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State of the Art on Production, Processing and Uses of Meal Worm *Tenebrio Molitor* (Tenebrionidae: Coleoptera)

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Abstract
Insects farming is a unique and alternate approach to produce protein rich food and feed. Insects convert organic wastes into biomass, which was successfully used to produce poultry and animal feed.Among the insects,meal worm due to its easy production and high nutritive worth is the best choices to be used as food and feed. This diverse beetle mainlyutilizes different feed products and byproducts, and generally habitatein barns, store, flour mills and grains etc. Its life cycle consists of four developmental stages: the eggs, larva, pupa and at last mature mealworm. The egg to new beetle may take up to 120 days; however, environmental conditions, like temperature, humidity and available diet have been found to reduce its developmental time.Mealworms are omnivorous and can consume all types of animal byproducts such as meat and feathers as well as plant materials. They usually fed on different cereals like wheat, maiz and oats and its bran or flour supplemented with fresh vegetable like potatoes,carrots, lettuce,and other fruits for moisture content with protein supplementation like skimmed milk powder, yeast, or soybean flour. According to FAO data mealworms have high protein content (13.68 to 22.32 gram per portion of 100 gram) and a significant amount of fatty acids (8.90 to19.94 gram per edible 100-gram portion). Mealworms are also graded as rich source of zinc and magnesium. Due to its high nutritional worth meal worm has successfully used as animal, poultry and fish feed, immunity enhancer, probiotic and waste degrader. Present review concluded that sustainable meal worm production will be the low cost, easy and environment friendly method to produce cheap but high-quality poultry and fish feed and feed supplements in future. Meal worm farming will be the best choice of rural women livelihood besides its support to poultry and fish feed industry in coming days.
Keywords: *Meal Worm , Tenebrio Molitor*

INTRODUCTION

Alternative feed sources, especially protein rich nutrients are needed for feeding poultry and animals to satisfy the hunger of continually growing world population. (Alexandratos and Bruinsma. 2012; Tilman and Clark. 2014). Meat-based diets are required to be reduced for saving environment, health, and economy (Springmann et al., 2016). The major poultry protein source used in poultry ration is soybean meal which is imported in Pakistan and its cost is continuously increasing (Rana et al., 2009). To decrease the cost of finished feed and reduce the reliance of Pakistan poultry industry on import of feed ingredients, search for alternatate sources are required. Furthermore, huge amount ofdifferent industrial byproduct is wasted which are not profitable for industry but can be used as feed source for insects after processing and help to convert diverse waste streams into quality protein. (Gustavsson et al., 2011).The term "Edible insects" used by research community is gaining attention with the passage of time.Its first use in 2007 recovered only 12 publications listed in Pub Med, which wasincreased to40pluse publicationsin 2016.

Worldwide more than 2000 edible insect species are reported and only few of them are commercially produced. (Jongema. 2015). Diversity in nutrient composition of these species has been reported yet they have been found good alternative protein source for humans,aquaculture, and livestock(Rumpold and Schlüter. 2013; Belluco et al., 2013). Despite of several potential safety issues these worms can easily be raredon sustainable bases with least possible damage to the environment.(Rumpold and Schlüter. 2013; Belluco et al., 2013; Nowak et al., 2016; Schlüter et al., 2016).

In this review, we havefocused on meal worm, the larvae of *Tenebrio molitor*for mass production, processing and uses.The larvae of this species are often used as pet foodand alternate protein-rich animal feed due its high protein contents (Finke. 2002). Mealworms are not only used as protein rich feed for poultry and animals but has also been found ideal food for humans. (Li et al., 2013). Due to their bio-regenerative properties meal worm have also been recommended as support system for space missions (Li et al., 2015).Companies such as Ynsect (Paris, France) are involved in mass-scale rearing of the mealworm and have gained the capacity of producing several tons of mealworm biomass on weekly basis. *T.molitor*is now a well known and representativemodel for research studies of native immunity, genome sequence of its mitochondria has been available (Chae et al., 2012). *T. molitor*is strongly related to beetles like*T.confusum*and *T.castaneum*,which are mostly used as model organisms for research on insect development and immunity, with a complete genome sequence published for *T. castaneum*. The available background knowledge on *T. molitor* as compared to other edible insects has supported to develop stateoftheart mass rearing management systems for their production.

This article will highlight the life cycle, nutritional and environmental requirements of the mealworms, followed by its processing and uses. Although scattered data on the mentioned aspects of the meal worms are available in literature. However, present review is an effort to provide all the relevant information on sustainable production of meal worm in single document.

MEAL WORM PRODUCTION

I Mealworm Biology and Life cycle

Mealworm, *T.molitor,*(Tenebrionidae: Coleoptera), is commonly known as Darkling Beetles. There are further three species of darkling beetles: *Zophobasatratus* (giant mealworm), *Tenebrio molitor* Linnaeus (yellow mealworm) and lesser mealworm *Alphitobius diaperinus* panzer. The larvae of darkling beetle are generally known as Mealworms.Theyare the harmfulpest of stored cereals grains like wheat, maiz and its flour, other food materials and fruits (Ramos-Elorduy et al. 2002); but its larvae are used as pets food due to high protein contents in many countries.It has been observed that heavy mealworm larvae with elevated protein contentscould be produced when provided with wheat bran indiet(Van Zyl and Malan, 2015).Commercial production of meal worm larveaas feed for reptiles, birds aned fish is in practice since long. Mealworms are economical and easy to rise with manimumdamageto the environment. (Wang et al. 2012).

Mealworms may be used as an interdisciplinary means for academic research (Harrell and Bailer 2004), as biological marker (Simon et al 2013) may be used tosupplemente poultry feed (Bovera et al., 2016). It has been reported by (Van Huis et al, 2013) that almost 2 billion people eat insects worldwide hence it can be used as human food. Despite of other parts of the world especially in china the *Tenebrio molitor* Linnaeus (meal worm) is a general native dish of people. The mealworm has an efficient system of converting plant wastes to protein hence can be successfully used in space to sustain bio-regenerative system and provide food to the Astronauts (Li et al, 2013).

Its life cycle consists of 4 developmental stages: egg, larva, pupa, and adult. This multiculturalmealworm mainly feeds on cereal products and byproducts, and generally occur in barns, mills, stored, flour and grains etc. Figure.1 shows thelifecycle of the mealworm.

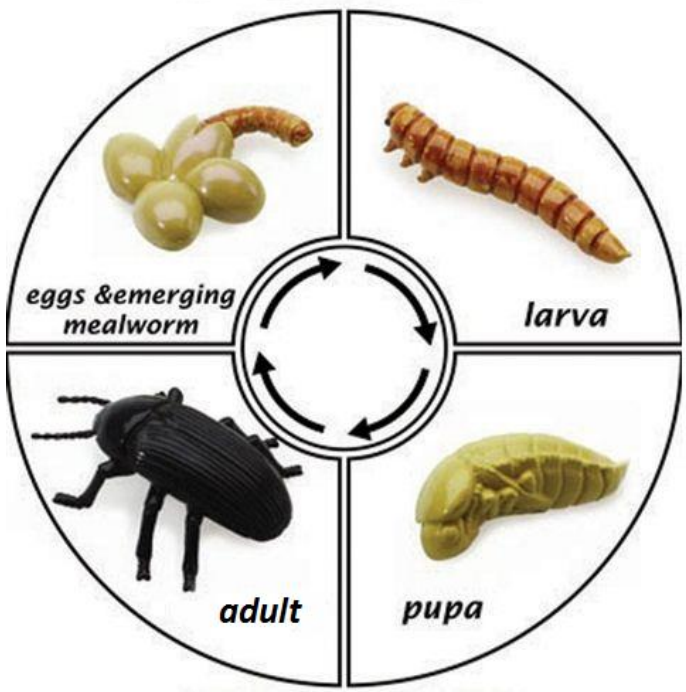

Fig. 1 The lifecycle of the mealworm

a. Egg:

The incubation period of eggs varies from four days at 26 to 30ºC to thirty-four days at 15ºC (Kim et al, 2016). Mealworm eggs have 70% hatchibility at 17.5 to 27.5 °C. Eggs during breeding are attached with the substrat or the floor of the container. After hatching the larvae come outand larval stage is started. The weight and egg stage are not influenced with age of parental flock but hatchiblity are definitely influenced with age factor of adult meal worm (Fiore, 1960).

b. Larva:

Upon emergence from egg, tiny larvae start the larval stage. The duration of larval stage is expected to range from 57 to 629 days in managed verses natural environments, respectively as reported in different studies (Weaver & McFarlane, 1990) with minimum period of 112 to 205 days (Miryam, Bar and Oscherov, 2000; Martin et al., 1976). Short possible lifecycle periods of *T. molitors*were reported as 75 and 90 days, respectively (Spencer, 2006; Hardouin and Mahoux, 2003). Miryam et al., (2000) investigated that larvae after 11 to 19 instar stages becomes a pupa. Park et al, (2014) reported that with successive instar at development the body length increases but after 19 instar stage it become decreases. The larva length can be 12-32 mm (Hardouin and Mahoux 2003; Hill 2002). Intially the larvae are whitish, which progressively changes to brown colour at 2nd instar. After a brief latency larvae are converted to pupa gaining a form of "C". Larvae are enrich protein diet for both animals and captive birds (Biasato et al, 2016).

c. Pupa

The pupa of mealworm cannot eat and move.The pupal duration as reported varied from 6 to 20 days (Hill, 2002 and Kim et al, 2015) before it becomes an adult beetle.

d. Adult

The young adults are tiny, soft, slowly darkening and can begin laying eggs within approximately three days after their emergence (Manojlovic, 1987). The adult darkling beetle of meal worm female lay typicaly of 400-500 eggs in its breeding area, especially in the bottom of substrate or at the wall of container (Spencer, 2006 and Hill, 2002).

According to Polkki et al, (2012), females are fascinated by the odour produced from out bred males. The authors have also noted that inbreeding reduced the identification of sexual senses or signals. At a temperature of 30°C the interval of adult life was lesser in comparsion to temperature variation of 20-25 °C (Fiore, 1960). In comparison the progeny from adults beetles showed lesser adult life than the offspring from the younger beetles (Tracey 1958). The entire life spanproceeds in the same environment and the length of various phases is mostly dependent on different issues likephysical and environmental factors and including relative humidity, temperature, population density, diet and nutrition affecting the rearing of the mealworms.

Meal Worm Nutritional requirements

Mealworms are omnivorous and can consume all types of animal byproducts likefeathers and meat **(**Ramos-Elorduy et al., 2002**)** as well as plant materials.They usually utilize bran or flour, of different cereals, (oat, wheat, maize**)** augmented with fresh fruit and vegetable (potatoes, lettuce, carrots**)** for moisture content and protein supplementation withyeast, skimmed milk powder, andor soybean flour (Hardouin et al, 2003). Balanced diet is required with 20% protein content (Ramos- Elorduy et al, 2002). The mealworms in accordance with nutritional requirements have the capability to select food items for balancing their nutritional intake (Urrejola et al, 2011; Rho and Lee 2014). *T.molitor* are usually fed with wheat bran, as it comprised of all required content at optimal level, but for better results supplemented diet are used at various stages of life (Morales-Ramoluencing develos et al. 2010). Wheat bran, fruits, fresh vegetables including apples, potatoes, cabbages respectively and others diets like yeast soya protein and casein are mostly used as supplemented diet both for mealworm for research and industry.

Nutrient consumption play a vital role in the *T.molitor* life cycle, effect growth time (Van Broekhoven et al, 2015; Rho and Lee, 2014) oviposition, instars and reproduction factors severity and length (Morales-Ramos et al. 2013) increased number of eggs, offspring development and reducing mortility of individual (Gerber and Sabourin, 1984).

Mealworms can make use of small quantities of water found in dry food, but water-deprived mealworms efficiency is reduced. It is better to provide a water source for better growth and to avoid cannibalism. It is important to have fresh food because it can also become moldy (Hardouin et al., 2003). Larvae are provided with complex feed ingredients containing all essential nutrients like wheat bran, cereal flour, beet pulp and are fed two times a week.

a. Protein in Diet of meal worm

Different biological attritubes of *T. molitor* is significantly affected by dierty protein of the diet.(Nuno Ribeiro et al., 2017). Dietsupplemented with huge amount of protein (33–39% dry mass) decreased pupation periods from 19–22days to 11–14daysat relative humidity 65% and 28ºC ascomparedto lower protein constituent (12% DM).Protein supplementation of diet improved their performance to 88% and 92%from 84% and 88%, respectively (Van Broekhoven et al, 2015).

Growth efficiency improved with the usage of protein. Yeast and whole ground wheat combined at 1:9 ratio over a 4-week cycle(John et al. 1979), increased the larval weight measuring from 2.3–2.9 mg per larva to 45.5–55.6 mg. Caseinin diet was found toincrease the rate of development from 4.08-6.16 g/g larva with its addition from3% to 20% (Davis 1970). The effects of including protein in the diet was observed in pupae where weight gains improved in range of 117-145 mg on low protein basal diet (5 % yeast) and 146-161 mg on high protein (40% yeast) respectively (Van Broekhoven et al, 2015).

Availability of protein in the diet may affects mealworms productiveness., where average female fecundity increases from three eggs per day with protein-free diets to 6-7 eggs per day with protein enriched diets (Morales Ramos et al, 2013). The increased egg production in female was observed by (Urrejola et al, 2011) from 5 to 12 eggs/d when yeast supplementation was increased to 20% as compared of 2% (w/w). Females raised with wheatfloor started laying on 12th to 15th days of maturity then than those raised onsoya flour where laying was started on 9th to 12th day of maturity.

Yeast is protein in nature and is an important source of proteinused in the diet at 5-10% concentration (Fraenkel 1950; Hare and Martin 1942). Other sources of protein which provide maximum efficacy includes casein, lactalbumin, Zein, gliadin, and protein hydrolysates,(Leclercq, 1948: Fraenkel, 1950;Leclercq andDavis 1969).Soybean is also a rich protein source, however itstrypsin inhibitor, affects larval growth (Birk et al., 1962).Mealworms result in similar body protein make up and have high level of protein constituent with 2-3-fold growths in crude protein content 11.9 to39.1% on dry matter bases (van Broekhoven et al. 2015).

The larval mealworm contain alanine 8.9to 9.9%, aspartic acid 7.9to8.7%. leucine 7.7to8.0%. phenylalanine 6.5to 6.8%. valine 6.5to 6.7%. proline 4.6to 7.5%. arginine 4.6to5.9%. threonine 2.8to2.9% histide. 1.8to1.9%. cysteine 1.5to 1.6%. and methionine 0.7to 0.8%. The optimal diet would provide a comparable concentration of amino acids as in larval tissue except for phenylalanine at 50% body mass minimal threonine and tryptophan aminoacidwhich are given at a concentration two times the concentration present in larvae.

b. Carbohydrates in Diet of Meal worm

Like other leaving creators the development of T.molitor is seriously affected with carbohydrate deficiency. The optimum range of carbohydrate is 80-85% (Fraenkel 1950). Davis's (1974) reportedthat growth with fructose, lactose or sucrose was less than with glucose in a mixture of amino acid-based diets. Likewise, as a source of carbohydrates, and compared to gulocose the bacteriologic dextrin induced gains of almost double of glucose (Davis, 1974).

The dietary carbohydrate protein ratio have significant effect on the life cycle of mealworms (Urrejola et al, 2011) and Rho and Lee (2014) investigated optimal ratio (1:1) protein and carbohydrates for better reproduction and events of life span. The meal worms fed with diet containing organic wastes yeast and mealworms excreta resulted in double body protein, (5-6 folds) high fat content than the diet with reduced values of carbohydrates and crude fiber (Ramos Elorduy et al, 2002). However, diet in low protein and carbohydrate (0:42 and 7:35) ratio resulted in high lipid content (Rho and Lee, 2014).

c. Fats in Diet of meal worm

The structure of mealworm fat is very stable as its diet is constituted with high in palmitic,oleicand linoleic acids (Oonincx et al. 2015). Consumption of improved polyunsaturated C18 acids was reported to decrease the quantity of monounsaturated fatty acid C18 in tissue of larvae (Van Broekhoven et al, 2015).

Low quantities of lipid are beneficial in the diet, while large quantities are detrimental and possibly unhealthy for the growth of the meal worm (Morales-Ramos et al. 2013). Although cholesterol is an essential feed constituent, lipid content level (1%) not improve lifec cycle of mealworms in its growth parameters and work as inhibitory factor at 0.3% concentration (Fraenkal, 1950). In comparison, fatty nutrients help the possible accumulation and lower ventilation of the mealworms follow-on in harmful breathing interferences (Alves et al. 2016).It has been established that 20% lipid substances upturn the vulnerability of parasitism (Shapira Ilan et al, 2008).

d. Vitamin in Diet of meal worm

T. molitor showed zero growth in the deficiency of vitamin particularly the Vitamin B complex (pyridoxine, nicotinic acid, carnitine, riboflavin, thiamine or pantothenic acid) while a bit slow growth was observed with lack of biotin (Martin and Hare 1942; Hardouin and Mahoux 2003). Leclercq (1948) also reported that larva after attaining enough size does not require vitamin to complete its development and to pupate.

Table 1 - Protein based diets for culturing of mealworm

Basal diets	Reference
Wheat bran + Water (vegetable or water)	(Baek et al., 2015; Allen et al., 2012; Dick, 2008; Houbraken et al., 2016; Li et al., 2015; Ravzanaadii et al., 2012; Siemianowska et al., 2013; Morales-Ramos et al., 2012.
Flour/Bran + Water (vegetable or water) + Protein Source	Kim et al, 2015, Oonincx et al, 2010, Tang et al., 2012, Lardies et al., 2014)
Varied artificial diet	(Alves et al., 2016; Urrejola et al., 2011, Menezes et al, 2014, Rho and Lee, 2014; Morales-Ramos et al., 2010; van Broekhoven et al., 2016)
Protein Source (Nuno et al. (2017)	
Beer yeast	(Lardies et al., 2014; Tindwa and Jo, 2015; van Broekhoven et al., 2015; Oonincx et al., 2015, 2010 ;Urrejola et al., 2011)
Casein	(Davis, 1978, 1970a, Murray, 1960; Rho and Lee, 2014)
soybean	Morales Ramods et al, 2013, Hardouin and Mahoux, 2003
Lactalalbumin	Davis, 1970a; Davis and Leclercq, 1969
Dried yeast	Connat et al, 1991; Murray, 1968, 1960
Aminoacid mixture	John et al, 1978, Davis, 1974
Albumin	(Morales-Ramos et al, 2013, 2010; Rho and Lee, 2014)
Dry potato	(Morales-Ramos et al., 2015b)

Bird feed	(Menezes et al., 2014)
Bocaiuva	Acrocomiaaculeata (Alves et al., 2016)
Cookie remains	(van Broekhoven et al, 2015; Oonincx et al, 2015)
Beef	Liver, muscle, blood (Martin and Hare, 1941)

Nuno et al, (2017). *Tenebrio molitor* for food or feed:

e. Water requirements of meal worm

T. molitor continue to exist tremendously in dry situation for extensiveperiod of time, having the ability to get the required water from the ingested food even with lower water content (Blewett andFraenkel 1944).The larvae nurture quicker in humid situation above 70% relative humidity. Although, the growth of mites, bacteria and other microbes is stimulated by such high level of humidity is notideal for the massive insects rearing. Mealworms produced on dry diets showedelevated rates of growth in presence of water (Oonincx et al. 2015; Mellandby and French 1958). Low moisture compounds having content of metabolic water per unit feed ingredient lower upto (24-35-gram water per 100 g feed), improvement may stop if there is no water intake.In absence of water, *T. molitor*larvae consume less nutrients, thereby reducing the consumed nutrient conversion rate to body mass (Murray 1968). Increasing the survival rate (80%) with the accumulation of water supply, such as carrots, decreases the growth period from 145 to 151 days to 91 to 95 days (Oonincx et al. 2015). The water content intake effect on the composition of biomass are controversial. It was observed by Urs and Hopkins (1973) that the accessibility of water surges the total lipid profile whereas, Oonincx (2015) described that additions of water source to the diets rises only the water content not fatty acid profile.

Relative humidity and temperature

The relative humidity and environmental temperature both are the important for period of the instars with a non-stop effect on the development of the mealworms, primarily due to their effects on the water absorption potential at various stages.Relative humidity is strongly related to fertility and adult activity. Temperatures often used to encourage meal worms production at 25 to 28ºC**(**Koo et al. 2013; Kim et al. 2015; Spencer and Spencer 2006; Ludwig 1956**)**, with ansecurelowermost of 10ºC and a uppermost of 35ºC. Pupal and young larval stages are the most susceptible phase to environmental temperature and humidity (Punza and Mutchmor, 1980).

Ovi-position ceased at 14ºC temperature with 65% RH. Even at supreme temperature of 27ºC when humidity is low **(**20%**)** ovi-position is reduced significantly **(**Dick, 2008**)**. It had been described that the action of adult female is most uptimum at 90 to 100% RH **(**Hardouin and Mahoux, 2003**)**. At 10ºC (Punzo and Mutchmor, 1980) and 12.5 ºC (Kim etal., 2015), water incorporation is condensed, and the embryological development is not accomplished.However, these minimum and maximum dots seem to be good and therefore the values for development of the conventional for *Tenebrio molitor* are 17ºC and 30 ºC (Koo et al, 2013). The temperature requirement have no major difference in the developmental stages of this specie however the fatal and chill coma temperature varies between 40-44 ºC **(**Martin et al., 1976**)** and 7 to 8 ºC **(**Mutchmor and Richards, 1961**)**, respectively, for exposure periods of 24 hours. While in dry circumstances with relative humidity (12%) initiate dehydration of eggs and lead to death of the mounting embryo (Punzo and Mutchmor, 1980). Increased growth rate of T. Molitor larvae was observed at 70% comparative humidity, the slower at 30% and hardly at 13% (Fraenkel, 1950).

In larval phase molts and number of instars at temperatrure of 30 °C was higher than 25 °C with longer larval period at 30°C (Ludwig, 1956). The temperature variation potentially below 10 °C and above 35 °C developed stress for mealworms (Punzo and Mutchmor, 1980).

The potentially extreme humidity and temperatures are also more critical for developmental stages of mealworm (Punzo and Mutchmor, 1980). *T.molitor* shows no strain even under harsh humidity and long disclosureto optimal temperatures of 25 to 27.5 ° C. In addition, a reduction in humidity in various developmental phases at temperatures of 25°C was found non substantial but at 10 °C caused an increase in death ratio (Punzo and Mutchmor, 1980). Mealworm larvaes can halt the food intake completely and become sluggishbelowenormously dry circumstances until relative humidity again becomes satisfactory (Ursand Hopkins, 1973).

The adult beetle of *T.molitor* are shady brown and is 12 to 20 mm in length. The larva is 2.5 to 3.5 cm in length with a weight of 0.2 g; when produced at most favorable growth temperature from 25 to 30°C (Lyon, 1991). Temperature is one of the chief physical factors that regulate growth of insects (Cossins and Bowler, 1987). high temperature commonly increases growth, and thus assembled the output, but when temperature gets too high, damaging effects are detected (Kingsolver et al., 2015) thus an optimal range has been worked out which could be further ellaborated for different serotypes of meal worms. Data on the effect of temperature on the life cycle of *T. molitor*available like, Van Broekhoven et al. **(**2014**)** reported the deviation in mass of *T. molitor* growing at 25 °C however, they did not report other temperatures. Sincegrowth time has been discovered to be extremelydependent on temperature, (Rueda and Axtell., 1996) it is therefore of great concern to know the linked variation in mass, predominantly in food production aspect. It is also important to note the effect of temperature on body work and the worth of the meal worm larvae produced. Relative lipid and protein content can vary significantly. Therefore, knowing of the most favorable temperature is significant for the producer to determine the necessary biomass and/or protein content**.**

The mealworms are flexible to humidity in comparsion to temperature, hence an extensive degree of relative humidity is used in laboratory production of meal worm. In all studies a great concern was to manage the relative humidity in the developmental stages of mealworm which varied upto 60 to 75 % (Manojlovic, 1987). Some authors have observed rise in growth rate with higher humidity above 70% (Fraenkal) or above upto level of 90-100% (Hardouin and Mahous, 2003) similarly, increase humidity values lead to molds growth on the substrate.

Impact of Meal worm Farming on Environment

Mealworms can turn low quality plant waste materials into high-quality feed, rich in oil, protein, and fat. The life-cycle analysis (LCA) from a cradle to a mill gate has shown (Tran et al., 2019) that the production of meal worm larvae has greater influence on the basis of per kg protein than soybean and fish meal (cumulative demand for energy, land usage, eutrophication potential, climate change and acidification potential,). The results of food and oil production and use of feed and power is greatly influenced. Productivity enhancement of mealworm is thus necessary to boost mealworm output environmental efficiency (Thévenot et al., 2018).

Mass production of animals in negatively effecting the environment due to ammonia and green gas emission and consumption of water, energy, and land resources. The water consumption per edible ton of mealworms is 4341 m3/t, which is equivalent to that of poultry meat and 3.5 times lower than that of beef production (Miglietta et al., 2015). The energy utilisedto produce one kg of fresh mealworms was equivalent to that consumedin the formation of beef and pork, but the land area essential was much less as compared to beef, chicken, and pork (Oonincx and Boer. 2012). The discharge of ammonia and greenhouse gasses (CO2, N2O and

CH4) was significantlylower for mealworms in comparison to livestock (Oonincx et al., 2010). Mealworms also require less land to produce one kg edible protein than livestock (Nowak et al., 2016). With establishment of prime diet, feed conversion efficiency is almost equal to poultry but higher than conventional livestock (Oonincx et al., 2015). The diet rich in protein can enhance the larvalgrowth and reduce the duration of its development (Oonincx et al., 2015). Mealworms can therefore be produced with least damage to the environment as compared to livestock, and almost equall in nutrition to that of animals and poulty for human consumption.

MEAL WORM PROCESSING

Pre-treatment of meal worm larvae

Meal worm larvae are blanched at a larva to water ratio of 1 ratio 12 (w / w) in boiling water for 10 minuts to avoid drop in water temperature.Thereafter the excess water is drained, and larvae are frozen individually at −38°C in a shock freezer for around 20 minutes in order to preserve pour-ability and then stored at -30°C for further usage. Frozen larvae are evenly placed on trays in a thin layer before drying and thawed at room temperature for one hour before use (Benedict et al., 2018).

Drying mealworm larvae

All drying methodolgies for the processingof meal worm larvae have uptimisedin many experiments to get lower the water content less than 7.0% with water activitybelow 0.60. To measure storage stability,additional research trials are required to be conducted for samples desired water content and activity. After drying the larvae are conserved in polyethylene bags to eliminate the entrance of moisture at 5 °C with 75% RH in a climatic chamber until further use (Kroncke et al. 2018). Although, mealworms are fed live to pet and poultry animals, but they are also available as dried,canned or in processed to powder form (Aguilar-Miranda et al, 2002; Hardouin et al, 2003; Veldkamp et al, 2012). The larvae are dried at diffferent temperature as 100°C for 3½ Hr (Wang et al, 1996), 50 °C for 24 Hr (Klasing et al, 2000), sun dried for 48 Hr (Ng et al, 2001), oven dried for 3 minutes at 60-100 °C after boiling in water for 3 minutes (Aguilar-Miranda et al, 2002).Convectional drying of hot air was carried out at ventilation stage 2 using a rotating air oven (Memmert, Schwabach, Germany). Convection oven packed with larvae thawed at 1.73 kg. The larvae were dehydrated to stable mass at 60 and 80°C for a time of 24 and 7 hrs, respectively. After drying, larvae were refrigerated to room temperature for 2 h, sealedin bags to keep away frommoisture and kept at room temperature for further use (Benedict et al, 2018). The same method is used by Kroncke et al. (2018) using a rotating rack oven. A layer of 800 g larvae was placed on plate having area of 80 x 60 x 2 cm at the center of rotating oven to dry out the solid larvae for 1 hr at 120 °C.Microwave aeration was carried out in a conservative microwave. Another procedure to dry off the frozen larvae a backing plate of (35 x 45 x 3 cm) were placed having 150 g of larval mass in microwave for drying at various time and power setting were examined. The results obtained that moisture content below 7 % would optimize at drying time at 10 minutes with power of setting of 850 watt, respectively (Kröncke et al, 2018).

Freeze drying of Meal worm larvae

The freeze-drying procedure of mealworm were adopted by using deep freeze dryer (Martin Christ, Germany) for 24 hrs. A mass of 200 g larvae was placed on the freezing plate in drying process, vacuum and -50 °Cwas applied on condenser (Kröncke et al, 2018).Larvae freeze-drying was done using a 0.2 mbar freeze-dryer benchtop test scale. A1.73 kg of frozen larvae was placed into the drying container. Lateron, the larval mass was in airtight containers and stored at room temperature (Benedict et al., 2018).

De-fatting Mealworm larvae

It is important to develop specific product types and test their properties earlier to use insects as alternate food item. Yang-Ju Son et al (2020), developed two specific trade items from mealworm, a common food insect (defatted powder and oil). A decent amount of protein contained in the defatted mealworm powder and a savory flavor owing to its plentiful free amino acids. However, mealworm oil was ideal for industrial uses for its predicted shelf life. In fact, mealworms had elevated rates of antioxidants and anti-inflammatory behavior, attributable to specific glucosamine derivatives and peptides. Moreover, mealworms oil along with defatted residual powder could be a new ingredient in food items effectively.

Preparation of Mealworm Powder and Oil Samples

According to Yang-Ju et al., (2020) for processing of meal worm,live worms are fasted to clean their guts washed three times in tap water and blanched for three minutes in hot water (1:5, w/w). For cleaning and extracting excess vapor, the bleached mealworms were placed on a chiller and water was removed on paper towel after 30 mintutes time. For the drying of mealworms, an automated air dryer (LH.FC-PO-150, Pocheon, Korea) for 12 hrs at 60^{o}C was used.

The resulting powders were able to pass the 535 mg 30-mesh sieve and the whole fat mealworm denoted as WF-M was made after pulverizing by a blender made of Netherland (HR-2860) from the dried mealworms.For the oil extracting five-fold n- hexane was poured into the WF-M mass positioned on shaker for proper mixing at 170rpm for 6 Hr. Whatman filter paper was used for extraction purpose the procedure was repeated threewith the help of an evaporator n-hexane was removed at 34 ^{o} C. With the help of nitrogen gas, n- hexane in oils is excluded after 10 mints of centrifugation and supernantent was collected as mealworms oil.From DF-M the 80% methanol was extracted on room temperaturein a conincal flask. The methanolic extract was placed on shaker for 12 hr at 200 rpm. The filtrate was filtered again,and remaining powder was twiced extracted after evaporation.The yield was 15.5% ± 0.6%.4.

MEALWORM COMPOSITION

Like other insects, *T. molitor larvae*are also rich in protein, having range from 43.3 to 66.8% on dry matter bases (Jin et al. 2016; Ghaly and Alkoaik 2009). Meal worm protein are of high quality with all vital amino acids requiredto human being and animal as1.39 to 4.8% isoleucine, 2.81 to 8.65% leucine, 1.6 to 6.6% lysine, 0.64 to 7.6% methionine þ cysteine, 3.99 to 13.05% phenylalanine þ tyrosine, 0.93 to 4.43% threonine, 3.14 to 7.61% valine, 1.61 to 3.64% histidine, and 0 to 1.8% tryptophan **(**Zielin´ska et al. 2015;Aguilar-Miranda et al. 2002; Ramos- Elorduy et al. 2002; Ghaly and Alkoaik 2009; Barroso et al. 2014; Jin et al. 2016**)**. Larvae also have a fat content of between (17-42.48%)per dry mass **(**Siemianowska et al. 2013;Adamkova et al. 2016**)**. Relative to total fatty acids, there is a prevalence of palmitic acid **(**9.33 to 23.7%**)**, oleic acid **(**36.5 to 52.94%**)**, and linoleic acid **(**3.8 to 33.58%) (Alves et al. 2016; Martin et al. 1976; Zhao et al. 2016; Adamkova et al. 2016; Jones et al. 1972**)**. Mealworm mineral contented varies from of Ca 0.32 to 0.75 mg /g, Mg 1.45 to 3.4 mg/g, P (5.35 to 13.45 mg/g), K (6.37 to 13.45 mg /g), Na 0.025 to 1.76 mg / g, Fe 0.032 to 0.13 mg/g, Cu 0.012 to 0.04 mg / g, and Zn 0.082 to 0.145 mg /g, on DM bases (Siemianowska et al. 2013; Barker et al. 1998, Simon et al. 2014; Zielin'ska et al. 2015).

Mealworms nutrient components may be graded as "strong in" and "source" by United Nation Food labeling (Nowak. 2016). Mealworms are rich source of zinc andmagnesium but having low levels of calcium.

Furthermore, mealworms are the bestsource of riboflavin, niacin,pyridoxine, folate, and vitamin B12 (Nowak. 2016). Mealworms are nutritionally balanced than beef and poultry (Payne et al. 2016). It is also well-built source for all prime amino acids (Rumpold. 2013).

Hundred grams of crude mealworm larvae possess 14-25 g proteinsand about 206 calories of energy (FAO, 2018). The larvae of mealworm contain various level of micro elements such as selenium, copper, iron, potassium, sodium,zinc,and greater level of vitaminsthat's why it is almost similar to beef (FAO. 2018; Schmidt et al., 2018).Larvae of mealworm contain high level of protein and fat content with low level of carbohydrates (Yang-Ju Son et al., 2020).The composition of chill dried meal wormis analogous to that ofdehydratedmealworms (Zhao et al, 2016).The WF-M had higher lipd content of about 32.3% ± 1.0% which had greater value found in soybean and meat (Brewer, 2012;Friedrich. 1982). After oils extraction with n-hexane, there are 70.8% ± 5.8% protein inDF-Mwith lipid content of 2.0% ± 0.2%. Amino acid values calculated on amount of crude protein ratio and amino acid was found lower as compared to poultry meat (0.75) and beef (0.7- 0.8)(Lee, et al., 2016; Franco, et al., 2010).Moreover, the branched amino acids (BCAA) was 2% lower than that of eggs, beef and chicken (Lee, et al., 2016; Franco, et al., 2010).

Table 2. Compositional profile of amino acid of whole fat (WF-M) and defatted mealworm (DF-M)

Composition profile	WF-M	DF-M
Protein (%)	52.2 to0.6	70.8 to5.8
Essential amino acids (g/100 g protein)		
Histidine	3.1 to 0.0	2.9 to0.2
Lysine	5.1 to 0.1	5.1 to0.4
Methionine	0.5 to0.0	1.2 to0.1
Phenylalanine	3.9 to0.0	3.9 to0.2
Threonine	4.8 to0.0	4.3 to0.2
Isoleucine	4.5 to0.0	4.5 to0.2
Leucine	7.5 to0.0	7.5 to0.4
Valine	6.4 to0.0	6.4 to0.4
Sub total	35.8 to0.0	35.6 to0.3
Non-essential amino acids (gram/100 g protein)		
Alanine	8.1 to0.0	8.1 to0.6
Aspartic acid	8.4 to0.0	8.4 to0.4
Arginine	5.7 to0.0	5.7 to0.3

Cysteine	N.D.	N.D.
Glutamic acid	13.0 to0.	0 13.2 to0.5
Glycine	5.3 to0.0	5.3 to0.4
Proline	5.2 to0.0	5.4 to0.4
Serine	4.8 to0.0	4.8 to0.3
Tyrosine	7.3 to0.0	7.6 to0.5
Sub total	57.7 to0.0	58.5 to0.4
Total (E + NE)	93.5 to0.0	94.1 to0.4
E/NE	62.0	60.9
BCAA contents (%)	19.4 to0.0	18.3 to0.4

The amino acid scores were planned with the criterion of FAO/WHO 1985. DF-M and WF-M both was limited as methionine. The WF-M and DF-M amino acid level varies due to loss of unlike amino acid, similarly methionine and lysine are also limited in soybean anad grains. Moreover, it is needed to supplement methionine in feed of mealworm to improve the amino acid score.

Table 3. Amino acid profile of (WF-M and DF-M) mealworm powders

Amino Acid profile	FAO/ WHO	WF-M	DF-M
Lysine	55	51.1	50.8
Histidine	20	30.7	28.9
Threonine	40	47.9	43.3
Phenylalanine + Tyrosine	60	111.6	114.5
Methionine + Cysteine	35	5.1	11.5
Leucine	70	75.4	74.5
Valine	50	63.9	64
Isoleucine	40	44.6	44.5
Limiting amino acids		Met	Met
Amino Acids Score (AAS)		14.6	32.9

USES OF MEALWORM

Meal Worm as Food and Feed

Traditional foods are recognized by the society as suitable and acceptable sources of food through habit and practice. Traditional food could be collected from agricultural or wild harvested locally and used within a given natural environment and is an important part of routine diet throughout the world. Indigenous people's food systems highlight the necessarypurpose of a new diet based on the indeginous animal and plant species and local foods.

In majority the preservation process and industrial useof food stuff for a long period leads to a decline in diet quality. In some countries and societies, the local food recipes are conserved to protect local food specialities, as in Mexico, it is common to find tortillas enriched with a yellow mealworm a conservative source of protein. Mealworms are edible for human and as well as processed item in various retail food items (Aguilar-Miranda et al., 2002).

Mealworms are mostly used for fish, fancy birds and reptiles as pet food, it is specially used for wild birds in time of nesting season. It has a high protein value and act of its use as human food is known as entomophagy. Business farmers use a juvenile hormone to gripthe larval form and to attain its length of 2 cm or more in the feeding course. (Finke and Winn, 2004). Worms are historically used in most of the south Asian countries and found in local venders markets as a street food alongsideof roads with other edible insects. Utalization of Baked/fried mealworms as a healthy snack goes back of centuries, moreover, mealworms are used in tequila flavoured novel candies nowadays.

Meal Worm as Poultry Feed

The major economic factor that increase the cost of poultry feed are soybean and fish meal as these have scrce nature of availability and ultimately affect the productioncost. (Adeniji, 2007). Soybean and fishmeal are mainly used as protein source in poultry feed. Poultry scientist are in search of alternative protein source to overcome the high import cost along with dependency of fish meal and soymeal and replace it with good alternate. Utilization of insects including black soldier fly larvae, maggot meal, earthworm and mealworm as protein source for the replacement of soya-bean and fishmeal in poultry ration is gaining interest (Van Huis et al, 2013; Khan et al, 2016, 2017). Mealworms is reported as best insect diet in comparision to silkworm and maggots meal on broiler performance and meat quality (Khan et al, 2017). The yellow mealworm has the potential to the lower feed conversion rate, thus resulting to reduce the overall expenses incurred on finished feed. (Ballitoc and Sun 2013). Generally, insects and mealworm in special is good alternative of soymeal in poultry diets with no negative effect on growth and palatability (Bovera et al, 2016).

Mealworm meal (MWM) is rich in protein, fat, energy, and fatty acids and can be successfully used as feedstuff in poultry diets. (Calislar et al., 2017) or may be a good alternative source in poultry ration, especially for replacing fishmeal or soymeal. The protein quality is like that of soymeal, only the methionine content is limiting for poultry (Ramos-Elorduy et al., 2002) which coul be increased through enrichment of meal worm feed. Due to its high amount of protein, fats, amino acid and mineral content; meal worm can easily be included in the poultry ration (Aguilar-Miranda et al. 2002)

The low calcium content in meal worm meal is also a limiting factor for its inclusion in poultry ration. Howeveer, calcium content and the calcium: phosphorus ratio of mealworms could be enhanced throghsome calcium-fortified diet offered to the worms for 1-2 days. The calcium supplied by calcium-fortified mealworms was highly available for supporting bone mineralization in growing chicks, although availability of calcium from enriched meal worm meal was slightly less than the Calcium from oyster shells (Klasing et al., 2000). Anderson, (2000) reported that short time (72 hours) feeding of mealworms with a Calcium-fortified commercial ration resulted in acceptable calcium levels in the next 24 hours.

In addition, the presence of digestive enzymes in insects could also influence protein properties after grinding (Lwalaba et al., 2010). Thus, drying insects via heating seems to be suitable for feed production. Proper processing of insects makes it gluten-free. (Mancini et al., 2020) although, heat treatment is beneficial from safety point of view, but denaturation and Millard reaction could affect the solubility and availability of essential amino acids. Still, there is much controversy about the use of dried and fresh form of the insect meal.

Insects are natural food sources for poultry, and they are considered a fundamental protein source for backyard poultry. Many insects have been used in poultry feed, such as grasshoppers (Hassan et al., 2009), house flies (Hwangbo et al., 2009), and mealworms (Ramos-

Elorduy et al., 2002).There are limited information on the use of mealworms in the diets of laying hens. Larvae from T. molitor and T. mauritanicus were found to be suitable for layers. Dried ground mealworms when replaced with fishmeal in the diets of laying hens resulted in 2.4% higher egg-laying ratio than that obtained with fishmeal-based feed (Wang et al., 1996).

Dried mealworms inclusion up to 10% (on DM basis) in soybean meal and sorghum based broiler starter ration could be used without adverse effect on feed intake, weight gain and feed efficiency. There was no observation regarding rejection of feed due to palatability, texture, or inclusion level (RamosElorduy et al., 2002). In another experiment (Schiavone et al., 2014) found that 25% mealworm, as a substitution of the basal diet, was suitable. Meat quality of chicken fed mealworm are reported juicy, however it was noted that 10 % inclusion of mealworm resulted heavier gizzard mass. Simlarly, inclusion level did not effect physiological properties of the ration which suggest the safe inclusion of mealworm in chicken ration (Ballitoc and Sun, 2013). It is added that mealworm in poultry diet have improved growth performance and feed efficiency (Hussain et al, 2017).

Lower albumin-to-globulin ratio observed in blood samples of broilers fed with meal worm (Bovera et al., 2015), suggested that feeding mealworms could improve the immune response of birds. It is associated with meal worm fed broilers is of prebiotic effects of chitin. Similarly, haemato chemical parameters and carcass traits of broiler chickens were improved when fed with yellow mealworm larvae. It was also observed the misutre contents of thigh meat were signifantlyincreaseed in chickens fed with 1% ground yellow mealworms. (Biasato et al. 2017).

Changes in health status of chicken fed with meal worm are also important to be considered. Assessing footpad print resulted a condition score of zero described that chicken fed on mealworm diet have no sign of footpad dermatitis (Biasato et al, 2016). The inclusion of mealworm in poultry diet could be measured on its economic aspect, health and welfare. However, when broiler chickens were fed 10% mealworm meal, in the ration the weight of only small intestine was increased as compared to the rest of gastro intestinal tracts (Ballitoc and Sun 2013). The chitin in insects is reported to decrease digestibility of protein in chicken (Khempaka et al, 2011), while in insect meal it potentially improve health status through its control on intestinal Escherichia coli, Salmonella and Lactobacillus spp. Ravzanaadii et al. (2012),observed no existence of E. coli and Salmonella spp. in larvae, adult, exovium and excreta of meal worm.

On basis findings, currently it is possible to host mealworm both in human and animal food. However, further research on infectious microorganism, assessed quality of edible insect and management strategies are required to mimimise risk factors.

Meal Worm as Fish Feed

Protein source in aqua feeds are mostly contained fishmeal as primary source. Due to its high protein content enriched with essential amino acids and palatable nature has increased the demand of fishmeal and fish oil in aquaculture and resulted increase in prices their prices (FAO. 2018). It is therefore search of sustainable and profitable protein source for aqua culture are under consideration to overcome the situation (Henry et al, 2015, Slater et al, 2018). In this instance plant protein as soybean, wheat have been possible alternative of high protein content (Gatlin et al., 2007, Olsen et al., 2012). However, vegetable-based feed ingredients have been reported to have low amin acid profile along some anti nutritional factor and low palatiblity (Ghosh et al., 2018). Insect meal based on its composition of aminoacid, minerals and vitamins has been reported as a natural alternative to fishmeal (Henry et al., 2015; Barroso et al., 2014). The CP of 50% to 82% on dry mass bases has been reported in insect meal, depending upon the insect species and processing method (Rumpold et al., 2013) are in valuable range in comparsion to fishmeal and palnt based protein source (Barrosoet al, 2014). Further more insect meal production relatively required less arable land and energy with low water need as compared to crops, roughages and crop by products (Miglietta et al., 2015). A life cycle assessment study reported a lower environment impact of insect proteins than fish meal over most of the impact criteria (Smetana et al., 2019). The beneficial features of insect life cycle are related to agriculture products and wastes substrates for and growth devlopement (Van Huis et al., 2017). Considering, its features insect meal of different as grasshopper, locust,mealworm, super worm, silkworm, house fly, black soldier and yellow mealworms have been evaluated for addition of aqua feeds (Henry et al., 2015).

Yellow mealworm (Tenebriomolitor) has been reported as a suitable candidate for mass production due to it easy feed and breed (Barroso et al., 2014; Belforti et al, 2016). Mealworm larvae feed on plant by-products and have comparatively short life cycle (Li et al, 2013). The life cycle of mealworm varies in different stages as 3-9 days egg stage, larval stage 26-76 days and pupal stage 5-17 days. Mealworm contained rich amount of protein and fats and has been processed and replaced of fish meal in the diet of aqutic species. Similarly, 25 % and 50 % of mealworms larvae has been replaced with no negative effect on performance of 33% and 74% fishmeal in the diet of gilthrad Sea bream (Sparusaurata) (Piccolo et al .,2017). However, inclusion of 25% mealworm resulted better weight gain, feed utilization with decreased in apparent digestibility on increasing level of inclusion in the ration (Piccolo et al., 2017). In African cat fish 17% inclusion level of mealworm on replacing 40% fishmeal resulted better performance (Khosrava et al, 2018). Juvenile rockfish (Sebastesschlegeli) performed better with inclusion level 32% on 38% fishmeal with no side effects on health status (Khosrava et al., 2018).

Similarly, rainbow trout () fed diet having fishmeal of 33% and 66 % replaced with inclusion of 25% and 50% mealworm respectively, revealed no differcne on growth performance while showed effect on feed utilization and fish survival rate (Belforti et al, 2016). Different studies have addressed that fishmeal could be replaced with mealworm based its relative high fat level (Dreassi et al., 2017) as it have excellent composition of amino acid with low quality amino acid profile (Henry et al., 2015). However de-fattening could improve its digestibility and palatability to make it suitable diet ingredient for aqua culture (Henry et al., 2015).

Meal Worm as Probiotic

Probiotic include different category of microorganisms that advance gut micro flora and manipulate local and general immune systems by releasing beneficial enzymes, non-toxic substances, antibacterial organic acids and vitamins once ingested (Jun et al., 2002)Insects are now being consider as a highly nourishing and fit food resource with improved protein, fat, vitamin, fiber, and mineral contents (Van Huis et al., 2014). Probiotic bacteria enhance the suitability of the host (Havenaar et al., 1992: Wan LY et al., 2016). These bacteria regulate the functions of epithelial barrier and provides the antimicrobial complexes to decrease the virulence of bacteria and boost up immune system (Oelschlaeger et al., 2010).

However, it is to investigate that how mealworms respond to probiotic bacteria during growth and illness, because of several bacteria are probiotic in one specie and pathogen in another, so prescreening of bacteria prior use on commercial scale worthwhile. Similarly, pseudomonas aeruginosa is probiotic inrohu (Labeorohita) and pathogen in human being (Hai et al,2009; Giri et al, 2012). Therefore, promising worth of mealwormare due its positive effect on probiotic bacteria to increase health promoting metabolites (LeBlanc et al.,2013; Rossi et al., 2011). It is added that probiotic effect of mealworm was noted in chicken supplemented with mealworm lower the level of pathogenic bacteria such as E coli and salmonella in gut flora (Islam et al, 2017). It imitate that uptake of larval micro biota in feed especially chitin fibers act as prebiotic in aqaua culture (Ringo et al., 2012; Song et al., 2014). It is therefore suggested that addition of probitic bacteria to diets of mealworm can mutualize the effect of both and can generateinsect based diet for human and livestock.

Meal Worm and Waste Disposal

Mealwormhave the ability to degenerate the polystyrene to valulabeorgamic matter on rate of 34-39 mg/day(Rob Jordan. 2015).It is based on one month experiment, mealwroms fed on conventional diet and Styrofoam have no difference (Jordan and Rob, 2016). Similarly, it was concluded that mealworm gut microflora are liable to degrade polystyrene and addition of antibiotic conceal degradation (Lockwood and Deirdre, 2019). The isolated colonies of microbes in the mealworm gut were found less effective at degradation than the bacteria in the gut. (Lockwood and Deirdre, 2019). The current of use of synthetic plastic is about 299Mt/year. Polystyrene are about 7.1% of the total consumed plastic in 2013, athough it is a durable product for short services time with low cost material led to build up waste in environment. Moreover, these solid waste are disposed off with municipal waste in landfills and even this debris is dispersed as white pollutant in environement as well (Barnes et al., 2000). Biodegradation of polystyrene is still thought that it cannot be degraded by microorganism(Gautam et al., 2007). However, a few strain of soil bacteria capable of being to colonized surfaces of polystyrene and change its physio-chemcial properties but still not proven how much it is effective in biodegradation process (Mor et al., 2008; Atiq et al., 2010). To answer this quarry Yang et al., (2015) conducted a study on the use of meal worm for this purpose and prove thatworms caneat Styrofoam as their sole diet. It is was stated that polystyrene degradation does not occur in gut of mealworm directly but after the passage way through gut systemthe Styrofoam mass is converted into CO_2 and biomass which confirm the degradation in larvael gut, hence the petroleum based plastic can be biodegraded in environment.

Consumer Acceptance of Meal Worm

The consumer preference varies on ground of differiernt factors as availability, taste, price and culture (Lensvelt, Steenbekkers. 2014; Verbeke. 2015 and House. 2016). Mostly, human being avoidsinsect-based food in general due to unpalatable nature (Barnes, Siva-Jothy. 2000). However, being process mealworm in various food products as burgers and tortillisetc which may attract the consumer indirectly. Moreover, it is added that consumer can be attracted for insect meal by providing information regarding potential benefits and risks openly (van Huis. 2016). Insect based livestock feed is highly acceptable because of being a part of natural food chain in both fresh water fishes and backyard poultry (Verbeke et al., 2015). Similarly, with the passage of time, consumer preference will change due to cost variation, currently mealworm-based diet priced at the rate of 15 €/kg, which is much costly than soybean meal 0.33€/kg and fishmeal 1.22 €/kg. It is predicted that in future, the cost of fishmeal and soybean will go high and whereas the price of insect will decline which encourage the consunmption and production of insect meal (Verbeke et al., 2015).

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