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RESEARCH ARTICLE

Environmental, Economic and Social Impact of Biological Control Interventions in Papaya Farming in Sindh, Pakistan

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ABSTRACT

Papaya (*Carica papaya* L.) is one of the important fruit crops in Sindh, Pakistan. However, in recent years, the papaya crop had been adversely affected with papaya mealybug. Centre for Agriculture and Biosciences International (CABI) initiated its project “Phytosanitary Risk Management Program (PRMP)” in Sindh province to implement an established technique of biological control of papaya mealybug during 2014 and is still in progress. The natural enemies of the papaya mealybug were explored prevailing in local environment and their mass rearing techniques were developed in PRMP Biological Control Laboratory Karachi. Furthermore, augmentative releases of natural enemies were made from the laboratory culture at farmer’s field and their population was strengthened with Natural Enemies Field Reservoirs (NEFRs) established among papaya growers. As biological control is a new concept in Pakistan to adopt as management strategy, a series of capacity building sessions were implemented for farmers, traders, and associated public and private sector services and input suppliers on this technique. To assess the efficiency and sustainability of the implemented program under PRMP, a survey was conducted during 2016, where environmental, economic and social impact of the biological control interventions was analyzed in Sindh province. The results showed that the population of papaya mealybug got reduced significantly due to biological interventions and papaya yield was increased from 19.43 to 23.04 tons per acre. Initially, 38% reduction was observed among respondents in using insecticides but after successful implication of biological interventions, about 90% of them were observed to adopt biological approach and replaced the use of insecticides on papaya crop. Furthermore, an increase of 63% was observed among respondents who started to consult extension agents for their farming issues. In case of clean cultivation, increase of 64% was observed among respondents who started to practice throwing away infested papaya thus avoiding dispersal of mealybug to healthy plants. These results also helped papaya farmers to revive their papaya industry and 83% satisfaction level was observed among respondents in cultivating papaya as compared to 35% a year ago. So, biological interventions resulted in reduced application of pesticides on papaya plants, increased papaya plantation and effective biological control of Papaya mealybug.

INTRODUCTION

Papaya (*Carica papaya* L.) belongs to the family Caricaceae. It was discovered from southern parts of Mexico. As a constant plant it is distributed over the whole tropical area. Papaya plants and its parts can be used as medicine, fruit flesh, flowers and seeds. Ample scientific investigations have been conducted and reported on biology, physiology, breeding of new hybrid lines, production technology, postharvest handling and technology, and nutritional importance of papaya (Vyas and Shah, 2016). In specific context of

Pakistan; two major varieties of papaya i.e. Sindhi and Bombay are commercially cultivated in areas surrounding Karachi (Nadeem et al., 1997). Papaya seed is planted during the month of March to establish nursery plants and nursery transplanting is done in April. Papaya plants continue to fruit throughout the year (Zhou et al., 2000; Singh et al., 2014).

Being rich in nutrients, papaya is called the powerhouse of nutrients (Singh et al., 2014). Different parts of papaya plant including leaves, seeds, latex and fruit have exhibited to have medicinal value (Subenthiran et al., 2013). Papaya fruit is a rich source of three powerful antioxidant vitamins: A, C and E (Aravind et al., 2013) and contains two important minerals i.e. magnesium and potassium. Additionally, the papaya fruit also contains a digestive curative enzyme - papaintha, which is an efficient treatment of trauma, allergies and sports injuries (Afolabi and Ofobrukweta, 2011). As a whole all the nutrients of papaya fruit improve cardiovascular system, protecting against heart diseases and heart attack, strokes and prevent colonel cancer (Begum, 2014). Papaya is also reported as Neutraceutical for its role in management of several other diseases like warts, corns, sinuses, eczema, cutaneous tubercles, glandular tumors, blood pressure, dyspepsia, constipation, amenorrhea, general debility and to expel worms (Aravind et al., 2013). The properties of various applications of alcoholic abstraction of papaya (root, shoot and seed) were found very effective for the circular development of plant against the pathogenic fungi viz. *Aspergillus niger, Aspergillus flavus, Candida albicans* and *Microsporum fulvum* (Kumar et al., 2013). Papaya leaf extract is also reported to have an antibacterial action against gram positive bacteria such as *B. cereus, B. subtilitis, β-hemolytic streptococcus* and *B. megaterium* (Orhue and Momoh, 2013).

Trade of papaya fruit is a source of income and livelihood for a huge number of small and medium scale families associated with this business all around the world. The international trade of papaya fruit also contributes to the earning of foreign exchange in papaya producing countries in the world. The international export of papaya fruit has seen an upward trend since 2002. However, despite the reported increase in export, only about 3% of the annual global production of papaya fruit is exported. Mexico, Brazil, and Belize are the top three exporters with a share of about 63% of the global trade (Evans and Ballen, 2012). Other papaya exporting countries also include Malaysia, India and the United States (Diop and Jaffee, 2005).

Commercial cultivation of papaya for fruit production is considered profitable. The input:output economic analysis (1:1.7) of papaya farms in Karachi Pakistan showed that the average gross income of papaya farmers was PKR 0.55 million ha^{-1} while their gross expenditures were PKR 0.20 million ha^{-1}. Thus, average net returns remained ~ PKR 0.35 million ha^{-1} during the crop season of 1999-2000 (Oad et al., 2001).

Beside the papaya fruit, all other parts of papaya plant are also of high economic value, although the potential use of papaya plant parts, other than fruit, has not yet been realized in Pakistan. For example the white pulp of raw papaya is used in cosmetic industry for improvement against pimples and wrinkles, papaya extract is used as bleaching agent in textile industry (Krishna et al., 2008) and the Papain enzyme is used as meat tenderizer in culinary industry (Ashie et al., 2002).

Several pests attack papaya plantations and damage various parts of the papaya plants. Pest damage is reported to be the largest source of plant and fruit damage (Bajwa et al., 2015). Some of the examples of pests of papaya and their damage on plant tissues include; Papaya Leaf-Distortion Mosaic Virus produces rosettes of leaves with slender stems on crown top and a bumpy swelling around the ring spots (Maoka and Hataya, 2005). Infected seedlings start to wilt, fall and eventually die. Phytophthora forms large lesions on leaves, stem, and fruit tissues and induces root rot in both the young and adult plants (Alvarez and Nelson, 1982). Papaya mealybug results in chlorosis of the damaged plant parts (Tanwar et al., 2010). At an advanced stage, the chlorotic areas are transformed to brown regions and ultimately the plant tissues are dried. On leaves, stem, and fruit; the damage symptoms can also be observed as clusters of masses of cotton. Adults and nymphs of white fly slurp the plant sap and compromise the plant vigor. In the instances of intense white fly infestation; the leaves turn yellow and drop. This insect naturally secretes honeydew. If its population on plantation is dense, the honeydew secretions favor the growth of sooty-mould on leaves and decrease the photosynthetic efficiency of the plants (Jones, 2003). Spider mites usually extract the cell contents from the leaves using their long, needle like mouthparts. This results in reduced chlorophyll content in the leaves, leading to the construction of white or yellow speckles on the leaves (HsiHwa et al., 1996). In intense infestations, leaves will completely desiccate and drop off. The mites also produce webbing on the leaf surfaces in severe conditions. Under high population densities, the mites move by using strands of silk to form a ball-like mass, which will be blown by winds to new leaves or plants, in a process known as "ballooning". The female fruit fly breaks outer wall of mature fruits with the help of its pointed ovipositor and insert eggs in small clusters inside mesocarp of mature fruits (Vargas and Carey, 1990). On hatching, the maggots feed on fruit pulp and the infested fruits start rotting due to further secondary infection.

Of the aforementioned pests of papaya, mealybug is the most notorious pest and causes maximum damages (Tanwar et al., 2010). It damages papaya crop and causes huge losses to both producers in the form of reduced income and consumers in the form of costly fruit. For example, this pest resulted in a loss of USD 29 million in Brazil (Oliveira et al., 2014). This translates into a loss of USD 820 ha^{-1}. In India, this pest attacked more than 60 crops including papaya during 2008 to 2010 and damaged 10-60% of the crops (Myrick et al., 2014). Heavy losses in production of papaya were also reported in Mexico due to papaya mealybug attacks (Piragalathan et al., 2014). Bajwa et al. (2015) reported that papaya farmers in Pakistan identified papaya mealybug the most significant technological problem in continuity of papaya production in the region. The survey respondents reported that even the increasing frequency of pesticide application could not manage the papaya mealybug population below the economic threshold levels. Rather, this resulted in environmental pollution due to heavy pesticide application. The damage due to papaya mealybug forced the papaya farmers of Sindh, Pakistan to replace papaya production with alternate sources of farm earnings. The aforementioned economic and environmental losses also resulted in social sufferings of the communities associated with papaya farming in Sindh Pakistan.

Owing to the huge economic, environmental, and social issues originating from the papaya mealybug, and the natural resistance of the insect against pesticide application; biological control had been successfully implemented in several world countries (Tanwar et al., 2010) which includes Dominican Republic (Kauffman et al., 2001), Guam (Meyerdirk et al., 2004), India (Lyla and Philip, 2010; Regupathy and Ayyasamy, 2012; Myrick et al., 2014), Malaysia (Mastoi et al., 2016), Puerto Rico (Kauffman et al. 2001), and Republic of Palau (Muniappan et al., 2006).

The Indian experience of releasing the parasitoids of papaya mealybug demonstrated a benefit of USD 14.25 million after the first year and the net present value over 5 years was USD 62.51 million (Myrick et al., 2014). Another study showed that India's bio-control program's economic benefits ranged from USD 121 million to USD 309 million. The net present value of benefits over 5 years was between USD 524 million to USD 1.34 billion (Myrick et al., 2014). This established the importance of biocontrol program for papaya mealybug.

Since the incidence of mealybug was reported as the serious most concern of the papaya farmers of Sindh (Bajwa et al., 2015); a holistic approach for mitigation of mealybug by implementation of a biological control program was developed. A fully equipped biological control laboratory was set-up at the premises of a partner organization. The mealybug species was collected from papaya plants and authenticated as ‘papaya mealybug’ by identification from the Natural History Museum in United Kingdom. As reported above, papaya mealybug is being managed in different parts of the world with conservation of its natural enemies and it drove the researchers in Pakistan to explore and conserve natural enemies for this notorious pest in the climate of papaya production areas of Pakistan. Complete physiology and life cycle of the papaya mealybug and its natural enemies were studied and the best stage of the pest for control by its natural enemies were scientifically verified and documented.

This paper describes the impact of the biological control interventions for papaya mealybug and their environmental, economic and social impact in the papaya production areas of Sindh after two years of implementation of biological control interventions in the target areas.

MATERIALS AND METHODS

A survey of the papaya farmers in geographical areas where PRMP had made biological control interventions was conducted during 2016. Owners of papaya farms where PRMP had made direct releases of parasitoids of papaya mealybug, papaya farmers who had participated in PRMP capacity building activities, and papaya farmers who were in the geographical area of PRMP intervention but had not been directly benefitted from PRMP interventions were randomly identified, with the support of the Department of Agriculture Extension Government of Sindh, for participation in the survey. A structured questionnaire was developed with the support of experienced scientists working in the area of biological control of papaya mealybug and the experts on monitoring and impact assessment of project-based interventions on the livelihood of target communities. The survey was implemented by the enumerators associated with Department of Agriculture Extension Government of Sindh. Prior appointments were made by the enumerators with the respondent papaya farmers and volunteer data collection was made to quantitatively determine the environmental, economic and social impact of PRMP biological control interventions in papaya production areas in Sindh.

Information collected from respondent farmers was entered in Microsoft Excel® data sheet and subjected to statistical analysis for interpretation of farmers’ responses into quantitative data for presentation in the following section.

RESULTS AND DISCUSSION

Of the survey respondents, 91% papaya farmers had participated in trainings associated with PRMP whereas 9% of the respondents had not participated in any capacity building activity. Entire population of representatives of papaya farmers who had attended PRMP trainings were aware of the concept of integrated pest management (IPM) and biological control of papaya mealybug. The respondents advised that, compared with a year ago, the average cultivable agriculture area had decreased from 17.3 to 13.4 acre per household that implies about four acre per household decrease over a period of one year. The major reason for reduction in cultivable land is the shortage of irrigation water. The respondents reported that papaya yield has, nonetheless, increased in one year from 458.7 to 575.6 mound per acre (one mound = 40 kg, 117 mound net increase per acre). This major contribution to this increase is biological control of papaya mealybug. Responses to survey questionnaire by the papaya farmers relevant to the environmental, economic and social impact of biological control of Papaya mealybug are described hereunder.

Pest management information sources

Among respondents, 7% reported to get information relating to pest management direct from CABI sources compared with none a year ago. After successful implementation of biological control interventions for papaya mealybug; papaya farmers doubled in number in a year to get advice from trained extension agents to address their pest problems. These extensions agents were trained by PRMP through different capacity building workshops on biological control of papaya mealybug. Dependence of respondents to find solution for their pests on agro dealers or other farmers was significantly decreased (65% and 100% respectively) as compared to a year ago. This reveals the positive impact of PRMP biological control interventions among papaya growing community of Sindh. Among the respondents who still use chemical pesticides; agro dealers remained the main source for selection of pesticide for specific pest a year ago. But, the dependency of respondents on agro dealers for this purpose significantly (21%) decreased this year and an increase of 63% among their population was observed who started to consult extension agents for pesticide selection as compared to one year ago. Consulting only with agro dealers for pesticide selection has been reported to generate many obstacles in getting proper control of pest. Most of the time, recommendation from dealer is based on information provided by grower and in many cases dealer gets the misleading information which results in selection of inappropriate chemical. This not only causes wastage of money for growers but also impose negative impact on ecosystem through its disturbance. In contrast, extension agents are properly trained manpower with complete knowledge about crop production and crop protection and have more consistent association with field conditions. Extension agent provides solutions on basis of direct field observation and current situation about prevalence of any pest on crop and the best possible control measure of IPM to control the pest by minimally compromising the environment (Figures 1 and 2).

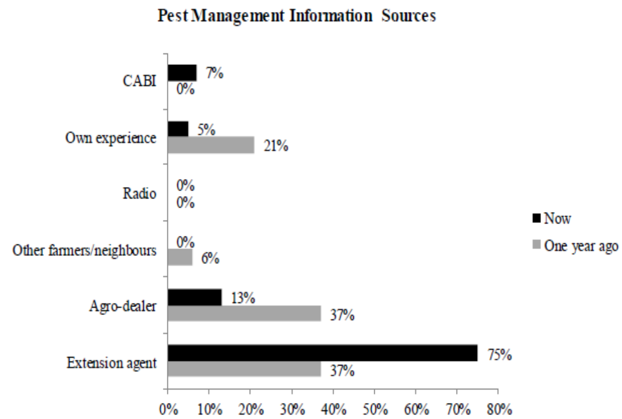

Fig. 1: Pest management information sources

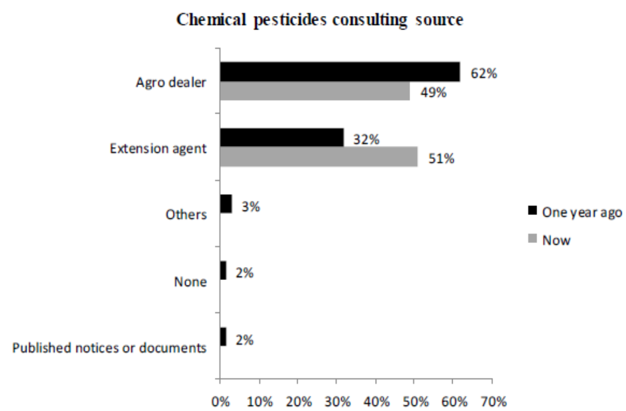

Fig. 2: Chemical pesticides consulting source

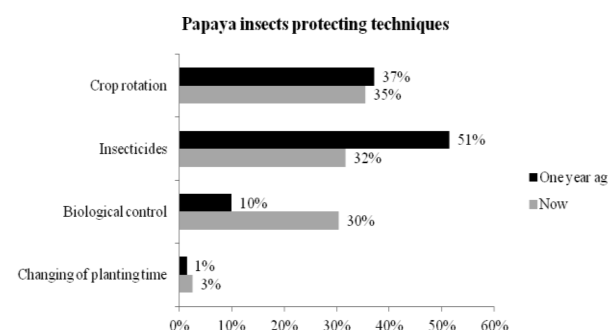

Fig. 3: Papaya insects protecting techniques

Papaya mealybug control measures

It was evident from respondents that insecticides was considered as main management tool followed by crop rotation to control their pests a year ago, and biological control was significantly neglected among papaya growing community. After implementing biological control interventions; 38% reduction was observed among respondents in using insecticides to control pest problems and there was significant increase of two folds in adaptation of biological control as management technique among papaya growers of Sindh as compared to year ago. A slight reduction was observed in using crop rotation practice. Growers mainly rely on chemical dependence due to its rapid control strategy against pest (Figure 3).

Non-judicial use of chemicals over long period of time resulted in deterioration of environment and even in some cases resistance development has been reported in many pests against number of chemicals. It has reduced the efficacy of chemicals in practice which propagates the pest population in cropping system. Adoption of alternate approaches like biological control, being safer to environment and human health, is getting greater attention all over the world. Concept of integrated pest management programs should be focused and developed among growers to combat pest problems in a sway that should be safer to environment and economically sound.

Replace pesticides

It was noted that a year before applying biological control interventions, there was significantly high rejection rate among papaya growers to replace pesticides with other suitable management techniques. Only 2% of the respondents were willing to replace pesticide at that time. While of the respondents, who were attending PRMP trainings and using biological control interventions, a significantly high adaption rate (90%) was observed in replacing pesticides with biological control interventions as management tool for their pest. The awareness among growers is considered as main driving force behind selection of any management approach. Most of the time, growers take chemicals as only management approach and they are seemed to be reluctant to adopt any alternate management approach. So, increasing awareness and knowledge level among growers through different resources and providing accurate information about pest activity can greatly influence the adoption level among growers (Figure 4).

Usage of infested papaya

For cultural practices, respondents were seemed to adopt interventions demonstrated during different PRMP trainings. Clean cultivation was practiced more precisely as compared to year ago and trend to leave infested papaya on field was reduced (12%), while practice of throwing away and burying the infested papaya was increased significantly (64% and 71% respectively). A reduction of 32% was also observed in using infested papaya as livestock feed. Ignorance of cultural practices plays an important role in establishment of pest in a field. Refuge of crop and fallen leaves acts as reservoir for hibernating pest and supports the development of next generation within micro climate of the crop. So, regular clean cultivation and removal of crop debris from the field can greatly reduce the pest population (Figure 5).

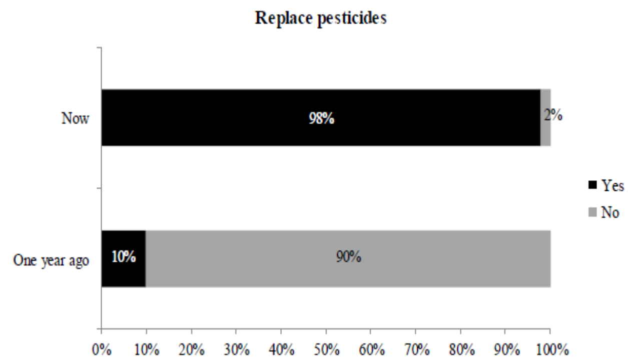

Fig. 4: Farmers willingness to replace pesticides (%) (Now only 14% farmers are using selective pesticides against Papaya mealybug while others controlling through biological control methods. 100% farmers used pesticide one year ago).

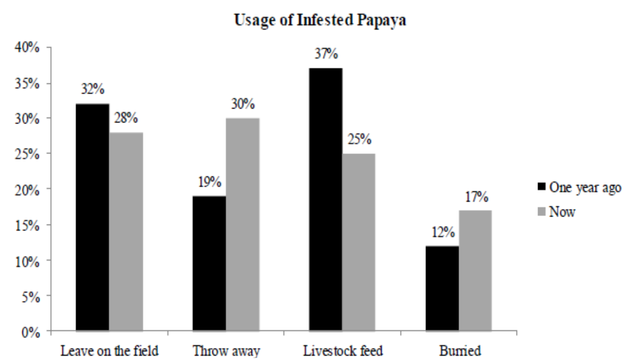

Fig. 5: Usage of infested papaya

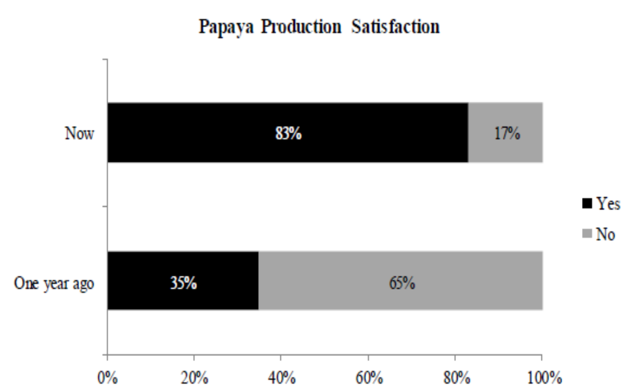

Fig. 6: Papaya production satisfaction

Papaya production satisfaction

A significant variation among papaya growers towards crop satisfaction was observed as compared to year ago. Respondents showed significantly high satisfaction (83%) in growing papaya for their income and livelihood as compared to a year ago that was only 35%. Cultivation of any crop solely relies on acceptance and satisfaction level of the growers. Apparently, growers correlate their satisfaction with the

Table 1: Papaya average per acre input costs (Rs.) in Sindh province, Pakistan

Period	Equipment	Seeds	Fertilizers	Manure	Agri. Labor	Plant Protection	Other	Total
Now	8,444.88	7,097.62	8,724.39	9,972.97	79,136.59	3,885.71	92,916.67	210,178.83
One year ago	7,290.70	6,253.49	11,192.86	9,279.07	83,511.63	8,467.50	72,130.43	198,125.68

Table 2: Economics of Papaya production (Rs.) in Sindh province, Pakistan

Categories	Now	One year ago
Papaya average rate per KG	Rs. 29.42	Rs. 30.93
Per annum total production	629.52 mounds	489.64 mounds
Total sale per acre	Rs. 654,365.85	Rs. 527,023.81
Net profit	Rs. 468,847.17	Rs. 407,700

profit of the crop that also depends on crop production techniques adopted by grower during the cropping season. It is clear from results that farmers ceased to grow papaya crop when they considered not to get good profit. This may be due to high economic loss to crop imposed by pest. So, provision of appropriate information facilities and transfer of fruitful knowledge to growers at right time through right persons like trained extension agents can aid in reducing crop loss. Ultimately, growers can get more profit and their satisfaction level for the concerned crop is increased (Figure 6).

Economics of papaya production

Papaya farmers reported that biological control interventions for papaya mealybug have significantly reduced the cost of plant protection and fertilizers application compared with the costs one year ago when the biological control interventions were not incorporated in IPM of Papaya mealybug (Table 1). Consequently, as responded by papaya farmers, the agriculture labor cost invested per acre of papaya farm has also reduced.

The lower the investment on plant protection, fertilizer application, and labor on papaya farming has significantly increased the per acre net profit of papaya farmers. Currently the average net profit per acre of papaya is PKR 468,847 that is PKR 61,147 per acre higher compared with the last year (Table 2).

Conclusions

Biological control interventions of PRMP for papaya mealybug have relieved papaya farmers who were depriving due to immense losses caused by the notorious pest. Farmers are willing to adopt biological control interventions for papaya mealybug because of its sustainability and profit generation. It also increased satisfaction level of papaya growers for continuation and rather increasing papaya farming as their primary source and income and livelihood. Furthermore, cyclic evaluation studies may also be conducted for continuously gauging the impact and for technological improvements, where applicable.

Author's contribution

All authors contributed equally in research, write-up and finally reading of this manuscript before submission.

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REFERENCES

Anonymous, 2017. Pakistan's 2016 horticulture exports rank 68th globally. The News (e-paper). (available at https://www.thenews.com.pk/print/218592-Pakistans-2016-horticulture-exports-rank-68th-globally retrieved on March 12, 2017).

Afolabi I and K Ofobrukweta, 2011. Physicochemical and nutritional qualities of *Carica papaya* seed products. Journal of Medicinal Plants Research, 5: 3113-3117.

Alvarez A and M Nelson, 1982. Control of Phytophthora palmivora in papaya orchards with weekly sprays of Chlorothalonil. Plant Diseases, 66: 37-39.

Aravind G, D Bhowmik, S Duraivel and G Harish, 2013. Traditional and medicinal uses of *Carica papaya*. Journal of Medicinal Plants Studies, 1: 7-15.

Ashie I, T Sorensen and P Nielsen, 2002. Effects of papain and a microbial enzyme on meat proteins and beef tenderness. Journal of Food Sciences, 67: 2138-2142.

Bajwa B, R Mahmood and S Ahmad, 2015. Baseline Survey & Need Assessment of Biological Control Interventions in Horticultural Crops of Sindh and Balochistan, Pakistan, Centre for Agriculture & Biosciences International, Rawalpindi, Pakistan, pp: 41.

Begum M, 2014. Phytochemical and pharmacological investigation of *Carica papaya* leaf. Bachelor of Pharmacy thesis. East West University, Dhaka, Bangladesh.

Diop N and SM Jaffee, 2005. Fruits and Vegetables: Global Trade and Competition in Fresh and Processed Product Markets: In Aksoy MA and JC Beghin (eds), Global Agricultural Trade and

Developing Countries, World Bank, pp: 237-257.

Evans EA and FH Ballen, 2012. An overview of global papaya production, trade, and consumption. EDIS #FE913. UF/IFAS Extension, Gainesville, FL, USA.

HsiHwa H, WH Liang, LW Tai and LK Chen, 1996. Studies on biological control of spider mites on papaya. Journal of Agricultural Research, 45: 411-421.

Jones DR, 2003. Plant viruses transmitted by whiteflies. European Journal of Plant Pathology, 109: 195-219.

Kauffman WC, D Meyerdirk, D Miller, M Schauff, HG Hernandez and JAV Jimenez, 2001. Papaya mealybug biological control in Puerto Rico and Dominican Republic. In: ESA Annual Meeting: An Entomological Odyssey of ESA (available online: http://creatures.ifas.ufl.edu/fruit/mealybugs/papayamealybug.htm).

Oad FC, AA Lakho, A Khan, AH Ansari, FM Sheikh and MUU Khail, 2001. Economics of Papaya in Malir district, Karachi–Pakistan. International Journal of Agriculture & Biology, 3: 477-481.

Krishna K, M Paridhavi and JA Patel, 2008. Review on nutritional, medicinal and pharmacological properties of Papaya (*Carica papaya* Linn.). Natural Product Radiance, 7: 364-373.

Kumar M, M Faheem, S Singh, A Shahzad and A Bhargava, 2013. Antifungal activity of the *Carica papaya* important food and drug plant. Asian Journal of Plant Sciences and Research, 3: 83-86.

Lyla K and BM Philip, 2010. Incidence of papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) in Kerala. Insect Environment, 15: 156.

Maoka T and T Hataya, 2005. The complete nucleotide sequence and biotype variability of papaya leaf distortion mosaic virus. Phytopathology, 95: 128-135.

Mastoi M, A Azura, R Muhamad, A Idris, B Solangi, A Arfan, M Bhatti and F Khoso, 2016. A Report of natural enemies of Papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in Peninsular Malaysia. Science International, 28: 371-374.

Meyerdirk D, R Muniappan, R Warkentin, J Bamba and G Reddy, 2004. Biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in Guam. Plant Protection and Quarantine, 19: 110-114.

Muniappan R, D Meyerdirk, F Sengebau, D Berringer and GVP Reddy, 2006. Classical biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in the Republic of Palau. Florida Entomologist, 89: 212-217.

Myrick S, GW Norton, KN Selvaraj, K Natarajan and R Muniappan, 2014. Economic impact of classical biological control of papaya mealybug in India. Crop Protection, 56: 82-86.

Nadeem A, T Mehmood, M Tahir, S Khalid and Z Xiong, 1997. First report of papaya leaf curl disease in Pakistan. Plant Diseases, 81: 1333.

Oliveira C, A Auad, S Mendes and M Frizzas, 2014. Crop losses and the economic impact of insect pests on Brazilian agriculture. Crop Protection, 56: 50-54.

Orhue P and A Momoh, 2013. Antibacterial activities of different solvent extracts of *Carica papaya* fruit parts on some gram positive and gram negative organisms. Internat Journal of Herbs and Pharmacology Research, 2: 42-47.

Piragalathan A, K Pakeerathan, G Thirukkumaran and G Mikunthan, 2014. Efficacy of different insecticides and bio-rationals against Papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococidae), infestation in home gardens. Middle-East Journal of Scientific Research, 21: 1689-1693.

Regupathy A and R Ayyasamy, 2012. Initiatives of papain industry by private-public-farmer linkages in classical biocontrol program for papaya mealybug in Tamil Nadu. Journal of Plant Protection Sciences, 4: 1-12.

Singh A, J Jaiswal, R Yadav, S Gupta, S Mishra and AK Singh, 2014. *In vitro* antimicrobial activity of medicinal plants Ashwagandha (*Withania somnifera*) and Papaya (*Carica papaya*) with commercial antibiotics. Discovery, 20: 59-64.

Subenthiran S, TC Choon, KC Cheong, R Thayan, MB Teck, PK Muniandy, A Afzan, NR Abdullah and Z Ismail, 2013. *Carica papaya* leaves juice significantly accelerates the rate of increase in platelet count among patients with dengue fever and dengue haemorrhagic fever. Evidence-Based Complementary and Alternative Medicine, 2013: 616737.

Tanwar R, P Jeyakumar and S Vennila, 2010. Papaya mealybug and its management strategies. NCIPM Technical Bulletin 22. National Centre for Integrated Pest Management New Delhi, India.

Vargas RI and JR Carey, 1990. Comparative survival and demographic statistics for wild oriental fruit fly, Mediterranean fruit fly, and melon fly

(Diptera: Tephritidae) on papaya. Journal of Economic Entomology, 83: 1344-1349.

Vyas MB and SK Shah, 2016. Review on nutritional and medicinal values of “Carica papaya”. Journal of Pharmacognosy and Phytochemistry 2016; 5: 284-286.

Zhou L, DA Christopher and RE Paull, 2000. Defoliation and fruit removal effects on papaya fruit production, sugar accumulation, and sucrose metabolism. Journal of American Society of Horticultural Sciences, 125: 644-652.