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Management practices of maize stem borer (*Chilo partellus* Swinhoe) in Nepal

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Abstract
Maize stem borer (*Chilo partellus* Swinhoe) is a major pest of economic importance damaging maize crop in Nepal. Severe damage of stem borer directly regulates on yield factors including effective panicle number and density of fertile tillers. The objective of this review is to unfold and examine the alternatives in management of the major prevailing pest of maize stem borer in Nepal which alone accounts for 18-28% losses in yield. Biological control, Cultural practices, convincing chemical control and Host plant resistance are among the best promising alternatives, while combination of diverse compatible strategies i.e., integrated pest management was underlined as the most sustainable directing substitute. This review paper would be a relevant prospect document for entomologists and breeders from across the world and also contribute in ongoing experimentation on maize crops.

Keywords: Maize, production, stem borer, integrated pest management, bio pesticides

Introduction

Lepidopterous stem borers substantially restrict potentially attainable maize yield by declining the maize yield throughout its growth stages from seedling to maturity. Nepal being an agricultural country, above 60% people is engaged in agriculture where maize cultivation equally holds integral parts enhancing the livelihood of society. Agriculture sector alone contributed 26.98 % GDP of Nepal in fiscal year 2019 (Prasain 2020) [69]. Maize is major cereal crop which occupy second rank after rice in terms of productivity contributing to 25% of total cereal production (MoALD 2020) [48]. Nepal has been producing 2.71 million tons of maize with increase in production by 2.72% annually which is unable to meet the increasing demand of maize i.e. 5% food demand, 11% poultry feed demand and 8.7% animal feed demand annually (Ghimire *et al.*, 2019) [20]. The trend of maize consumption as Nepalese food source in Terai is 20% but then, maize as a source of poultry feed alone occupies 80% for which it is regarded as the major raw materials in poultry industry (Prasain 2020) [69]. During maize cultivation, farmer has to encounter challenges such as erratic weather, heavy lodging, chemical injury, weed competition, infestation of disease and pest etc. among which infestation of disease and pest is major problem in attaining the yield.

Out of 66 insects reported in maize field, there are 14 major pests such as Maize stem borer (*Chilo partellus* Swinhoe), Fall Army worm (*Spodoptera frugiperda* Smith), White grub (*Phyllophaga rugosa* Melsheimer,1845), etc. among which Maize stem borer *Chilo partellus* is more complex nowadays. *Chilo partellus* was first mentioned by Charles Swinhoe in 1885 (CABI 2019) [10]. *C. partellus* is cosmopolitan in nature having its origin in Asia and its severity was also reported in African region. It is considered as a serious pest in north-eastern India, major pest in Pakistan (Pathak and Khan 1967) (Inayatullah *et al*., 1986) [64, 26] and in several world regions which holds significant complication in successful cultivation of maize and other cereal crops. *Chilo partellus* is a major biotic constraint in all maize growing agro-ecological zones of Nepal (Paudyal *et al*., 2001) [67]. It accounts for 18% -28% yield loss, out of 42 % total insect loss of maize in 2015 (Achhami, BK and Bhandari 2015) [34] which was 20-80% in 1985 (F. P. Neupane *et al*., 1985) [53]. At first, it was considered as primary pest of maize in Kaski, Parbat and Bhaktapur districts. In southern parts of Nepal, where maize and rice are rotated, *C. partellus* is found as a dominant borer species in rice (F. P. Neupane *et al*., 1985) [53].

Maize is the source of food security among people of mid and high hills where 86% of produced maize is used for household consumption. In this regard, using proper management practices is the only alternative in mitigating certain avoidable yield loss caused by *Chilo partellus* that contributes in achieving zero hunger by the end of this decade to some extent. In Nepal, maize stem borer is predominantly controlled by the use of conventional pesticides in farmers field which upgrade the yield and grain quality despite non-judicious use of wide spectrum insecticides, resulting increased management cost, environment hazards and associated health issues (S. Neupane *et al*., 2016) [54]. Along with the introduction of new high yielding resistance varieties and advance farming technology, the adoption of winter cultivation proved to be best for low pest infestation but the use of local seeds following traditional methods is practiced by Nepalese unaware farmers (KC *et al*., 2015) [34]. Early plantation, crop rotation, field sanitation, proper irrigation, recommended fertilizer application, intercropping, trap crop, home based bio-control methods need to be used collectively to control such devastating pest. Thus, to alleviate the major constraints of maize production i.e., maize stem borer, government needs to work on both varietal development and dissemination of information from crop management research that must be implemented in an integrated approach in farmers' field.

Materials and Methods

This review completely uses secondary sources of information. Section of literature were collected from different Journal articles, Agricultural Institutes, other sources like MOALD, CABI and relevant reports were analyzed and the major findings were summarized. Also, advice from related Professors and officers were considered in the paper.

Insect Biology

Maize stem borer (*Chilo partellus,* Swinhoe) (Lepidoptera: Pyralidae) is considered as a major devastating pest and is reported as a major entomological problem in maize and other Poaceae family crops in Nepal (S. Neupane & Subedi, 2019) [55].

C. partellus has various growth stages in life history: egg, larva, pupa, and adult among which larval period is the longest (29-36days) followed by pupal (7-12days) and then incubation period lasting from 3-6days (S. Neupane & Subedi, 2019) [55]. Adult female oviposits on the aerial portion of host plants, generally on leaves. Fecundity of *Chilo partellus* is 150-160 eggs per female and is flat, oval, creamy white in color which later changes to darker color representing head of larvae and hatches within 5-6 days early in the morning measuring 0.75 to 1.25 mm in length (Peddakasim *et al*., 2018) [68] (Thippeswamy *et al*., 2010) [85] (S. Neupane & Subedi, 2019) [55]. (F. P. Neupane *et al*., 1985) [53] reported 72% of the eggs were laid on the lower surfaces of leaf blades of maize plants, mostly near midribs.

The incubation period varies as per the season and it is higher i.e. (6-7 days) during September to February while lower i.e. (4-5 days) during May to August. Likewise, the larval period lasts 35-36 days in winter season and 29-30 days in summer season comprising at least five instar stages (S. Neupane & Subedi, 2019) [55] (Peddakasim *et al*., 2018) [68], while six instar stages have also been reported (Thippeswamy *et al*., 2010) [85] (Rauf *et al*., 2017) [72] (Jal~li & Sihgh, 2003) [28]. Adults emerge from pupae in the late afternoon or early evening and are active at night (CABI 2019) [10]. Early instar larvae finally enter into the whorls of young maize where they scrape off the chlorophyll from the leaves then move down feeding on the growing stem of the young plants resulting in dead hearts. After third moult, they bore into the stem and start tunnelling (F. P. Neupane *et al*., 1985) [53].

Insect habit and nature of damage

C. partellus is a serious pest of *Zea mays*, in various parts of Asia and Africa and most severe in the dry season in lowland area (Overholt *et al*., 1994) [61] and being increasingly important at higher elevations as well (Kfir, 1997) [35]. *C. partellus* exhibits polyphagous feeding behaviour on several cultivated gramineous crops i.e. sorghum>maize>rice>sugarcane>millets on the basis of host preference (F. P. Neupane *et al*., 1985) [53] and other non-cultivated host plants. They have alternative hosts in the cyperaceous, Gramineae, Juncaceae and Typhaceae families (Panchal & Kachole, 2013) [62].

Adult moths lay eggs in the youngest unfolded leaf, then the larvae move into the leaf whorls to feed. On average 50% potential larvae (eggs) are lost after oviposition, approximately 25% of the original number of eggs disperse in the field with 30-70cm mean dispersal distance and 20% only remain on the oviposition plant (PÄts & Ekbom, 1992) [65]. The third instar, from the larvae, make tunnels in the stem where they feed before pupation and from that hole the adult will emerge out (Fazeel 2015) [17].

Thus, activities of young ones feeding terminal leaf producing patterns of small holes are called "window panes". Later they eat growing points that kill the central shoot causing a dead heart where the plant does not bear any ear at all. Then the older larvae expand in a tunnel in the stem making the stem weaker so that it breaks and falls over. Culminate yield loss due to dead heart, reduced translocation, lodging, ear damage, leaf senescence, and complete crop failure (Iqbal *et al*., 2017) [27] accounts 20-80% where leaf windowing, pinholes are categorized under minor damage and dead heart as major damage (Subedi 2019) [81].

Bio-pesticides, Biocontrol agents and botanical pesticides

Biological management is an approach to uphold pest population below the Economic Injury Level (EIL) where natural enemies are manipulated. (Van Den Berg *et al*., 1997) [89] Reported an ETL for susceptible and resistant plants to be 2% and 20% respectively possessing visible whorl damage symptoms. Similarly, ETL for dead hearts was reported to be 10% (ENTO 331 : Lecture 04 : Pests of Maize, n.d.). Furthermore, 3.2 and 3.9 larvae plant were the consequent EIL which (Seshu Reddy & Sum, 1991) [76] observed for 20 and 40 days old plants successively.

Numerous organisms such as insects, fungus, virus and bacteria are considered as bio control agents. Bio-pesticides like *Beauveria bassiana*, *Bacillus thuringiensis* (Sufyan *et al*., 2019) [82], Biocontrol agents such as *Trichogramma chilonis, Apanteles flavipes parasitoids* (F. P. Neupane *et al*., 1985) [53] and Botanical pesticides comprising *Lantana camara*, neem products, *Tephrosia vogelii*, general ash, *Tagetes minuta* are the most eco-friendly approach to IPM and an effective biological control measure against *C.*

partellus (Ogendo *et al*., 2003) [59]. Due to their effectiveness even in small quantities, easily affordable, quickly decomposing nature and non-resistance to pests, bio-pesticides are often recommended as a suitable approach in controlling disease pests over conventional pesticides.

Among the biotic agents, hymenopterous parasitoids seem to be of major importance in controlling *C. partellus* (F. P. Neupane, 1990) [52]. *Apanteles flavipes* in India (Rao, *et al*. 1969) [70], Nepal (F. P. Neupane *et al*., 1985) [53] and Pakistan (Attique *et al*., 1980) [3] is dominated and most widely distributed parasitoid of *C. partellus*. The extent of parasitisation in Nepal was upto 30% (F. P. Neupane *et al*., 1985) [53] and 0.2-79.9% in Punjab state (India) (Satish *et al*., 1975). (F. P. Neupane *et al*., 1985) [53] reported *T. chilonis* parasitization upto70% for the first time in Chitwan Nepal. (Kakar, 2016) [32] outlined the efficacy of triple release of trichocard in contrast to single and double release in reducing the pest infestation as utmost parasitism (32.82 %) of *C. partellus* was recorded in plot handled with triple (30 cards/plot) release accompanied by double (26.20%) and single release (20.62%).

Isolates of insect pathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* were reported to be strongly pathogenic encouraging 90 to 100 % mortality in seven days after treatment (Tefera & Pringle, 2004) [83]. Also, combined use of *B. bassiana* (1×108 coni-dia/ml) and *B. thuringiensis* (0.75 µg g–1) showcased higher efficacy on percent mortality of 2nd (96.58%) and 4th instar (90.87%) of *C. partellus* (Sufyan *et al*., 2019) [82].

Similarly, Spores of protozoan *Nosema marucae* suppressed larval infestation of *C. partellus,* deducing foliar damage up to 87.5% over control (Odindo & Mbai, 1993) [58].

Seed soaking with botanicals such as *Tephrosia vogelii*, general ash, *Lantana camara*, *Tagetes minuta*. *L* extracts at 0.85-1.70%w/v lowered stem borer loads by 29-79% strengthening maize grain yields by 10- 62% contrast to the untreated control. Nevertheless, *T. minuta*, general plant ash and *T. vogelii* when applied with crude powders at 15-30 kg/ha lessened the population of borer by 18-63% with an increase in highest yield up to 70% (Ogendo *et al*., 2003) [59].

Among 12 plant products i.e (Neem seed kernel, Neem oil, garlic clove, ghikanvar, oak, datura, papaya, lantana, Tulsi seed, henna, mint and ipomea), 1% Neem oil showed highest mortality of borer after treating them for about 12-48 hrs (Pareek and Batta 1993) [63]. Similarly, Botanicals using neem products, neemazal and azadirachtin lowered egg laying capacity of females and resulted in high egg mortality (Bhanukiran, 1999) [9]. Several studies have revealed that approach to botanical formulations strengthened yield higher than 60 %, minimizing borer load by 55% in contrast to the control (Oben, *et al*. 2015) [57].

Cultural and mechanical method

Different agronomic practices like manipulation of planting dates, mixed cropping, field sanitation, crop residue management etc. are crucial to reduce borer infestation. The main aim of these practices is to alter land and crop status creating the unfavorable condition for growth and development of the pest. In Chitwan, early sown maize had low infestation of stem borer (Ghanashyam, *et al*. 2012) [19]. Similar findings were found by workers in India, Pakistan and Kenya (Gowda, *et al*. 2013) [22] (Chabi-Olaye *et al*., 2005) [11] (Kuria and Warui 1983) [43]. (Bhandari G 2018) [7] noted optimum time for planting summer maize, winter maize and spring maize to be July, September and end of January respectively. Though maize can be grown all year round, winter maize has lower infestation (Thakur *et al*., 2018) [84]. Since, larva of *Chilo partellus* undergoes diapause in the crop residue, it is important to destroy maize stubbles, stalk and cobs during dry season (Päts & Päts, 1996) [66] (Kfir Rami 2002) [36]. Tillage after harvest can destroy larva by exposing them to predators (ants, spiders, reduviids etc.), unfavorable weather conditions or causing mechanical damage to the aestivating structures. Mixed cropping with beans like broad bean, haricot bean, cassava, cowpea etc. reduces the host finding ability contributing to lower infestation of borer than monocropping (Olaye, *et al*. 2005) (Girma Hailu 2018) [60, 21]. Among edible legumes, maize-cowpea intercropping in the ration 1:1 to 2:1 reduced no of dead hearts and infestation with highest B:C ratio (G. Singh *et al*., 2018) [79] (M Anuradha 2010) [47]. However, maize-lablab intercropping though reduced the infestation, loss of yield due to crop competition was observed (Maluleke *et al*., 2009) [46]. Optimum level of N must be applied as nitrogen level is positively correlated to borer population and plant vigor ultimately providing net-benefit to maize (Baidoo 2004) (Arshad *et al*., 2013) [4, 2]. However, (Jiang & Schulthess, 2005) [29] reported that increase in survival rate of *C. partellus* with increase in N fertilization can be seen only in depleted soils. High plant stand in field can compensate the damage caused by the borer (F. P. Neupane, 1990) [52]. Similarly, removal of the infested plant by rouging or cutting can prevent dispersal of larva reducing severity of infestation (Ullah Khan *et al*., 2015) [86]. Insect light traps can be used for trapping of both male and female moths reducing carry over population (Bhandari *et al*., 2018) [8]. Male moths were found to be more attracted to light traps than female pyrilad moths. (Coppel H.C 1985) [13]. Workers collected sixty-seven maize stem borer adults in traditional light trap, accompanied by 297 in black light trap from mid-February to end of October during 2017 in field trials conducted in NMRP Chitwan, finding black light traps to be more effective than that of traditional light traps as the latter lacked striking and sieving mechanism.

Resistant cultivars

Considering planting resistant cultivars as most effective and economic method of borer control, different cultivars have been evaluated time and often for borer resistance. According to CIMMYT country report-1999, Rampur-1, Arun -1, Dholi 8694, Th 8645 and Rampur composite are resistant to borer (Rijal 1999) [73].

In the field experiments carried at Rampur Chitwan for two consecutive years 2014 and 2015 in spring maize, it was reported that R-POP-2, RampurSO3F8, RampurSO3FQ02 and RampurS10F18 among Open Pollinated Variety (OPV), RML-5\RML-8 among hybrid and SOOTLYQ-AB, S99TLYQ-B and S99TLYQ-AB among quality protein maize, cultivated in Nepal as most resistant to borer infestation with Rampur composite, Arun-2, Deuti-1, and Posilo makai-1 as standard check .The mean percentage damage in the year 2013 and 2014 respectively were found to be 18% and 19.3 % in R-POP-2, 24.4 % and 37.3% in RamporSO3F8, 30.6% and 26.1% in RampourSO3FQ02, 23.8 and 25.9% in RampurS10F18, 21.4 % in RML-5/8, 21.2% and 30.1 % in SOOTLYQ-AB, 20.6% and 38.4% in S99TLYQ-B along with 22.1 and 33.1% in S99TLYQ-AB (Bhandari *et al*., 2016) [6].

Out of varieties screened at NMRP-Rampur, the varieties showing minimum damage at tasseling stage were KKT 03 (4.33%), S00TLYQ-B (5.67%) and KEW-POP (6.67%) followed by Rampur Composite (6.67%) at tasseling stage under glass house condition. Similarly, varieties like RML-86/ RML-96 (2.60 t/ha), Rampur hybrid-4 (2.40 t/ha), R-POP-14 (2.33 t/ha), S00TLYQ-B (2.18 t/ha) and S03T-123 LYQ-AB-02 (2.05 t/ha) were found to have more yield despite infestation (Maize, 2017) [45].

Different researches have shown antixenosis, antibiosis and tolerance to be operating together as well as independently in different resistant germplasm. Presence of trichomes, and surface waxes were found to be the antixenosis mechanism deterring the ovipositional preference of *Chilo partellus* (Rasool, *et al*. 2017) [71]. Apart from physical characteristics, presence of allelochemicals, phenolic acids, micronutrients, starch as well as proteins were found to govern the mechanism of host plant resistance where phenolic acids, particularly ferulic acid and *p*-coumaric acid and proteins were found to cause antibiosis (Chaudhary and Dhillon 2015) [12]. However, the resistance mechanism in aforementioned varieties is yet to be diagnosed in Nepal.

Sex pheromone

The use of pheromones can be a successful tool to limit the pest population due to their high efficacy and less toxicity to the biological environment. Synthetic (Z) 11-hexadecanal (Z 11-16: Ald) and (Z) 11-hexadecen-1-ol (Zll-16: OH) (Nesbitt *et al*., 1979) (Hansson *et al*., 1995) [50, 25] can be exploited as pheromone traps for attracting male of *Chilo partellus*. The formulations should be independently used as they can react with each other interrupting distortion of the signal which must be perceived from synthetic pheromones by male moth for the utility of pheromone traps (Lux, *et al*. 1994) (Nesbitt and Campion and Brenda 1983) [44, 51].

Pheromones can reduce the moth population either by mass trapping i.e., pheromone-baited traps or by disruption of mating i.e., creating difficulty for male moths to precisely locate calling female moths. At high pest population density, mass trapping of male pyrilad moth by the use of pheromone won't be feasible in the field because of competition within pheromone traps as well as with calling female virgin pyrilad moth (Unnithan and Paye 1991) (Unnithan & Saxena,1991) [87, 88]. So, rather population of the borer can be suppressed by delaying or disrupting mating through the use of synthetic (Z) 11-hexadecanal (Z 11-16: Ald), which is more effective than former, as it inhibits the mating and hovering of male pyrilad moths, reducing total viable eggs.

Pheromones can precisely time the pesticide application reducing the haphazard use of chemicals. Field trials conducted in China showed that pheromones traps, when used at the rate of 30/ha or 40/ha gave the maximum result with % reduction of ear damage due to Asian corn borer by 72.8% and 79.5%, followed by 90 % reduction in damage when used with insecticides (RI-ZHAO CHEN 2013) [74]. However, commercial production of synthetic pheromones is yet to be exploited in case of *C. partellus* and thus limiting its use to monitoring of pest population. Similarly, the use of pheromones in field condition to control stem borer is very limited in Nepal.

Chemical control

Despite all the risk and environmental threats, chemical control is considered a relevant option to mark in situation where the pest population is already established. Also, it is used as a foremost IPM component to boost varietal resistance or cultural practices. Chemical control is considered as one of the key effective methods due to its rapid knockdown effect (intoxication and partial paralysis, proceeds death). Due to its quick and immediate result, it is considered the best method despite its hazard. The haphazard use of a chemical is neither eco-friendly nor economic. Thus, the biological study is a must to use insecticides systematically and economically. The time of spray, mode, and formulation of insecticides are warranted by pest biology which helps in selection and increases the effectiveness of the spray.

Time of spray

Though application is based on infestation rate, it is recommended to spray chemical pesticides twice i.e. first at 15 days after emerging (i.e.10-15 DAS) or 4 weeks after sowing and second before tasselling stage (i.e.50-70 DAE) or 2 weeks after the first spray (Iqbal *et al*., 2017) [27] (S. Neupane *et al*., 2016) [54]. The spray of insecticides too early is waste and at a late stage is ineffective because the larvae are protected inside the stalks.

Nature of insecticides

Insecticides such as Comfortis (Spinosad), Durban (chlorpyrifos), Imidacloprid (confider), Evident (thiamethoxam), Margosom (azadirachtin), Furadan (carbofuran), Padan (Cartap), Ripcord (cypermethrin), Sevin (carbaryl), Rogor (dimethoate), Fipforce (fipronil) etc. are mostly used with different concentration and combination. The use of contact (chlorpyrifos, cypermethrin) and systemic (carbofuran, dimethoate) insecticides are most effective at the initial stage before borrowing into stem (Rauf *et al*., 2017) [72] but during the later stage, the stomach (Spinosad, cypermethrin) insecticides also show the best results. Side dresser (imidacloprid, thiamethoxam) and liquid (Monocrotophos) are effective during early growth whereas granules (chlorpyrifos) and dust(cypermethrin) application to the leaf whorl show the effect on later stage by increasing yield, reducing pollution, decreasing pesticides resistance and limiting harmful effect on the non-targeted organism (Sharif 2016) [77]. Many researchers reported the efficacy of insecticides on *Chilo partellus* throughout the world. Dimethoate 30% EC, 1.5mlltr^{-1} of water and Thiamethoxam 12.6% EC+ Lambda-cyhalothrin 9.3% EC, 1ml per 4 litres of water at the rate of 500ltr ha^{-1} have been reported by Krishi diary (Krishi diary 2077) [38].

In Pakistan, Furadan 3G verified as the most effective in reducing percent dead hearts (5.52%), pest infestation, and in increasing of stalk and cobs weight succeeded by Ripcord 100 g/l EC and Tamaron SL 600 at the medium and high dose (Amjad 2000) [1]. In a field study conducted at Katvi Agriculture Farm Loralai (Balochistan), four granular insecticides *viz*. Basudin 10G, Temik 10G, Furadan 3G, and Padan 4G, were tested, among which Furadan proved to be the best one (Kakar, *et al*. 2003) [31]. Most of the works on the use of insecticides reveal that the most effective one is Furadan 3G (carbofuran). However, with a view to prevent threat on human health and animals, because of their toxicity, persistence, tendencies of accumulation and biomagnifications and long-term impact such pesticides are banned in Nepal.

Furthermore, in the experiment using conventional pesticides on control of maize stem borer in Rampur, Chitwan, all pesticides had a significant effect on percent damage and crop yield over control where Spinosad 45% EC at 0.5mlltr^{-1} of water was most effective on both 2015 and 2016 with high crop yield (4.52 t per ha and 4.58 t per ha respectively), lowest insect score (1.00) and lowest plant damage (5.3%) and highest percent damage control (79.06%) (Neupane, *et al*. 2016) [54]. In punjab, roper district experiment on Economic evaluation of biorational and conventional insecticides for the control of maize stem borer *Chilo partellus* (Swinhoe) in *Zea mays*, biorational treatment (chlorantriniliprole 18.5 SC) was superior to control leafy injury and dead heart incidence resulting in higher grain yield and economic returns than conventional insecticide (Deltamethrin 2.8 EC) (Kumar & Jindal, 2015) [40]. In Pakistan, granular (Carbofuran, cartap and monomehypo) and new chemistry foliar insecticides (Chlorantraniliprole, fipronil, spinosad and flubendiamide) was used to evaluate the comparative potency against *C. partellus* along with their effect on entomophagous arthropods (coccinellids and spiders' species), where carbofuran and fipronil killed the maximum population of *C. partellus*, but also cause mortality of natural enemies. Thus, soft chemical pesticide like Spinosad should also be included (Rauf *et al*., 2017) [72].

Moreover, to study the efficacy of safer granular insecticides (Fipronil 0.3G and Thiocyclam hydrogen oxalate 4G, Imidacloprid 0.3G) against stem borer and to review the efficacy of presently recommended insecticide Diazinon 5G, an experiment was conducted during 2008 and 2009 at Sri Lanka where the percentage damage reduced to <8% in treated plot from >35% in untreated control plot. Fipronil 0.3G (@12kg/ha) and Thiocyclam hydrogen oxalate 4G (@20 kg/ha) found to be significantly superior in controlling borer damage. Therefore, for effective management of maize stem borer, whorl application of these two granular insecticides can be recommended (Gunewardena & Madugalla, 2011) [23].

Likewise, the experiment was conducted to study the bio-efficacy of safer pesticides (chlorantraniliprole 20 SC, novaluron 10 EC, flubendiamide 480 SC, deltamethrin 2.8 EC) with carbofuran 3G at research farm of Tirhut College of Agriculture, Bihar where the maximum yield with highest mean per cent reduction over control in plant infestation as well as dead heart was recorded in chlorantraniliprole 20 SC @ 0.3 ml/l followed by carbofuran 3G @ 7 kg/ha treated plot. Also, the highest benefit: cost ratio was evinced in insecticidal treatment flubendiamide 480 SC @ 0.2 ml/l. Thus, the newer insecticides have long lasting activity with new mode of action, effective at very low dose, low residual effect and safe to non-target species (Kumar & Alam, 2017) [39].

The persistent nature of chemicals pollutes the environment, lack of knowledge and proper precaution creates health problems leading to death, application of high doses of insecticides causes mortality of natural enemies and the continuous spray of particular pesticides may develop the resistance in pest. Thus, it is unsafe and difficult to manage the pest with pesticides only. So, the adoption of chemical control along with IPM practices is recommended to flourish the production and save the environment.

Integrated pest management

IPM, a holistic approach and the decision-based process deals with synchronized use of collective tactics in order to enhance and direct all classes of pest in an ecologically as well as economically sound manner. The concept of using IPM method to control Maize stem borer came in effect after the trend of heavy increment of using pesticides by 20% annually (G.C and Ghimire 2018) [18]. Heavy use of pesticides brought negative effect on natural enemies ultimately decreasing their population, created environment pollution, built resistance in pest for which an outlook to IPM technique in the field is must for the farmers (Kaur & Garg, 2014) [33]. Practices like Pull and Push Technology, AESA (Agroecosystem Analysis), ITK (Indigenous Technical Knowledge), chemical pesticides, pheromone control, Host plant resistance method, intercropping, no mulching, crop rotation, protection of natural enemies etc. are collectively considered as effective IPM approaches to reduce the stem borer in maize field.

Pull and Push Technology

Push and Pull Technology (PPT) which is based on intercropping practices is considered as one among the major tactics for farmer nowadays in controlling maize stem borer (Khan *et al*., 2008). Two species of Desmodium plant (*Desmodium uncinatum* i.e silverleaf and *Desmodium intortum* i.e Green leaf) as repellant and Napier grass (*Pennisetum purpureum*) as both attractant and trap plant used as intercrop along with border plant in maize showed significant result against stem borer than maize sown in monoculture (khan, *et al*. 2016).

Desmodium grass produces smell that pushes the stem borer to Napier grass where they lay eggs but their larval stage doesn't survive in it. Hence, it acts as trap or pull plant where Pull and Push technology works (FAO 2011) [16].

About 12-43% of larvae were parasitized in maize when maize plants were intercropped with Desmodium and Napier grass which is less than maize when intercropped with Napier and Molases grass (56-78%) (Khan, *et al*. 2001). Hence, this technology is highly adapted in Ethiopia and around 96% farmers interest is in using PPT technology.

AESA based IPM

In traditional IPM practices, priority is given to the ETL system but in modern IPM packages, AESA is given priority where farmers will observe the big range area of the field (FAO, 2002). There are some components of AESA:

- Built-in compensation abilities of plants
- Pest and defender population dynamics
- Soil condition
- Climatic factor
- Farmer's past experience

Agroecosystem Analysis (AESA) is totally new concept as well as an insightful attempt for farmers in the IPM field leading to high yield and healthy plants.

Methodology to be considered while carrying out AESA

Firstly, field should be observed for pests which are to be performed after 20 Days of sowing. Five spots should be randomly chosen in each field (four in corner and one in center) then from each plot four plants are selected incidentally.

Field Observation is a must in order to succeed in the AESA model where certain rules should be taken into consideration. Insects are gathered in the box using a sweep net while monitoring the field. Proper observation of insects is to be done drawing AESA CHART MODEL that helps to show the field situation. It should be conducted weekly in the morning ideally before 9 a.m. where a decision on management practices is based on AESA and Pest(P): Defender(D) ratio only because P:D ratio helps to point out the number of pest and beneficial insects which makes farmers comfortable to manage insect and pest in field (Kumar, *et al*. 2014) [41].

Use of Chemical measure as means of IPM

Spinosad (Tracer 45% SC at 0.5ml L^{-1}water) was found to be most effective against *C. partellus* when sprayed twice i.e at first 15 days after emergence and before tasseling stage, lowering percent damage (4.32%), higher crop yield (4.58t ha-1), also Confidor 70WP@250 gm/acre at 6-8 plant leaf stage showed similar results (S. Neupane *et al*., 2016) [54].

Crop Rotation

IPM practices under crop rotation includes plantation of maize in first year followed by cotton in second year, leguminous plants in third year, ultimately planting maize in fourth year (JICA 2016). Through this practice, less infestation of borer is reported in the maize field.

Indigenous Technical knowledge (ITK)

Combination of local knowledge of farmers i.e. indigenous knowledge with scientific knowledge of researchers (IPM) has key role in a successful Farming System Approach (FSA) (Nkunika, 2002) [56]. ITK comprises local consciousness that are distinct to a given culture or society relating environment that has the element to solve the problems pertaining to agriculture and allied activities by the use of indigenous natural products.

Botanicals such as cow urine and cow dung, plants like: *Azadirachta indica, Vitex nedundo, Ricinus communis, Gliricidia sepium, Euphorbia milli, Euphorbia tirucalli,* Khirro *(Sapium insigne*) are some of technical knowledge used mainly by the indigenous communities of Kohalpur district of Nepal and are proved to be the best natural pest control plants (Deshmukh 2015) [14]. Derivatives of home-grown domestic plants like: *Tephrosia vogelii* and *Piper guineense* were enumerated by the farmers in most parts of Africa after their potential effect in controlling pests(Ogendo *et al*., 2003) [59] (Bekele *et al*., 1997) [5]. Ashes from burnt wood or collected ash from household kitchens mixed with dry soil or some conventional pesticides such as Mocap (ethopropos), Sevin, Gamalin, kerosene and using them in form of sprays were some indigenous techniques outlined by farmers (Oben *et al*., 2015) [57].

Use of Natural Enemies

Repelling pest by attracting natural enemies is significant to control the maize stem borer. Some Natural enemies of Maize stem borer are presented in table.

	Natural enemies	Life stage
Maize stem Borer	*Cotesia flavipes*	Larval Parasitoid
	Cotesia sesamiae	Larvae Parasitoid
	Dentichasmias busseolae	Pupa Parasitoid
	Lixophaga diatraeae	Larvae Parasitoid
	Trichogramma chilonis	Egg Parasitoid
	Trichogramma evanescens	Egg Parasitoid

Source: (CABI 2019) [10]

In the research done in Uganda on comparative study of PPT (Pull and push technology) and intercropping, the use of PPT is found more reliable for control of maize stem borer (Hailu *et al*., 2018) [24]. Nowadays use of pesticides is globally accepted under IPM practices. Release of *Trichogramma chilonis* @ 1,60,000 /ha. On 7- and 15-days old crop is subsequently used as a means of biological pesticides (M. Singh *et al*., 2014) [80]. Thus, IPM is most relevant method for practicing sustainable method because it doesn't show any negative effect on soil and plants reducing infestation of stem borer which accounts on higher yield of maize.

Result and Discussion

Maize stem borer is a polyphagous insect that feeds severely on graminaceous crops including maize. On account of its devastating boring nature, stem borer infestation resulted heavy losses in yield of maize 18%-28% in Nepal. Therefore, management of the borer pest is of utmost importance in order to increase the yield from the maize as well as other graminaceous crops.

Using the resistant cultivars like R-POP-2, RampurSO3F, RampurSO3FQO8 and RampurS10F14 among OPV and RML-5\RML-8 among hybrid was found to be the most effective and economic method. So, they can be used by farmers as their first line of defence.

Furthermore, farmers dependency on chemical pesticides is intense for its potency even so it is neither eco-friendly nor economic. Inappropriate and haphazard use of pesticides such as carbofuran, furadon, fipronil, cartap causes the hazard that can be reduced by use of safer insecticides like Spinosad followed with insecticides rotation and other IPM practices.

Aside from using chemical pesticides, several studies have revealed that approach to botanical formulations such as neem products, *Lantana camara,* garlic, general ash, clove, *Tagetes minuta. L,* oak, *Tephrosia vogelii,* extracts strengthened yield higher than 60 %, minimizing borer load by 55%. Bio-control agents like *Bacillus thuringenesis*, *Trichogramma chilonis* and *Apanteles flavipes* seem to have considerable importance in controlling *C.partellus*.

However, none of these approaches alone are influential to fully terminate the pests. On that account, our focus should be on practicing the most relevant and sustainable method i.e., IPM. Practices including crop rotation, use of ITK, sex-pheromones, manipulation of planting dates, mixed cropping, field sanitation, crop residue management and natural enemies as barrier to pests in IPM can create moderate effects on pest population scaling down the destruction to some extent. However, constructive application of these practices can minimize the potential losses and significantly assist in reducing the infestation in maize along with higher yield.

The most successful and relevant management of this pest can be brought about only by a holistic and coordinated approach to effective IPM practices where PPT (Pull and Push Technology), AESA (Agro Ecosystem Analysis) are completely new approaches to farmers that showed significant result against stem borer.

Hence, practicing coordinated approaches involving cultural and mechanical; chemical and bio- pesticides method demonstrates more convincing perspective to control the stem borer than exercising any one of these methods alone.

Conclusion

The stem borers describe a group of insects of economic importance to maize in Nepal. Owing to the style of their attacks and the intricacy of their biology, the success of the control options will depend on the integration of various strategies ranging from cultural practices to host plant resistance, biological control and moderate use of systemic chemical when necessary. The cultural practices and host plant resistance remains the prime component of the IPM of maize stem borers. They can be supported by the biological and chemical control. The cultural practices involve producers' involvement and cooperation. As for varietal resistance, more research action is essential to determine or develop varieties that tolerate the stem borers attack. The most successful and relevant management of this pest can be brought about only by a holistic and coordinated approach to effective IPM practices where pull and push technology (PPT), Agroecosystem analysis (AESA) are completely new approaches to farmers that showed significant result against stem borer. Hence, practicing coordinated approaches involving cultural and mechanical, chemical and bio-pesticides method demonstrates more convincing perspective to control the stem borer than exercising any one of these methods alone.

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