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(Review Article)

Insect pests in apple (*Malus domestca* Borkh) gardens: Review

Emilly Kamusiime [1, 2, *], Judith Ssali Nantongo [2] and Cosmas Wacal [1]

[1] *Faculty of Agriculture, Uganda Martyrs University Nkozi, P. O. Box 5498, Kampala, Uganda.*

[2] *National Agriculture Research Organization, National Forestry Resources Research Institute, P. O. Box 1752, Kampala, Uganda.*

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Abstract

Apple (*Malus domestica*), is one of the most important fruit trees cultivated in temperate regions but, newly introduced in Uganda for its income and nutritional importance. However, apples are found to be susceptible to arthropod pests, some known to cause damages on both the plant and fruits. Some of these insect pests are known while others are still unknown and could be effectively managed through integrated pest management methods. For any effective Integrated insect Pest Management, it is necessary to have enough information about the biology and ecology of a given pest, including, spatial distribution and factors that affect pest species' distribution. Therefore, in this paper, systematic information on insect pests damaging apple fruit trees was reviewed. Different recent literature on insect pests hosted by apples under different agroecological systems of the world was reviewed. The review focused on classifying common insect pests, preferred varieties and their ecological distribution. This was achieved by using the ISI Web of Science bibliographic database and search terms such as apple entomofauna and insect pests were used, with specific keywords of [apple*] AND [insect*] AND [pest]. It was found out that, insect pests in apples belong to several groups of invasive pests which include Coleoptera and Polydrusus (beetles, weevils), Diptera (leaf, seed, fruit flies), Hemiptera (aphids, psyllids, bugs and scales), Hymenoptera (sawflies, wasps ants, bees), Thysanoptera (thrips), Trombidiformes (mites) and Lepidoptera (moths and butterflies) that are of economic value. This work, again reveals dramatic rates of appearance of isect pests in orchards in Africa and elsewhere, which have compromised apple industry's growth. The review pieced together known information about the insect pests that occurs in apples in different geographical locations. But, information on insect pest in Uganda's apple orchards remained scanty, which calls for an immediate detailed study on the same.

Keywords: Apples; Insects; Insect Pests; Distribution; Apple Varieties; Geographical locations

1 Introduction

Apples (*Malus domestica* Borkh.) are widely cultivated and are important economic fruits with nutritive and medicinal importance. Widespread and growing intake of apples and apple products is due to their rich phytochemical profile which suggests their potential to positive effects on health of human populations. It is generally, recognized as being nutritious and is represented in the quite popular statement "an apple a day, keeps the doctor away (4). Apples are commonly consumed as unprocessed fresh fruit and fresh apples are available worldwide all year round (131). Apple trees also provide vital ecosystem services, such as combating desertification, maintaining biodiversity, enhancing carbon sequestration, and play an important role in preserving social and cultural values (150). Apples have religious and mythological significances in many cultures including Norse, Greek and European Christian traditions (21). Therefore, appearing in many religious

* Corresponding author: Emilly Kamusiime; Email: emillykamusiime@gmail.com

traditions, often as a mystical or forbidden fruit (Genesis 2:7). However, in the Bible the word "apple" is used as a generic term for all (foreign) fruit, other than berries, and nuts, as late as the 17th century (64).

The tree originated in Central Asia, where its wild ancestor, *Malus sieversii*, still exists (149). Apples are typically temperate trees, where most commercial varieties satisfy their required chilling temperature, often expressed as hours at less than 7 °C (107). But, (107), said that, apples' dormancy could also occur in tropics as well as in temperate conditions. Therefore, various temperate crops including apples are found increasingly being produced in many sub-tropical and tropical countries (10). In Uganda, specifically, in Kigezi highland agroecological zone, apple growing was increasing and the in the recent past, apples covered 20% of farm land (7). In this region, apples grow in high altitude areas ranging from 1500-2700 m a.s.l. Where the mean temperature is 18˚C with maximum of 24.4˚C and minimum of 10.9˚C and the relative humidity ranges between 90% - 100% in the mornings and decreases to 42% - 75% in the afternoons throughout the year (141). These climate conditions allow the area to reach chilling conditions required by apples, thus, reaching their maximum productivity. Despite their fascinating benefits which includes nutritional benefits and increased incomes among the growers in Uganda, apples are susceptible to insect pests such as aphids and other unidentified caterpillars (140). However, (21), said that, apple cultivation heavily depends on climatic condition and is susceptible to several diseases caused by fungi, bacteria, viruses, insects, etc.

According to literature, Northern Hemisphere has accumulated the largest number of naturalized insect pest species and have been the major donors of naturalized alien insect pests to all other continents (71). Due to higher potential pest pool already existing in the area where they are introduced, majority of the introduced plant species frequently suffer attacks from insect pest communities. These alien crops have suffered from insect pests, for example, the apples of Uganda. Yet, in Uganda, information on economic important insect pests in apple fruits is scanty. Even in Europe, data gathered on insect pests, other than sets retained for the Alert List, insect pest information is still preliminary and partial (particularly data on the distribution and or host list may be incomplete or erroneous) (130).

Therefore, this review provides a synopsis of recent advances in the understanding of the distribution of herbivore insect pests in contemporary apple agroecosystems, intended to provide new insights into the study of diversity and distribution of economically relevant insect pests (84) that damage apple fruits on farm. This is important data for comparing pests in different apple orchards and will help in shaping pest management planning for Uganda's apple agronomies. But also, is intended to help in strengthening the apple agroecology, aimed at ensuring that Uganda's' apple attain international standards of quality and quantity fruits, with effective pest management. But, this, requires reliable information on the occurrence of the pest, the biology, ecology, diversity, distribution and pest impacts on apple stand ecosystems (55).

Whereas, information on insect pests on commercial trees such as eucalyptus is available in industrialized countries, this is opposite in non-industrialized countries (147). This follow suit information gaps on arthropod pests associated with apples, introduced in the tropics, among the small-scale farmers of Uganda. According to (74), there are 200 million insects for every human and 40 million insects for every acre of land. This explains how insects are unique not only in diversity, but also, in their distribution. However, the big challenge is that, insect fauna of most places are not yet fully studied, particularly in developing countries, specifically Uganda (100). Therefore, there are possibilities of recording several new insect species in near future, once specific studies are conducted in specific agriculture disciplines.

On the other hand, these pests need to be managed for improved crop productivity, thus, a call for insectary studies focused on pest behavior and crop damage for improved efficacy of their control strategies (104). However, progress in understanding of insect pest behavior and their ecology in Uganda's apples has been hampered by their cryptic coloration which mask their location, identity, and movement in different ecologies. This has been hastened by the apparent lack of good insectary services and facilities in the country, and the associated lack of adequate monitoring techniques (100). Thus, insect pests in Uganda's apples remaining unknown to date. Therefore, this paper reviews different insect pest resources in apple orchards (12). With the fact that, information gathered will guide in designing effective pest management in Uganda's apples and elsewhere. Similarly, this review, seeks to document insect pests associated with apple varieties and their distribution in different habitats. It tackles active research avenues on insect pests in apples and damages caused by different insect pests which harbors a yet unexploited potential to support pest management in the face of land use changes.

2 Methodological approaches to literature review

An on-line comprehensive literature search was performed using the ISI Web of Science bibliographic database and keywords of [apple*] AND [arthropod*] AND [insect*] AND [pest] were used, which resulted in reviewing a variety of articles. Other references were obtained from experts, as well as from citations within references and grey literature. These included; progressive reports by the apple growers, scientific articles and farm records of apple growers. Reports that focused on individual species, pest outbreaks or invasive species were also included. We mostly, selected surveys that considered many species in a tax on (e.g., family or order) within large areas (i.e., a region, or a country) or smaller areas that were intensively surveyed over longer periods of even up to 10 years. Finally, surveys that reported changes in quantitative data over time, either on species richness or abundance, were considered. In this respect, both short and long-term insect pest surveys in apples conducted over a period of years were also considered. Finally, this review covered more than 154 reports on insect pests' occurrences in apple orchards in various parts of the world.

3 Results and Discussions

Though, more than 100 apple varieties are consumed worldwide (31), in Uganda, a few apple varieties have been promoted including; Anna, Dorset and winter (37). But, (137), differentiated 475 genotypes of apples and these were distinguished based on multi-locus microsatellite variation. Within the different apple varieties, spread of insect pests in different places underlies their abundance and distribution in space and time, hence, the extent of damages inflicted on crops (121). But, some plants have the capacity to resist pest attacks. Therefore, (89), observed that, plant's resistance to insect pest attacks strongly depends on plant characteristics which affect herbivore preference or performance. This specific characteristic is expressed by different plant genotypes that lead to differential resistance to herbivores on plants.

It has been noted that farmers use different management practices in controlling insect herbivores. However, there is inadequate information about farmers' knowledge, perceptions and practices in the management of key insect pests (96). Okonya and team, found out that, majority (93%) of farmers perceived insect pests to be a very serious problem in Uganda. Though, these pest could be controlled along the garden margins, (136), said that, little is known of the importance of field margins in supporting natural enemies of insect pests in tropical agriculture. More still, (96), mentioned that, despite of some studies done, there is little knowledge among stakeholders about arthropod pests especially the fruit fly pests in terms of its economic importance, pest status, economic impact and control strategies. This have hindered development of effective pest management approaches for smallholder farmers. In a strange way, insect pests continue to exact a high toll on agricultural production, in spite of intense agrochemical input. So, (84), said that, movements of insect pests from one place to another underlies their abundance and distribution in space and time, hence, the extent of damage they cause. Nonetheless, (13), noted that, fruit flies are a major threat to the horticulture industry in Africa owing to their damage incidence and economic losses to fruit and vegetables.

Africa is generally, known to be the place of several fruit flies, introduced and established worldwide, the most notorious species being the Mediterranean fruit fly, the *Ceratitis capitate* (13). He confirms that, invasion of alien insect pest species could cause extensive economic and ecological damage, with unpredictable negative effects on plant populations. (13), warned that, some insect pest species' impact on plants through direct habitat destruction. But also, invasive species could alter succession patterns, mutualistic relationships, community dynamics, ecosystem functions and resource distributions, causing extinction of native species which ultimately reduce on both local and global species diversity. Therefore, (20), said that, the most successful invaders and most devastating agricultural pests recognized worldwide is the tephritid fruit flies (Diptera: Tephritidae). Among them, are the Mediterranean fruit fly (*Ceratitis capitate*) and the South American fruit flies in the genus anastrophe that were found attacking apples elsewhere. Thus, a potential threat in tropical fruit production and conservation (127), especially in apples.

Insects are one of the most successful groups of animals. They constitute about three-fourths of the total organisms present on earth (73). He said that, out of the 5.57–9.8 million estimated animals in the world, 4–8 million species are known to be insects. Again, (129), said that, there are about 1837 apple pests listed worldwide, of which about three quarters (77.5 %) are insects, followed in quantity by fungi (14.5 %), Arachnida (3.4 %) and viruses, viroids and virus-like diseases (2.0 %), nematodes (1.4%), bacteria (1%) and gastropods (0.2%). Insect pests can damage apples in different forms. For example, winter moth and apple sawfly have the capacity to damage apple fruits to a significantly higher extent (116). Also, (23), found out that, *grapholita molesta* (Busck) was one of the main pests, which lived on shoots and fruit of apples. Besides, in southern Brazil, this pest was found in old branches and structures similar to aerial roots, commonly referred to as burr knots. On the other hand, (90), observed that, *Plum curculio* and *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), was the important apple pest that significantly hindered sustainable apple production in eastern North America. Yet again, for *Rhagoletis pomonella* (Walsh) (apple maggot), *(*117), recorded a host range of 55 plant species in ten genera in the family Rosacea, widely distributed in the USA. Hitherto, it was known to be restrict in temperate region. Moreover, insect pest that damage apples were noted to be diverse in different regions as described in (Table 1) below;

Table 1 Regional insect pest diversity and distribution in apples

Regions	Scientific names	Common names	Scientific names	Common names	No References
Europe	*Anthonomus pomorum*	Apple blossom weevil	*Eriosoma lanigerum (Hausmann)*	Woolly apple aphid	*67*
	Rhagoletis pomonella	Apple maggot	*Edwardsiana crataegi*	leafhoppers	
	Lygocoris pabulinus	Common green capsid	*Campylomma verbasci*	Mullein plant bug	
	Ceratitis capitata	Mediterranean fruit fly	*Lepidosaphes ulmi*	Apple mussel scale	
	Aphis pomi	Apple aphid (green apple aphid)	*Synanthedon myopaeformis*	Red-belted clearwing	
	Cydia pomonella	Codling moth	*Yponomeuta malinellus*	Apple ermine	
	Dysaphis plantaginea	Rosy apple aphid	*Thripidae spp.*	Thrips	
	Phyllocoptes malinus	Phyllocoptes malinus	*Aculus schlechtendali*	Apple rust mite	
	Rhopalosiphum insertum	Apple-grass aphid	*Tetranychus urticae*	Twospotted spider mite	
	Hoplocampa testudinea	Apple sawfly	*Tetranychus viennensis*	Fruit-tree spider mite	
	Oniscidea	Woodlouse	*Adoxophyes orana*	Summer fruit tortrix	
	Zeuzera pyrina	Leopard moth	*Phyllonorycter elmaella*	Western tentiform leafminer	
	Adoxophyes reticulana	_	*Zeuzera pyrina*	Leopard moth	
North America	*Anthonomus piri*	Apple bud weevil	*Psylla mali*	Apple sucker	*19*
	Xyleborus dispar	Pear blight beetle	*Quadraspidiotus ostreaeformis*	European fruit scale	
	Phyllocoptes malinus	Phyllocoptes malinus	*Panonychus ulmi*	European red mite	
	Dasineura mali	Apple leaf curling midge	*Hoplocampa testudinea*	Apple sawfly	

	Curculionidae nenuphar		*Thripidae spp.*	Thrips	
	Rhagoletis pomonella	Apple maggot	*Tetranychus urticae*	Twospotted spider mite	
	Eriosoma lanigerum	Woolly apple aphid	*Phyllonorycter crataegella*	Apple blotch leafminer	
	Halyomorpha halys	The brown marmorated stink bug	*Stigmella malella*	Banded apple pigmy	
	Campylomma verbasci	Mullein plant bug	*Spilonota ocellana*	Bud moth	
	Tetranychus mcdanieli	McDaniel spider mite	*Zeuzera pyrina*	Leopard moth	
	Cydia pomonella	Codling moth			
South America	*Dasineura mali*	Apple leaf curling midge	*Thripidae spp.*	Thrips	*3*
	Panonychus ulmi	European red mite	*Eriosoma lanigerum*	Woolly apple aphid	
Asia	*Dasineura mali*	Apple leaf curling midge	*Hoplocampa testudinea*	Apple sawfly	*20*
	Tephritidae	Tephritid fruit flies	*Yponomeuta malinellus*	Apple ermine	
	Thripidae spp.	Thrips	*Adoxophyes orana*	Summer fruit tortrix	
	Eriosoma lanigerum	Woolly apple aphid			
New Zealand	*Dasineura mali*	Apple leaf curling midge	*Stigmella malella*	Banded apple pigmy	*1*
	Eriosoma lanigerum	Woolly apple aphid	*Thripidae spp.*	Thrips	
	Edwardsiana crataegi	leafhoppers			
Africa	*Eriosoma lanigerum*	Woolly apple aphid	*Thripidae spp.*	Thrips	48
	Ceratitis. Capitata	Fruit fly (African invader fly)	*Pseudococcus longispinus* (Targioni Tozzetti)	Mealy bug	
Total					100

3.1 Profiled common apple varieties in different regions

Though many apple varieties such as: Anna, Golden Dorset, Rome Beauty, and Winter Banana were introduced in apple growing regions of Uganda (58), after selection and re- selection, a few were picked which had proved to give good yields. These were varieties of Golden Dorset, by 56.1%, Anna, by 40.9% (7) and the rest apple varieties promoted including Rome beauty (37) which contributed 3% only. But, other apple cultivars including; Almena Green, Winter Banana, James Drif, Gloster and Anna are doing well within the Lake Victoria crescent region (Central Uganda) (Grey lit, sourced from MuZARDI). Similarly, common varieties of Anna, Golden Dorsett, Badskoop, Red Jonathan, Winter Banana, swizz orange, james grieve, dvelmera, golden smith, Fuji, Gramy smith, green giant, Golden delicious, Gloster and un identified variety were grown in Mt Elgon region of Uganda (52). Compared to Uganda, other countries in the region, for example in

Zimbabwe, Matsu apple varieties was common (107), and in Tanzania; Rome beauty, Red jonathans, Graven stein, James grieve and Winter Banana were common. But, in the Ethiopian Highlands, majority of apple cultivars introduced never meet demands of both growers and consumers in terms of produced volumes and fruit quality (10). This resulted into search for other cultivars with high chilling requirements such as; Red delicious, Royal delicious and Golden delicious which were integrated (105).

In S. Africa, differences in the choice of apples cultivars in different areas was attributed to their management in breaking dormancy to enhance bud development for both shooting and flowering. This led to coming up with; Golden Delicious and the red cultivars (i.e. Cripps' Pink, Cripps' Red and Rosy Glow (50). However, in Ethiopian high lands, commonly used rootstalks were MM106, MM111, M26, M27, M9, and M4 what is locally known as CH6. Varieties used as scion wood were Anna, BR, CP29, Crispin, Princesa, Dorset, Red delicious, Jonica, Red Jonagold, and Gala, among others and, MM106 was the widely used variety (5). Furthermore, apple groupings in Ethiopia followed climatic variations in different areas. For example, Low chill varieties included; Anna, Princissa, Golden Dorsett and CP-92 and the medium chill varieties of Gala, Fuji and Primicia (6) were incorporated. Nonetheless, in USA, varieties of Red Delicious, Gala, Granny Smith, Fuji, Golden Delicious, Honey Crisp, Mclntosh, Rome, Crisps, Pink Lady and Empire were generally grown (79). This resulted into high yields, and United States alone advanced and had about 7500 apple producers who grew apples to an average of 240 million bushel of apples each year. It was realized that, some apple varieties and or cultivars almost appear everywhere on the globe. Specifically; Anna, Golden delicious, Golden Dorset, Crisps, and Winter Banana (Table 2) below.

3.2 Insect pests' distribution and damages in apples

According to (63), insect pests have continued to spread throughout the globe, for example, the brown marmorated stink bug, *Halyomorpha halys* which emerged as a harmful invasive insect pest in North America and Europe, yet, was known to be a native to eastern Asia. Most importantly, this pest is highly polyphagous in nature, it can be hosted by more than 120 different host plants which enhances its rapid spread worldwide. Also, studies by (15), revealed that, *Cacopsylla melanoneura* (Förster) is a vector *of Candidatus Phytoplasma* Mali, the causal agent of one of the most serious diseases in European apple orchards. Yet again, *(*76), recognized that, winter moth *Operophtera brumata* (L.) was a serious introduced pest of apple trees in Nova Scotia. But, (78), warned that, early detection of invasive alien species and the ability to track their spread are critical for undertaking appropriate management decisions. So, he recommended for inhabitant science surveys, because, they are potentially valuable tools important for quick information gathering on species' biodiversity and distributions. But, *(*75), suggested that, increasing global importance of invasive pest of many agricultural crops requires more coordinated actions in order to slow their spread and mitigate negative effects in invaded crops.

Generally, in terrestrial ecosystems where apples grow, insect pests were noticed to cause a considerable reduction in apple productivity. For example, (122), said that, the most commonly known temperate fruit insect pests in commercial and small scale apple farms in Sothern Highlands of Ethiopia were aphids, weevil, and scale insects. Admittedly, pests are known to alter fruiting and shoot development, and could hasten the spread of other viruses (112). Majority of these pests are transitory, and have been considered as serious or chronic pests at some point in time (19). According to, (113), a number of insect pest species were noticed to increasingly get adapted in different agroecological zones, which resulted to production losses of major crops. For example, in Brazil, insect pests caused an average annual loss of 7.7% in crops (97).

Consequently, (62), said that, insect pest complexes are a pattern of ecological homologues emerges that reveals pests and their preferred hosts. Among these pests, are those belonging to different families including; Coleoptera (i.e., beetles, weevils), Diptera (flies), Hemipteras, Hymenoptera (i.e., sawflies, wasps, ants, bees), Thysanoptera (thrips), Trombidiformes (mites) and the Lepidoptera (moths). These pests attack apples and damage apples differently. Several insect pests, such as banded fruit weevil (BFW) which is indigenous to South Africa, was known to have a limited distribution throughout the world. But, it was reported present in Western Cape, South Africa, New Zealand and Australia. Where, it causes damage by feeding on the leaves and fruits, fruit stalks and shoots (46)**.** Another time, (92) noted that, though, damages from insect herbivores may appear to be slight, they impact on plants in meaningful way, consequently, constraining orchard productivity. Following this, a distribution list of insect pests, their damaging intensity on apples was generated in (Table 2) below. This shows how geographically invasive insect pests, their preferred apples varieties are distributed, targeted apple parts by the pests and their references in (Table 2).

Table 2 Geographical location of the insect pests and apple parts they damage

Apple variety	Insect pest Latin name	Common name	Part affected (fruit, leaf or stem)	Generalist / Specific	Location (geographical distribution)	References
Coleoptera (beetles, weevils)						
Earliest flowering apple varieties (Malus Sylvestris Mill)	Anthonomus piri	Apple bud weevil	Leaves, apple buds	Buds and roots	Mexico	(154), (115)
Regona, Julia, Florina, Discovery, Retina, Ariwa and Rewena, which	Anthonomus pomorum	Apple blossom weevil	flowers	Generalist	European apple orchards (NW Spain)	(88), (86)
Malus pumila	Curculionidae nenuphar	-	dropped apples	Generalist	North America in Quebec	(104)
Polydrusus						
'Rome Beauty'	Xyleborus dispar	Pear blight beetle	Bark, leaves, tree trun	Generalist	NewYork (Ohio, Lake Ontario)	(3)
Diptera (flies)						
Gala, Red Delicious, Golden Delicious, Granny Smith, Kanzi, Morgen Dallago and Fuji, Granny Smith, Red Delicious and Morgen Dallago	Ceratitis capitata	Mediterranean fruit fly	fruits	Generalist	Europe (spra, Italy) and Trentino Alto Adige Region	(151)
Braeburm Apples	Dasineura mali	Apple leaf curling midge	Fruits and shoots (terminal and lateral shoots)	-	New Zealand, Central Otago, Tiwan , India and California	(145)
M. domestic and various hawthorn species	Rhagoletis pomonella	Apple maggot	fruit	Generalist	Europe, Eastern North America, Canada USA and Mexico	(19)
Apple (Mauls domestice)	Tephritidae	Tephritid fruit flies	fruits	Generalist	Pakistan.	(48)
Hemiptera						

Red delicious, Lord Derby, Spartan, Bramley's Seedling, D'Arcy Spice)	Aphis pomi	Apple aphid (green apple aphid)	Fruit, leaves	Generalist	Poland, Nottinghamshire, UK	((43), (61), (126), & (9)
Granny Smith, Starkrimson, Golden Smoothee, Red Delicious, Golden Delicious, Boshghabi, and Shaki	Dysaphis plantaginea	Rosy apple aphid	leaf	Generalist	Ardabil province in Iraq	(109)
Prima Rouge, Delberd Steval, Early Gold, Starking Delicious, Harmony, Golden Smoothee, Fuji, Melrose, and Golden Delicious.	Eriosoma lanigerum	Woolly apple aphid	roots, trunk and branches	Generalist	Washington, eastern North America and South Africa and New Zealand, Germany	(40), (145), (65), & (9)
Apple fruit trees	Edwardsiana crataegi	leafhoppers	Leaves and fruit contamination	specific	Central Otago, New Zealand and Uk in Kent	(137)
Stayman, Braeburn, Granny Smith, Winesap Fuji. Pink Lady. York	Halyomorpha halys	The brown marmorated stink bug	fruit	specific	mid-Atlantic region of the United States (i.e., New Jersey, Penn-sylvania, Maryland, Penn-sylvania, and Virginia)	(67)
'Delicious' and 'Golden Delicious'.	Campylomma verbasci	Mullein plant bug	Shoots and fruits	Generalist	Netherlands, British Colombia and Washington	(44),
McIntosh, Red Delicious and Golden Delicious,	Lepidosaphes ulmi	Apple mussel scale	Shoots, bloom and petal and fruits	Generalist	Geneva, New York and southern New England, Canada, Washington and Netherlands, British Columbia, Ontario, Que´bec and Canada.	(69)
Bramley's Seedling and Cox's Orange Pippin),	Lygocoris pabulinus	Common green capsid	leaves, shoot tips, flower buds and fruitlets.	Generalist	England,	(60)
Fuji,' 'Starkrimson Delicious,' 'Golden Delicious,' and 'Granny Smith	Psylla mali	Apple sucker	shoots and	-	central North America	(19)

Newtown and Winesap apples, Rome Beauty, Delicious, Newtown, McIntosh, Hyslop crab and Rome Beauty	Quadraspidiotus ostreaeformis	European fruit scale	Fruit and stem	Generalist	British Columbia	(53)
Bramley	Rhopalosiphum insertum	Apple-grass aphid	shoots	Generalist	South Bulgaria, Netherlands, Britain, Northern Ireland	(9), & (54)
Hymenoptera (sawflies, wasps ants, bees)						
Idared	Hoplocampa testudinea	Apple sawfly	fruit	Generalist	Europe, Croatia	(19), & (35)
Organic apple varieties	Isopoda (woodlouse)		Roots	Generalist	Lagundo (BZ), Italy, USA, Israel, Netherlands, Japan and England	(99)
Thysanoptera (thrips)						
Granny Smith	Thripidae spp.	Thrips	blooming plants and fruits.	Generalist	Worldwide esp, in California, Hawaii, Turkey, Chile, Washington State and in northern Oregon	(19) , & (85)
Trombidiformes (mites)						
Apple trees	Aculus schlechtendali	Apple rust mite	leaves, Flower and fruit	Generalist	Iran, Brazil	(18),(24), (56), & (104)
Fuji.	Panonychus ulmi	European red mite	leaves	Generalist	Turkey and south America	(70), & (123)
cider apple, Apples	Phyllocoptes malinus	_	Under bark	Specialist	Britain, California	(135)
Red Delicious	Tetranychus mcdanieli	McDaniel spider mite	leaves at the base of the fruit	Generalist	Utah	(132)
Amasya' Golden, Granny Smith Delicious, Starking Delicious' and 'Starkrimson Delicious, Antonówka and Novama, Romus, Priam and Florina, Jonafree and Freedo, Novamac and	Tetranychus urticae	Twospotted spider mite	Leaves	Generalist	Iran, Canada, Frence, America and Poland	(54), & (125)

Lodel, Primula, VI-17D2 and Witos						
early-season apple cv. Katja	Tetranychus viennensis	Fruit-tree spider mite	fruit	Generalist	Poland	(145), & (125)
Lepidoptera (moths)						
Discovery, Bramleys and Cox, Fuji	Adoxophyes orana	Summer fruit tortrix	Leave, fruits	Generalist	England, Europe and Asia, including China	39), & (73)
('Golden Delicious' and 'Starkrimson), Batul', 'Pónyik' 'Sóvári and Jonathan.	Adoxophyes reticulana		fruit	Generalist	Romania	(16), & (139)
Apple	Amphipyra pyrimadoides	Humped green fruitworm	developing buds and fruit	Generalist	North America (New York), Europe, Canada	(111), & (19)
Fuji	Adoxophyes orana	Summer fruit tortrix	fruit	Generalist	China, Japan. European (Yugoslavia, Italy, Holland, England, Western Serbia)	(73), & (137)
Jonagold and Topaz	Archips rosana	The rose tortrix moth	leaves, flower buds and fruit buds	Generalist	Turkey, Poland, Bulgaria, and Germany	(49), & 102)
Idared, Bramley, Ligol' , Elstar, Gala', 'Jonagold', 'Cortland', 'Idared', 'Lodel', 'Szampion, 'Lobo' and 'Jonathan', 'Rubinette', 'Starkrimson' and 'Gloster	Archips podana	Large fruit-tree tortrix	Buds, young leaf/flower and fruits	Generalist	Bohemia, e Czech Republic, North America, Italy, Northern Ireland, United Kingdom and Netherlands	(110), (41), & (103)
York and Golden Delicious	Archips breviplicanus	Asiatic leafroller	Fruits	specific	Asia, Europe, North America - northern Virginia	(19)
Elstar, Ligol, Cortland, Jonagold, Gloster, Starkrimson, Rubinette, Alwa, Jonathan and Lobo	Archips argyrospila	-	fruits and leaves	Generalist	Utar	(103), & (90)
Red Delicious, Gravenstein, Rome Beauty, Golden Delicious, and Jonathan predominate, Yellow Newtown and Red Delicious, Granny Smith, Red Delicious, Golden Delicious, Rome Beauty, and Winesap, Granny Smith, Fuji, and Gala. (éli aranypármen', 'Bőralma',	Cydia pomonella	Codling moth	fruit	Generalist	Southern California, Romania	(66), & (16)

'Cigányalma' and 'Tányéralma')						
Sturmer Pippin,	Epiphyas postvittana	Light brown apple moth	fruit	Generalist	New Zealand, Tasmania, Hawaii, England, and California	(28), 129), & (40)
Fuji and a corn	Grapholita molesta	-	Fruit, shoots	Generalist	Brazil, Asia, Europe, the Americas, Africa and Australia	(23), & (117)
Apple cultivar	Lithophane antennata	Widestriped green fruitworm	Fruits, buds and leaves	Generalist	North America (i.e., New York, Georgia, Oklahoma, Colorado, Utah, and California, Canada)	(45), & (110)
Red Delicious, Fuji, Rome, Fuji and Gala.,	Lacanobia subjuncta	Lacanobia fruitworm	foliage and fruit	Generalist	Canada, Mexico, Washington and Oregon	(67), & (100)
Primrouge, Cooper Sel.4 and Granny Smith w	Malacosoma Neustria	Lackey moth	foliage	Generalist	Bulgaria, Tuckey, Russia, India - Western Himalayas, United States, Canada, Europe, Asia and Africa	(9)
Malus sylvestris Mill	Operophtera brumata	Winter moth	flower Buds, fruit, leaf	Generalist	mid-coast Maine, England, Holliday, Norway, Canada, Nova Scotia, Portland, Oregon, Britain, France and Japan	(47), (27), & (86)
Apple trees	Orthosia incerta	-	Leaves, fruits	Generalist	Netherlands	(40)
Delicious, Golden Delicious, Stayman, and Rome Beauty	Phyllonorycter crataegella	Apple blotch leafminer	Leaves, fruits	Generalist	USA - northeastern North America	(76), & (151)
James Grieve M7, Golden Delicious M9 and Cox's Orange Pippin M9	Phyllonorycter elmaella	Western tentiform leafminer	leaves	Generalist	Netherlands.	(17), & (82)
McIntosh, Delicious, Spartan, and apple Red	Spilonota ocellana	Bud moth	fruit-bud	Generalist	British Columbia, Canada	(84), & (123)
Gala and Ambrosia apple	Stigmella malella	Banded apple pigmy	Fruit and leaves	Generalist	North America, New Zealand, British Columbia	(51)
Mondial Gala, MM106, M9 and the semi-dwarfing rootstock M26 , Gala, Ligol, Cortland, Paulared, Red Delicious, and Golden Delicious,	Synanthedon myopaeformis	Red-belted clearwing	Root burr knots on trunk	Generalist	Jordan, Poland, Germany, Italy, and Bulgaria,	(11), & (14)

Paulared, Red Delicious, Golden Delicious, and Jonagold.						
Golden Delicious, James Grieve and Coxs O.P.	Yponomeuta malinellus	Apple ermine	Defoliator i.e leaves	Generalist	China, Japan, Kazakhstan and Korea, Czech Republic, Finland, France, Georgia, Germany, Italy, Lithuania, the Netherlands, Sweden, Turkey, Ukraine, the United Kingdom, Armenia, Azerbaijan, Iran, Pakistan, Uzbekistan and Canada	(92), & (82)
Golden Delicious and Red Delicious	Zeuzera pyrina	Leopard moth	Leaves, shoots, branches and wood of the seedlings	Generalist	IRAN, Bulgaria, Italy, USA,	(71), & (132)

3.3 Pest managemet methods

According to *(*95), insect pests were found to be a major threat to the horticulture industry in Africa, owing to their damage incidence and economic losses to fruit growing industry. But, farmers have always managed apples well to avoid damages and losses caused by insect pests. Additionally, (151), found out that, main apple varieties grown in any region serve as a cornerstone to the management of a particular pest. Over decades, herbivorous insects and mites, plant diseases and weeds were major impediments to the production of food crops. Farmers and growers relied on chemical pesticides for pest management. For example, (128), noted that, if a valued tree is attacked heavily by psyllids over consecutive seasons, and an insecticide is correctly applied, can give the tree some relief, and allow the canopy to recover. But, use of these chemicals in control of pests turned out to be more difficult due to the evolution of resistance in pest populations and product withdrawals, both of which reduced the availability of effective compounds (32). Furthermore, reduction on use of conventional chemicals in pests' control in agriculture, were hastened by farmers and growers' responses to demands from retailers and markets who demanded for organic produces. Moreover, (42) observed that, even though most of the pest management strategies relied on the use of synthetic pesticides, a wide array of innovative and environmentally friendly tools were available as possible alternative to the pesticides. So, (42) acknowledged that, increased public fears about the role of pesticides and their potential adverse effects on human health, wildlife, soil water, and overall environment quality led to the development of alternative low risk control tool. Therefore, best ways for most farmers to maintain profit without sacrificing both environment and human/animal life was sought. This yielded to a call for pest management practices that required use of sustainable pest management approached. Where, a focus on; biological, cultural, physical and chemical tools were combined in a way that minimizes economic, health and environmental risks.

3.4 Biological controls

Biological pest control, this involves use of living organisms as pest control agents. (134), observed that, it is an important alternative to the use of chemical pesticides and, therefore, a potential means of reducing pesticide use. According to, (1), natural enemies to crop pests play important roles in limiting pest populations and are in three categories. These include; predators, parasitoids and pathogens. There are many examples of successful use of biological control, such as, the complex of imported parasites, which controls alfalfa weevil (107). More still, use of biological pest control allows qualitative and quantitative evaluations of the impacts between the pest and its natural enemy populations. For example, (26), noticed that, bird communities in integrated pest managed orchards corresponded to changes in treatment schedules in organic orchards. Therefore, birds were recommended for insect pest control in apples, because, of the noticed reduction in pest numbers. Furthermore, (25), said that, there are other predator species including stigmaeid predator *Agistemus fleschneri*, anystid *Anystis baccarum* (L.) and erythraeid *Balaustium* sp which exist naturally controlling insect pests, however, they are generally present in very smaller numbers. Besides, if a biocontrol is planned, their multiplication would be recommended. Likewise, (134), appreciated that, the success rate of biocontrol, led to <40% of introduced agents against weeds and insects to result into their substantial control.

More still, (36), stated that, introductions and maintenances 'of *Liotryphon caudatus* (Ratzeburg) (Hymenoptera: Ichneumonidae) wasp, paralyzed its host by depositing eggs on cocooned codling moth. So, its parasitoid larva emerges and fed on the host's body contents, and finally killed it. Furthermore, (121), said that, predatory mites were widely used in crop protection, though, not common in unprotected crops. However, predicting effects of biological agents before they are released was very difficult. This resulted from lack of demonstratable farms which deterred their confidence and uptake. Particularly, approaches which include use of entomopathogenic fungi (EPF) and nematodes. More still, conservation biological control, can take years to fully establish and sometime growers are not willing to test and demonstrate efficacy of new biological controls (121). However, some contradictions have stated that, numerous biocontrol agents introduced have adversely affected non-target native species, which was propelled by inadequate research done on potential risks in biocontrol studies. Therefore, (134), advocated for, detailed studies to address perception on safety of the discipline of biocontrol practices and agent before they are disseminated.

3.5 Organic pest control

According to, (147*)*, insect pest management in organic agriculture involves the adoption of scientifically based and ecologically sound strategies as specified by international and national organic production standards. Then, these could be effective in insect pest management in one way or the other. For examples, (81), found out that, birds influenced fruit production positively through control of the economically important insect pest (codling moth (*Cydia pomonella*). So, (80), said that, adoption of cultural practices such as diverse of crop rotations, enhances soil quality by incorporating specific cover crops and inclusion of soil amendments, and use of selected resistant varieties may help to prevent pest outbreaks. Stating that, in organic farming systems, a number of groups of microbial insecticides are approved. These specifically, contain the common three active ingredients of; neem extract, natural pyrethrin, and Spinosad (59).

Therefore, for best results in bio pest controls, frequent monitoring and scouting on the garden is paramount. According to (29), monitoring involves spending time examining the garden and familiarizing yourself with the normal growth and development of plants as they mature and as fruit ripen. Because, some fruit damages /problems may be caused by physical, chemical, or environmental factors in organically managed gardens. But, (29), warned that, organic insecticides and fungicides often work slowly and dissipate more quickly than conventional or synthetic pesticides, which means that, organic products tend to be more effective when applied early in the pest lifecycle before the pest damage becomes evident. Still, microbial insecticides are based on microorganisms that cause different pathological reactions (sometimes death) of target insects. They may be based on viruses, protozoa, bacteria, and fungi. There are many microbial biopesticides on the market (59). In another time, (57), advised that, use of coloring bags and kaolin particle film treatments may serve as a physical barrier around the apple, which mitigates colonization by insect and other microbial organisms within an orchard.

On the other hand, some organic pest management practices help to improve on soil fertility, such as cover crops. These could be important in protecting and amending soil properties, thus, adding nitrogen and organic matter content (121) into the soil. Again, they could contribute to wildflower mixes for the long-term management of orchards which provide habitats with beneficial insects such as pollinators. So, (121), suggested that, varietal choice of crops / varieties is a primary consideration in preventing pest damage to fruit trees. On the other hand, proper timing for crop management is paramount for a good quality and quantity harvest. Therefore, (64), stressed that, farmers need to ensure the availability of suitable and sufficient floral biodiversity and interventions because short-term practices (e.g. mowing regime and weed maintenance, cover crops), help in establishing durable ecological infrastructures (e.g for perennial flower strips, hedgerows). Again, re-design of the crop system, for example, intercropping and agroforestry could be meaningful in pest management. However, it is debated that, fully organic systems alone will not meet the increasing food demand for our expanding populations (121).

3.6 Chemical control

For many years, conventional insecticides (mainly synthetically produced chemicals) have been used against the Colorado potato beetle, primarily due to their rapid action (59). According to (33), the discovery of synthetic pesticides such as DDT, marked a new era in pest control. This approach helped in reducing crop losses due to pests in 1940s. For example, in the situations, where new pests are increasing in numbers, culminating to new threats from non-indigenous (i.e. invasive) pest species, new generation of chemical products with very good environmental and human safety characteristics are recommended (32). According to, (98), pesticide effectively control insect pests, mite pests and diseases, when applied at the listed rates and timings. So, (98), added and said that, pesticides are used as elements of Integrated Pest Management programs. Furthermore, (143), advised that, chemical pest management should be done when the main trust of aforementioned approaches to insect pest management based on pesticides applied action has exceeded pest threshold. This however, should not lead to indiscriminate use of synthetic pesticides.

Equally, in majority crops, pesticides are a viable method for crop protection, for such a crop in lieu of alternatives, where damage threshold could be much. In order to dodge the potential economic loss due the multitude of insect pests encountered, (78), said that, chemical use could work better. Because, pesticides have been found to provide many benefits to crop producers, including: (1) consistent availability; (2) rapid kill; (3) reliable and consistent control; (4) increased crop production and quality; (5) they may be used to prevent movement of invasive pests; (6) they are less expensive (in general) than alternatives; (7) they may reduce plant pathogenic transmission; and (8) they may be used in conjunction with natural enemies. According to (22), pesticide use might continue to be a significant strategy for dealing with insect pests, so that, crop growers including ornamental producers can stay competitive in both national and international markets. Therefore, integrating these in order to develop an alternative pest control paradigm, such as the concept of Integrated Pest Management (IPM) would be important. Therefore, an interdisciplinary pest control approach that relies heavily upon natural mortality factors, such as natural predators and environmental conditions, combined with further control mechanisms would be the best hope for all crop growers.

3.7 IPM / Cultural control

IPM is the process in pest management, where, efforts are directed to the judicious and coordinated use of multiple tactics in ways that complement one another in maintaining pest damage below acceptable levels, while minimizing hazards to humans, animals, plants, and the environment (33). This follows the observation in Uganda's' eucalyptus tree, which were infected by *Leptocybe invasa*. So, (94), advised for integrated pest management strategies: i.e. exploring the possibilities of using *L. invasa* resistant genes; be identified and integrated, evaluation and introduction of natural enemies for classical biological control. Likewise, evaluation of silvicultural practices such as weeding, site matching, pruning to control the pest, polyculture (growing eucalyptus with other tree species or agricultural crops) versus monoculture; evaluation of eucalyptus germplasms against *L. invasa* infestations in different agroecological zones.

According to (143), the first stage of IPM, resulted into increased awareness on biological control programs. Like in commercial apple (*Malus* spp.) orchard ecosystem in Quebec which had a diverse fauna of predacious mites which included; *Amblyseius fallac*is (Garman), *Typhlodromus caudiglans* Schuster (Acari: Phytoseiidae), and *Agistemus fleschneri* Summers (Acari: Stigmaeidae) as the most abundant species. Other were phytoseiids, *Typhlodromus conspicuous* (Garman), *Typhlodromus herbertae* Chant, *Typhlodromus longipilus* Nesbitt, *Typhlodromus bakeri* (Garman), *Typhlodromus pyri* Scheuten, *Amblyseius okanagensis* (Chant), and *Amblyseius finlan*dicus (Oudemans). In all these, biological control was inadequate. However, the phytophagous mites were effectively controlled with an oil concentrate pre-bloom spray, cyhexatin in midsummer (25). Most importantly, (105), said that, alternative control tactic could be engaged where overwintering site favorable for Coleoptera (all weevils) that feed on apples were attracted and killed by application of a pesticide. Like, in New Zealand, where Pome fruit are grown and exported to more than 70 countries worldwide, innovations including new cultivar of high production efficiency are developed. Efficacy, may include: low-residue crop protection system that are shaped by industry structures and organization progress of apple pest management (144), were encouraged. But also, Walker and team, realized that, geographic isolation limits diversity of natural enemies. This combined with the absence of indigenous Malus species may restricted the establishment of fruit pest. In addition, insect pest management in New Zealand apples was based on selective insecticides that had minimal activity against important natural enemies such as use of codling moth pheromone mating disruption (36). So, (153), noted that, in apple orchards, deterministic and stochastic factors play important roles in shaping community composition and structures, but, the connection between community assemblages and ecosystems functions remains elusive.

Nevertheless, in France, exclusion nets were used successfully against codling moth *Cydia pomonella* (L.) since the early 2000s. This system was adapted for North American conditions and in Southern Quebec, Canada. The exclusion system proved to be effective protection devices for the vast majority of key pests including insect pests of apple fruit for a long time (34). However, damages of oblique banded leaf roller *Choristoneura rosaceana* (Harris), increased over the years to the point of being significantly more important in netted apple plots. This connoted that, smaller foliar pests were not generally affected by this control method (34). This led, (120), to recommend that, key insect pests in apple orchards be managed by practicing IPM. Where activities, such as pest scouting need to be conducted, so as to guide in the proper insecticide sprays' timing. But also, other advanced strategies such as monitoring, combinations of multiple tactics (e.g., mating disruption and biocontrol agents and traps) be used. Also, use of bio-pesticides was recommended, but with frequent orchard monitoring. At the sometime, (34), recommended that, ecological pest management strategies which take advantage of natural ecosystem processes be integrated. Equally, (25), encouraged apple growers to think of identifying other measures possibly by developing and introducing resistant varieties in order to reduce on use of chemicals for improved apple production. However, for pests like light brown apple moth, woolly apple aphid, and San Jose scales which are known to have developed resistance to the organochlorine insecticide DDD, a selective botanical insecticide and natural enemies would be referred to prevent their economic damage (44). Even so, *(*59), said that, mulch generates microenvironments that benefit pest predators including beetles, ladybirds and lacewings, which feed on eggs and younger larval stages of Colorado potato beetles (CPBs), specifically those that damage potato plants in Colorado. This is followed by (75), who said that, for proper managements of potential serious risk for agriculture worldwide, it is necessary to develop an early detection tool and a field monitoring strategy. For example, the brown marmorated stink bug, *Halyomorpha halys*, found in Asia, Italy, Southern Switzerland, suspected to have the potential of extending beyond the territories of first detection (78), monitoring and its immediate control would be paramount.

4 Conclusions

The review indicated a number of insect pests which potentially affect apples productivity. The most common insect pests occur nearly all over the world. Yet, in Africa and Uganda in particular, little research has been done on important insect pests that affect apple productivity and their relationships with hosts. Therefore, without further research and information, future infestations and damages are likely to occur and may negatively change apple growing landscape in Uganda. But also, affect apple farmers' incomes and Uganda's objectives of the vision 2040 which aim at transforming Uganda's society from a peasantry to a modern and prosperous society. So, in order to enhance apple productivity in Uganda and in the rest of the tropics, apple conservation management is vital and this cannot be achieved without proper knowledge about the common insect pests present in apples and their appropriate management.

Recommendation

Information compiled herein, on apple insect pest distribution is either incomplete or is lacking, especially on the East Africa and Uganda's side in particular. The above literature records, used accurate scientific data on entomofauna distribution and population abundance in apple orchards in different geographical regions of the world. Wherefore, with the current trend of increasing apple growing in different regions of the world. It is important that, insect pests in apple orchards of Uganda be identified and their conservation and protection measures be established at the field level for enhanced apple productivity and boost of apple farming in Uganda. This is why, I strongly encourage, further detailed study on insect pest diversity and distribution status in Uganda, where common pests will be identified and their appropriate and acceptable pest control methods would be identified and promoted for improved apple productivity.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

Statement of ethical approval

All work was conducted with formal approval from the Uganda Martyrs University and was done in the library. This work did not involve any research on animals or on human subjects.

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