



Review article

An overview on possible management strategies for coffee white stem borer *Xylotrechus quadripes* Chevrolat (Coleoptera: Cerambycidae) in Nepal



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ABSTRACT

The Coffee White Stem Borer (CWSB) is one of the most dreadful and destructive pests of coffee in Asian nations, causing significant production loss each year. CWSB has a narrow host range, with *Coffea arabica* as their principal host. Once they bore into the stem of *C. arabica*, the whole plant must be uprooted. The study on the cumulative effects of the invasion of pests in the Nepalese agriculture system is quite vague. Farmers use a variety of methods to combat CWSB, but most of them are ineffective and wasteful. To effectively combat pests, it is important to understand the variety and abundance of natural enemies as well as the botanicals that have pesticide potential. If the management of CWSB in the Nepalese context goes unaddressed, it will prompt an alarming issue to coffee production in Nepal. Hence, it is of utmost necessity to develop rational management strategies of CWSB for promoting organic coffee in Nepal, which has garnered a reputation of excellent quality in the global market. This paper seeks to provide comprehensive information on the CWSB's management technique for using bio-rational compounds to aid Nepalese farmers cultivating organic coffee.

1. Introduction

Coffee (*Coffea* sp.) is one of the most widely grown cash crops in the world and is an income source for many farmers in developing nations like Nepal (Tiwari, 2010). Primarily, two species of coffee namely *Coffea arabica* L. (Gentianales: Rubiaceae) and *C. canephora* Pierre ex A.Froehner (Gentianales: Rubiaceae) are grown for commercial purpose (Bajracharya et al., 2015). With a global production of 163.7 million tons in 2019/2020, down from 172.5 million in 2018/2019, coffee is one of the highly favored beverages. Organic coffee farming is one of the most important commercial aspects of Nepalese agriculture. As per the data available at National Tea and Coffee Development Board, Nepalese coffee is rated in 7th position in the world based on its taste (Shrestha, 2021). Coffee was first introduced in the Gulmi district of Nepal in 1938 AD by bringing ascetic sowed coffee seeds from Myanmar. At present, it is grown in more than 40 districts of Nepal (NTCB, 2020). From a local to a

global level, Nepalese coffee is known for its authentic taste. Japan, United States, Canada, South Korea, and European countries are the major importers of Nepalese coffee (EKishaan, 2021). Due to its low caffeine content, Nepalese coffee is rapidly gaining popularity on the global market.

Although coffee cultivation has enormous advantages, its successful cultivation is quite difficult. From the plantation to marketing, every stage necessitates extensive care. In Nepal, most coffee growers apply organic pesticides and manures as input during cultivation (EKishaan, 2021). Nepal has a high potential for production but has not yet reached its target production level (Tiwari, 2010). Several constraints hold back the profitable coffee business and cause a decline in the yield of coffee. The major problems include invasive insect pests, diseases, erratic rainfall, drought events, unusual seasonal changes, and increased global warming. Common diseases in coffee plants are anthracnose (*Glomerella cingulate* (Cooke) J.A.Stev. & Wellman), twig dieback, summer dieback,

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stalk rot of berries and leaves, the brown blight of leaves leaf rust (*Hemileia vastatrix* Berk. & Broome), berry blotch (*Cercospora coffeicola*), wilting (*Gibberella xylarioides* R. Heim & Saccas), damping off (*Pythium vexans*), and brown eyespot (*Cercospora coffeicola*) (Dahal, 2020; Tuladhar and Khanal, 2020).

Coffee White Stem Borer is the most threatening and dreadful coffee pest known in Nepal. Once it infects, the whole plant has to be uprooted (Venkatesha and Dinesh, 2012). A study by National Entomology Research Center shows that CWSB is responsible for up to 70% of the loss in coffee production in Nepal (NARC, 2007). Affected young crops (up to 7–8 years old) die within a year, while older plants endure the attack for a few more seasons (Venkatesha and Dinesh, 2012). Crops infected by CWSB exhibit externally visible symptoms such as ridges around the stem, wilting, and yellowing. CWSB damage is more severe in arabica coffee than robusta as robusta coffee has considerably thicker, harder stem, and primary branches, which reduces the infection possibilities of larvae. Also, females do not prefer to lay eggs on the bark of robusta coffee as its smoother bark makes the eggs more vulnerable to predation (Venkatesha and Dinesh, 2012). CWSB directly invades leaves during flight and eventually lays eggs in the stem (Rajus et al., 2021). Young trees are particularly vulnerable to stem borer damage, with severe harm to trees of less than two years. When older trees get attacked, they are less likely to die, but it often results in lower yield.

X. quadripes is endemic in many Asian nations and pressure from CWSB has forced many coffee farmers to switch from planting arabica varieties to robusta varieties. According to Gana Shruthy (2016), the heavy damage caused by CWSB was the only reason that 90% of all coffee farmers in India's Kodagu district switched from growing arabica to robusta coffee varieties. Moreover, it has been reported that around nine million trees are destroyed annually by CWSB, leading to \$40 million in loss in India (Hall et al., 2006).

The effective management of CWSB is difficult but possible. The CWSB infestation can be controlled with the use of a botanical pesticide called “Jaibik bishadi” with “EM1” (Effective Microorganisms) processed locally. Jaibik Bishadi is prepared with the help of locally available plants having pungent smell, pesticidal properties and mixed with animal urine and water in the ratio of 1:5:5 (ICMOD, 2020). Cultural practices like mixed cropping of cultivating coffee alongside water-holding plants, shading facilities to protect from extreme sunlight (EKishaan, 2021), and pheromone traps are preferably used. Integrated Pest Management (IPM) is a widespread practice to reduce pest infestations. It stems from the belief that combining suitable biological, chemical, cultural, physical, and botanical methods would have a synergistic effect on insect management. In India and other Asian nations, a number of techniques have been used, including shade management, insecticide applications, bark scrubbing, stem wrapping to prevent oviposition, mass trapping with the aid of pheromone-baited traps, and uprooting and burning of affected plants to manage CWSB. However, it continues to be a threatening pest for Asian coffee farmers (Hall et al., 2006; Rajus et al., 2021; Venkatesha and Dinesh, 2012). The reason behind its uncontrollability could be local climate variability, altitude, lack of consistent monitoring, and the prohibitive cost of workforce required to practice those methods. The egg-laying nature of female adult *X. quadripes* leads to laying eggs deep inside the stem that protects the egg, larva from non-systemic insecticides (Rajus et al., 2021). Generally, spraying of contact and systemic pesticides is not recommended as several studies have already stated that those chemical residues get accumulated in coffee beans and affect other non-targeted creatures (Reis et al., 2015). Although the use of chemical pesticides is prohibited in organic farming, several insecticides are used to control the white stem borer. For a better understanding of the insect and its successful control, an in-depth study on its management strategies is necessary. The main objective of this review paper is to draw the attention of coffee growers towards the adoption of an eco-friendly and cost-effective method of controlling the CWSB. Therefore, this paper suggests a combined strategy that focuses on developing control methods to eliminate CWSB without harming natural enemies.

2. Organic coffee production in Nepal

Figure 1 shows the increasing trend in production and plantation area from 2015/16 to 2018/19 with an all-time high of 2761 ha achieved in the year 2018/19. In the fiscal year 2019/20, an overall coffee production of 296.5 mt was obtained from the plantation in 2360 ha of land. The year 2019/20 observed the lowest ever coffee production in a decade, due to reduced plantation area. Kavrepalanchok (34 mt) accounted for the highest volume of coffee production, followed by Gulmi (24 mt) and Ilam (18.5 mt). Although about 2 ha land area of Doti was planted with coffee, there was no production, which indicates that the resources and inputs invested for coffee production in Doti during the year 2019–2020 gave no significant output. Similarly, Eastern Rukum, Kailali, Ramechhap, Rolpa, Salyan, Surkhet, and Okhaldhunga produced 0.5 mt in 1 ha, 2 ha, 3 ha, 1 ha, 1 ha, 4 ha, and 3 ha, respectively. Comparably, the highest number of farmers engaged in coffee farming was found in the Kaski district (4125) followed by Kavrepalanchok (2850) and Gulmi (1645), respectively. While Doti had no farmers involved in coffee production, a handful number of farmers were found in Kailali (5) and Nawalpur (8). Rolpa, Okhaldhunga, and Jajarkot each had 15 farmers involved in coffee production in 2019–2020.

3. Origin and distribution of CWSB

CWSB, a damaging pest of arabica coffee (*Coffea arabica* L.), is widely prevalent in Asian countries (i.e., Burma, Bangladesh, Cambodia, China: Fujian, Guangdong, Guangxi, Hainan, Hunan & Yunnan; India, Indonesia, Laos, Myanmar, Nepal, Philippines, Sri Lanka, Taiwan, Thailand, and Vietnam) (CABI, 2022; Hayashi and Makihara, 1981; Le Pelley, 1968; Rhainds et al., 2001; Yousheng et al., 2002). The first infestation of CWSB was recorded in India in 1838 (Venkatesha and Dinesh, 2012). CWSB is rarely found in South Africa (Hanks, 1999). However, the African CWSB, *Monochamus leuconotus* (Pascoe), was unjustifiably stated by Schoeman (1990) as CWSB, a wrong identification mentioned by some successive researchers (Venkatesha and Seetharama, 2000).

The first appearance of CWSB in Nepal was reported in 1998. By 2016, the infestation had turned into an epidemic in Gulmi district, the coffee hub of Western Nepal (Joshi, 2018). Previously, this infestation was observed only in plants of lower altitude. However, the rising temperature has caused it to spread as high as 1300 masl (Perfect Daily Grind, 2016).

4. Life cycle of CWSB

The life cycle of CWSB completes in four stages: egg, larva, pupa, and adult, in its principal and most favored host, *C. arabica* (Venkatesha and Dinesh, 2012). However, the infestation sometimes is also seen in *C. robusta*. But, due to the phenotypic character of smooth and hard wood, the borer cannot complete its life cycle inside *C. robusta* (Reddy et al., 2019). Among the four stages, the larva of the borer is destructive for coffee plants (Desikan, 2021). Adult female borers, having distinct flight periods, lay eggs in the cervixes of plant bark (Hall et al., 2006). The eggs are oval, elongated, and milky white in color that later changes into yellow (Venkatesha and Dinesh, 2012). Generally, these eggs hatch to larvae in 14 days. The mature destructive larva is cylindrically segmented and yellow-colored with a dark brown head capsule (Venkatesha and Dinesh, 2012). The larva are 7–25 mm in length and 2.3–5 mm in width (Le Pelley, 1968; Rajbhandari, 2021). Once the first instar has reached a certain stage, it begins to tunnel the stem through the cambium and wood (Rajus et al., 2021). After six months, this larval stage develops to the pupal stage through six larval instars, and then finally pupa transitions into an adult in 30–40 days (Waller et al., 2007). These adults are elongated and black in color with white markings and have grey color pubescence on the head, thorax, and abdomen (Le Pelley, 1968; Venkatesha and Dinesh, 2012). The adult female generally lives for

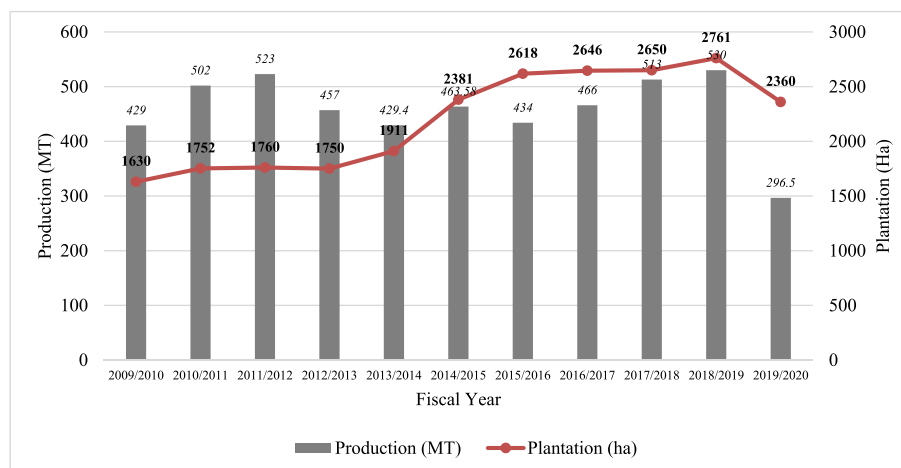


Figure 1. Scenario of organic coffee production in Nepal. Source: (NTCB, 2020).

29 days which is very active in the daytime. Hence, it mates in a sex ratio of 0.62 during the daytime (Visitpanich, 1994a). Le Pelley (1968) in India reported that the life cycle of *X. quadripes* gets completed within 12 months in coffee, but (Kung, 1997) in China contradictorily mentioned that CWSB completes two generations in a year. The photographs of different stages of life cycle of CWSB can be found at (Venkatesha and Dinesh, 2012).

Both males and females attract potential mates around them using pheromones (Rajus et al., 2021). The beetles don't use visible cues during selection of mate, but the antennae play role during courtship and mating (Venkatesha et al., 1997; Venkatesha and Dinesh, 2012). CWSB usually do not aggregate but may aggregate for mating in patchy distribution of infestations in an area without shade trees or with dead coffee plants. Observation on mating behavior suggests that male within 10 cm of female rushes toward her to mount on (Rhainds et al., 2001). If accepted, copulation occurs to allow union of genitalia. Majority of mating occurs between 09:00h and 12:00h, and 15:00h and 17:00h (Seetharama et al., 2004). Mating location varies on leaves, branches, main stem, and fruits of coffee plants (Venkatesha and Dinesh, 2012).

The emergence period of CWSB varies according to climatic conditions. The flight of the CWSB occurs in two periods: pre-monsoon flight (April to May) and post-monsoon flight (October to November) (Manikandan et al., 2019). Maximum infestation was found during October–November emergence period (Reddy et al., 2019). Although egg-laying is performed on the stem, CWSB prefers to approach Arabica coffee plants in flight and land on the coffee leaves (Rajus et al., 2021).

5. Nature of damage caused by CWSB

The tunneling of *X. quadripes* larvae to cambium and wood obstructs nutrient flow in plants resulting in wilted and yellow foliage. Young trees die as a result, and old trees become unproductive (Rajus et al., 2021; Waller et al., 2007). The CWSB larva tunnels the hardwood into powder and feeds on the fine powder, which picture can be found in Newton (2016). Moreover, the photos showing nature of damage is provided in Manikandan et al. (2019). After that, its fecal pellet and dust fill the tunnel to prevent attack from natural enemies (Hall et al., 2006; Venkatesha and Dinesh, 2012). As a result, tearing the affected stem or branch with a tunnel tightly packed with white frass will reveal whether it has infested a tree. Borers are also spotted if they are in larval or pupal stage (Santosh et al., 2011). The infested plant stem has distinct ridges, exit holes, defoliated & wilted leaves, and dead branches (Lan and Wintgens, 2004; Santosh et al., 2011). Additionally, these larvae dig tunnels that are visible on main stems, primary branches, and occasionally in the main root. The severity of damage can be observed

according to the number of larval populations in plants (Venkatesha and Dinesh, 2012).

6. Host plants of CWSB

CWSB has a narrow host range, that include plants such as *Cudrania javanensis* Trecul (Moraceae); *Gardenia* spp., *Ixora coccinea* L., *Randia dumetorum* L., *Randia spinosa* (Thunb.), *Wendlandia myriantha* F.C. How, *Psilanthus bengalensis* (Heyne ex J.A. Schult), Leroy (all Rubiaceae); *Jasminum dispersum* Wallich and *Olea dioica* Roxb. (both Oleaceae); *Oroxylum indicum* L. (Bignoniaceae); *Rhus semiciliata* L. (Anacardiaceae); *Pterocarpus marsupium* Roxburgh (Fabaceae); *Premna pyramidata* Wall ex Schauer (Verbenaceae); *Trema orientalis* (L.) (Cannabaceae); *Canarium* sp. (Burseraceae); and *Tectona grandis* L. (Lamiaceae) in Asia (Duffy, 1968; Santosh et al., 2011). Since many of the borer's native hosts belong to the Rubiaceae family, it is possible that over time, it evolved to prefer arabica coffee in a number of Asian countries. The plants which can function as alternative host of CWSB with their common name is given in Table 1. However, these alternative host plants do not allow massive duplications of the pest (CCRI, 2003).

CWSB barely invades weak robusta coffee plants and *Coffea liberica* Hiern (CCRI, 2003). CWSB has some extensive potential alternative host plants that include *Cudrania javanensis* Trecul (Moraceae); *Gardenia* spp., *Ixora coccinea* L., *Randiadumetorum* L., *Randia spinosa* (Thunb.), *Wendlandia myriantha* F. C. How, *Psilanthus bengalensis* (Heyne ex J.A. Schult), Leroy (all Rubiaceae); *Jasminum*.

7. Economic loss due to CWSB

When the trees heavily infested with CWSB were ripped out, a yield loss of 17.8–20% was recorded in India. Even after following integrated

Table 1. Alternate host plants of coffee white stem Borer.

S.N	Botanical name	Common name
1	<i>Tectona grandis</i> (L.f.) Kuntze	Teak
2	<i>Jasminum dispersum</i> Wallich	Jasmine
3	<i>Ixora coccinea</i> L.	Flame of wood
4	<i>Olea dioica</i> Roxb.	Rose sandal wood
5	<i>Randia spinosa</i> (Poir.)	Indigo berry
6	<i>Cudrania javanensis</i> LC	Cockspur thorn
7	<i>Wendlandia myriantha</i> Kaare	Kaare
8	<i>Oroxylum indicum</i> (L.) Benth. ex Kurz	Trumpet flower
9	<i>Psilanthus bengalensis</i> (L.) Benth. ex Kurz	Paracoffee

Source: (CCRI, 2003).

management approaches of CWSB control, 2.3–12.5% yield loss was observed (Subramaniam, 1934). Studies have shown that coffee plants in hilly areas are more prone to CWSB infestation (9.7%) than those in lowland (6.6%) (Shylesha and Veeresh, 1995). When the level of borer incidence was studied in plants of different ages in India, the maximum infestation of 8.3% was observed in old plants and 0.7% in very young plants (Shylesha and Veeresh, 1995). CWSB is developing into a very dangerous problem in Nepal, where annual yield losses from infected trees have reached 60% (Joshi, 2018). According to a study of coffee growers in Hokshe Municipality in the Kavre district, CWSB affected 93.33 percent of the farmers, leading to a high yield loss (Dahal, 2020).

7.1. Reasons for outbreak of CWSB

The outbreak of white stem borer is associated with the moisture availability of soil. Most scientists agree that dense precipitation followed by a long dry spell creates a favorable breeding environment for different varieties of insects, including the white stem borers (Joshi, 2018). The distribution of CWSB was found to be significantly predicted by variables related to precipitation, according to Kutwayo et al. (2013), who also suggested that climate change had an impact. Similarly, Liebig et al. (2018) found that rainfall, altitude, and shade mainly control the distribution of CWSB in Uganda. Weather factors affect the life cycle and emergence patterns of CWSB. Egg development and survival of larvae are unlikely to be successful in cold temperatures while warm temperatures are favourable for the insect (Evangelista et al., 2011; Jaramillo et al., 2011). Coffee plants require proper shade management to reduce the incidence of borer infestation. However, coffee growers often remove shade to improve crop yield that increases borer incidence. Unmonitored and unsupervised farms become a source of pest inoculum.

8. Management strategy

Different management contrivances have been deployed against CWSB, but these strategies are inconsistent. The use of chemical pesticides is strongly discouraged in Nepal while organic coffee production is being practiced and promoted. Since chemical pesticide caused destruction of beneficial insects and natural enemies, as well as for CWSB. Thus, biological strategies are the recommended avenue to produce organic coffee. Handpicking, scrubbing, use of pheromone traps, and local pesticides are some of the common farm-level practices for the management of CWSB as per the study carried out by Panthi (2014) in the Lalitpur and Gulmi district of Nepal. He added that organic manure, botanicals, irrigation, shade structures, and an intercropping pattern with leguminous crops, fruits, and fodder plants are all used in the management of organic coffee at the farm level. Along with regular training and pruning of the coffee plant to maintain its proper canopy, attention should also be paid to the sanitation of the coffee orchards. The affected and pruned parts should be either buried or burnt.

8.1. Cultural method

CWSB can be controlled through several cultural methods. Among them, the best approach would be growing coffee in the optimum shade as borers prefer to lay eggs in bright sunny areas (Venkatesha and Dinesh, 2012). According to Kutwayo et al. (2013), rainfall had a positive influence on the adult emergence of the white stem borer. Thus, it's likely that the increased humidity due to shade was advantageous. But, intense shade can sometimes increase the incidence of fungal disease and coffee berry borer *Hypothenemus hampei* (Ferrari) in Asian countries (Beer et al., 1998). Extreme care and management are needed while pruning and providing shade which can be done by avoiding the exposure of main stem and primary branches during pruning. One can also plant borer incidence check trees having low canopy shade like *Erythrina subumbrans* (Hassk.) Merr. & *Grevillea robusta* A.Cunn. ex R.Br. (Rao, 2004).

Immediately after transplantation, thatches made up of bamboo, wooden materials, grasses, and straws are used for providing shade over coffee plants. After two years, the plants are shaded by temporary shade species. *Tephrosia candida* DC, *Leucaena leucocephala* (Ipilpil), *Cajanaus cajan* (Lam.) de Wit (Rahar) (perennial type), *Erythrina lithosperma* Miq., and other fruit species such as banana (*Musa paradisiaca* Linn) and papaya (*Carica papaya* L.) are some of the common temporary shade species used in coffee orchards. According to the study carried out by Jonsson et al. (2015), temporary-shade species, fast-growing species, and evergreen varieties should be planted before transplanting coffee into the main field. Permanent-shading species such as *Albizia lebbek* (L.) Benth., *Albizia moluccana*, *Artocarpus integrifolia* L.fil., *Artocarpus heterophyllus* Lam., *Cedrella toona* Roxb. ex Rottl. & Willd., *Dalbergia latifolia* Roxb., fruit species such as Citrus species, Avocado, Macadamia nut, and spice trees such as *Cinnamomum* species (Dalchini and Tejapatta) can also be planted in the coffee orchard. Similar to this, small-scale farmers can also grow coffee as part of a multi-cropping system with other trees and fodder (Panthi, 2014). Jonsson et al. (2015) stated in their study that agroforestry is inefficacious in the management of CWSB in Eastern Uganda.

A profitable coffee business in Nepal continues to be difficult to achieve due to a lack of skilled workers to perform training and pruning on shade trees. Farmers frequently hesitate to combine shade-loving plants with coffee due to the misconception that they will compete with coffee for nutrients, light, and moisture.

8.2. Mechanical method

Important mechanical tactics of CWSB control are identifying, uprooting, and eliminating borer-infested plants based on the appearance of borer ridges on the main stem and thick primary branches before the flight period starts (Venkatesha and Dinesh, 2012). CWSB should be detected, removed, and destroyed before the borers hatch during March and September (Rajbhandari and Thapa, 2015). Hand-picking of larvae and beetles is a common technique in coffee-growing regions. However, it is neither dependable nor efficient because only a small number of adult CWSB are destroyed, and it is done only to get rid of the CWSB infesting the coffee plant. The CWSB problem can be made worse by using uprooted stems as firewood after being wetted for 7–10 days to kill the CWSB borer's developmental stages (Venkatesha and Seetharama, 2000). Covering the stems with a barrier prevents the adults from emerging and laying eggs. Nylon mesh, polythene, paddy straw, newspaper, gunny strips, and other materials can be used to create barriers and rubber coats. Scrubbing against the stem of coffee can be practiced once a year to remove eggs and young larva. There is a need for the mechanization of this task because manually cleaning stems is very labor-intensive.

8.3. Use of pheromone trap

A synthetic pheromone is found to entice CWSB (Hall et al., 2006). Generally, male adults release a sex pheromone to attract female adults whose primary constituent is (S)-2-hydroxy-3-decanoate (Hall et al., 2006). Other sex pheromone components: 3-hydroxy-2-decanone and 2S, 3S-dihydroxyoctane and four other compounds: 2-hydroxy-3-octanone, 2-phenylethanol, octanoic acid and 2,3-decanedione have been identified in volatiles from male beetles (Rhains et al., 2001; Pang et al., 2018). Cross vane pheromone traps are mainly used to attract the beetles during the peak flight periods (April–May and October–December) (Rajus et al., 2021). Trapping can be effective in bringing down the pest incidence at low densities and also helps in proper monitoring of the field (Venkatesha and Dinesh, 2012). Farmers have reported that as high as 30 to 40 CWSB adults with other insects like houseflies, bugs, and grasshopper can be trapped per day in infested orchards (Panthi, 2014). A sticky and white-colored cross vane trap made up of polyethylene rather than sachets is more effective (Venkatesha and Dinesh, 2012). The cross vane is fixed on a wooden stake with an overall height of 6–6.5 feet from

Table 2. Plants having the potent to affect the normal growth and development of CWSB and are available in Nepal.

Local name	Common name	Scientific name	Parts used	References
Aalas	Linseed	<i>Linum usitatissimum</i> L.	Oil	(Rajbhandari and Thapa, 2015)
Aamala	Emblic	<i>Emblica officinalis</i> L.	Fruits	(Panthi, 2014)
Aangeri	Drude	<i>Lyonia ovalifolia</i> (Wall.) Drude (1897)	Leaves/buds	(Panthi, 2014)
Aasuro	Adhatoda	<i>Justicia adhatoda</i> L.	Leaves	(Panthi, 2014)
Aduwa	Ginger	<i>Zingiber officinale</i> Roscoe	Bulb	(Panthi, 2014)
Bakaino	China berry	<i>Melia azedarach</i> L.	Fruits, leaves	(Panthi, 2014)
Banmara	Siam weed	<i>Eupatorium adenophorum</i> Spreng	Sooth, leaves	(Panthi, 2014)
Bojho	Sweet flag	<i>Acorus calamus</i> L.	Root	(Panthi, 2014)
Chiuri	Bachni	<i>Bassia butyracea</i> Roxb.	Oilcake	(Panthi, 2014)
Dhaturo	Angel trumpet	<i>Datura metel</i> L.	Fruits, leaves	(Panthi, 2014)
Kagati	Lemon	<i>Citrus limon</i> L.	Fruit	(Panthi, 2014)
Kaju	Cashew	<i>Anacardium occidentale</i> L.	Oil	(International Coffee Council, 2008)
Kantakari jhar		<i>Solanum aculeatissimum</i> Jacq.	Leaves	(Panthi, 2014)
Ketuke	Century plant	<i>Agave americana</i> L.	Leaves	(Panthi, 2014)
Khirro	Tallow tree	<i>Sapium insigne</i> (Royle) Trimen	Leaves	(Panthi, 2014)
Khursani	Chilli	<i>Capsicum frutescens</i> L.	Fruit	(Panthi, 2014)
Lasun	Garlic	<i>Allium sativum</i> L.	Bulb	(Panthi, 2014)
Neem	Neem tree	<i>Azadirachta indica</i> A.Juss.	Seeds, leaves	(Panthi, 2014)
Nimbu	Lime	<i>Citrus × aurantiifolia</i>	Fruits	(International Coffee Council, 2008)
Pudina	Field mint	<i>Mentha arvensis</i> L.	Leaves	(Panthi, 2014)
Pyaj	Onion	<i>Allium cepa</i> L.	Bulb	(Panthi, 2014)
Rato Sirish	Red Siris	<i>Albizia julibrissin</i> Durazz	Leaves	(Panthi, 2014)
Sayapatri	Marigold	<i>Tagetes</i> L.	Flower	(Rajbhandari and Thapa, 2015)
Sisnoo	Stinging nettle	<i>Urtica dioica</i> L.	Whole plant	(Panthi, 2014)
Siudi	Cactus	<i>Opuntia</i> spp.	Whole plant	(Panthi, 2014)
Surti	Tobacco	<i>Nicotiana tabacum</i> L.	Leaves	(Panthi, 2014)
Timur	Prickly ash	<i>Zanthoxylum armatum</i> DC.	Fruits	(Panthi, 2014)
Titepati	Mug wort	<i>Artemesia indica</i> Willd	Leaves	(Panthi, 2014)
Tori	Mustard	<i>Brassica campestris</i> L.	Oil's cake	(Panthi, 2014)

*The plants obtained from field survey by Panthi (2014) are local plants used to prepare botanical pesticides in Gulmi and Lalitpur, Nepal.

the ground. The traps are spaced in a grid at a distance of 20 m or placed after every 8 to 10 plants (NTCDB, 2017). However, light traps are not as much effective as pheromone traps (Panthi, 2014). However, pheromone-based trapping of female might not be operational strategy in management. Due to the complex mating behavior of CWSB i.e. attraction of potential mates by both sexes, the females are not directly attracted to the pheromone source (Rhains et al., 2001).

8.4. Biological approach

Biopesticide refers to the non-chemicals that incorporate plant extracts, living microorganisms, their derivatives, and other natural compounds for pest management. Biopesticides are gaining popularity as a safer way to control pest populations such as weeds, plant diseases, and insects while posing minimal risks to people and the environment due to their lower environmental toxicity, target specificity, and non-target organism safety (Kumar et al., 2019). It is not a novel idea to use biopesticides and biofertilizers made from naturally occurring formulations that can manage pests through non-toxic methods while still being advantageous to the environment. These products have been in use for decades. Since the potential use of biopesticides ensuring environmental safety is well-established, the increased demand for organic food has stimulated attention. Although the use of agrochemicals is required to meet the ever-increasing needs for food, feed, and fodder, there are some crops and niche regions where biopesticides can be employed as a part of an integrated pest management strategy (Kumar and Singh, 2015).

8.4.1. Botanical pesticide

Nepalese organic coffee has been able to establish a special place in the international coffee market. So, the application of chemical pesticides is strictly restricted while cultivating Nepalese coffee. The use of botanical pesticides is the most suitable option in biologically controlling CWSB for organic coffee production. Koirala and Tamrakar (2014) found that pesticides and agrochemicals are not applied in the production of high-value crops in Gulmi and Lalitpur of Nepal. Usually, the botanical pesticides are opted for, until and unless the severity of pest infestation is uncontrollable and all other biological, cultural, and mechanical measures have failed. Chemical control measures are conventionally regarded as a last resort.

According to Panthi (2014), farmers applied 'Jaibik bisadi', a locally made organic pesticide made up of coffee pulp and husk. 'Jaibik Bisadi' also serves as fertilizer, which indirectly reduces the infestation of CWSB as CWSB is more likely to infest coffee grown in soil with low levels of organic matter, nitrogen, and pH (Thapa and Lantinga, 2016). Panthi (2014) also found that the farmers preferred botanicals like *Allium sativum* L., *Allium cepa* L., *Azadirachta indica* A.Juss., *Eupatorium adenophorum* Spreng., *Urtica dioica* L., *Artemesia indica* Willd., *Zanthoxylum DC* for the control of CWSB. Table 2 shows the name of plants with their plant parts having their pesticidal value and can be used for the management of CWSB in Nepal. The chopped botanicals are mixed in water and allowed to ferment for 18–22 days in a plastic drum of 50 L capacity. The properly fermented liquid is diluted in 8 L of water before spraying. For more effectiveness, farmers use the solution of

Table 3. Natural enemies of Coffee White Stem Borer.

Natural enemy	Country	Reference
Parasitoids		
Aulacidae		
<i>Pristaulacus</i> spp.	Thailand	(Visitpanich, 1994b)
<i>Pristaulacus nigripes</i> Kieffer	Vietnam	(Le Pelley, 1968)
Bethylidae		
<i>Apenesia</i> sp.	India	(Venkatesha et al., 1997)
<i>Apenesia sahyadrica</i> Azevedo & Waichert	India	(Azevedo and Waichert, 2006)
<i>Mysepyris grandiceps</i> Kieffer	Vietnam	(Kieffer, 1921)
<i>Sclerodermus domesticus</i> Klug	Vietnam	(Kieffer, 1921)
<i>Sclerodermus</i> sp.	India	(Shylesha et al., 1992)
<i>Sclerodermus vigilans</i> Westwood	India	(Shylesha et al., 1992)
Braconidae		
<i>Allorhogas pallidiceps</i> (Perkins)	India	(Prakasan et al., 1986)
<i>Campyloneurus</i> sp.	India	(CCRI, 1998)
<i>Doryctes bistriatus</i> Kieffer	Vietnam	(Le Pelley, 1968)
<i>Doryctes brevipes</i> Kieffer	Vietnam	(Le Pelley, 1968)
<i>Doryctes compactus</i> Kieffer	India	(CCRI, 1998)
<i>Doryctes coxalis</i> (Turner)	India	(Shylesha et al., 1992)
<i>Doryctes picticeps</i> Kieffer	Vietnam	(Le Pelley, 1968)
<i>Doryctes stroliger</i> (Kieffer)	Vietnam	(Le Pelley, 1968)
<i>Doryctes tristriatus</i> Kieffer	Vietnam	(Le Pelley, 1968)
<i>Iphiaulax</i> sp.	India	
<i>Promiscolus sesquistriatus</i> Kieffer	Vietnam	(Le Pelley, 1968)
<i>Pristodoryctes striativentris</i> Kieffer	Vietnam	(Venkatesha et al., 1997)
Encyrtidae		
<i>Avetinella</i> sp.	India	(Shylesha et al., 1992)
Eupelmidae		
<i>Metapelma</i> sp.	India	(Subramaniam, 1934)
Eurytomidae		
<i>Eurytoma</i> sp.	India	(Shylesha et al., 1992)
<i>Eurytoma xylotrichi</i> Ferriere	Vietnam	(Ferrière, 1933)
Gasteruptionidae		
<i>Gasteruption</i> sp.	India	(CCRI, 1998)
Ichneumonidae		
<i>Epixorides caeruleus</i> (Morley)	Ceylon	(Thompson, 1947)
<i>Mesostenini</i> (tribe)	Thailand	(Visitpanich, 1994b)
<i>Paraglypta tuigera</i> (Kieffer)	Vietnam	(Le Pelley, 1968)
Stephanidae		
<i>Diastephanus</i> sp.	Thailand	(Visitpanich, 1994b)
Avian Predators		
Megalaimidae		
<i>Megalaima</i> sp.	India	(Subramaniam, 1934)
<i>Megalaima viridis</i> (Boddaert)	India	(Yahya, 1982)
Fungal pathogens		
Trichocomaceae		
<i>Aspergillus tamarit</i> Kita	India	(CCRI, 1998)
Cordycipitaceae		
<i>Beauveria bassiana</i> (Bals.-Criv.) Vuill.	India, China	(Balakrishnan et al., 1994) (Jia-ning & Rong-pid, 2002)

Source: (Venkatesha and Dinesh, 2012).

fermented liquid, water and cattle urine at the ratio of 1:5:1. (Panthi, 2014). Neem Seed Kernel (NSK) is effective against CWSB. But the repeated application of the extract is not budget-friendly, especially for Nepalese farmers, as per projects conducted in India, Malawi, and Zimbabwe. The study also mentioned the effective use of a mixture of nimbecidine, cashew oil, and butanol. Also, DDL fevicol along with 10% lime brought satisfactory control of CWSB (International Coffee Council, 2008). Paste of neem or chinaberry leaves, garlic, and marigold flowers

mixed with linseed oil when applied on the stem twice a year (September & March) helps direct control of CWSB (Rajbhandari and Thapa, 2015). Before administering the paste, the stems are rubbed with rough cloths or jute sacks. The effects of neem oil do not last for many days, so they are sprayed at an interval of 15–20 days (NTCDB, 2013). Furthermore, research should be carried out to see the most potent plant and its part that hinders the normal growth and development of CWSB.

8.4.2. Natural enemy

So far, no distinct CWSB predator has been identified. Table 3 shows the recorded twenty-nine species of parasitoids, two species of general avian predators and two species of fungal pathogens as the natural enemies of CWSB. Various parasitoids of families Aulacidae, Bethyidae, Braconidae, Encyrtidae, Eupelmidae, Eviidae, Gasteruptionidae, Ichneumonidae, and Stephanidae were found to attack the CWSB. A significant control due to these parasitoids was observed in India, Vietnam and Thailand. India also reported the use of birds that feed on the larval stage of these borers (Vega et al., 2006). *Beauveria bassiana* (Bals.-Criv.) Vuill. is preferably used among other bio-pesticides. A study in India managed to destruct the pests within six days of inoculation of *Beauveria bassiana* (CCRI, 2017). This application on instars and adult borers is economical over chemical pesticides such as omethoate and methamidophos (Jia-ning & Rong-pid, 2002).

8.5. Use of chemicals

Insecticides are employed to suppress the insects. However, their effectiveness is relatively minimal to their cryptic life cycle inside the trunk (Vega et al., 2006). The use of chemicals is not encouraged while promoting organic coffee in Nepal. Paint mixed with insecticides can be applied over the stem surface to kill the eggs and larvae. Since CWSB invades the stem deeply and non-systemic insecticides do not act at the depth of the stems, the effectiveness of many insecticides seems low in regards to controlling CWSB (Rajus et al., 2021). Also, chemical insecticides kill non-target beneficial species that can intensify the loss due to CWSB. However, farmers who are tempted to eradicate CWSB use chemical insecticides. According to the experiment conducted by Manikandan et al. (2019), the highest cherry yielding plots of *Coffea arabica* were those treated with chlorpyrifos 20 EC + azadirachtin % EC (52.58 and 51.32 kg/30 plants), followed by chlorpyrifos 20 EC (51.86 and 50.86 kg/30 plants) and *Beauveria bassiana* (Hypocreales: Cordycipitaceae) % A.S. (47.47 and 46.94 kg/plants). In the context of Nepal, in April–May, spray of azadirachtin 0.15 % (NSKE based) at 5 ml/L or chlorpyrifos 20 percent EC at 1.5 ml/L water, and repeat of same solution in October can be applied. Seetharama et al. (2004) discovered that in vitro laboratory tests, chlorpyrifos was more successful against eggs, carbosulfan was more effective against larvae of the fifth instar, and both chlorpyrifos and carbosulfan were successful against adults. But the carbosulfan is already listed as the banned pesticide in 4th August, 2019 in Nepal. In the field, lime (10 percent in water) application on the stem gives some protection against the CWSB by filling the gaps on the stem, hence preventing egg deposition by the beetles (Vinod Kumar et al., 2009).

Alternatively, stems can be swabbed with carbaryl 50 WP diluted in 200 L of water at a rate of 4 kg per 200 L of water. However, the use of carbaryl as pesticides was banned in 31st December, 2018 in Nepal. Also, it can be managed by spraying with Fipronil insecticides, such as Regent 50 SC or Mortel 5 percent SC, at the start of the rainy season in the prescribed dosage. However, according to Reddy et al. (2019), Chlorpyrifos 50EC + Cypermethrin 5EC is a suitable option in the integrated treatment of the borer. We should avoid using broad-spectrum insecticides to protect natural enemies like parasitic wasp (*Afrocoelichneumon didymatus* and *Phleideole megacephala*; CABI, 2018). It is also suggested to spray chlorpyrifos 20 EC at 600ml in 200 L of water with 200ml of wetting agent, in two doses—once in April–May and another at the end of October. Application of carbaryl 50 WP at 4kg diluted in 200 L of water makes the stem swabbed and controls the pests to some extent (Jayaraj and Muthukrishnan, 2013).

9. Integrated pest management (IPM)

IPM is perceived as an approach in which coordinated use of cultural, mechanical, and biological strategies are prioritized. With consideration for the protection of beneficial insects, chemical strategies are frequently seen as a last resort to destroy harmful pests. In Nepal, biological contrivances for the management of CWSB are emphasized for the production of organic coffee. IPM is an ecologically and environmentally sound approach that incorporates all available control strategies of CWSB. IPM strategies aim to use selective pesticides as a last resort when other methods are ineffective while maximizing the use of natural predators or parasites to control pests. Sometimes, IPM is confused with organic practices. While IPM does not encourage farmers to use chemicals, it does suggest they use specific pesticides in the right amounts as needed for their crops (Farm Biosecurity, 2021).

10. Research activities related to coffee and CWSB in Nepal

Despite having a small place in the world coffee arena, Nepalese farmers produce coffee in the hilly areas from east to west of Nepal. Coffee is not a traditional crop of Nepal. Currently, the Arabica coffee grown in Nepal has two varieties: Bourbon and Typica (Adhikari, 2018). These are brought in from Burma, India, Brazil, Papua New Guinea, and El Salvador. Within these varieties, 23 genotypes are under the evaluation stage (KC et al., 2013). Among them, 'Tekisic', 'Selection-10', 'Yellow Catura' & 'Arghakhachi Local' perform better in western mid-hills conditions (KC et al., 2016) (see Table 4).

The major organizations at the government level that participate in coffee promotion in Nepal are the Nepalese Agriculture Research Council (NARC), established in 1991, Nepal Tea and Coffee Development Board (NTCDB), established in 1993 and Nepal Coffee Producers' Association (NCPA), established in 2016. National Coffee Research Program (NCRP), Gulmi, and Horticulture Research Station, Pokhara are two research farms working under NARC (Acharya and Pun, 2016). International development partners include Helvetas Nepal since 1956, Good Neighbors International (GNI) Nepal since 2002, and Beautiful Coffee Nepal (BeaCoN) since 2014 (Tuladhar and Khanal, 2020). Nepal Good Agricultural Practice (N-GAP) for coffee was also implemented jointly by the Department of Agriculture (DoA) and the Department of Food Technology and Quality Control (DFTQC).

Realizing the issue of White stem borer, Prof. Jose Carlos Verle Rodrigues, Ph.D., (an expert on coffee white stem borer) from the University of Puerto Rico, USA, was invited to Nepal for volunteering through the "Farmers to Farmers Program" of Winrock International. Winrock International and the Entomology division of NARC together organized a six days workshop cum training program on 17–22 December 2014 (Karki, 2020). As per the workshop, various strategies were formulated in the workshop (Bajracharya et al., 2015). The strategies were categorized into short-term, medium-term, and long term.

Short term strategies:

- Implementation of recommended packages of practices for CWSB (scoring/priority attached)
- Establishment of commercial coffee orchard establishment
- Strengthening the production of insurance mechanism

Medium term strategies:

- Adoption of updated package of practices based on research findings
- Publish manual for management
- Training, capacity building, visit, exposure, demonstration in/out of country

Long term strategies:

- Adoption of Standardized package of practices (export and domestic consumption)
- Coffee estate promotion
- Coffee market hub establishment.

The main issue with Nepal's research sector is that most research activities only concentrate on agronomic practices, neglecting insect pest identification and integrated management. Despite being the most vulnerable pest of coffee, enough research have not been conducted for CWSB management. Although NTCBD and Coffee Promotion Program, Helvetas have recommended sticky trap and sanitation as control measures, their results have not been documented sincerely (Acharya and Pun, 2016). Some studies have been done to choose organic, non-toxic, and affordable CWSB control methods. To opt for organic, non-toxic, and cheap methods of CWSB control, some research have been conducted. The studies recommend integrated management practices, including managing optimal shade, monitoring infected plants annually before flight periods, collar pruning, uprooting infected roots, burning them, removing loose scaly bark from main stems and thick primaries without damaging stems, spraying or swabbing with 10 percent lime and wetting agent on the main stems and primaries, and all of the above (Rajbhandari and Thapa, 2015). Cross-vane traps with lures and maintenance of soil moisture are also recommended (Panthi, 2014).

11. Conclusion

Coffee White Stem Borer, the striped black colored beetle, is one of the most ravaging and destructive pests in coffee plants, especially in Asiatic countries. Nepal suffers a heavy economic loss and reduced coffee yield annually. Hence, farmers are in dire need of an integrated management strategy to deal with these borers. Without affecting coffee production, such control strategies would help preserve the natural biodiversity in the agricultural environment. Government should provide adequate funds and technical assistance to support the research activities. While these suggestions are likely to offer better advances for CWSB control in the future, there remains plenty of scope for further research into the formulation and application of technology to facilitate successful adoption by end-users. As Nepal promotes organic coffee, farmers should keep shade on their coffee plants, uproot and destroy the plant once it becomes infested with CWSB, and use biological pesticides wisely.

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Table 4. List of varieties of Arabica coffee under evaluation stage (Acharya and Pun, 2016).

Name of Varieties	Tekisic, Typica, Bourbon Amarillo, Bourbon Vermelho, Mundo Novo, Indo team team, San Roman, Pacas, Pacamara, Yellow Catura, Catura Amarillo, Catura Vermelho, Huwail Kona, Indonesia, Selection-10, Cauvery, Catuai Amarillo, Catuai Vermelho, Catimor, Catistic, Chetradip, Syangja Special, Arghakhachi Local, Kaski Local & Puranchaur Local
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Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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