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Cotton Bollworm *Helicoverpa Armigera* (Hubner, 1809) (Lepidoptera: Noctuidae) and Development of Integrated Pest Management Platform

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Abstract

The cotton bollworm *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae),is a polyphagous and adaptive pest that currently attacks several crops including cotton.The present article undertakes the assessment of feeding preference and damage potential of this pest as well as better control options are made. In cotton, all stages of plant growth may be attacked, but reproductive tissue is preferred by this pest. Seedlings can be tipped out when terminal buds are eaten, chewing damage to squares and small bolls may cause them to shed, and injury to maturing bolls can prevent normal development leading to secondary fungal infections such as boll rot. Consequently, cotton bollworm larvae damage to squares, flowers, green bolls and tender shoots results in significant reduction both in yield and quality of cotton. Third instar larvae prefer to feed more on flowerswhile fifth instars on bolls. In case of *H. armigera* pest'scontrol, the most appropriate alternative to insecticidesis to adopt a system to monitor the pestilence and the level of pesticide control in order to make a proper decision. A direct egg and first instar caterpillar count is recommended for cotton crop for two times per week at the beginning of the plant's germination and until 30 or 40% of the plants shown open buds. The light traps and pheromone traps are sensitive for the detection of initial populations, they are more specific and make counting easier and quicker.Destroy left over material from crop and use resistant materials like genetically modified plants, which expel *Bacillus thuringiensis* (Bt) toxins.Biological control is mentioned as a supporter in the management of *H. armigera*, wherein more than 15 species of the parasitic *Trichogramma*, attack to the eggs.Management of beneficial parasites or insects and the use of microbial agents like baculovirus can be encouraged. Chemical pesticides should be used at pest's levels of action and use selective pesticides, with rotation of the mechanism of products action, in order to alleviate the pressure from the selection of active ingredients. The strategy to prevent insecticide resistance includes rotation between chemical groups with different modes of action, limiting the time period during which an insecticide can be used and limiting the number of applications of one particular insecticide. A regional approach is suggested for the management of *H. armigera*, by taking into consideration the number of generations, migration capacity and its highly polyphagous quality.

Keywords: Cotton Bollworm; *Helicoverpa armigera*; Biocontrol Agent; Environmentally-Friendly Compounds; Pyrethroid Resistance Management.

Introduction

The cotton plant has an indeterminate growing pattern (fruit are present for most of the season), which allows some pests to develop through several generations. Insect pests that feed on plant structures which directly produce yield, such as growing tips and fruiting structures, are generally the greatest problem in a cotton crop (Sarwar, 2017 a; 2017 b; 2017 c). Among these insects, the cotton bollworm *Helicoverpa armigera* (Hubner, 1809) (Lepidoptera: Noctuidae) is a pest over much of the world. Young larvae (2^{nd} and 3^{rd} instars) cause up to 65percent losses to cotton yield (Rasool et al., 2002).One larva m^{-2} can result in up to 50% shedding andthree larvae m^{-2} to almost total shedding of fruitingbodies of cotton (Tomar et al., 2000).Intensive use of the chemical insecticides against *H. armigera*has led to the development of resistance to the major chemical families of insecticides. In particular, the evolution of resistance to sprayed insecticides has been a major factor in the increase of cotton pest control costs. Thus, this paper is aimed at controlling of *H. armigera*by using parasitoids, predators, micro-organisms, plants extracts as well as other environmentally-friendly compounds, for their possible use on cotton as part of crop protectant (Sarwar and Sattar, 2016).

Moths of *H. armigera*are generally active after dusk, particularly in the early part of the night, feeding on nectar or other food sources, with females active rather earlier than males.There is a good deal of variation in color including lighter and darker forms of both caterpillars and moths known in this species. In its adult form, it has the appearance of a stout-bodied moth of typical noctuid expression,broad across the thorax and then tapering. The color is variable, but males are usually greenish-grey and females orange-brown. It has a 35 to 40 mm wide wing span, a yellow color on its first set of wings and a dark spot that is partly visible. The second set of wings is lighter in color with a large, dark distal stripe. Forewings have a line of seven to eight blackish spots on the margin and a broad, irregular, transverse brown band. Hindwings are pale-straw color with a broad dark-brown border that contains a paler patch, they have yellowish margins, strongly marked veins and a dark comma-shaped marking in the middle. Antennae are covered with fine hairs and this is a migratory species with great capacity for flight (Kriticos et al., 2015).

Adults emerge in the first 3 weeks of May and 2-6 days later (rarely 10) oviposition begins. Emerging female moths must feed before their ovarioles are mature. Hairy surfaces are preferred for oviposition, which is closely linked with the period of bud burst and flower production in most host plants. The females lay eggs on weeds and host plants of economic importance, but the oviposition period lasts for about 20 days. The female deposits its eggs in an isolated manner laid on plants or near flowers or fruit and on leaves or laid on plants which are flowering and are about to produce flowers. It is capable of laying 1000 to 1500 eggs per cycle, singly and mainly at night. The eggs are yellowish-white and glistening at first and they turn to dark-brown before hatching during development. Pomegranate-shaped eggs are 0.4-0.6 mm in diameter, the apical area surrounding the micropyle is smooth, the rest of the surface sculptured in the form of approximately 24 longitudinal ribs, and alternate ones being slightly shorter, with numerous finer transverse ridges between them. At 25°C, they hatch in 3 days, but can take 10-11 days in colder weather (Fitt, 1991).

The caterpillar’s coloration is generally variable, and it is recognizable for dark green stripes on its back and other lighter stripes as well as black bristles scattered throughout its body with a dark rounded base. This caterpillar is initially pale green, sometimes with black dots, and a pattern of thin dark lines running along the body, and the lines being darker around the second and third segments. In later instars, the dark lines become less conspicuous and the black spots develop red areas around them. The first and second larval instars are generally yellowish-white to reddish-brown in color, without prominent markings, head, prothoracic shield, supra-anal shield and prothoracic legs are dark-brown to black, as are also the spiracles and tuberculate bases to the setae, which give the larva a spotted appearance, prolegs are present on the third to sixth and tenth abdominal segments, and the caterpillars have dark triangles on the first abdominal segment. Fully grown larvae are 30-40 mm long, the head is brown and mottled, the prothoracic and supra-anal plates, legs are pale-brown, only claws and spiracles remaining black, and the underside is uniformly rather pale. The first generation larvae (the larval progeny of the overwintering generation) appear in May and feed for 24-36 days, those of the second generation feed for 16-30 days, and those of the third generation (at 25-26°C) develop in 19-26 days. The duration of larval development depends on the temperature and on the quality of the host food. The caterpillar when disturbed has characteristic posture, it lifts its head and curls it under the front of the body, and while if even more disturbed, it lets go and drops, and rolling into a spiral. The number of larval instars varies from five to seven, with six being most common (Kuldeep and Ram, 2007).

Pupa is brown, 14-18 mm long, with smooth surface, rounded both anteriorly and posteriorly, and with two tapering parallel spines at posterior tip. When fully fed, the larvae descend to the soil and after 1-7 days pupate in an earthen cell, 2-8 cm below the surface. The overwintering pupae remain in the soil for 176-221 days, whereas this stage lasts 13-19 days in the first generation, 8-15 days in August and up to 44 days in colder weather during September. Once the larvae stage is complete, the chrysalis caterpillar is found on the ground, in a soil filled cocoon at 5 cm from the surface and goes into diapause (an interruption in development) induced by short days (11 to 14 hours of daylight per day) until the appearance of favorable conditions. About 80% of pupae enter diapause at the beginning of October which is induced by short day lengths (11-14 hours/day) and low temperatures (15-23°C) experienced. Diapausing pupae may remain in that state for several months and durations of over 1 year have been recorded in the laboratory. A summer diapause, in which pupae enter a state of arrested development during prolonged hot and dry conditions, has been recorded. The duration of the adult stage depends upon the availability of food as sucrose or nectar, pupal weight (as fat body content), temperature activity, and with female moths generally living longer than males. In captivity, longevity varies from 1-23 days for male and 5-28 days for female *H. armigera*. The organism’s life cycle depends on the temperature, which under optimum conditions would be 35-40 days per cycle, which figures out to be 3 to 4 generations per crop cycle (Imosanenand Singh, 2005; Ahmad and Sarwar, 2013).

Pest’s Hosts and Damage

On eclosion, the neonate larva usually eats some or all of the empty eggshell before wandering for some distance and starts to feed on the plant, usually in a secluded place such as a flower, flower bud, or the underside of a leaf. Larger larvae prefer to feed on immature fruiting bodies, these are often hollowed out in cotton, but can feed on leaves in their absence, larvae often move about between feeding sites on or between adjacent plants. The most important crop hosts of which *H. armigera* is a major pest are cotton, pigeon pea, chickpea, tomato, sorghum and cowpea; other hosts include groundnut, okra, peas, field bean (*Lablab* spp.), soybean, lucerne, *Phaseolus* spp., other Leguminosae plants, tobacco, potato, maize, flax, a number of fruits (*Prunus*, *Citrus*), forest trees and a range of vegetable crops. A wide range of wild plant species support larval development and it mostly feeds on fruits, leaves, sprouts and flowers. In the wild, it has been found on annual sowthistle (*Sonchusoleraceus*, Asteraceae), but it is a serious pest internationally on various crops including sunflower (*Helianthus annuus*, Asteraceae), zucchini (*Cucurbita pepo*, Cucurbitaceae), beans (*Phaseolus vulgaris*, Fabaceae), leeks (*Allium porrum*, Liliaceae), cotton (*Gossypiumhirsutum*, Malvaceae), maize (*Zea mays*, Poaceae), plum (*Prunusdomestica*, Rosaceae), lemon (*Citrus limon*, Rutaceae), lettuce (*Lactuca sativa*, Asteraceae), and tomatoes (*Lycopersicumesculentum*, Solanaceae), as well as ornamental plants and flowers, including pinks (*Dianthus*, Caryophyllacea) and geranium (*Pelargonium zonale*, Geraniaceae) (Gireesh et al., 2012).

On cotton the young (first instar) larva after eclosion, moves to a feeding site normally in a flower bud or flower if available. Feeding in flower buds usually causes the plant to shed the bud.On cotton, larvae bore holes are visible at the base of flower buds, the latter being hollowed out. Bracteoles are spread out and curled downwards. Leaves and shoots may also be consumed by larvae. As the larvae grow they prefer to feed on buds (squares) and young bolls, though cotton bollworm is capable of feeding on leaves if necessary. Larger larvae bore into maturing green bolls and young bolls fall after larval damage. Adults lay fewer eggs on smooth-leaved varieties. Smaller larvae may feed wholly inside the developing cotton boll, but older larvae normally feed with the head in the boll and the rest of the body protruding. Molts between instars take place on the leaf surface and the larvae frequently move to different feeding sites, and even different plants, between instars. On flowering cotton, larvae normally damage several fruiting points, with up to seven feeding sites being normal. Larvae can move between adjacent plants where the canopies are touching. All stages of plant growth may be attacked, but damage to squares, flowers, green bolls and tender shoots results in significant reduction both in yield and quality of cotton (Mastrangelo et al., 2014; Ahmad et al., 2011).

Integrated Pest Management (IPM) Platform

In view of the need to make use of and exploit the existing spectra of natural enemies, and to reduce excessive dependence on chemical control, particularly where there is resistance to insecticides, various IPM programs have been developed in which different control tactics are combined to suppress pest numbers below a threshold. These vary from the judicious use of insecticides, based on economic thresholds and regular scouting to ascertain pest population levels, sophisticated systems almost exclusively for cotton, using computerized crop and population models to assess the need, and optimum timing and product for pesticide application. A major constraint to the development of IPM for *H. armigera*, particularly on cotton, has been the need to deal with a complex of pests where control needs may be incompatible, as for example in the characteristics of the cotton plant which can either be unfavorable to *H. armigera* or to other pests in terms of leaf hairiness, and in the withholding of early season applications to encourage the build-up of natural enemies against the need to control pests which can be severe on young plants (Tanweer and Rao,1997; Sarwar, 2013 a).

Monitoring and Treatment Decisions

In cotton, scout once or twice weekly and initiate scouting in the second week of squaring or once blooms appear. Examine five entire plants in each of 10 locations for signs of cotton bollworm eggs, larvae or feeding damage. Start sampling of plant terminals for bollworms as soon as bolls are present and continue until most bolls mature. Check five adjacent plants at each halt as observer passes through the field. Choose the first plant at random, then check its main stem terminal and those of the four plants next to it. For standard sampling, select at least 100 plants and continue scouting until the last effective boll matures. There are two treatment thresholds for bollworms in fields that have not been treated with broad-spectrum insecticides, and treat when there are 20 small bollworms per 100 plants. In fields that have been treated previously, treat when 8 small bollworms per 100 plants are found. For sampling, check for larvae on the terminal growth of at least 100 plants chosen at random. Divide fields of up to 80 acres into quarters and check 25 plants in each quarter. Divide larger fields into more areas and check 25 plants in each area. The treatment threshold is 10 to 12 small bollworm larvae per 100 plants. Later instar larvae are the most destructive, but are very resistant to insecticides, therefore, aim treatments at first or second instars (Bueno et al., 2014). The use of light traps is useful in the detection of species present in determined areas and to learn about population fluctuation throughout the crop cycle (Anju et al., 2004).

Sanitary Control Methods

Post-harvest cultivation (pupae busting) to reduce the overwintering stage of *Helicoverpa* is one of the most important traditional control practices available. Cultivation to a depth of at least 10 cm can damage or disturb to pupae, seal their emergence tunnels and trap emerging moths. Cultivation also leaves survivors opened to attack by birds, mice, earwigs and wasp parasites.

Traditional manipulations of the crop or cropping system and land management have been tried as tactics to manage *H. armigera* populations. Trap cropping and planting diversionary of hosts have been widely applied and recommended in the past, although with limited success. In the case of cotton, the diversionary hosts maize and sorghum have too short an attractive period to sustain populations, and the tendency of these and earlier-planted crops to augment or create

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infestations are major disadvantages. The importance of ploughing cotton stubble to reduce overwintering populations of pyrethroid-resistant *H. armigera* has been stressed and post-harvest cultivation to destroy pupae of bollworms has received considerable attention. However, all in situ traditional control tactics (including area-wide management of early season populations on wild hostsand the concept of a close season during which food plants are denied for over one generation, would seem to be largely invalid where the immigration of adults into the protected habitats is the key consideration (Johnson, 2011; Sarwar, 2013 b).

Host-Plant Resistance

Many crop species possess some genetic potential which can be exploited by breeders to produce varieties less exposed to pest damage, this can take the form of antibiosis (unpalatability), antixenosis (non-preference) and tolerance. The planting of crop varieties that are resistant or tolerant to *H. armigera* has received major attention, particularly for cotton. This is a tactic of considerable importance within IPM systems, however, where there is a pest complex, interactions may not always be favorable. For example, fewer eggs are laid on plants having the glabrous leaf character in cotton, however both larval survival and susceptibility to jassid attack are higher. In recent years, genetic engineering techniques have enabled genes carrying the toxic element of *Bacillus thuringiensis* to be introduced into crops such as cotton. Although the technique is still very much in its early stages, transgenic crop varieties offer considerable promise for use in IPM systems against *H. armigera*. As with the use of all resistant crop varieties, however, care still needs to be taken to avoid excessive selection pressure against the resistance factor, so that in such systems a mixture of both resistant and susceptible varieties is often recommended to lessen it. Other forms of transgenic cotton (with Cry proteins) are being developed and introduced into the commercial market (Sarwar et al., 2013).

Cultural Control

Cotton bollworms are attracted to succulent and rank-growing cotton plants,so, keep water, fertilizer and plant density at recommended levels to avoid rank growth. Because populations seldom reach damaging levels before late summer, manage the crop for early maturing and plan to defoliate by late September.Other indirect cultural methods which could be included under this heading are the regulation of crop agronomy, variety (such as the okra-leaved varieties of cotton), spacing and fertilizer regimes, and more accessible to insecticides or microbial formulations applied by conventional means.The study has been designed to investigate the impact of water stress on varietal response to cotton cultivars against *H. armigera* and its associated entomophagous insects [*Chrysoperla carnea* (Stephens) and *Habrobraconhebetor* (Say)] as well as the feasibility of different Integrated Pest Management (IPM) modules. On the basis of cost benefit ratio, integrated implementation of Spinosad, Neemosal, *C. carnea* and *H. hebetor*enlightened highest yield and proved economical and effective IPM module. Water stress condition has positive impact on *H. armigera* feeding-damage (bi-trophic interaction), butnegative impact on parasitism (Noor-ul-Ane et al., 2015).

Biological Control

Use of biological control agents, their unassisted suppression of *H. armigera*populations below an economic threshold without the use of insecticides would be a major advantage, both in ecological and economic terms particularly if this is sustainable. Egg parasitoids Trichogrammatoideaspp., a tachinid late-larval parasitoid *Linnaemyalongirostris* (Macquart) and banded caterpillar parasite onpupae are the most common parasitoid species for parasitism. Of the large complex of predators, only anthocorids and ants (predominantly *Pheidole* spp., *Myrmicaria* spp., and *Camponotus* spp.), are sufficiently common and widespread to be of importance in suppressing of *H. armigera*. The relative specificity, potential activity, environmental safety and immunity to insecticides have made microbial pesticides a favored component of IPM strategies, and *B. thuringiensis* and *H. armigera* nuclear polyhedrosis virus are most promising agents and commercially viable products (Van den Berg et al., 1993). Parasitism (especially by egg parasitoids such as *Trichogramma*wasps which seem always to be present) being significant in some situations, for example when senescing sorghum is close to infected cotton. Mid-stage larval mortality is particularly caused by wasps of the families Braconidae and Ichneumonidae e.g., *Campoletischloridae*, and older larvae suffer particularly from the attacks of parasitic flies of the family Tachinidae (Alavo, 2006).

With a view to use parasitoids and predators in integrated pest management of the target pest *H. armigera* in cotton, basic studies on the egg parasitism, toxicity of insecticides to parasitoids and predators and compatibility of nuclear polyhedrosis virus on the basis of pheromone trap threshold level (7 moths/ trap per night) reveal a significant superiority of the IPM strategy in terms of both cost versus benefit and environmental safety over conventional control methods.To this end, substantial efforts are consistently necessary either to introduce exotic natural enemies or to augment existing populations of parasitoids and predators to achieve satisfactory levels of pest control. There have been attempts to enhance mortality of *H. armigera* due to natural enemies by the introduction of *Trichogramma pretiosum*, *T. perkinsi*, *Chelonusblackburni*, *Eucelatoriabryani*, *Braconkirkpatricki*, *Cotesiamarginiventris*, *Glabrobraconcroceipes*, *Cotesiakazak*and *Hyposoterdidymator*, but because of the low tolerance for insect damage in crops, insecticides are still needed. In most areas, species of *Telenomus* and Trichogrammatidaeare important egg parasitoids, and larvae are parasitized by at least one species each of Braconidae, Ichneumonidae and Tachinidae(Reddy and Manjunatha, 2000).

Chemical Control

In most cases where *H. armigera* attacks high-value crops like cotton, its control with insecticides, alone or within the context of an IPM program, is necessary. But, it is clear that economic thresholds is need to be carefully applied for best results.Most insecticide applications are targeted at the larval stages, but as these are only really effective when larvae are small, the need to scout for eggs and spray soon afterward is paramount. Young larvae are difficult to find and older larvae soon burrow into the floral organs where they become less accessible to contact insecticides, so, there require higher doses to kill pest and prevent economic loss. Moreover, resistant larvae are still susceptible while less than 4 days old, so that targeting of neonates is essential in areas where resistant populations are present(Ahmad et al., 1995). Insecticides from different chemical groups have been tested by laboratory bioassay to verify the percentage mortality of *H. armigera*. The results demonstrate that chlorpyrifos,spinosad,flubendiamide, acephate, methomyl, dimethoate, chlorantraniliprole, abamectin, indoxacarb andfipronil have good responses for control of *H. armigera*(Carneiro et al., 2014).

Prevention of Insecticide Resistance

Bollworm*H. armigera*has developed resistance against most insecticides, however, with the introduction of genetically modified cotton, biopesticides and more selective insecticides, insecticide resistance to older chemistry has been decreased. The considerable selection pressure which *H.armigera* has experienced, particularly to the synthetic pyrethroids, has further resulted in the development of resistance to the major classes of insecticides in many of the areas where these have been used. Insecticide resistance management strategies have been aimed either at preventing the development of resistance, or containing it. All rely on a strict temporal restriction in the use of pyrethroids and their alternation with other insecticide groups to minimize selection for resistance. And while the strong propensity of *H. armigera* to disperse confers the advantage of diluting resistant populations through the influx of susceptible insects from unsprayed hosts, the same tendency ensures that the genes for resistance are spread more widely than their area of origin. Pyrethroid resistance in *H. armigera* may be conferred through three separate mechanisms, detoxification by mixed-function oxidases (metabolic resistance), nerve insensitivity, and delayed penetration. Metabolic resistance may be inhibited by piperonylbutoxide and other synergists, providing a (costly) means whereby the use of pyrethroids might be prolonged in populations where this is the principal mechanism (Forrester et al., 1993). Though, *H.armigera* has been known resistant tomany insecticides, but the use of more selective options is encouraged to help in preserving of natural enemies.In order to prevent insecticide resistance, the cotton industry has developed the insecticide resistance management strategy. This strategy is reviewed annually to delay development of resistance in*H. armigera* to conventional insecticides. The core insecticide resistance management principles includerotation between chemical groups with different modes of action, limiting the time period during which an insecticide can be used and limiting the number of applications of one particular insecticide. Thus, it is essential to find the underlying causes of this resistance and how it may be managed in a small-farmer situation (Sarwar and Salman, 2015; Sarwar, 2016).

Conclusion

The bollworm (*Helicoverpa armigera*Hubner, Lepidoptera: Noctuidae) has become a serious pest of several agricultural plants including cotton. The relatively high fecundity and ability of this species to invade new host plant areas mean that although the impact of parasites, predators and disease may be considerable in particular local areas and seasons, it does not appear that these factors regularly bring cotton bollworm numbers down below damage thresholds over any considerable area or time. Bollworms, which feed on the growing fruit buds, flowers and developing cotton bolls, are the most significant pests in most areas. Chewing damage to squares and small bolls may cause them to shed, and chewing damage to maturing bollsmay prevent normal development and can lead to secondary fungal infections such as boll rot.Therefore, different biorational based IPM packages viz., IPM package comprising pheromone trapping of *H. armigera* along with sequential release of biocontrol agents (*Trichogramachilonis*+ *Braconhebetor*@ 1 jar (1000-1200 adults)/ha/week) and spraying of *B. thuringiensis* (Bt) @ 0.4g/ liter of water, pheromone trapping in addition to sequential release of bio-control agents and spraying of *Helicoverpa* nuclear polyhedrosis virus @ 0.1g/ liter of water against this pest reveals the best performance to reduce damage and provides significantly the highest yield. Consequently, the highest benefit cost ratio can also be recorded from this package. Hence, biocontrol agent releases along with installation of sex pheromone traps and spraying of polyhedrosismay be recommended for effective pest management.Resistant plant genotypes or hybrids can play an important role in managing population of *H. armigera*, however, it is often difficult to develop a genotype or hybrid which is highly resistant to a number of insect-pests, without sacrificing yield. Nevertheless, it is significant to identify varieties and hybrids which could tolerate pest pressure and are the least preferred. The introduction of Bt cotton has resulted in a significant reduction of insecticide use by growers.So, a resistance managementplan is essential to ensure that these valuabletraits remain effective.

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- Dr. Muhammad Sarwar, Principal Scientist, is going through 27th years of Service experience in Research orientated Department of Agriculture (16-05-1991 to 31-05-2001, Government of Punjab), and Pakistan Atomic Energy Commission (01-06-2001 to date).
- Have 245 publications in National (61) and Foreign (184) Journals with suitable Impact Factor & sufficient Citation.
- Award of Higher Education Commission of Pakistan "Post-Doctoral Scholarship-2006" for Post Doc., research work at Chinese Academy of Agricultural Sciences, Beijing, China.
- Shield award, Letters of Appreciation, and Certificates of performance and honor granted from Chinese Academy of Agricultural Sciences, Beijing, China.
- Awarded Gold Medal-2010 by Zoological Society of Pakistan (International) in recognition of research contributions in the field of Insect Science.
- Granted Research Productivity Award-2011, by Pakistan Council for Science and Technology.
- Included in Panel of approved Supervisor of Higher Education Commission **(**HEC), Pakistan.
- Completed "Basic Management Course" organized by Pakistan Institute of Engineering & Applied Sciences (PIEAS), Islamabad, held from 31 January to 18 February, 2011.