on per cent infestation and per cent weight loss were recorded for 6 months. The details are presented in Table 4.14 (Fig 4.6) and Table 4.15 (Fig 4.7).

After one month of storage, the infestation varied from 2.48 to 3.32%. The infestation in the plastic jar was minimum with 2.48% and the maximum

Table 4.14 Effect of storage structures on infestation by *C. chinensis* on ricebean cultivar *Sipheghonu*

Storage structures	*Infestation (%)					
	After 1 month	After 2 months	After 3 months	After 4 months	After 5 months	After 6 months
Cloth bag	3.31[a] (1.90)	25.23[a] (14.61)	56.60[a] (34.47)	69.43[a] (43.97)	78.95[a] (52.14)	90.54[a] (64.87)
Plastic jar	2.48[b] (1.42)	18.76[b] (10.81)	37.89[d] (22.27)	48.39[d] (28.94)	54.76[d] (33.20)	76.65[d] (50.04)
Jute bag	3.30[a] (1.89)	23.95[a] (13.86)	47.56[b] (28.40)	62.23[b] (38.49)	73.72[b] (47.50)	87.63[b] (61.20)
Bamboo basket	3.32[a] (1.90)	22.25[a] (12.85)	45.64[c] (27.15)	59.50[c] (36.52)	68.69[c] (43.38)	82.48[c] (55.57)
SEm±	0.11	0.53	0.23	0.24	0.20	0.18

*Figures in the table are mean values
Figures in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

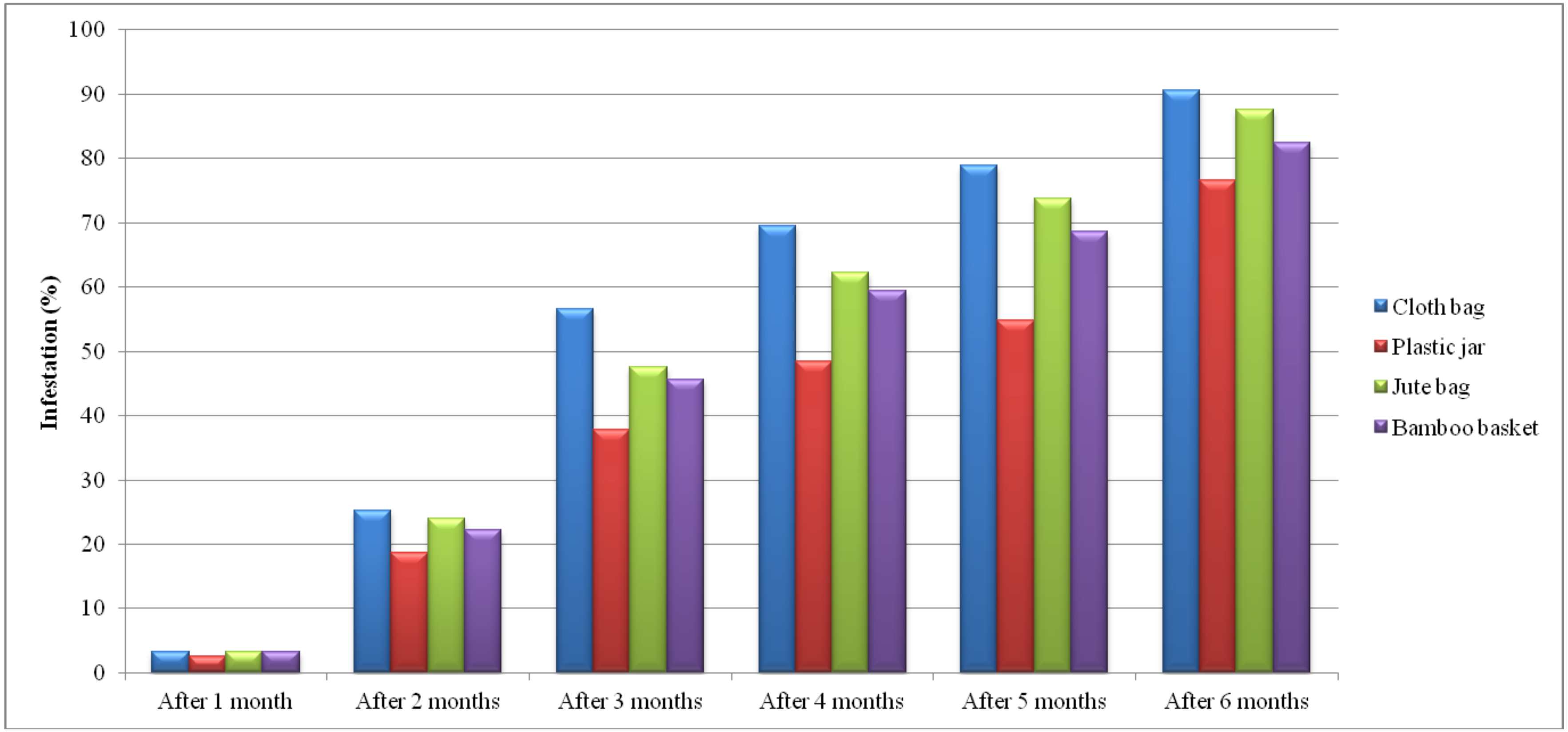

Fig 4.6 Effect of storage structures on infestation by *C. chinensis* on ricebean cultivar *Sipheghonu*

Table 4.15 Effect of storage structures on weight loss by *C. chinensis* on ricebean cultivar *Sipheghonu*

Storage structures	*Weight loss (%)					
	After 1 month	After 2 months	After 3 months	After 4 months	After 5 months	After 6 months
Cloth bag	0.42[ab] (0.24)	3.21[a] (1.84)	11.58[a] (6.65)	16.07[a] (9.25)	23.92[a] (13.84)	25.08[a] (14.52)
Plastic jar	0.29[b] (0.17)	1.89[b] (1.08)	5.71[d] (3.27)	9.30[c] (5.33)	15.63[d] (8.99)	16.20[d] (9.32)
Jute bag	0.45[a] (0.26)	3.02[a] (1.73)	8.75[b] (5.02)	12.52[b] (7.10)	21.32[b] (12.31)	22.14[b] (12.79)
Bamboo basket	0.46[a] (0.26)	2.74[a] (1.57)	7.85[c] (4.50)	12.26[b] (7.04)	18.26[c] (10.52)	19.27[c] (11.11)
SEm±	0.03	0.13	0.07	0.08	0.07	0.09

*Figures in the table are mean values
Figures in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

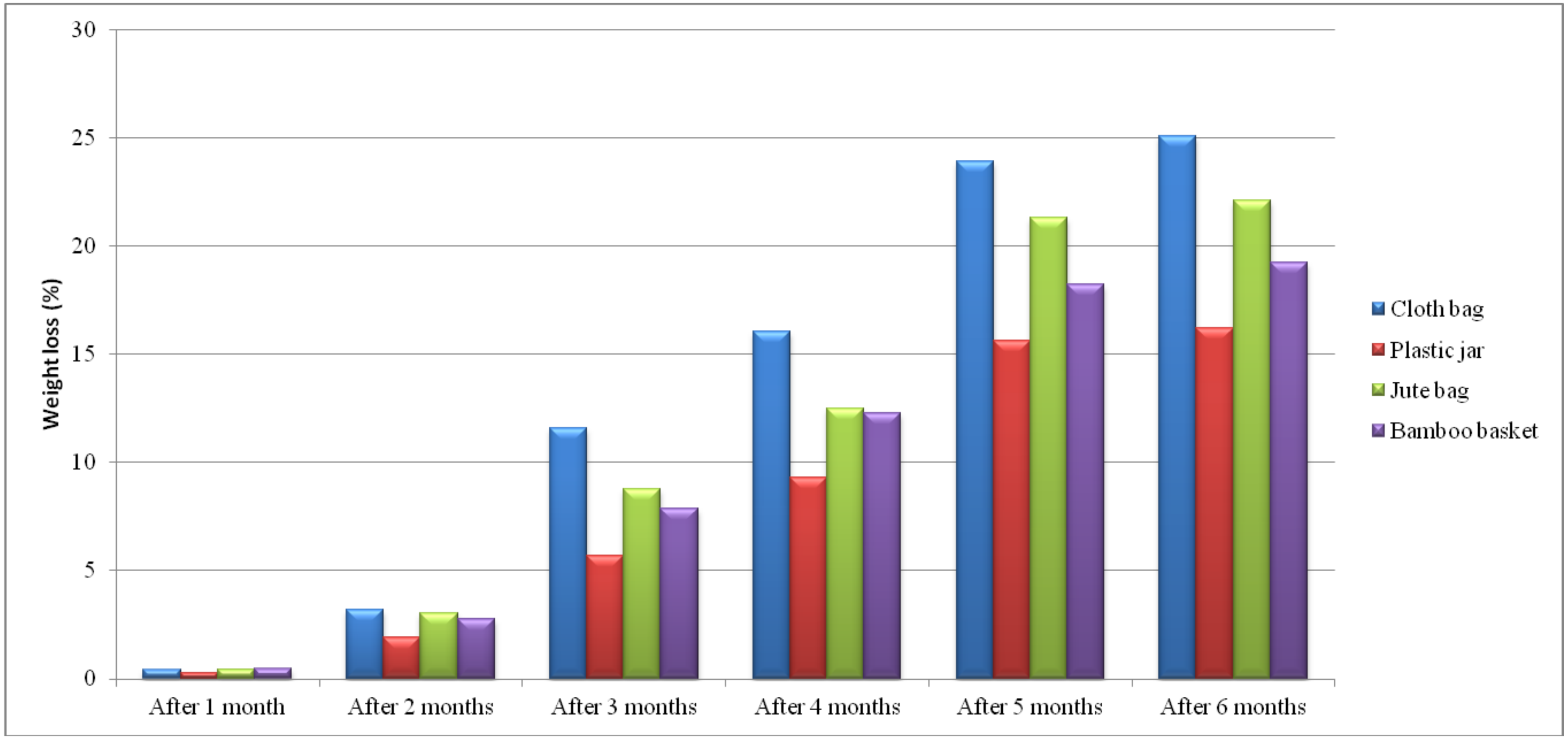

Fig 4.7 Effect of storage structures on weight loss by *C. chinensis* on ricebean cultivar *Sipheghonu*

was in bamboo basket with 3.32 % followed by cloth bag with 3.31% and jute bag with 3.30 %. The per cent infestation in bamboo basket, cloth bag and jute bag were not significantly different.

The weight loss varied from 0.29 to 0.46%. The maximum weight loss was observed in bamboo basket (0.46%) followed by jute bag (0.45%) and cloth bag (0.42%) with no significant difference among them.

After two months of storage, the infestation increased with the highest infestation in cloth bag (25.23%) followed by jute bag (23.95%) and bamboo basket (22.25%) with no significant difference among them. The minimum infestation was found in plastic jar (18.76%). The significant increase in infestation may be due to infestation from the first generation after one month.

The per cent weight loss also increases significantly with the increase in infestation. The weight loss varied from 1.89 to 3.21%. Plastic jar recorded the minimum weight loss (1.89%) with a significant difference from the other storage structures. The maximum weight loss was observed in cloth bag (3.21%) followed by jute bag (3.02%) and bamboo basket (2.74%) with no significant difference among them.

After three months of storage, all four storage structures showed significant difference in per cent infestation. The highest was in cloth bag (56.60%) followed by jute bag (47.56%), bamboo basket (45.64%) and the minimum was in plastic jar (37.89%). Likewise, the per cent weight loss was also found with a significant difference in all the storage structures. The maximum weight loss was found in cloth bag (11.58%) followed by jute bag (8.75%) and bamboo basket (7.85%), while plastic jar recorded the minimum weight loss (5.71%).

After four months of storage, the per cent infestation ranged from 48.39 to 69.43 with the highest in cloth bag and lowest in plastic jar. A similar trend in the increase in per cent infestation was found after five and six months of storage with per cent infestation ranging from 54.76 to 78.95 and 76.65 to

90.54, respectively with a significant difference among all the four storage structures. After 6 months (180 days) of storage maximum per cent infestation was found in cloth bag, while the minimum infestation was found in plastic jar.

The per cent weight loss after four months of storage varied from 9.30 to 16.07 with minimum in plastic jar and the maximum in cloth bag. Similar trend was also observed after five and six months of storage with 15.63 to 23.92% and 16.20 to 25.08% weight loss, respectively. The highest weight loss was recorded from cloth bag and the lowest from plastic jar after 6 months of storage.

In the present study, the per cent infestation and weight loss up to 6 months (180 days) of storage in various storage structures ranged from 2.48 to 90.54 and 0.29 to 25.08, respectively. The result indicates that all the storage structures were subjected to infestation by pulse beetle and did not show a complete reduction in per cent infestation which resulted in significant weight loss. Up to 3 months of storage the weight loss was negligible but the infestation of the pest increased with an increase in the storage period. Similar result in increased infestation of pulse beetle in storage was reported by Charjan *et al.* (2006). Gadewar *et al.* (2011) reported an increased infestation of 25.10% at 3 months and 59.28 % at 6 months of storage. Based on the storage structure the order of reducing the per cent infestation and weight loss was: plastic jar > bamboo basket > jute bag > cloth bag.

The findings of the present study are in conformity with Sudini *et al.* (2015) who reported that triple-layer bags were more effective than cloth bag in retaining seed weight at four months of storage. Baributsa *et al.* (2017) reported 28.7 per cent weight loss of groundnut stored in woven bags at 6-7 months of storage. Pareek *et al*. (2013) evaluated seven storage structures and reported the effectiveness in the order as metal bin > plastic fibre bag > cloth bag > polythene bag > gunny bag >*Matka* bin > *Kuthla*.

Nehra *et al*. (2021) investigated various packaging materials *viz.* polythene bags, cloth bags, gunny bags and jute bags and reported variations in weight loss (2.83 to 49.58 %). They observed minimum weight loss in polythene bags followed by gunny bags. The highest weight loss was observed in cloth bags and jute bags. Ramesh and Vaidya (2001) found that local storage structures such as gunny sacks and bamboo bins resulted in greater weight loss. Howlader *et al.* (2004) and Rolania *et al*. (2021) also reported more insect population, per cent infestation and weight loss in gunny bags compared to plastic bags and metal structures.

Among the storage structures, plastic jar showed lower infestation and weight loss which could be due to air-tight sealing reducing the oxygen availability to the pest affecting its growth and development. The other three storage structures were well aerated in comparison with the plastic jar. The present findings are in similarity with Ganiger *et al*. (2022) who found that decreasing oxygen access by storing greengram seeds in vacuum-packed bags protected greengram seeds for up to 9 months of storage. Ahn *et al*. (2013) also reported that cowpea bruchid larva and adults development is affected in an environment where oxygen is limited and their growth and development can be reduced by storing them in sealed containers. Similar findings were also reported by Roja *et al*. (2021) who evaluated different storage structures against pulse beetle. They revealed that polythene bag and plastic bin with 3 cm sand above the grain were more effective in reducing infestation compared to earthen pot, metal bin and gunny bag due to less amount of oxygen available for insect development.

4.2.2 Effect of storage structures on per cent grain moisture

Moisture content was recorded before and after 6 months of storage. Grain moisture content was determined by randomly selecting 100 grains in each bag and was estimated with help of an Electronic Moisture Meter. The details are presented in Table 4.16 and illustrated in Fig 4.8

The results of the present investigation showed that the per cent grain moisture increased with an increase in storage periods. The grain moisture content at initial varied from 9.03 to 10.09%. The grain moisture in jute bag was 10.09% followed by plastic jar (9.75%), cloth bag (9.44%) and bamboo basket (9.03%) with no significant difference among them.

After 6 months of storage, the moisture content was determined and found an increase in moisture content from all the storage structures which varied from 13.84 to 15.54%. The highest moisture content was found in cloth bag (15.54%) followed by bamboo basket (14.14%), plastic jar (14.06%) and the least was found in jute bag (13.84%). There was no significant difference among them.

The results in the present study showed an increase in per cent moisture of grains after 6 months of storage. The increase in moisture content could be due to infestation by the pest and also the environmental factors (temperature and humidity). In the present study, the per cent infestation in all the storage structures increased with the increase in storage period with the highest infestation of 90.54% recorded from cloth bag after 6 months. The grain moisture content was also found to be the highest in grains stored in cloth bag with 15.54%.

The present findings are in conformity with Ashish *et al*. (2019) who reported increased in moisture content of 10.91% at 3 months to 12.26% at 6 months due to infestation of pulse beetle in storage. Sujeetha *et al.* (2014) and Sawant *et al*. (2012) also reported that due to the respiration activity of insects, the temperature and moisture increases inside the storage structure which results in increased moisture content of the grains. Similarly, Rolania *et al*. (2021) reported a positive correlation between pulse beetle infestation and moisture content.

Table 4.16 Effect of storage structures on per cent grain moisture

Storage structures	*Moisture content (%)	
	Initial	After 6 months
Cloth bag	9.44[a] (5.42)	15.54[a] (8.94)
Plastic jar	9.75[a] (5.59)	14.06[a] (8.08)
Jute bag	10.09[a] (5.79)	13.84[a] (7.95)
Bamboo basket	9.03[a] (5.18)	14.14[a] (8.13)
SEm±	0.18	0.36

*Figures in the table are mean values
Figures in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

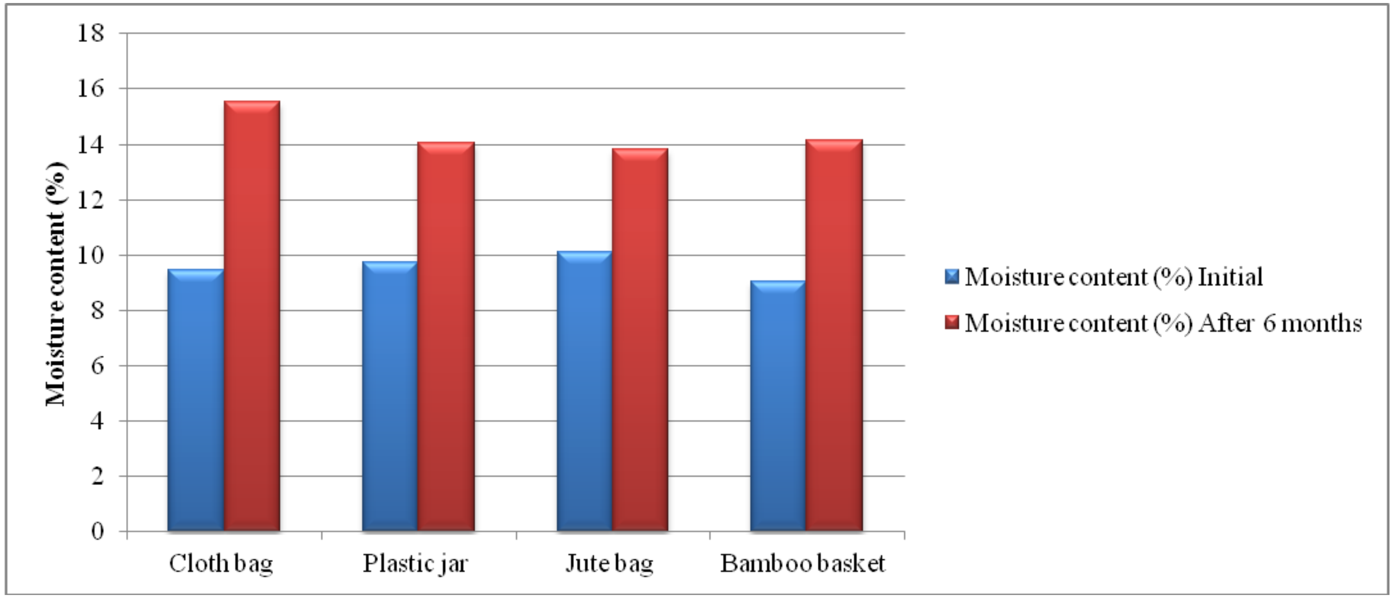

Fig 4.8 Effect of storage structures on per cent grain moisture

4.3 Efficacy of botanicals against pulse beetle, *C. chinensis*

A total of 7 plant materials and jatropha oil was tested for their efficacy against *C. chinensis* during 2019 and 2020. Both powder and extract of the plant materials along with Jatropha oil was used for the study. Malathion 50 EC and Malathion 5% dust was used as a standard check and one untreated control was taken for comparison. The seeds of the most susceptible cultivar *i.e., Sipheghonu* was used for this experiment.

4.3.1 Bioassay on the toxicity of plant extracts on adult *C. chinensis*

In the present study, the mortality at 24, 48 and 72 hours due to direct toxicity of plant extracts, Jatropha oil and Malathion 50 EC at different concentrations shows variations in per cent mortality ranging from 0 to 100%. The details are presented in Table 4.17. Jatropha oil and *P. nigrum* extract @ 2% concentration reported the highest mortality followed by *L. citrata* extract @ 2% at 24 hours after treatment. While *E. globules*, *A. sativum, A. indica* and *P. pinnata* @ 2% no mortality were found at 24 hours after treatment. The results show that the per cent mortality increases with the increase in concentration and time after treatment.

Based on the per cent mortality, the concentration mortality line was calculated using probit analysis. The details of the probit analysis for 24, 48 and 72 hours are presented in Table 4.18. The results from the probit analysis at 24, 48 and 72 hours showed that the standard check Malathion 50 EC was the most toxic. For the plant products, at 24 hours Jatropha oil and *P. nigrum* were the most toxic followed by *L. citrata.* While in *O. tenuiflorum* and *A. sativum* significant result could not be found. The LC50 values at 24 hours were *A. indica* 14%, *P. nigrum* 4%, *O. tenuiflorum* 56% (non significant), *E. globules* 14%, *A. sativum* 16% (non significant), *P. pinnata* 13%, *L. citrata* 5%, Jatropha oil 4% and Malathion 50EC 0.04%. Similar results were obtained at 48 hours. However at 72 hours, *P. nigrum* was the most toxic at the lowest LC50 value followed by Jatropha oil and *L. citrata.* The *A. sativum* extract was

Table 4.17 Mortality of pulse beetle, *C. chinensis* at 24, 48 and 72 hours with plant extracts and Jatropha oil treatment

Plant extract	Dose (%)	Insect mortality rate (%)		
		24 HAT	48 HAT	72 HAT
1. A. indica	2	0.00	6.90	10.71
	4	13.33	20.69	28.57
	6	20.00	41.38	46.43
	8	23.33	44.83	53.57
	10	36.67	51.72	57.14
2. P. nigrum	2	26.67	34.48	50.00
	4	43.33	58.62	64.29
	6	66.67	75.86	89.29
	8	86.67	100.00	100.00
	10	93.33	100.00	100.00
3. O. tenuiflorum	2	6.67	6.90	14.29
	4	10.00	20.69	28.57
	6	13.33	24.14	32.14
	8	16.67	27.59	46.43
	10	23.33	48.28	60.71
4. E. globules	2	0.00	6.90	10.71
	4	10.00	12.07	17.86
	6	23.33	34.48	35.71
	8	26.67	37.93	39.29
	10	30.00	48.28	60.71
5. A. sativum	2	0.00	0.00	0.00
	4	0.00	3.45	7.14
	6	0.00	6.90	13.33
	8	6.67	13.79	30.00
	10	13.33	20.69	13.64
6. P. pinnata	2	0.00	0.00	0.00
	4	0.00	3.45	14.29
	6	13.33	13.79	21.43
	8	20.00	24.14	32.14
	10	33.33	34.48	60.71
7. L. citrata	2	16.67	27.59	39.29
	4	36.67	44.83	50.00
	6	56.67	86.21	92.86
	8	66.67	100.00	100.00
	10	83.33	100.00	100.00
8. Jatropha oil	2	26.67	31.03	42.86
	4	33.33	55.17	67.86
	6	56.67	68.97	75.00
	8	73.33	89.66	100.00
	10	100.00	100.00	100.00
9. Malathion 50 EC	0.03	33.33	44.83	85.71
	0.04	46.67	53.33	92.86
	0.05	66.67	86.21	100.00
	0.06	70.00	96.55	100.00
	0.07	83.33	100.00	100.00

HAT=Hours after treatment

Table 4.18 Probit analysis for toxicity at 24, 48 and 72 hours of plant extracts and Jatropha oil treatment against pulse beetle, *C. chinensis*

Name of extract	LC50 (%)	95% fiducial limit	Slope ± SE	Goodness of fit chi squared
A. At 24 hours				
A. indica	14	8.654-5.89E+09	2.47±1.22	0.52
P. nigrum	4	2.226-5.147	2.96±0.85	1.00
O. tenuiflorum	56(NS)	-	1.09±1.00	0.08
E. globules	14	8.188-1.216E+063	2.43±1.23	0.53
A. sativum	16(NS)	-	5.30±4.72	0.16
P. pinnata	13	9.066-1.130E+021	4.35±2.20	0.44
L. citrata	5	3.178-7.364	2.64±10.83	0.28
Jatropha oil	4	2.700-5.929	2.89±0.84	3.62
Malathion 50 EC	0.04	0.019-0.051	3.68±1.47	0.19
B. At 48 hours				
A. indica	9	6.205-91.216	2.16±0.91	0.21
P. nigrum	3	1.661-4.195	3.15±0.89	1.15
O. tenuiflorum	14(NS)	-	1.78±0.93	0.50
E. globules	11	7.128-450.764	2.184±0.96	0.36
A. sativum	20(NS)	-	2.82±1.87	0.05
P. pinnata	13	9.015-3.45E+08	3.55±1.75	0.05
L. citrata	3	2.229-4.449	3.75±0.95	1.90
Jatropha oil	3	1.821-4.723	2.88±0.85	1.07
Malathion 50 EC	0.04	0.023-0.041	5.70±1.75	1.14
C. At 72 hours				
A. indica	8	5.318-65.906	1.99±0.85	0.13
P. nigrum	2	1.068-3.228	3.45±1.04	1.53
O. tenuiflorum	10	5.825-27732.885	1.74±0.83	0.32
E. globules	10	6.442-207.611	2.07±0.89	0.48
A. sativum	15	-	3.08±1.62	0.48
P. pinnata	10	7.421-34.408	3.47±1.34	0.78
L. citrata	3	1.517-4.178	2.97±0.86	1.90
Jatropha oil	3	0.874-4.043	2.47±0.83	1.02
Malathion 50 EC	0.01(NS)	-	2.00±1.84	0.13

NS=Non significant

found to be the least toxic among the plant extracts. The LC50 values at 72 hours were: *A. indica* 8%, *P. nigrum* 2%, *O. tenuiflorum* 10%, *E. globules* 10%, *A. sativum* 15%, *P. pinnata* 10%, *L. citrata* 3%, Jatropha oil 3% and Malathion 50 EC 0.01% (non significant). The order of toxicity of plant products based on probit analysis was *P. nigrum* >Jatropha oil > *L. citrata* > *A. indica* > *E. globules* > *O. tenuiflorum* > *P. pinnata* > *A. sativum*. Based on the result of the bioassay study the concentration of the plant extracts, jatropha oil and Malathion 50EC were determined and used in the study for oviposition, adult emergence, per cent infestation and per cent weight loss. The treatment details are presented in Table 3.2.

4.3.2 Effect of treatment on oviposition

The result of the plant powder treatments shows a significant reduction in oviposition ranging from 3.14 to 38.38%. The details are presented in Table 4.19 (Fig 4.9). The number of eggs laid on treated seeds varied from 137 to 215.33, whereas in untreated control it was 222.33. In the standard check (Malathion 5% dust) there was no oviposition. The highest number of eggs was laid in seeds treated with *P. pinnata* powder, while the minimum was in *L. citrata* treated seeds. Among all the powder treatments, the highest reduction in oviposition was found in *L. citrata* seed powder treatment with 38.38% followed by *A. indica* leaf powder with 24.73% and *P. nigrum* seed powder with 19.03 %. The minimum reduction was found in *P. pinnata* leaf powder with 3.14% followed by *O. tenuiflorum* with 3.74% and *A. sativum* with 4.34%. Based on per cent reduction of oviposition the effectiveness of plant powders was *L. citrata* > *A. indica* > *P. nigrum* > *E. globules* > *A. sativum* > *O. tenuiflorum* > *P. pinnata.*

In the case of plant extracts treatment (Table 4.20, Fig 4.10) the results showed that the number of eggs laid on treated seed varied significantly (39.33 to 210.00). Oviposition was highest in *P. pinnata* (210.00) followed by *O. tenuiflorum* (201.00) and the minimum was found in Jatropha oil treatment

Table 4.19 Effect of plant powders on reduction of oviposition and adult emergence during 2019 and 2020 (Pooled data)

Treatments	Dose (% w/w)	**No. of eggs laid on 25 seeds	*Reduction of oviposition (%)	*Adult emergence (%)
A. indica	5	167.33[b] (12.95)	24.73[c] (14.32)	65.53[cd] (40.94)
P. nigrum	5	180.00[b] (13.49)	19.03[c] (10.97)	61.11[de] (37.67)
O. tenuiflorum	5	214.00[a] (14.65)	3.74[d] (2.14)	68.53[bc] (43.26)
E. globules	5	205.00[a] (14.34)	7.79[d] (4.47)	69.43[bc] (43.97)
A. sativum	5	212.67[a] (14.60)	4.34[d] (2.49)	69.28[bc] (43.85)
P. pinnata	5	215.33[a] (14.69)	3.14[d] (1.80)	73.37[ab] (47.20)
L. citrata	5	137[c] (11.73)	38.38[b] (22.57)	55.23[e] (35.53)
Malathion 5% Dust	1	0[d] (0.71)	100.00[a] (90.00)	0.00[f] (0.00)
Untreated control	-	222.33[a] (14.93)	-	77.96[a] (51.22)
SEm±		1.81	1.05	0.71

Figures in the table are mean values
*Figures in the parentheses are angular transformed values
**Figures in the parentheses are square root transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

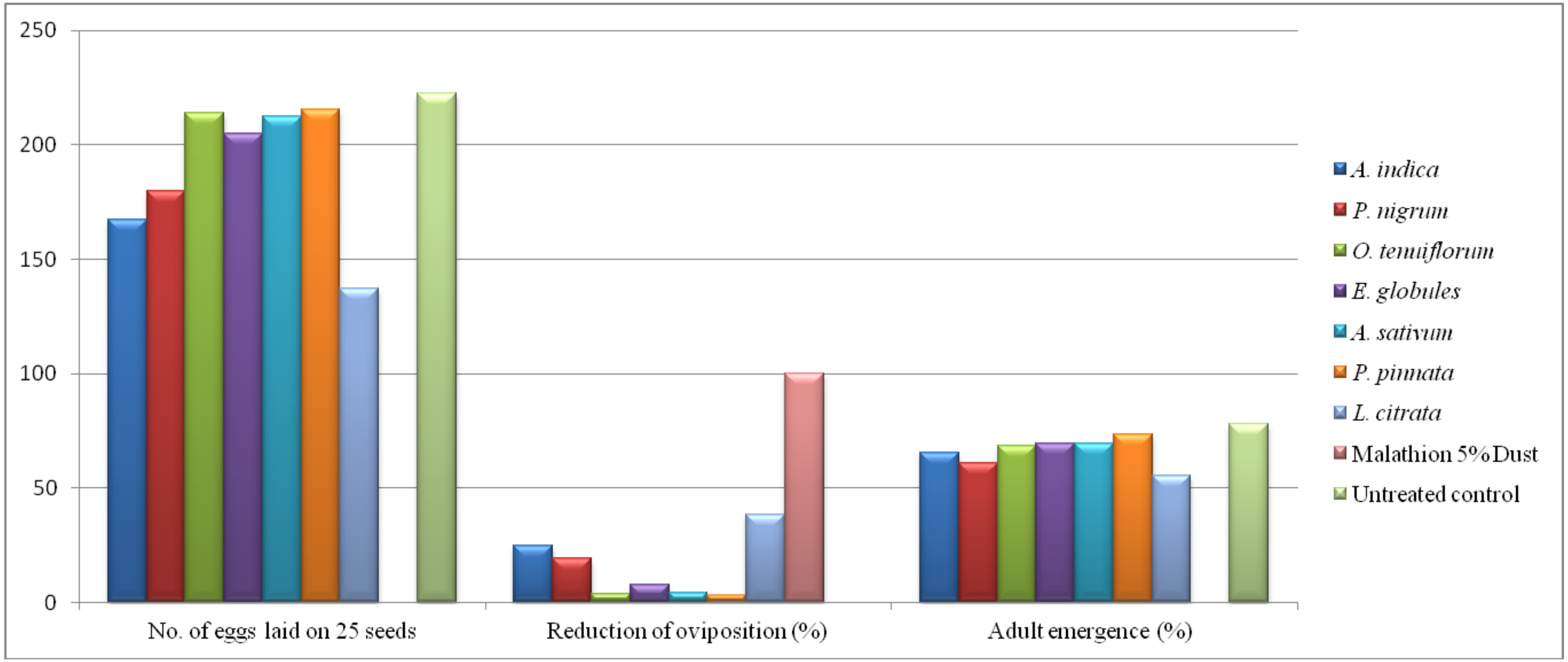

Fig 4.9 Effect of plant powders on reduction of oviposition and adult emergence during 2019 and 2020 (Pooled data)

Table 4.20 Effect of plant extracts and Jatropha oil on reduction of oviposition and adult emergence during 2019 and 2020 (Pooled data)

Treatments	Dose (%)	**No. of eggs laid on 25 seeds	*Reduction of oviposition (%)	*Adult emergence (%)
A. indica	8	185.00[cd] (13.62)	16.78[de] (9.66)	67.03[b] (42.09)
P. nigrum	2	173.00[d] (13.17)	22.18[d] (12.81)	65.13[b] (40.64)
O. tenuiflorum	10	201.00[bc] (14.20)	9.59[ef] (5.50)	66.83[b] (41.94)
E. globules	10	196.33[bc] (14.03)	11.68[ef] (6.71)	67.24[b] (42.25)
A. sativum	15	197.00[bc] (14.05)	11.39[ef] (6.54)	70.06[ab] (44.47)
P. pinnata	10	210.00[ab] (14.51)	5.53[fg] (3.17)	70.31[ab] (44.68)
L. citrata	3	142.67[e] (11.97)	35.82[c] (21.00)	56.08[c] (34.11)
Jatropha oil	3	39.33[f] (6.31)	82.30[b] (55.38)	15.78[d] (9.08)
Malathion 50EC	0.04	2.00[g] (1.58)	99.10[a] (82.31)	0.00[e] (0.00)
Untreated Control	-	222.33[a] (14.93)		77.96[a] (51.22)
SEm±		1.97	1.40	0.82

Figures in the table are mean values
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**Figures in the parentheses are square root transformed values
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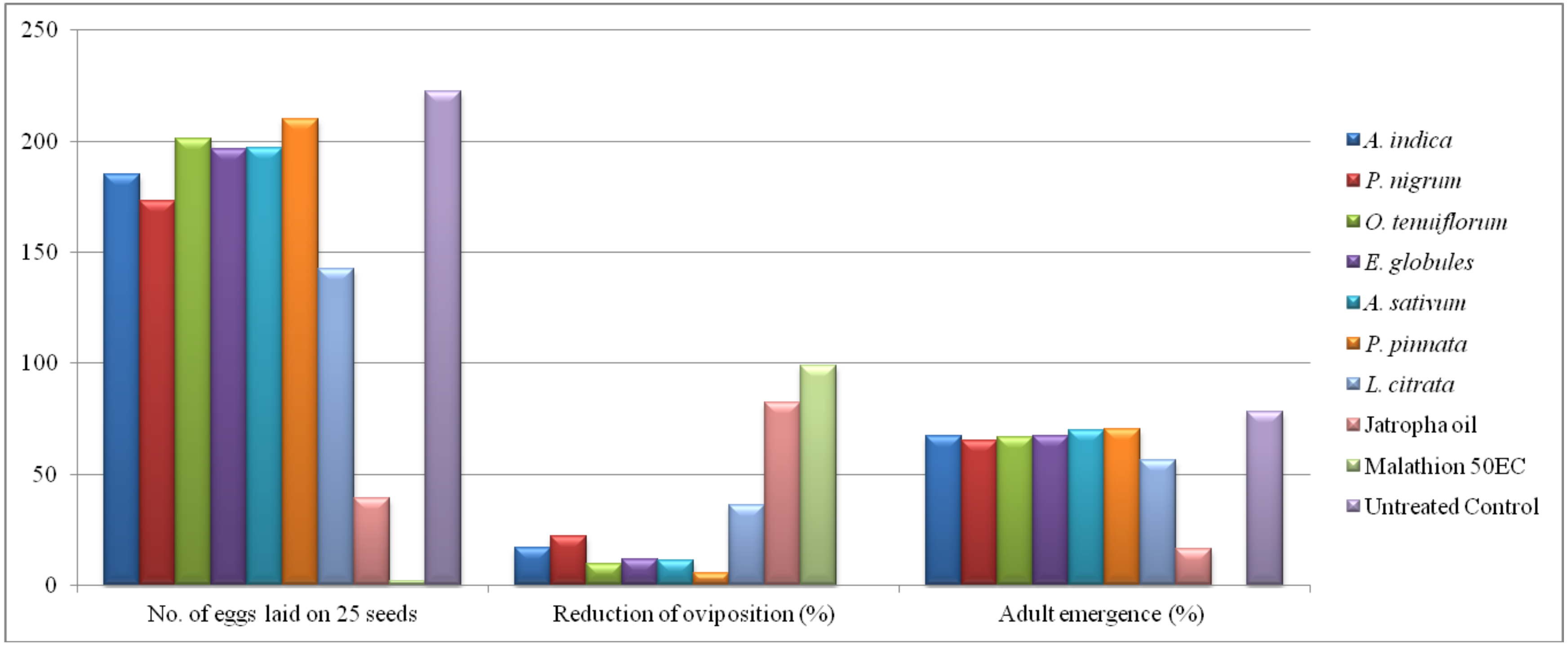

Fig 4.10 Effect of plant extracts and Jatropha oil on reduction of oviposition and adult emergence during 2019 and 2020 (Pooled data)

(39.33). The seeds treated with Jatropha oil showed the highest reduction in oviposition (82.30%) followed by *L. citrata* (35.82%) and *P. nigrum* (22.18%) with significant difference among them. In the other treatments, it varied from 5.53 to 16.78%. Based on per cent reduction of oviposition the effectiveness of plant extracts and Jatropha oil was Jatropha oil > *L. citrata* > *A. indica* > *P. nigrum* > *E. globules* > *A. sativum* > *O. tenuiflorum* > *P. pinnata.*

In the present study, both plant powder and extracts treatments showed their effectiveness as grain protectants. Among all the treatments, Jatropha oil was the most effective in oviposition reduction (82.30%) followed by *L.citrata* seed powder and extract (38.38 and 35.82%). Powder and extracts of *A. indica* and *P. nigrum* also showed significant oviposition reduction. The least effective was found in *P. pinnata* (3.14 and 5.53%). While in the standard check (Malathion 5 % dust and 50EC) complete inhibition of oviposition was found. Among the plant powder and plant extracts, *L. citrata* and *A. indica* showed higher oviposition reduction in the powder treatment compared to the extract treatment. While in the other plant products, the extract treatments exhibited comparatively higher oviposition reduction than the powder treatment.

The effectiveness of Jatropha oil over the other treatments could be due to the physical barrier provided by the oil film over the seed coat. The insecticidal property of Jatropha oil against pulse beetle has been reported by Van Huis (1991) and Adabie-Gomez *et al.* (2006). Similar findings were reported by Kosar and Srivastava (2016) who investigated the ovipositional deterrent properties of euphorbiaceae plant extracts against *C. chinensis* and found Jatropha extract to be the most effective oviposition deterrent. Boateng and Kusi (2008) reported the repellent property of Jatropha oil against pulse beetle and can protect grains up to 60 days of storage. Sabbour and Abd-El-Raheem (2013) reported that apart from oviposition deterrent, Jatropha oil also adversely affect the fecundity of pulse beetle. Similarly, Adebowale and

Adedire (2006) investigated the insecticidal properties of Jatropha oil and found that it significantly inhibited egg development.

The efficacies of botanicals in the reduction of oviposition have been reported by various workers (Srivastava *et al*., 1988; Talukder & Howse, 1993; Mathur *et al*., 2005; Gautam *et al*., 2000; Tripathi *et al*., 2002; Singh, 2003; Gehlot & Singhvi, 2006; Rahman & Talukder, 2006; Mishra *et al*., 2007). The present findings are in similarity with Neog and Singh (2013) who evaluated 9 plant powders against pulse beetle on ricebean seeds. Among the treatments they found *L. citrata* and *P. nigrum* to be the most effective in oviposition reduction by 63.14 and 50.49 %, respectively. Shitiri *et al*. (2014) reported the efficacy of *L. citrata* among other plant treatments to be at par with monocrotophos. Mahmoud *et al*. (2020) studied the effect of neem, castor, datura and jatropha extract against *C. chinensis* and found neem extract to be the most effective in the reduction of oviposition. Thakur and Pathania (2013) investigated 5 plant powders *viz.,* neem, black pepper, aonla, curry leaf and five leaf chaste tree against pulse beetle. They found black pepper (*P. nigrum*) to be the most effective with complete inhibition of oviposition @ 3 and 5 g/kg and it provided protection up to 150 days of storage. Singh (2011) studied six plant extracts *viz., Nerium indicum*, *Prosopis cineraria*, *A. indica*, *E. globulus, Lycopersicum esculentum* and *Brassica compestris* and four plant powders *viz*., *P. nigrum, A. sativum, Ocimum sanctum* and *Curcuma longa* for oviposition deterrence against pulse beetle and found *A. indica* leaf extract with maximum oviposition reduction (55.86%) and minimum in *A. sativum* powder (36.98%). Similar findings were also reported by Akter *et al*. (2007) and Hossain and Haque (2010). Rahman and Talukder (2006) studied the effect of plant treatments in the reduction of oviposition of pulse beetle and reported nishida to be the most effective followed by eucalyptus at 3% concentration. However, in the present study *E. globules* treatment did not show effective result in oviposition reduction. The result of *O. tenuiflorum* treatment also did not show effectiveness against oviposition which is in conformity with Jadhav *et al*. (2015) who studied the efficacy of different plants against *C. maculatus* in cowpea seeds and reported tulsi leaf powder to be the least effective in oviposition reduction.

4.3.3 Effect of treatment on adult emergence

The results of *C. chinensis* adult emergence from different plant powder treatments are presented in Table 4.19 (Fig 4.9). The adult emergence varied from 55.23 to 73.37% in the plant powder treatments, whereas it was 0% in standard check and 77.96% in the untreated control. The highest adult emergence was found in *P. pinnata* (73.37%) treated seeds followed by *E. globules* (69.43%), *A. sativum* (69.28%), *O. tenuiflorum* (68.53%), *A. indica* (65.53%), *P. nigrum* (61.11%) and minimum was found in *L. citrata* (55.23%).

Among the plant extracts and Jatropha oil treatments, the adult emergence varied from 15.78 to 70.31% (Table 4.20, Fig 4.10). The results varied significantly with the lowest adult emergence reported from Jatropha oil (15.78%) followed by *L. citrata* (56.08%). In the remaining, it ranged from 65.13 to 70.06%.

In the present study, among the plant powders, *L. citrata* was found to be the most effective with 55.23% adult emergence compared to untreated control (77.96%). *P. nigrum* and *A. indica* also reported effective result against *C. chinensis* with 61.11 and 65.53% adult emergence followed by *O. tenuiflorum* (68.53%), *A. sativum* (69.28%) and *E. globules* (69.43%). The least effective against adult emergence was found in *P. pinnata* leaf powder treatment. Among the plant extracts and Jatropha oil, Jatropha oil was the most effective against *C. chinenesis* adult emergence with only 15.78%, while the plant extracts showed a similar trend with the powder treatments. At present the literatures on the efficacy of Jatropha oil against adult emergence of pulse beetle are not available; however, the use of plant oils as grain protectant have been reported by several authors (Ali *et al*., 1983; Khaire *et al.,* 1992; Talukder and Howse, 1995; Tapondjou *et al.,* 2002; Singh, 2003; Ratnasekera & Rajapakse, 2009). Srinivasan (2008) investigated the efficacy of plant oil *viz.,* castor, eucalyptus, sunflower and neem oil against *C. chinensis* and reported neem oil to be the most effective with least in oviposition, per cent seed infestation and weight loss after 6 and 9 months of storage. Bhardwaj and Verma (2012) studied the efficacy of six vegetable oils *viz*., mustard, neem, karanj, cedar, apricot and olive against *C. chinensis* and reported the highest mortality (22.22%) and minimum adult emergence from neem oil treatment followed by karanj oil (16.67%).

The efficacy of botanical treatments on adult emergence has been reported by various authors (Rajapakse *et al*., 1998; Jayakumar, 2010; Devi & Devi, 2013). The findings of the present study are in conformity with Neog and Singh (2013) who studied nine different plant powders against pulse beetle, *C. chinensis* and reported 66.16% adult emergence from *L. citrata* seed powder and 59.50% from *P. nigrum* seed powder treatment. Chaubey (2008) studied the efficacy of black pepper against pulse beetle, *C. chinensis* and reported its effectiveness in the reduction of adult emergence. Islam *et al*. (2013) reported the lowest adult emergence (11.11%) in gram seeds treated with *P. nigrum* seed powder at 1.00 g/kg. Suthar and Bharpoda (2016) studied the effect of neem leaf, garlic bulb and eucalyptus leaf powder @ 2% (w/w) against pulse beetle and reported a significant reduction in adult emergence in 6 months of storage. Parmar *et al.* (2018) also reported the effectiveness of neem leaf powder against adult emergence of pulse beetle in mung bean seeds. Similarly, Manju *et al*. (2019) studied 12 plant powders against pulse beetle, *C. maculatus* and reported minimum adult emergence from *C. annum* and *P. nigrum* powder treatment with 28.4 and 30.0%, respectively.

4.3.4 Effect of treatment on infestation

The observations on per cent infestation of seeds treated with plant powder and the extract were done at 2 months, 4 months and 6 months of storage. The details are presented in Table 4.21 and Table 4.22 (Fig 4.11 and Fig 4.12)

After 2 months of storage, the infestation varied from 16.12 to 67.82% among plant powder treatments, while in the untreated control it was 69.23%. The minimum infestation was found in *L. citrata* treated seeds (16.12%) followed by *P. nigrum* (31.67%) and *A. indica* (51.54%). The highest infestation was in *P. pinnata* treated seeds (67.83%) while in the standard check (Malathion dust) it was 0.00%.

Among the plant extracts and Jatropha oil treatments, the infestation varied from 1.40 to 69.01%. The minimum infestation was observed in jatropha oil treated seeds (1.40%) followed by *L. citrata* (17.61%), *P. nigrum* (26.18%) and *A. indica* (53.72%). The highest infestation was in *P. pinnata* with 69.01% followed by *E. globules* (68.11%). In the *O. tenuiflorum* and *A. sativum* treated seeds, it was 63.24 and 64.02%, respectively with no significant difference between them.

After 4 months of storage, the infestation in plant powder treatments increased significantly and varied from 52.11 to 95.93% among the different treatments, while in the untreated control it reached 97.92%. The infestation was highest in *P. pinnata* treated seeds (95.93%) followed by *O. tenuiflorum* (92.11%). No significant difference was seen in *E. globules* (86.26%) and *A. sativum* (88.69%) treated seeds. The minimum infestation was in *L. citrata* with 52.11% followed by *P. nigrum* (61.50%) and *A. indica* (72.63%).

Among the plant extracts and Jatropha oil treatments, Jatropha oil inhibited the infestation significantly compared to the other treatments. The infestation among the plant extracts treatments varied from 2.11 to 97.97%. The infestation in control (97.92%) was at par with the infestation of treatments with *P. pinnata* (97.97%), *E. globules* (96.93%), *P. nigrum* (96.49%), *O. tenuiflorum* (96.45%) and *A. indica* (96.02%). The minimum

Table 4.21 Effect of plant powders on per cent infestation during 2019 and 2020 (Pooled data)

Treatments	Dose (% w/w)	*Infestation (%)		
		After 2 months	After 4 months	After 6 months
A. indica	5	51.54[d] (31.03)	72.63[d] (46.57)	100.00[a] (90.00)
P. nigrum	5	31.67[e] (18.47)	61.50[e] (37.95)	100.00 [a] (90.00)
O. tenuiflorum	5	67.22[ab] (42.24)	92.11[b] (67.10)	100.00 [a] (90.00)
E. globules	5	64.10[c] (39.87)	86.26[c] (59.59)	100.00 [a] (90.00)
A. sativum	5	64.84[bc] (40.42)	88.69[c] (62.43)	100.00 [a] (90.00)
P. pinnata	5	67.82[a] (42.71)	95.93[a] (73.59)	100.00 [a] (90.00)
L. citrata	5	16.12[f] (9.28)	52.11[f] (31.41)	98.81[b] (81.17)
Malathion 5% Dust	1	0.00[g] (0.00)	0.00[g] (0.00)	0.00[c] (0.00)
Untreated control	-	69.23[a] (43.81)	97.92[a] (78.31)	100.00[a] (90.00)
SEm±		0.28	0.34	0.06

*Figures in the table are mean values
Figures in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

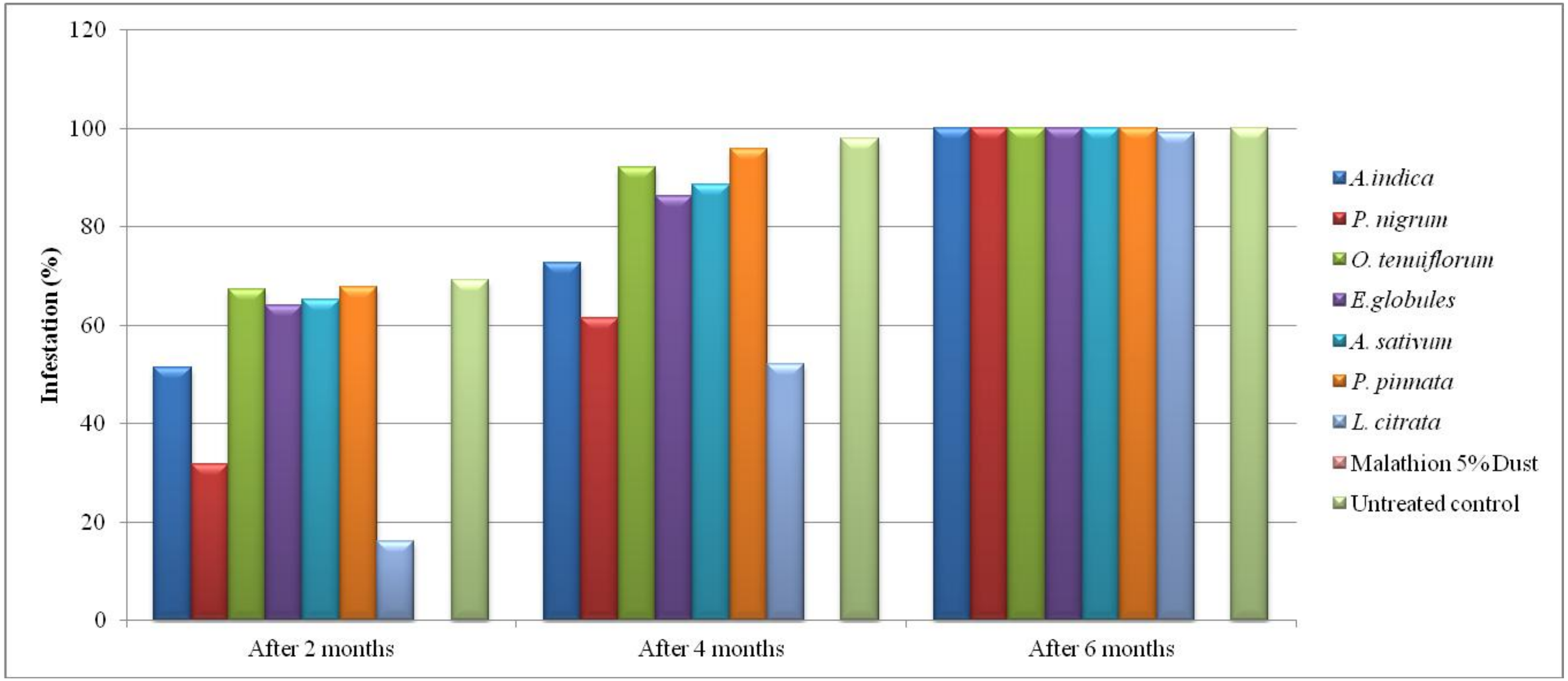

Fig 4.11 Effect of plant powders on infestation during 2019 and 2020 (Pooled data)

Table 4.22 Effect of plant extracts and Jatropha oil on per cent infestation during 2019 and 2020 (Pooled data)

Treatments	Dose (%)	*Infestation (%)		
		After 2 months	After 4 months	After 6 months
A. indica	8	53.72[c] (32.49)	96.02[a] (73.77)	100.00[a] (90.00)
P. nigrum	2	26.18[d] (15.19)	96.49[a] (74.76)	100.00[a] (90.00)
O. tenuiflorum	10	63.24[b] (39.23)	96.45[a] (74.70)	100.00[a] (90.00)
E. globules	10	68.11[a] (42.93)	96.93[a] (75.75)	100.00[a] (90.00)
A. sativum	15	64.02[b] (39.81)	80.82[b] (53.92)	100.00[a] (90.00)
P. pinnata	10	69.01[a] (43.62)	97.97[a] (78.45)	100.00[a] (90.00)
L. citrata	3	17.61[e] (10.14)	72.73[c] (46.66)	100.00[a] (90.00)
Jatropha oil	3	1.40[f] (0.80)	2.11[d] (1.21)	4.65[b] (2.66)
Malathion 50EC	0.04	0.00[f] (0.00)	0.00[d] (0.00)	0.00[c] (0.00)
Untreated control		69.23[a] (43.81)	97.92[a] (78.29)	100.00[a] (90.00)
SEm±		0.27	0.28	0.24

*Figures in the table are mean values
Values in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

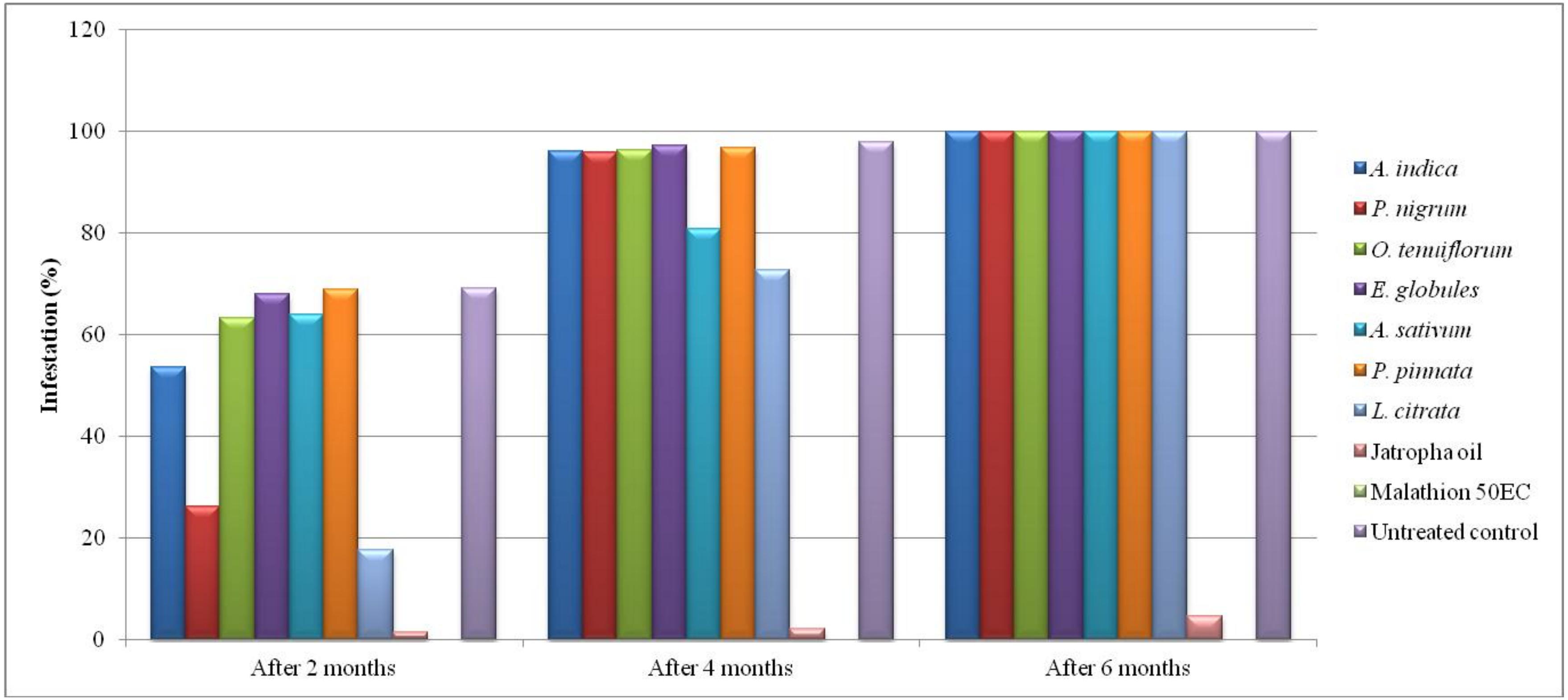

Fig 4.12 Effect of plant extracts and Jatropha oil on infestation during 2019 and 2020 (Pooled data)

infestation was in seeds treated with Jatropha oil (2.11%) followed by *L. citrata* (72.73%).

After 6 months of storage, 100% infestation was found in all the plant powder treatments, while in the standard check no infestation (0.00%) was recorded. Similarly, in plant extract treatments 100% infestation was found in all the treatments with exemption in Jatropha oil treatment where it reported only 4.65% infestation.

In the present study both the standard check (Malathion 5% Dust and Malathion 50EC) provided complete protection throughout the study period of 6 months. While among the plant products, Jatropha oil was the most effective with only 1.40, 2.11 and 4.65% infestation after 2, 4 and 6 months, respectively. Jatropha oil provided protection at par with standard check (Malathion 50EC) up to 4 months of storage. Srinivasan (2008) reported the effectiveness of indigenous plant oils @5 and 10 ml/kg which protect seeds up to 9 months of storage against *C. chinensis*. Similarly, Sahoo *et al*. (2013) also reported the efficacy of edible and non-edible oils against *C. chinensis* at 0.25 ml/100g and observed minimum damage from karanj oil treated seeds with 9.25 and 30.39 % after 45 and 90 days, respectively.

L. citrata seed powder and extract also provided effective protection with an infestation of 16.12 and 17.61%, respectively after 2 months of storage followed by *P. nigrum* seed powder and extract with infestation of 31.67 and 26.18%, respectively. While the remaining plant product treatments were not effective as grain protectants. The infestation was more than 50% after 2 months of storage. The per cent infestation in all the treatments increases with the increase in storage period could be due to the non persistent nature of the plant products losing their toxicity over a period of time. The results of the present study are in conformity with Neog and Singh (2013) who reported *L. citrata* to be superior to other plants treatment and provided effective protection up to 2 months of storage. Swamy and Wesley (2017) reported that at 0.4% black pepper powder effectively minimized grain damage by *C. maculatus* up to 80 days of storage. Several authors (Jilani and Saxena, 1990; Rajapakse *et al*., 1998; Poornasundari & Thilagavathy, 2015) have reported neem to be effective as grain protectant; however, in the present study neem was not found effective which could be due to environmental factors, differences in the concentration used in the study and the plant parts used.

4.3.5 Effect of treatment on weight loss

The results showed a significant difference in the per cent weight loss due to infestation by *C. chinensis* on ricebean seeds treated by plant powders and extracts. The details of the findings are presented in Table 4.23 and Table 4.24 (Fig 4.13 and Fig 4.14).

After 2 months of storage, the weight loss in seeds treated with plant powders varied from 2.40 to 21.87%, while it was 23.72% in the untreated control. The highest weight loss was found in seeds treated with *P. pinnata* leaf powder (21.87%) and the minimum weight loss was found in *L. citrata* treated seeds (2.40%) followed by *P. nigrum* (6.93%) *and A. indica* (9.20%). In the remaining treatments, it ranged from 12.80 to 14.78% with no significant difference among them. The weight loss in *L. citrata* (2.40%) treated seeds was found at par with the standard check Malathion dust (1.01%).

In the plant extracts and Jatropha oil treated seeds the weight loss varied from 2.36 to 20.18%. The highest weight loss was found in *P. pinnata* treatment (20.18%) which was at par with *E. globules* (19.39%) and *A. sativum* (18.51%) treatments. The lowest weight loss (2.36%) was found in Jatropha oil treatment which was at par with the standard check Malathion 50EC (1.83%) followed by *P. nigrum* (5.60%), *A. indica* (12.87%) and *O. tenuiflorum* (13.48%).

After 4 months of storage, the per cent weight loss increased with an increase in the infestation. In the plant powder treatment, the weight loss varied from 10.49 to 32.62%. The minimum weight loss was found in *L. citrata*

Table 4.23 Effect of plant powders on per cent weight loss during 2019 and 2020 (Pooled data)

Treatments	Dose (% w/w)	*Weight loss (%)		
		After 2 months	After 4 months	After 6 months
A. indica	5	9.20[c] (5.28)	25.89[d] (15.01)	39.39[d] (23.20)
P. nigrum	5	6.93[d] (3.97)	14.44[e] (8.30)	32.53[e] (18.98)
O. tenuiflorum	5	14.23[b] (8.18)	32.34[b] (18.87)	40.47[d] (23.87)
E. globules	5	12.80[b] (7.35)	29.81[c] (17.34)	41.58[d] (24.57)
A. sativum	5	14.78[b] (8.50)	30.07[c] (17.50)	45.92[c] (27.33)
P. pinnata	5	21.87[a] (12.63)	32.62[b] (19.04)	52.04[b] (31.36)
L. citrata	5	2.40[e] (1.37)	10.49[f] (6.02)	29.33[f] (17.06)
Malathion 5% Dust	1	1.01[e] (0.58)	1.33[g] (0.76)	3.06[g] (1.75)
Untreated control		23.72[a] (13.72)	34.93[a] (20.45)	58.94[a] (36.11)
SEm±		0.23	0.20	0.25

*Figures in the table are mean values
Values in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

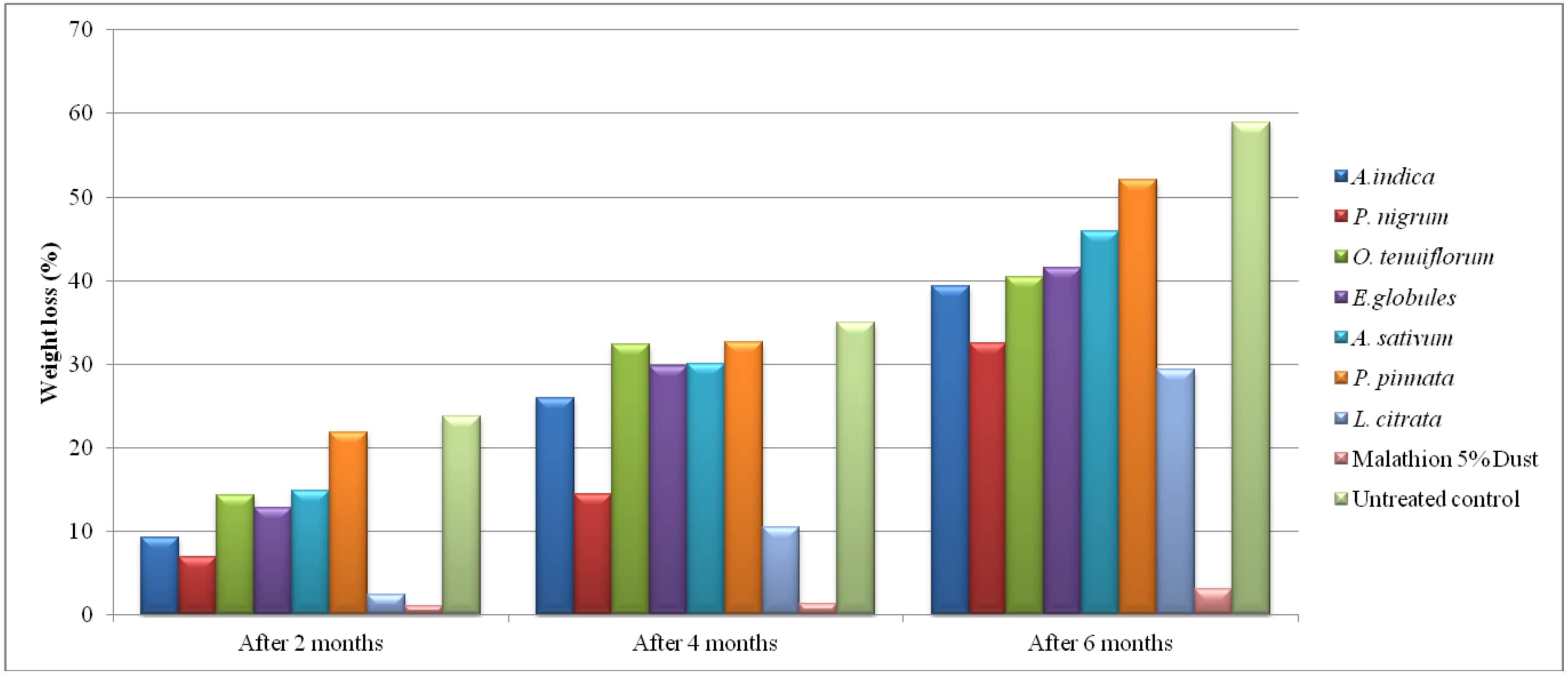

Fig 4.13 Effect of plant powders on weight loss during 2019 and 2020 (Pooled data)

Table 4.24 Effect of plant extracts and Jatropha oil on per cent weight loss during 2019 and 2020 (Pooled data)

Treatments	Dose (%)	Weight loss (%) *		
		After 2 months	After 4 months	After 6 months
A. indica	8	12.87[c] (7.40)	27.24[c] (15.81)	40.33[d] (23.78)
P. nigrum	2	5.60[d] (3.21)	22.66[d] (13.10)	33.43[f] (19.53)
O. tenuiflorum	10	13.48[c] (7.75)	31.76[b] (18.52)	42.66[c] (25.25)
E. globules	10	19.39[b] (11.18)	23.17[d] (13.40)	37.42[e] (21.97)
A. sativum	15	18.51[b] (10.66)	24.14[d] (13.97)	40.77[cd] (24.06)
P. pinnata	10	20.18[b] (11.64)	31.54[b] (18.39)	51.63[b] (31.09)
L. citrata	3	4.10[d] (2.35)	11.87[e] (6.82)	27.56[g] (16.00)
Jatropha oil	3	2.36[e] (1.35)	2.91[f] (1.67)	3.23[h] (1.86)
Malathion 50EC	0.04	1.83[e] (1.05)	1.87[f] (1.07)	2.01[h] (1.15)
Untreated control		23.72[a] (13.72)	34.93[a] (20.45)	58.94[a] (36.11)
SEm±		0.18	0.15	0.24

*Figures in the table are mean values
Figures in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

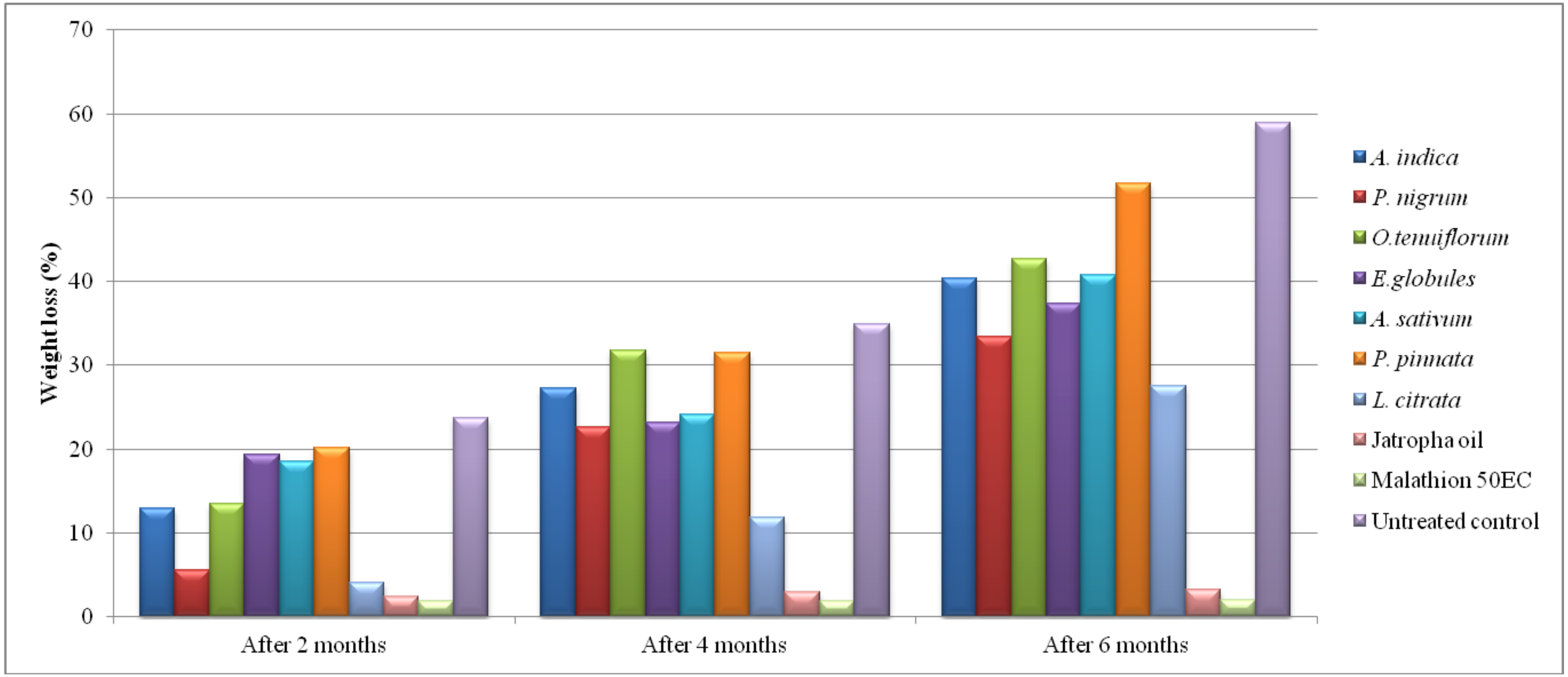

Fig 4.14 Effect of plant extracts and Jatropha oil on weight loss during 2019 and 2020 (Pooled data)

treatment (10.49%) followed by *P. nigrum* (14.44%) and *A. indica* (25.90%). The weight loss in treatments of *E. globules* and *A. sativum* were not significantly different with 29.81 and 30.07%, respectively. The highest weight loss was found in *P. pinnata* treatment (32.62%) followed by *O. tenuiflorum* (32.34%). While in the standard check (Malathion dust) and untreated control, the weight loss was 1.33 and 34.93%, respectively.

Among the plant extracts and Jatropha oil treatments, the weight loss varied from 2.91 to 31.54%. The lowest weight loss was found in Jatropha oil treatment (2.91%) which was at par with the standard check Malathion 50EC (1.87%) followed by *L. citrata* (11.87%). The weight loss in treatments of *P. nigrum*, *E. globules* and *A. sativum* were at par with each other (22.66, 23.17, and 24.14%, respectively). The highest weight loss was found in *O. tenuiflorum* (31.76%) and *P. pinnata* treatment (31.54%) followed by *A. indica* (27.24%).

After 6 months of storage, the weight loss varied from 29.33 to 52.04% among the different plant powder treatments. The minimum weight loss was found in *L. citrata* treatment (29.33%) followed by *P. nigrum* (32.53%). The weight loss in *A. indica*, *O. tenuiflorum* and *E. globules* were at par (39.39, 40.47 and 41.58%, respectively). The highest weight loss was found in *P. pinnata* treatment (52.04%) followed by *A. sativum* (45.92%).

In the plant extracts and Jatropha oil treatments, the weight loss varied from 3.23 to 51.63%. The minimum weight loss was found in Jatropha oil treatment (3.23%) which was at par with standard check malathion 50EC (2.01%) followed by *L. citrata* (27.56%) and *P. nigrum* (33.43%). The highest weight loss was found in *P. pinnata* (51.63%) followed by *O. tenuiflorum* (42.66%), *A. sativum* (40.77%) and *A. indica* (40.33).

The present study reveals an increase in per cent weight loss over the storage period which is due to an increase in infestation by the pulse beetle. The minimum weight loss after 6 months of storage was found in standard check (Malathion 5% Dust and Malathion 50EC) with 3.06 and 2.01%, respectively, while the maximum was in the untreated control (58.94%). However, no infestation was recorded in both the standard check treatments. The per cent weight loss recorded could be due to environmental factors affecting the seeds in storage over the study period. Among all the treatments, Jatropha oil was the most effective with minimum weight loss of 2.36, 2.91 and 3.23% at 2, 4 and 6 months of storage, respectively as against 23.72, 34.93 and 58.94% in untreated control. The result of Jatropha oil was at par with the standard check Malathion 50EC.

In the plant powder and extract treatments, *L. citrata* and *P. nigrum* were found to be effective with significant difference in per cent weight loss in comparison to untreated control. After 2 months of storage the weight loss in *L. citrata* seed powder treatment was 2.40% as against 23.72% in untreated control and was at par with the standard check Malathion 5% dust. While in the seed extract treatment the weight loss was 4.10%. The seed powder treatment was fairly more effective than the seed extract up to 2 months of storage. After 4 and 6 months it was 10.49 and 29.33% in powder treatment against 34.93 and 58.94% in the untreated control. In the case of *P. nigrum* seed powder treatment, the weight loss after 2, 4 and 6 months of storage was 6.93, 14.44 and 32.53%, respectively and for seed extract treatment it was 5.60, 22.66 and 33.43%, respectively. Similar results were reported by Islam *et al*. (2013) who observed a minimum weight loss of 29.00% in gram seed treated with black pepper powder at 1g/kg against 77.10% in control.

In the present study, the least effective was found in *P. pinnata* treated seeds with 52.04 and 51.63% weight loss both in powder and extract treatment, respectively after 6 months of storage. This was followed by *O. tenuiflorum* (40.47 and 42.66%), *A. sativum* (45.92 and 40.77%), *E. globules* (41.58 and 37.42%) and *A. indica* (39.39 and 40.33%). Akter *et al.* (2007) reported a significant difference in weight loss caused by *C. maculatus* in different treatments. They found the highest per cent weight loss in garlic clove extract treatment followed by eucalyptus and the lowest weight loss was found in neem leaf extract. Singh *et al*. (2017) reported 9.76% weight loss from seeds treated with neem leaf powder @ 5g/kg seeds at 6 months of storage. However, in the present study neem was not effective resulting in 39.39 to 40.33% weight loss after 6 months of storage.

The findings from the present investigation based on reduction in oviposition, adult emergence, per cent infestation and per cent weight loss reveal Jatropha oil to be the most effective grain protectant in storage followed by *L. citrata* and *P.nigrum*. The effectiveness of these plant products could be due to their biochemical content having insecticidal properties in higher concentrations than the other plant product resulting in mortality of adults, reduction in oviposition and adult emergence. However, as per literature search, there are very limited literatures available on the use of Jatropha oil and *L. citrata* as grain protectants. Therefore more detailed research works needs to be done to better understand their potential in the management of storage pests. From the present study, it was also observed that the per cent infestation and damage increases with the increase in storage period which reveals that the plant products are non persistent in nature and their efficacy reduces over a period of time. The results of the present study show variation with the works of various authors which could be due to environmental factors, plant parts used and differences in the doses used in the study.

4.3.6 Effect of treatment on seed germination

After 6 months of storage, a germination test was conducted with 25 healthy seeds samples taken at random from all the treatments. The results are presented in Table 4.25 and Table 4.26. The germination of seeds ranged from 82.67 to 89.33% in plant powder and Malathion dust treatments, while 82.67 to 85.33% in plant extracts, Jatropha oil and Malathion 50EC treatments with 89.33% in the untreated control. The results from the germination test did not

Table 4.25 Effect of plant powders treatment on seed germination during 2019 and 2020 (Pooled data)

Treatment	Dose (% w/w)	*Germination (%)
A. indica	5	86.67[a] (60.07)
P. nigrum	5	88.00[a] (61.64)
O. tenuiflorum	5	85.33[a] (58.58)
E. globules	5	85.33[a] (58.58)
A. sativum	5	89.33[a] (63.30)
P. pinnata	5	86.67[a] (60.07)
L. citrata	5	82.67[a] (55.76)
Malathion 5% Dust	1	84.00[a] (57.14)
Untreated Control	-	89.33[a] (63.30)
SEm±		0.90

*Figures in the table are mean values
Figures in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

Table 4.26 Effect of plant extracts and Jatropha oil treatment on seed germination during 2019 and 2020 (Pooled data)

Treatment	Dose (%)	*Germination (%)
A. indica	8	85.33[a] (58.58)
P. nigrum	2	84.00[a] (57.14)
O. tenuiflorum	10	85.33[a] (58.58)
E. globules	10	82.67[a] (55.76)
A. sativum	15	84.00[a] (57.14)
P. pinnata	10	82.67[a] (55.76)
L. citrata	3	85.33[a] (58.58)
Jatropha oil	3	82.67[a] (55.76)
Malathion 50EC	0.04	82.67[a] (55.76)
Untreated Control	-	89.33[a] (63.30)
SEm±		1.35

Note: Figures in the table are mean values
* Values in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

show any significant difference among the different treatments. Thus, the treatments did not affect the germinability of the seeds. Similar findings were reported by various workers (Meghwal & Bajpai 2012; Neog & Singh, 2013; Khinchi *et al.*, 2017; Rathod *et al*., 2019).

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

Pulses are important food crops providing the nutritional needs of a large number of populations. Among the various pulse crops, ricebean [*Vigna umbellata* (Thunb.) Ohwi and Ohashi] is an important food legume cultivated in Nagaland. Like any other pulse crop, ricebean is also attacked by insects both in the field and storage conditions. Among the insect pests, pulse beetle, *C. chinensis* is one of the most important pest that causes considerable damage in storage. Therefore, the present investigation entitled "Screening of some ricebean [*Vigna umbellata* (Thunb.) Ohwi & Ohashi] cultivars against pulse beetle [*Callosobruchus chinensis* (L.)] and its management with botanicals" was carried out to study the preference of *C. chinensis* in different local ricebean cultivars, to evaluate storage structures on the incidence of *C. chinenesis* and to study the efficacy of botanicals as grain protectants. The significant findings from the experiment are summarized below:

1. A total of 16 local ricebean cultivars *viz.*, *Akixi Anila, Rhüjo, Ashei Nyakla, Kurhi Süre, Pinchong Wethroi, Kerhü, Mügo Rhi, Rhüse, Hera Ragei*, *Hera Rahau*, *Rhüdi*, *Manyhü Rhi*, *Kurhi Rhide*, *Khueishuei Shumei*, *Rhüluo* and *Sipheghonu* were collected from different parts of Nagaland for the experiment.
2. In the no-choice test, oviposition was highest in cultivar *Sipheghonu* (131.33 and 121.67 eggs/ 25 seeds) at both controlled and normal room temperature. The least was found in *Manyhü Rhi* (32.67 eggs/25 seeds) at controlled temperature and in *Rhüjo* (21.67 eggs/25 seeds) at normal room temperature. Based on oviposition the order of preference was *Sipheghonu*> *Kurhi Rhide*> *Rhüdi*> *Mügo Rhi*> *Rhüluo*> *Kurhi Süre*> *Akixi Anila*> *Ashei Nyakla*> *Hera Rahau*> *Hera Ragei*> *Rhüse*> *Khueishuei Shumei*> *Pinchong Wethroi* > *Kerhü* > *Rhüjo* > *Manyhü Rhi*.

3. At both controlled and room temperature, the adult emergence was highest in the cultivar *Sipheghonu* (73.60 and 72.33%) and the least was in *Rhüjo* (58.00 and 56.92%).
4. Among the different cultivars, the mean development period of *C. chinensis* was shortest in *Kurhi Rhide* (21.60 days) at controlled temperature and at room temperature, it was *Sipheghonu* (20.28 days). The highest number of days for the development was found in *Mügo Rhi* (33.10 days) at controlled temperature and at room temperature it was found in *Rhüjo* (30.58 days).
5. At controlled temperature, the highest growth index was found in the cultivar *Kurhi Rhide* (0.086) and the least was found in *Rhüjo* (0.057). At normal room temperature, the highest growth index was found in cultivar *Siphegonu* (0.090) and the least was found in *Rhüjo* (0.057).
6. Based on the growth index, at controlled temperature the cultivars *viz., Rhüjo, Akixi Anila* and *Manyhü Rhi* were moderately resistant; *Pinchong Wethroi, Hera Ragei, Rhüluo, Ashei Nyakla, Hera Rahau, Kerhü* and *Rhüse* were moderately susceptible; *Kürhi Süre, Rhüdi* and *Khueishuei Shumei* were susceptible and the highly susceptible cultivars were *Sipheghonu, Mügo Rhi* and *Kurhi Rhide.*
7. Among the ricebean cultivars, the maximum infestation was observed in cultivar *Sipheghonu* (63.67 and 60.85%) and the least infestation was observed in cultivar *Rhüjo* (7.10 and 7.01%) both at controlled and room temperature, respectively.
8. At both controlled and room temperature, the weight loss was highest in the cultivar *Sipheghonu* with 11.07 and 10.33%, respectively and the minimum weight loss was in the cultivar *Rhüjo* with 3.73 and 3.41 %, respectively.
9. Among the 16 local ricebean cultivars the colour varied from green, light green, yellowish-green, dark blue, creamy white, light yellow, light

yellow with black spots, brown, light brown and light brown with black spots. The seed texture was smooth in all the cultivars. The shape varied from nearly round to oblong. Out of 16 cultivars, two cultivars were found to be nearly round (*Ashei Nyakla* and *Pinchong Wethroi*) and the remaining cultivars were oblong.

10. The seed coat thickness of the cultivars varied from 0.057±0.004mm to 0.103±0.011mm. The maximum seed coat thickness was found in *Pinchong Wethroi* (0.103±0.011mm) and the minimum in *Hera Rahau* (0.057±0.004mm).
11. The largest seed size was cultivar *Sipheghonu* (118.54±2.36mm^2) and the smallest was *Hera Rahau* (19.46±0.71 mm^2). Based on seed size, the 16 cultivars were found in the following order: *Sipheghonu> Kurhi Rhide > Mügo Rhi> Kurhi Süre > Khueishuei Shumei > Ashei Nyakla> Akixi Anila > Rhüdi> Pinchong Wethroi> Rhüluo>Manyhü Rhi> Rhüjo > Hera Ragei >Rhüse >Kerhü > Hera Rahau.*
12. The highest seed index (100 seed weight) was found in *Sipheghonu* (47.84±0.014g) and the least was in *Rhüjo* (5.28±0.008g).
13. The highest protein content among the cultivars was found in *Sipheghonu* (21.12 %) and the least was in *Pinchong Wethroi* (17.20 %).
14. The highest fat content among the cultivars was found in *Kurhi Süre* (1.23%) and the least was in *Kurhi Rhide* (0.51%).
15. The highest phenol content was found in *Ashei Nyakla* (747.19 mgGAE/100g) and the least was in *Sipheghonu* (80.06 mgGAE/100g).
16. The highest tannin content was found in *Rhüjo* (1181.67 mgTAE/100g) and the least was found in *Sipheghonu* (808.57 mgTAE/100g).
17. The highest starch content was found in *Sipheghonu* (57.89%) and the least was found in *Rhüjo* (51.11%).

18. The correlation studies, both at controlled and room temperature revealed a significant positive correlation of oviposition with adult emergence, growth index, infestation and weight loss and a significant negative correlation with the development period.
19. The seed coat thickness was not correlated with the biological parameters of *C. chinensis viz.,* oviposition, adult emergence, growth index, infestation and weight loss.
20. Seed size and seed index showed a positive significant correlation with oviposition, adult emergence, growth index, infestation and weight loss, while a negative significant correlation was found with the development period of the pest.
21. Protein and starch content showed a positive significant correlation with oviposition, adult emergence, growth index, infestation and weight loss and a negative significant correlation with the development period.
22. Phenol content showed a negative significant correlation with oviposition and infestation.
23. Tannin content showed a negative significant correlation with oviposition, adult emergence, growth index, infestation and weight loss, while a positive significant correlation was found with development period.
24. Fat content did not show any significant correlation with the biological parameters of *C. chinensis*.
25. Among the different storage structures, after 6 months of storage, the highest infestation and weight loss were found in cloth bag (90.54 and 25.08%, respectively). The lowest was found in plastic jar (76.65 and 16.20%, respectively).
26. Based on the storage structure the order of reducing the per cent infestation and weight loss was: plastic jar > bamboo basket > jute bag > cloth bag.

27. The grain moisture content increased with the increase in the storage period.
28. The order of toxicity of plant products based on probit analysis was *P. nigrum* > Jatropha oil > *L. citrata* > *A. indica* > *E. globules* > *O. tenuiflorum* > *P. pinnata* > *A. sativum*.
29. The seeds treated with Jatropha oil @ 3% concentration showed the highest reduction in oviposition (82.30%)
30. Among all the different plant powder treatments @ 5% w/w, the highest reduction in oviposition was found in *L. citrata* seed powder (38.38%) followed by *A. indica* leaf powder (24.73%) and *P. nigrum* seed powder (19.03 %). In the plant extract treatments, the highest was in *L. citrata* @ 3% (35.82%) followed by *P. nigrum* @ 2% (22.18%).
31. Based on per cent reduction of oviposition the order of effectiveness was: Jatropha oil > *L. citrata* > *A. indica* > *P. nigrum* > *E. globules* > *A. sativum* > *O. tenuiflorum* > *P. pinnata.*
32. Similarly, adult emergence was lowest in Jatropha oil @ 3% treatment (15.78%) followed by *L. citrata* powder @ 5% w/w (55.23%) and extract @ 3% (56.08%).
33. *L. citrata* seed powder @ 5% w/w and extract @ 3% provided effective protection up to 2 months of storage with an infestation of 16.12 and 17.61% and weight loss of 2.40 and 4.10%, respectively followed by *P. nigrum* seed powder @ 5% w/w and extract @ 2% with an infestation of 31.67 and 26.18% and weight loss of 6.93 and 5.60%, respectively.
34. The per cent infestation in all the treatments increased with the increase in storage period.
35. Among all the treatments, Jatropha oil was the most effective with minimum seed infestation (1.40, 2.11 and 4.65%) and weight loss (2.36, 2.91 and 3.23%) at 2, 4 and 6 months of storage, respectively. The result

of Jatropha oil was at par with the standard check Malathion 50EC up to 4 months of storage.

36. The treatments did not affect the germinability of the seeds.

CONCLUSION

The following conclusions are drawn based on the above findings:

1. The cultivar *Sipheghonu* was most susceptible among the different cultivars with the highest oviposition, adult emergence, per cent infestation and weight loss. The cultivars *viz., Rhüjo, Akixi Anila* and *Manyhü Rhi* were moderately resistant.
2. The physical characteristics *viz.,* seed size and seed index and biochemical contents *viz.,* protein, starch, phenol and tannin highly influence the host preference of the pest.
3. Plastic jar performed better in regard to reduction of infestation and weight loss in storage condition.
4. Jatropha oil @3% was the most effective grain protectant against pulse beetle, *C. chinensis* in storage.
5. Among the plant extracts and powders *L. citrata* and *P. nigrum* showed effective results.

FUTURE LINE OF WORK

For a better understanding of the biochemical basis of resistance in the different cultivars, further studies on biochemical content influencing the host preference at the molecular level can be taken up.

Further evaluation of storage structures along with botanical treatments, quality management of grains based on safe storage time and drying of seeds by solarization techniques that are eco-friendly and cheap needs to be focused.

Identification of the active ingredient of *L. citrata* and its insecticidal action on different insect pests can be taken up.

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APPENDIX

APPENDIX-A

Room temperature and relative humidity during screening of ricebean cultivars against pulse beetle

Date	Week	Temperature (°C)		Relative humidity (%)		Period of Experiment
		Max.	Min.	Max.	Min.	
01-Jan-18 - 07-Jan-18	1	23.7	10.8	97.0	68.7	1. Oviposition studies in no choice test (15th January – 26th January, 2018) 2. Development period observation (15th January – 20th February, 2018) 3. Infestation and weight loss estimation (22ND February – 26th February, 2018) 4. Bioassay study (20rd March – 5th April, 2018)
08-Jan-18 - 14-Jan-18	2	22.5	7.5	97.1	60.3	
15-Jan-18 - 21-Jan-18	3	24.2	11.5	97.0	68.9	
22-Jan-18 - 28-Jan-18	4	24.7	10.0	97.0	57.7	
29-Jan-18 - 04-Feb-18	5	22.9	8.9	96.0	54.6	
05-Feb-18 - 11-Feb-18	6	27.3	9.5	96.4	46.9	
12-Feb-18 - 18-Feb-18	7	27.3	9.5	96.4	46.9	
19-Feb-18 - 25-Feb-18	8	26.6	11.2	96.4	55.3	
26-Feb-18 - 04-Mar-18	9	27.3	13.6	97.7	54.0	
05-Mar-18 - 11-Mar-18	10	29.8	15.2	94.0	51.3	
19-Mar-18 - 25-Mar-18	11	30.7	14.0	95.6	43.3	
26-Mar-18 - 01-Apr-18	12	30.9	15.8	96.3	50.9	
02-Apr-18 - 08-Apr-18	13	32.6	17.1	91.7	46.3	

APPENDIX-B

Room temperature and relative humidity during the study of storage structures and efficacy of botanicals

Month	Temperature (°C)		Relative humidity (%)		Period of Experiment
	Max.	Min.	Max.	Min.	1. Study on different storage structures on the incidence of *C. chinensis* on ricebean (Infestation and weight loss). (7th Jan - 12th July, 2019) 2. Study on the efficacy of botanicals on oviposition and adult emergence. (7th Jan - 15th Feb, 2019 & 2020) 3. Study on the effect of botanicals on infestation and weight loss of ricebean by *C. chinensis* and the effect of treatments on seed viability. (18th Feb – 20th Aug, 2019 & 2020)
January, 2019	24.75	8.11	95.19	46.42	
February, 2019	26.38	10.08	94.29	46.96	
March, 2019	29.22	14.27	94.03	45.55	
April, 2019	30.75	18.52	92.23	57.90	
May, 2019	32.24	21.67	90.48	64.03	
June, 2019	33.52	24.05	91.23	68.97	
July, 2019	33.01	24.85	93.48	71.77	
August, 2019	34.07	24.94	92.65	72.52	
January, 2020	22.36	9.65	96.90	60.58	
February, 2020	24.79	11.15	96.45	50.66	
March, 2020	30.05	14.07	94.13	40.77	
April, 2020	30.73	17.07	90.43	52.30	
May, 2020	31.10	21.15	90.42	64.32	
June, 2020	32.52	23.78	92.47	71.80	
July, 2020	32.44	24.49	93.52	74.32	
August, 2020	33.74	25.05	92.90	70.00	

APPENDIX-C

Effect of plant powders treatment on reduction of oviposition and adult emergence during 2019 and 2020

Treatments	Dose (% w/w)	2019			2020		
		**No. of eggs laid on 25 seeds	*Reduction of oviposition (%)	*Adult emergence (%)	**No. of eggs laid on 25 seeds	*Reduction of oviposition (%)	*Adult emergence (%)
A. indica	5	166.00[b] (12.90)	25.89[c] (15.01)	64.86[c] (40.44)	168.67[c] (13.01)	23.56[c] (13.63)	66.21[d] (41.46)
P. nigrum	5	178.33[b] (13.37)	20.39[c] (11.76)	60.93[c] (37.54)	181.67[c] (13.50)	17.67[c] (10.18)	61.28[d] (37.80)
O. tenuiflorum	5	213.67[a] (14.63)	4.61[d] (2.64)	67.71[b] (42.61)	214.33[ab] (14.66)	2.87[d] (1.64)	69.36[bc] (43.92)
E. globules	5	205.33[a] (14.35)	8.33[d] (4.78)	69.97[b] (44.40)	204.67[b] (14.32)	7.25[d] (4.16)	68.89[c] (43.55)
A. sativum	5	212.33[a] (14.59)	5.21[d] (2.99)	68.76[b] (43.44)	213.00[ab] (14.61)	3.47[d] (1.99)	69.80[bc] (44.26)
P. pinnata	5	215.67[a] (14.70)	3.72[d] (2.13)	72.02[b] (46.07)	215.00[ab] (14.68)	2.57[d] (1.47)	74.73[ab] (48.36)
L. citrata	5	137.33[c] (11.74)	38.69[b] (22.76)	55.58[d] (33.77)	136.67[d] (11.71)	38.07[b] (22.37)	54.88[e] (33.28)
Malathion 5% Dust	1	0.00[d] (0.71)	100.00[a] (90.00)	0.00[e] (0.00)	0.00[e] (0.71)	100.00[a] (90.00)	0.00[f] (0.00)
Untreated control	-	224.00[a] (14.98)	-	78.27[a] (51.51)	220.67[a] (14.87)	-	77.64[a] (50.94)
SEm±		2.17	1.45	0.78	1.62	0.93	0.83

Note: Figures in the table are mean values
* Values in the parentheses are angular transformed values
** Values in the parentheses are square root transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

APPENDIX-D

Effect of plant extracts and Jatropha oil treatment on reduction of oviposition and adult emergence during 2019 and 2020

Treatments	Dose (%)	2019			2020		
		**No. of eggs laid on 25 seeds	*Reduction of oviposition (%)	*Adult emergence (%)	**No. of eggs laid on 25 seeds	*Reduction of oviposition (%)	*Adult emergence (%)
A. indica	8	184.00^{cd} (13.58)	17.86^{de} (10.29)	66.67^{b} (41.81)	186.00^{cd} (13.66)	15.71^{de} (9.04)	67.38^{d} (42.36)
P. nigrum	2	170.67^{d} (13.08)	23.81^{d} (13.77)	65.63^{b} (41.01)	175.33^{d} (13.26)	20.54^{d} (11.86)	64.64^{e} (40.27)
O. tenuiflorum	10	200.33^{bc} (14.17)	10.57^{ef} (6.06)	66.39^{b} (41.60)	201.67^{abc} (14.22)	8.61^{ef} (4.94)	67.27^{bc} (42.28)
E. globules	10	195.00^{bc} (13.98)	12.95^{ef} (7.44)	68.38^{b} (43.14)	197.67^{bc} (14.08)	10.42^{ef} (5.98)	66.10^{cd} (41.38)
A. sativum	15	198.00^{bc} (14.09)	11.61^{ef} (6.67)	68.35^{ab} (43.12)	196.00^{bc} (14.02)	11.18^{ef} (6.42)	71.77^{b} (45.86)
P. pinnata	10	207.33^{ab} (14.42)	7.44^{f} (4.27)	69.61^{ab} (44.12)	212.67^{ab} (14.60)	3.63^{f} (2.08)	71.00^{b} (45.24)
L. citrata	3	145.00^{e} (12.06)	35.27^{c} (20.65)	55.63^{c} (33.80)	140.33^{e} (11.87)	36.40^{c} (21.35)	56.53^{f} (34.42)
Jatropha oil	3	36.00^{f} (6.04)	83.93^{b} (57.06)	12.04^{d} (6.91)	42.67^{f} (6.57)	80.66^{b} (53.77)	19.53^{g} (11.26)
Malathion 50EC	0.04	3.33^{g} (1.96)	98.51^{a} (80.10)	0.00^{e} (0.00)	0.67^{g} (1.08)	99.70^{a} (85.55)	0.00^{g} (0.00)
Untreated Control	-	224.00^{a} (14.98)	-	78.27^{a} (51.51)	220.67^{a} (14.87)		77.64^{a} (50.94)
SEm±		2.02	1.70	1.01	2.07	1.34	0.73

Note: Figures in the table are mean values

* Values in the parentheses are angular transformed values

** Values in the parentheses are square root transformed values

Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

APPENDIX-E

Effect of plant powders treatment on per cent infestation during 2019 and 2020

Treatments	Dose (% w/w)	2019 Infestation (%)*			2020 Infestation (%)*		
		After 2 months	After 4 months	After 6 months	After 2 months	After 4 months	After 6 months
A. indica	5	52.40[c] (31.60)	72.92[c] (46.82)	100.00[a] (90.00)	50.67[d] (30.45)	72.33[d] (46.33)	100.00[a] (90.00)
P. nigrum	5	31.15[d] (18.15)	61.04[d] (37.62)	100.00[a] (90.00)	32.19[e] (18.78)	61.95[e] (38.28)	100.00[a] (90.00)
O. tenuiflorum	5	67.98[a] (42.83)	92.85[a] (68.21)	100.00[a] (90.00)	66.47[abc] (41.66)	91.36[bc] (66.01)	100.00[a] (90.00)
E. globules	5	64.46[b] (40.14)	85.40[b] (58.65)	100.00[a] (90.00)	63.74[c] (39.60)	87.13[c] (60.61)	100.00[a] (90.00)
A. sativum	5	64.59[b] (40.23)	85.52[b] (58.78)	100.00[a] (90.00)	65.08[bc] (40.60)	91.87[bc] (66.74)	100.00[a] (90.00)
P. pinnata	5	68.22[a] (43.02)	95.92[a] (73.57)	100.00[a] (90.00)	67.43[ab] (42.40)	95.93[ab] (73.61)	100.00[a] (90.00)
L. citrata	5	15.05[e] (8.65)	51.70[e] (31.13)	99.40[b] (83.73)	17.20[f] (9.90)	52.52[f] (31.69)	98.23[b] (79.19)
Malathion 5% Dust	1	0.00[f] (0.00)	0.00[f] (0.00)	0.00[c] (0.00)	0.00[g] (0.00)	0.00[g] (0.00)	0.00[c] (0.00)
Untreated control	-	69.43[a] (43.97)	98.21[a] (79.13)	100.00[a] (90.00)	69.03[a] (43.65)	97.64[a] (77.53)	100.00[a] (90.00)
SEm±		0.33	0.47	0.03	0.29	0.53	0.09

Note: Figures in the table are mean values

* Values in the parentheses are angular transformed values

Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

APPENDIX-F

Effect of plant extracts and Jatropha oil treatment on per cent infestation during 2019 and 2020

Treatments	Dose (%)	2019			2020		
		Infestation (%)*			Infestation (%)*		
		After 2 months	After 4 months	After 6 months	After 2 months	After 4 months	After 6 months
A. indica	8	52.76[b] (31.84)	94.32[a] (70.60)	100.00[a] (90.00)	54.68[c] (33.15)	97.71[a] (77.71)	100.00[a] (90.00)
P. nigrum	2	25.08[c] (14.52)	96.80[a] (75.47)	100.00[a] (90.00)	27.28[d] (15.83)	96.17[a] (74.09)	100.00[a] (90.00)
O. tenuiflorum	10	66.19[a] (41.44)	95.89[a] (73.51)	100.00[a] (90.00)	60.34[b] (37.11)	97.02[a] (75.98)	100.00[a] (90.00)
E. globules	10	65.87[a] (41.20)	96.42[a] (74.62)	100.00[a] (90.00)	70.44[a] (44.79)	97.43[a] (76.98)	100.00[a] (90.00)
A. sativum	15	66.11[a] (41.38)	78.50[b] (51.72)	100.00[a] (90.00)	62.00[b] (38.32)	83.14[b] (56.25)	100.00[a] (90.00)
P. pinnata	10	67.51[a] (42.46)	98.33[a] (79.50)	100.00[a] (90.00)	70.51[a] (44.83)	97.62[a] (77.47)	100.00[a] (90.00)
L. citrata	3	16.49[d] (9.49)	71.99[c] (46.05)	100.00[a] (90.00)	18.71[e] (10.78)	73.54[c] (47.34)	100.00[a] (90.00)
Jatropha oil	3	1.39[e] (0.79)	1.76[d] (1.01)	5.11[b] (2.93)	1.42[f] (0.81)	2.46[d] (1.41)	4.18[b] (2.39)
Malathion 50EC	0.04	0.00[e] (0.00)	0.00[d] (0.00)	0.00[c] (0.00)	0.00[f] (0.00)	0.00[d] (0.00)	0.00[c] (0.00)
Untreated control		69.43[a] (43.97)	97.91[a] (78.25)	100.00[a] (90.00)	69.03[a] (43.65)	97.93[a] (78.33)	100.00[a] (90.00)
SEm±		0.37	0.47	0.26	0.38	0.51	0.21

Note: Figures in the table are mean values
* Values in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

APPENDIX-G

Effect of plant powders treatment on per cent weight loss during 2019 and 2020

Treatments	Dose (%)	2019			2020		
		Weight loss (%)*			Weight loss (%)*		
		After 2 months	After 4 months	After 6 months	After 2 months	After 4 months	After 6 months
A. indica	5	9.03^{d} (5.18)	27.07^{d} (15.71)	39.54^{d} (23.29)	9.37^{d} (5.38)	24.72^{d} (14.31)	39.24^{d} (23.10)
P. nigrum	5	6.24^{e} (3.58)	14.54^{e} (8.36)	31.11^{e} (18.13)	7.63^{d} (4.37)	14.34^{e} (8.24)	33.94^{e} (19.84)
O. tenuiflorum	5	15.40^{b} (8.86)	31.73^{b} (18.50)	39.94^{d} (23.54)	13.07^{c} (7.51)	32.95^{ab} (19.24)	40.99^{d} (24.20)
E. globules	5	11.87^{c} (6.82)	30.90^{bc} (18.00)	41.20^{d} (24.33)	13.73^{c} (7.89)	28.72^{c} (16.69)	41.95^{d} (24.81)
A. sativum	5	14.84^{b} (8.53)	29.17^{c} (16.96)	45.48^{c} (27.05)	14.73^{c} (8.47)	30.97^{b} (18.04)	46.35^{c} (27.61)
P. pinnata	5	21.79^{a} (12.59)	31.71^{b} (18.49)	51.33^{b} (30.89)	21.94^{b} (12.67)	33.52^{a} (19.59)	52.73^{b} (31.83)
L. citrata	5	1.58^{f} (0.91)	10.74^{f} (6.17)	28.08^{f} (16.31)	3.21^{e} (1.84)	10.24^{f} (5.88)	30.58^{f} (17.81)
Malathion 5% Dust	1	1.03^{f} (0.59)	1.15^{g} (0.66)	2.62^{g} (1.50)	0.99^{e} (0.57)	1.51^{g} (0.87)	3.48^{g} (1.99)
Untreated control		22.90^{a} (13.24)	35.75^{a} (20.95)	59.20^{a} (36.30)	24.54^{a} (14.20)	34.11^{a} (19.95)	58.67^{a} (35.92)
SEm±		0.30	0.22	0.32	0.27	0.23	0.32

Note: Figures in the table are mean values
* Values in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT

APPENDIX-H

Effect of plant extracts and Jatropha oil treatment on per cent weight loss during 2019 and 2020

Treatments	Dose (%)	2019 Weight loss (%)*			2020 Weight loss (%)*		
		After 2 months	After 4 months	After 6 months	After 2 months	After 4 months	After 6 months
A. indica	8	13.07[d] (7.51)	26.46[c] (15.34)	39.60[d] (23.33)	12.67[c] (7.28)	28.02[c] (16.27)	41.05[c] (24.23)
P. nigrum	2	5.40[e] (3.09)	22.03[d] (12.72)	32.37[e] (18.88)	5.81[d] (3.33)	23.29[de] (13.47)	34.49[d] (20.18)
O. tenuiflorum	10	13.73[d] (7.89)	32.20[b] (18.78)	43.08[c] (25.52)	13.22[c] (7.60)	31.32[b] (18.25)	42.24[c] (24.99)
E. globules	10	18.82[bc] (10.85)	24.15[d] (13.98)	38.47[d] (22.62)	19.95[b] (11.51)	22.19[e] (12.82)	36.37[d] (21.33)
A. sativum	15	17.94[c] (10.33)	23.61[d] (13.65)	39.48[d] (23.25)	19.07b (11.00)	24.67[d] (14.28)	42.05[c] (24.87)
P. pinnata	10	21.45[ab] (12.38)	30.25[b] (17.61)	51.04[b] (30.69)	18.91[b] (10.90)	32.82[ab] (19.16)	52.22[b] (31.48)
L. citrata	3	3.78[ef] (2.16)	10.68[e] (6.13)	27.07[f] (15.71)	4.41[de] (2.53)	13.07[f] (7.51)	28.05[e] (16.29)
Jatropha oil	3	2.65[ef] (1.52)	2.49[f] (1.43)	2.18[g] (1.25)	2.08[ef] (1.19)	3.34[g] (1.91)	4.28[f] (2.45)
Malathion 50EC	0.04	1.29[f] (0.74)	1.37[f] (0.78)	2.06[g] (1.18)	2.36[f] (1.35)	2.37[g] (1.36)	1.95[f] (1.12)
Untreated Control	-	22.90[a] (13.24)	35.75[a] (20.95)	59.20[a] (36.30)	24.54[a] (14.20)	34.11[a] (19.95)	58.67[a] (35.92)
SEm±		0.32	0.24	0.29	0.23	0.23	0.33

Note: Figures in the table are mean values
* Values in the parentheses are angular transformed values
Within column values followed by different letter(s) are significantly different (P=0.05) by DMRT