



Research Article

IMPACT OF LEGUMES ON GROWTH PERFORMANCE OF YELLOW MEALWORM, *TENEBRIO MOLITOR* L.

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Abstract

Yellow mealworm, *Tenebrio molitor* L. (Coleoptera: Tenebrionidae) has been recognized as a renewable protein source due to its amazing ability to process organic waste. Diet optimization is a key to achieve the better outcomes in the commercial farming of mealworms. Some previous studies have shown that various legume based proteinaceous diets can positively affect biological characteristics of mealworms. In the present study, we evaluated different combinations of three legumes i.e. *Vigna unguiculata* L. (lobia) and *Cicer arietinum* L. (chickpea) and *Vigna radiata* L. (mungbean) regarding their impact on biological responses of mealworms. There was a significant difference ($p < 0.05$) in legume diet mixes in terms of larval period, larval weight, pupal period, pupal weight and total development period to adult. The mealworms fed on 100 percent mungbean showed the shortest larval and pupal periods (76.8 ± 0.51 and 15 ± 0.258 days, respectively) while those fed on 100 percent lobia showed the longest larval and pupal periods (92.3 ± 0.44 and 23.2 ± 0.327 days, respectively). Similarly, mealworms fed on 100 percent mungbean exhibited the highest larval and pupal weights (0.12 ± 0.001 and 0.938 ± 0.002 g, respectively) and required shortest developmental period to reach adulthood (91.85 ± 0.612 days) compared with those reared on 100% lobia. There was no significant difference in pupation and emergence rates among the treatments. Overall, mungbean diets improved growth performance and development rate of yellow mealworms. Future research should evaluate supplementation of traditional wheat bran with mungbean in order to achieve the optimum mealworm production on sustainable basis. Subsequently, how prolonged feeding on mungbean diet can impact growth performance should also be studied.

Keywords: Legume diets, *Tenebrio molitor*, Larval development, Pupal performance, Lifecycle, Biology.

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1. INTRODUCTION

The larvae of yellow mealworm *Tenebrio molitor* L. (Tenebrionidae: Coleoptera) play a crucial role as detritivores by consuming both grains and stored food products (Barrett *et al.*, 2023). *Tenebrio molitor* is originated across multiple areas of the world and has been spread across the globe due to its extensive scientific and industrial use. This species advances through four developmental stages i.e., egg, larva, pupa and adult. The

most important stage is larva because it contains high nutritional value (Dreyer *et al.*, 2021). The species has a life cycle that normally goes up to ten weeks however, it may extend up to many weeks depending on environmental variables thus it is regarded as a low-maintenance species (Savio, 2023). Scientists currently examine *T. molitor* larvae as nutritious dietary food sources suitable for human consumption (Siddiqui *et al.*, 2023). Over the last few decades, this species has



seen an upsurge in laboratory research and practical testing as scientists discover its exceptional reproduction and strong survival properties (Hong *et al.*, 2020). Research on the nutritional features of *T. molitor* larvae improved their usage potential, since specialists view them as prospective alternative protein resources (Grau *et al.*, 2017). The nutritional value of *T. molitor* larvae includes > 50% protein and valuable fats with added essential micronutrients such as iron, calcium and zinc (de Carvalho *et al.*, 2020). Their larvae exhibit valuable traits that make them acceptable for use as food ingredients in nutrition systems that incorporate both human and animal diets, considering it about conventional animal farming (Van Huis, 2013). Together with other insect species, *T. molitor* acts as a sustainable food alternative because it needs minimal water, feed and space while produces fewer greenhouse gas emissions than livestock (Lin *et al.*, 2023). The modern sustainable production and consumption systems emphasize their usage because traditional protein sources are difficult to maintain in certain regions and are associated with huge environmental footprints and loss of biodiversity. This species has gained attention because alternative proteins are expected to become essential for future global food security in upcoming decades (Tang *et al.*, 2019). Their larvae also demonstrate commercial potential in pharmaceutical production as well as cosmetic development alongside their utilization in agricultural applications. There has been increasing academic interest in *T. molitor* as protein alternatives to traditional animal diets because conventional meat production either has become unsustainable or unavailable (Rumpold and Schlüter, 2013). Together with other edible insects, it delivers premium nutritional proteins at lower resource expenses thus serving as economical protein solution to fight world

protein protein deficiencies (Veldkamp *et al.*, 2012).

Research that explores substitute feeding materials for insect farming has become essential because of intensifying needs to identify sustainable protein sources. For instance, combination of chickpeas and lentils peas and beans can serve as a nutritionally rewarding feed substitute for *T. molitor* instead of traditional grain feed. The protein and fiber content in legumes serve as a possible cost-effective yet nutritious food supply for insect cultivation (Van Huis and Oonincx, 2017). Legumes stand out from other feed sources because they provide multiple advantageous aspects particularly around sustainability. Legumes function as perfect agricultural resource because they thrive under various climates and demand less farming operations than other crops therefore they become accessible to marginal farming areas. The environmental impact of legumes remains lower than cereal grains since they need reduced amounts of water and pesticides and fertilizers (Foley *et al.*, 2011). The soil benefit from legume nitrogen-fixing capacity allows farmers to avoid synthetic fertilizer usage while maintaining healthy soil environments (Kebede, 2021). The ecological advantages of legumes as insect feed source match current trends in sustainable agriculture and circular economics thus making them desirable additives in insect-based diets.

The high levels of protein available in legumes improve both growth speed and biomass development in insects. Legumes contain amino acids that offer better developmental and reproductive benefits for insects than cereals do as substitute insect feed sources (Van Huis, 2013). The protein concentration in dry legume ranges between 20 to 40% (de Carvalho *et al.*, 2020). The larvae that received a diet of legume-based meals developed higher protein content in their bodies and displayed superior fat-

protein relations compared to those fed standard cereal-based meals (de Carvalho *et al.*, 2020). Research shows that *T. molitor* larvae fed legume-based diets exhibit rapid growth followed by early pupation depending on which legume they consume (Siddiqui *et al.*, 2023). Faster growth rates from legume diets shortens development times which makes them suitable for operating efficient insect farming operations on an industrial scale. Research on different insect species reveals that protein-rich nutrition enhances both reproductive outcomes and produces larger eggs (Lee *et al.*, 2008).

The world's population is increasing day by day that is also increasing global challenges such as food security. To fulfill the food requirement of the increasing population more livestock production is required and for its production conventional inputs are being used that causes greenhouse gas emissions, excessive land use and water consumption (Van Huis, 2013). By adapting sustainable farming of this insect, we can fulfill future demand of protein with sustainable and environmentally friendly approach. Legume based diets can be used to enhance insect growth and development; therefore, it can help in sustainable rearing of insects on commercial scale. This study was therefore planned to determine the impact of different legume diet mixes (lobia, chickpea and mungbean) on growth performance of *T. molitor* in terms of biological parameters i.e., larval period, larval weight, pupation rate, pupal weight, pupal period, emergence rate and days to become adult male and female.

2. MATERIALS AND METHODS

The experiment was conducted in the Entomology Research Laboratory, Faculty of Agriculture and Environmental Sciences, Baghdad-ul-Jadeed Campus, Islamia University of Bahawalpur (29°22'16.3"N 71°45'52.9"E; 181 meters above sea level) Punjab, Pakistan from November 2024 to February 2025. The stock culture of

Tenebrio molitor was maintained at the Entomological laboratory of the Department of Entomology, Faculty of Agriculture and Environment, The Islamia University of Bahawalpur.

In systematic dietary experiments, nine legumes diet mixes were prepared (Table 1). Three legumes were combined in three different ratios and each dietary treatment was named after the most abundant diet in each combination.

There were three replications and 30 larvae (3 to 5 days old) in each dietary treatment i.e., 10 larvae per dietary treatment per replication. The larvae were gently collected from stock culture with the help of camel brush and shifted into plastic boxes (10.9 cm x 16.1 cm x 6.6 cm). The lid of plastic boxes was closed properly to avoid infestation of other insects. 10 grams of each diet combination was provided in each treatment. The temperature of 26°C± 2°C, relative humidity of 70±5% and light and dark schedule of 8/16 hours was maintained.

The biological parameters i.e., larval period, larval weight, pupal period, pupal weight, pupation rate, emergence rate, days to become adult male and female were recorded. The duration of larval period was recorded as time taken to reach pupal stage after the hatching from the egg. When larvae finished their feeding and reached at wandering stage, they were weighed using electronic balance and then shifted into plastic jars containing saw dust where they pupated. The five days old pupae were weighed using electronic balance and then shifted into petri dishes. The time taken for the emergence of adults was also noted. The pupation and emergence rates were regarded as the percentage of larvae that successfully pupated and percentage of successfully emerged adults from pupae, respectively. All these biological parameters on each diet were recorded over one generation.

Table. 3.1: Nine different diet mixes based on different combination of three legumes

Diets	Mungbean	Chickpea	Lobia
50% Mungbean diet mix	50%	25%	25%
50% Chickpea diet mix	25%	50%	25%
50% Lobia diet mix	25%	25%	50%
75% Mungbean diet mix	75%	12.5%	12.5%
75% Chickpea diet mix	12.5%	75%	12.5%
75% Lobia diet mix	12.5%	12.5%	75%
100% Mungbean diet	100%	0	0
100% Chickpea diet	0	100%	0
100% Lobia diet	0	0	100%

The nine diet mixes were compared in terms of larval period, pupal period, larval weight, pupal weight, pupation rate, emergence rate by using one-way analysis of variance (ANOVA) followed by tukey's test (LSD) test at alpha 0.05.

3. RESULTS

There was a significant difference among all the diets in terms of larval period (df=8, F=129, p<0.000). Larval period was the maximum (92.3±0.44 days) in 100% lobia diet and the minimum (76.8±0.51 days) in 100% mungbean diet (Fig. 1). There was also a significant difference among all the diets in terms of larval weight (df=8, F=202, p<0.000). The maximum larval weight (0.1253±0.000 g) was recorded in 100% mungbean diet and the minimum (0.1074±0.001 g) in 75% lobia diet (Fig. 2). However, there was no significant difference among all the diets in terms of pupation rate (df=8, F=1.18, p=0.3213).

The pupal period also differed significantly among all the diets (df=8, F=75.9, p<0.000). The maximum pupal period (23.2±0.327 days) was observed in 100% lobia diet and the minimum (15±0.258 days) was observed in 100% mungbean diet (Fig. 3). Likewise,

there was also a significant difference among all the diet mixes in terms of pupal weight (df=8, F=29.2, p<0.000). It was the maximum (0.938±0.002 g) in 100% mungbean diet and the minimum (0.89±0.003 g) in 75% lobia diet (Fig. 4).

There was no significant difference among all the diets in terms of emergence rate (df=8, F=0.60, p=0.7741), however, they differed significantly in terms of days to become adults (df=8, F=0.23, p=0.0024). Larvae fed on 100% lobia transformed into adults significantly ahead of those fed on 100% lobia i.e., 115.75±0.67 days and 91.8±0.612days, respectively (Fig. 5).

4. DISCUSSION

The diets significantly affected the larval duration in this study. 100% lobia diet took 92.3 days to complete larval duration compared with 100% mungbean i.e., 76.8 days. Larval development responds strongly to different protein and carbohydrate contents in the dietary formulas. Fast growth occurred due to mungbean's protein-packed nutritional content with its essential amino acids (Gunathilake *et al.*, 2016). The low protein content of lobia compared to mungbean led to slower development of larval stages thus

prolonging their time until reaching pupation. Research studies indicate that dietary compositions with increased protein levels enhance development rates of larvae while decreasing their overall maturation times (López *et al.*, 2017).

Pupal development period was also shortest for 100% mungbean diet (15 days) compared with 100% lobia diet (23 days). The lobia-fed pupae lasted longer since lobia contained fewer proteins compared to available carbohydrates thus reducing the available energy for pupation. Mungbean's superior nutrition enabled the pupae to develop as well as emerge more quickly. Mealworm development shows better results when protein is high in their dietary intake thus indicating that protein improves general growth speed.

The emergence rate among dietary treatments remained identical in this study, indicating diet composition impacts development time more than it does the success rates of pupation and emergence in *T. molitor*. Other researchers documented similar results showing these rates have decreased sensitivity to dietary changes in adequate nutritional diets (Li *et al.*, 2019). The research demonstrates how dietary content affects *T. molitor* development while mungbean consumption can enhance growth-related performances by shortening laboratory stages.

Adult emergence took the longest time (115.75 days) in 100% lobia diet but the shortest (91.8 days) in 100% mungbean diet. Mungbean diet shortened the time to adulthood because its elevated protein level helped promote more efficient growth and earlier sexual maturity. Scientific literature confirms that high-protein diets speed up growth rates of mealworms and reduce their time to sexual maturity (Van Broekhoven *et al.*, 2015). The overall weight of larvae was highest (0.1253 g) when fed exclusively with mungbean and lowest (0.1074 g) when fed on

75% lobia. The nutritional advantages of mungbean diet outperformed other food sources to accelerate the growth process of the larvae. Numerous studies confirm that *T. molitor* larvae need both protein and essential fatty acids in their diet for weight gain because these substances enable proper growth and developmental processes (Diener *et al.*, 2011). The high protein content in mungbean served to increase the weight of the larvae since proteins determine optimal development across generations. The larvae fed on 100% mungbean diet showed greater pupal weight at 0.938g compared with those fed on 75% lobia diet (0.89 g). The nutritional richness of mungbean appears to enable optimum pupal growth since it provides essential resources needed for larvae to become pupae. Published scientific research confirms that well-balanced diets create larger body mass growth throughout the entire life cycle of *T. molitor* (De Smet *et al.*, 2018). The experimental results indicate that legumes especially mungbean enhance the growth output of *T. molitor*. Diet composition serves as a main element which determines the development parameters of growth rates alongside weight gain and developmental time.

In the present study, the tested dietary treatments resulted in equivalent pupation and emergence rates. Research on mealworms generates opposing results regarding diet impacts on pupal development and emergence timing based on divergent findings (Pinto *et al.*, 2017; Köhler *et al.*, 2018). Besides genetic components and physiological aspects of the lifecycle adult emergence probabilities of mealworms are more influenced by environmental factors including temperature and humidity as well as suitable substrates rather than their diet consumption (De Smet *et al.*, 2018).

In the present study, the mealworms fed on pure lobia reached adulthood after 115.75±0.67 days whereas those given pure

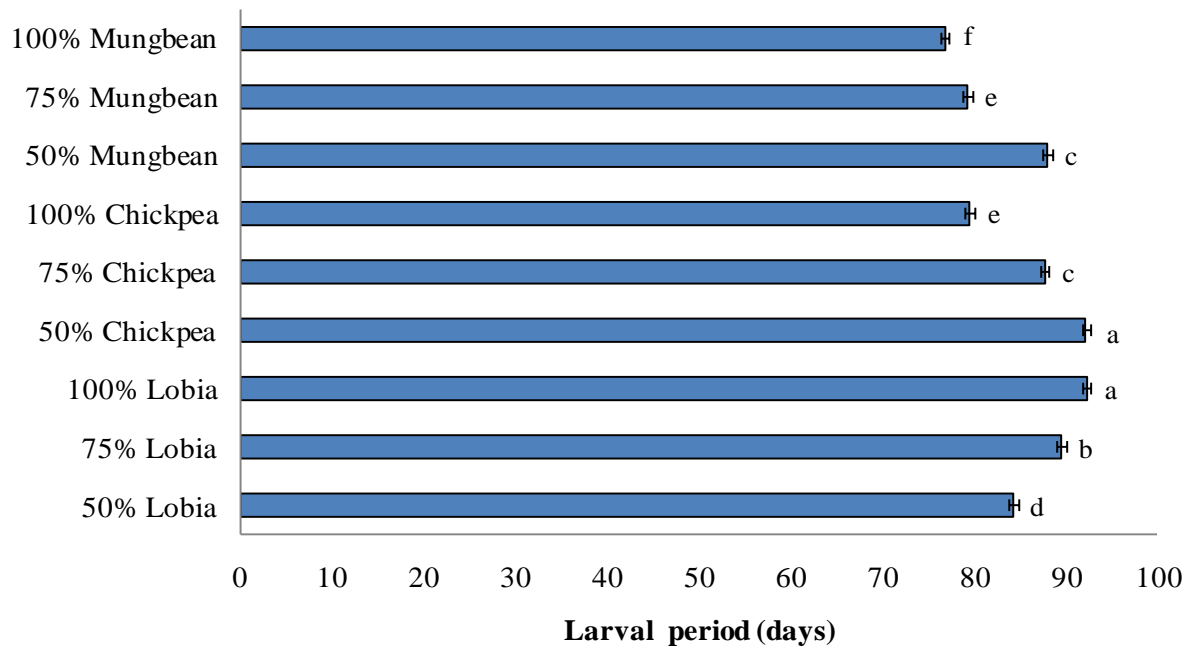


Figure. 1: Effects of different legume diet mixes on the pupal period of mealworms, means sharing similar letters are statistically non-significant at alpha 0.05.

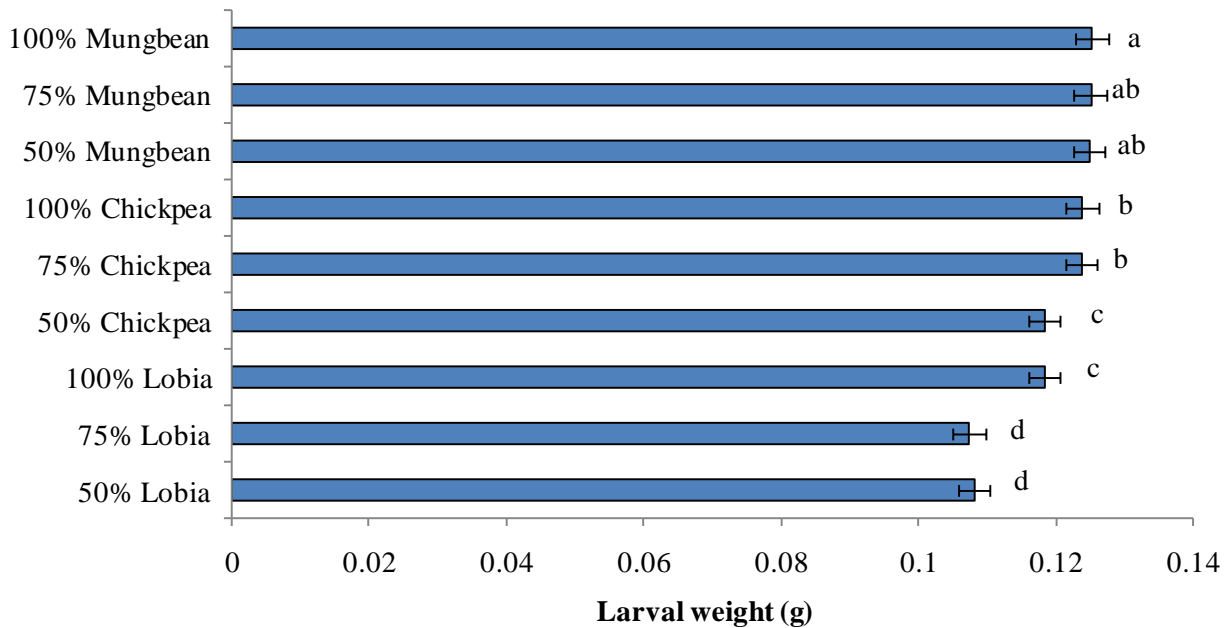


Figure. 2: Effects of different legume diet mixes on the larval weight of mealworms, means sharing similar letters are statistically non-significant at alpha 0.05.

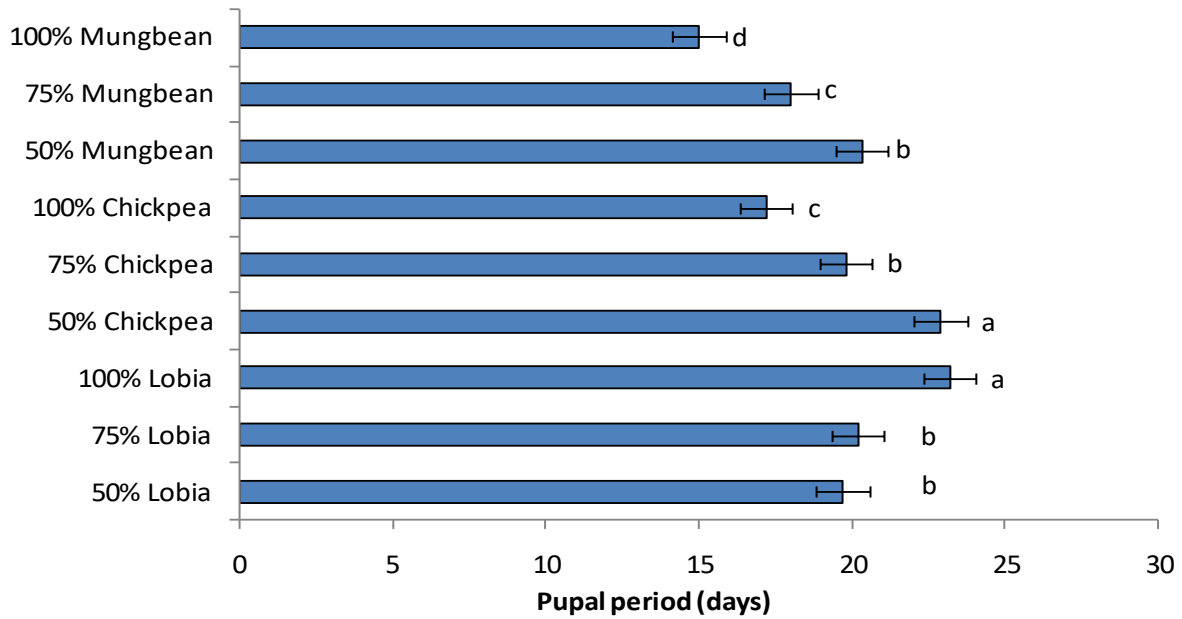


Figure. 3: Effects of different legume diet mixes on the pupal period of mealworms, means sharing similar letters are statistically non-significant at alpha 0.05.

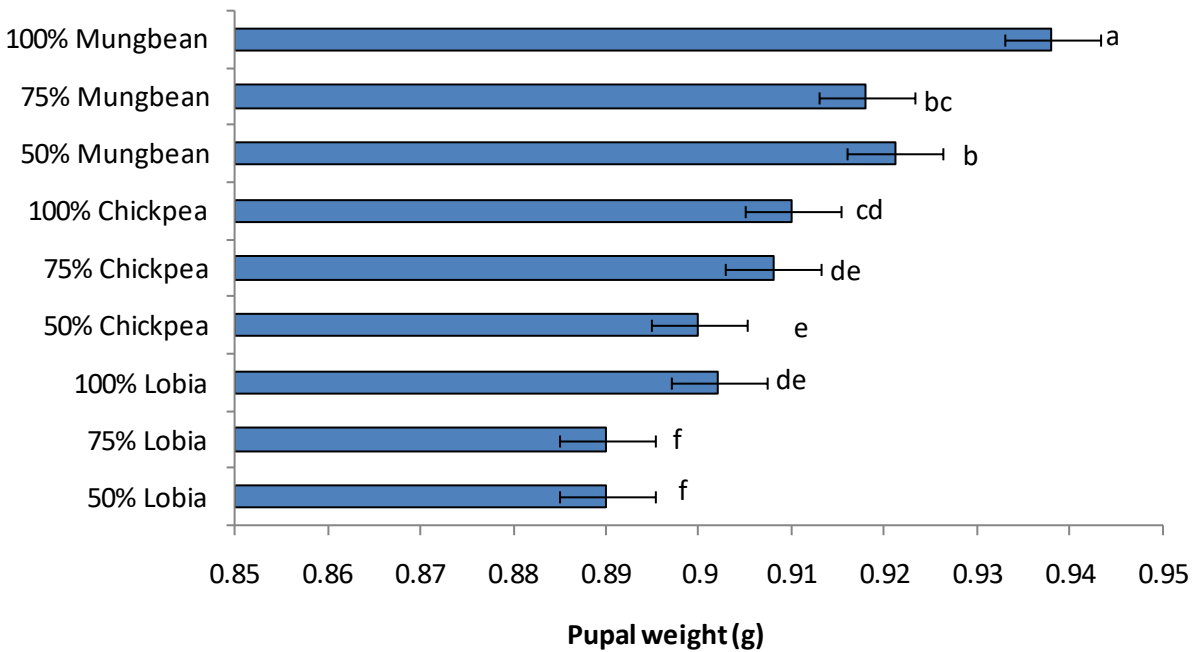


Figure. 4: Effects of different legume diet mixes on the pupal weight of mealworms, means sharing similar letters are statistically non-significant at alpha 0.05.

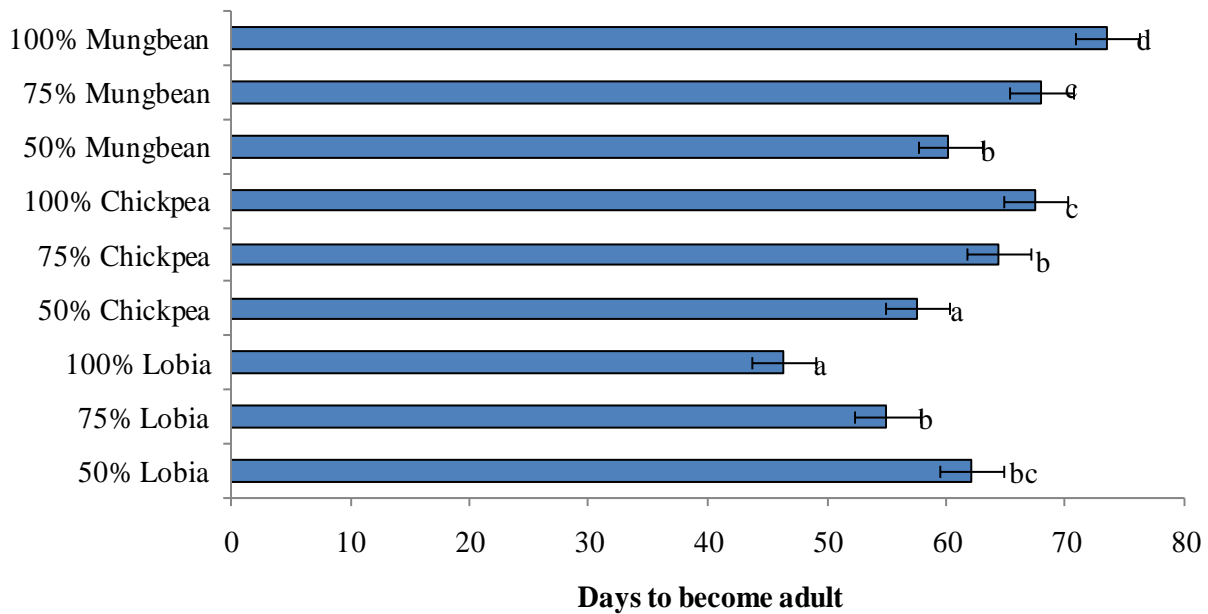


Figure. 5: Effects of different legume diet mixes on the days to become adults of mealworms, means sharing similar letters are statistically non-significant at alpha 0.05.

mungbean reached adulthood after 91.8 ± 0.61 days. Previous research demonstrates that various types of nourishment control the developmental pace of mealworms as noted previously. The mungbean outpaces lobia in mealworm development because it contains higher protein and carbohydrate content together with its fibrous structure and reduced nutrient amounts (Gunathilake *et al.*, 2016). Hwang *et al.*, (2019) and Jeong *et al.*, (2020) demonstrated that mealworms fed with legumes (containing enhanced nutritional value) underwent faster growth than those restricting their feeding to fibrous diets confirmed that *T. molitor* development time and body mass tracked protein levels in the diet.

The determination of the extended period until adulthood occurs in mealworms remains critical for mass production. When certain situations need mature mealworms to reach desired sizes then the development rate should align with requirements. The ability to control mealworm maturation by diet

manipulation would help optimize production timetables during industrial farming of these insects. In the present study, the larval weights differed significantly among different diet mixes. The larvae fed on 100% mungbean achieved the highest weight gain (0.1253 ± 0.000 g) while lowest (0.1074 ± 0.001 g) in larvae fed on 75% Lobia. The dietary compositions play a role in influencing the weight of developing mealworm larvae. The high protein and carbohydrate content in mungbean allowed the mealworms to develop bigger because they received the required nutrients. The cellular growth of insects depends heavily on protein because it helps promote growth at the cellular level as well as developmental processes. The smaller mealworm larvae resulted from the inadequate nutritional makeup of lobia failed to adequately fuel their development process. Studies indicate that feeding mealworms protein-rich diets results in increased larval weight (Oregon *et al.* 2021).

Mealworms fed on 100% lobia exhibited the longest development period (115.75 ± 0.67 days) whereas those on 100% mungbean diet only (91.8 ± 0.612 days). Adult emergence of mealworms using 100% lobia diet took longer because its slower growth rate affected the developmental stage of larvae and pupae. The rapid development within the 100% mungbean diet indicates that this diet supports fast development because of its nutritious content. Richards *et al.*, (2019) demonstrated that mealworms develop faster with protein-rich diets because the protein content influences the duration of insect life cycles.

The growth performance of *T. molitor* undergoes substantial changes because different legume diets generate unique effects throughout the larval and pupal development periods as well as weight measurements. The findings can support the businesses engaged in sustainable protein production based on mealworms. The selection of suitable diets as a cultivation method enables faster mealworm growth alongside lower production costs while maintaining economical commercial operation of mealworm farms. The 100% mungbean diet proved beneficial for industrial biomass producers because it shortens developmental times and yields heavier insects. Future studies should investigate nutritional analysis of dietary legumes because their protein composition with fat and carbohydrates could show distinct effects on mealworm developmental processes.

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