Proceeding of
2nd International
Conference on
Horticulture
Godavari, Lalitpur
3-4 April 2023

TECHNICAL PAPER

Emerging Pest Threats in Citrus Fruit and their Management in Nepal

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Abstract

From time immemorial, Nepal has been growing citrus as one of its major fruit crops. In addition to supporting grower's livelihood in the hilly region, citrus crop turns out to be prime source of income. According to MoALD out of 50,235 ha only 64.07% citrus orchards are in productive stage with productivity of 9.67 mt/ha. However, the number of productive orchards has been declining and citrus production has plummeted despite the large scope of area expansion and commercialization. A number of biotic factors have threatened the vitality of citrus trees in Nepal, together with the weak orchard establishment and management technology adoption. This study outlines the most significant diseases and insects that pose a threat to citrus cultivation in Nepal. The major diseases in citrus orchards are citrus greening, citrus tristeza virus, phytophthora root rot, sooty mold and powdery mildew. The citrus greening disease has invaded orchards of majority of districts and the extent of disease severity is presented in the paper. Chinese citrus fly, fruit sucking moth, scale insects and mites which were secondary pest in the past are key insects now causing major fruit losses. The past management recommendation for these pests are not working due to tolerance, effect of climate change (movement of Asian citrus psyllid to higher elevation), unavailability and/or banning of previously recommended pesticide while secondary pest resurgence is also evident for some pests (fruit sucking moths, rust mites). To rejuvenate senile orchards, the effort should focus on updating integrated management recommendations and using it for specific pests by all research and development partners.

Keywords: Citrus, disease, insect, management, research

Introduction

Citrus is one of the traditional Nepalese fruit crop. It promotes the nation's nutrition, economics and living standard. Additionally, it offers great opportunities for international trade (Acharya & Shrestha, 2021, Adhikari & G C, 2020). Citrus fruits are typically eaten fresh. Citrus fruits are also used to make marmalade, squash and other flavored drinks. On the global market, rind oil is an expensive product. Citrus peels are used to make vinegar, lactic acid, feed yeast and citric acid. Citrus has valuable medicinal properties in its dried bark, leaves, flowers, peels and fruits (Lamsal, Adhikari, & Dhakal, 2021). Of the total fruit growing area in Nepal, citrus accounts for 28.29% (50,235 ha) area (MoALD, 2022). This show that citrus is the main fruit grown in Nepal and has a vital contribution to the economic prosperity of Nepalese farmers. Citrus is thus a significant agricultural sub-sector in Nepal (Acharya & Adhikari, 2022). However, the country's demand for citrus cannot be supplied by the present level of production (Dahal, Shrestha, Bista, & Bhandari, 2020). In the past 15 years, the productivity of citrus orchard has decreased from 10.86 mt/ha. in year 2006/07 to 9.67 mt/ha in year 2020/21 harvest (MoALD, 2022).

The main challenge for citrus growers in Nepal has been citrus decline (Poudel, Shapkota, Pandey, Oli, & Regmi, 2022). Due to biotic and abiotic issues, citrus orchard production and productivity could not be enhanced to a satisfactory level (Acharya & Adhikari, 2022). The incidence of disease and pests, harsh weather conditions, poor soil fertility, low-quality planting materials and poor orchard management techniques have all been demonstrated to have an impact on citrus decline. Citrus decline is a state in which the tree displays a number of issues that lead to decreased productivity, a shorter productive life and poor fruit quality (Panth & Dhakal, 2019; FAO, 2011). According to Bove (2006) and Roistacher (1996), huanglongbing (HLB) is the primary factor causing the decline of citrus in Nepal. They also cautioned that "greening will damage the citrus industry in Nepal slowly but surely if

necessary, actions are not implemented in time." They suggested that Nepal should implement the Certification Program.

Citrus production in Nepal is at severe risk to the use of subpar and uncertified seedlings, poor and/or improper orchard management methods, nutritional problems, extensive inter-cropping with exhausted crops, occurrence of phytophthora, citrus tristeza virus (CTV), canker and powdery mildew, as well as insect-pests like fruit flies, citrus psylla, scale insects, bugs, leaf miners, stem borer and others (FAO, 2011). Citrus decline was reported by nearly two-thirds of the growers in Gorkha district (Poudel, Kattel, & Adhikari, 2021). Kharal & Bhandari (2019) reported insect pests and diseases as the major production constraints in mandarin production in Syangja district, Nepal. Similarly, Insect pests are the major problems of citrus production in Gulmi district (Chettri, Bhatta, Kafle, Dahal, & Subedi, 2021). The farmers ranked die-back, citrus greening, powdery mildew, root rot, sooty mould, pink disease, gummosis and scab disease as the major diseases in Gorkha district (Dahal, Pant, Bhusal, Koirala, & Niraula, 2021). Citrus decline in Nepal has been caused by different biotic causes such as citrus greening (Acharya & Adhikari, 2022, FAO, 2011), (foot/root rot or gummosis by *Phytophthora species* (FAO, 2011), Chinese citrus fly (Sharma, Adhikari, & Tiwari, 2015), citrus psylla, scale insects etc. (Nath & Sikha, 2019). In light of this, there is a great opportunity to deploy advanced technology to boost productivity and production.

Methodology

This manuscript is based on a key informant survey, review of the literature and the authors own experiences. Using a semi-structured questionnaire prepared on google form, 54 agriculture technical respondents across the country who worked on commercial citrus growing districts (working on citrus research and development related organizations such as; Agriculture Knowledge Centers (AKC), research stations under Nepal Agricultural Research Council (NARC), Prime Minister Agriculture Modernization Project (PMAMP) Super/Zone and Local Levels) were interviewed in January and February, 2023. In order to identify important causes contributing to citrus decline, major insects, pests and diseases; a ranking index based on the respondents' prioritized responses was conducted (Acharya & Shrestha, 2021). Data from the survey were entered into Microsoft Excel and then analyzed using the formula below. By looking into the information in national and international journals, conferences, reports, newsletters and books, an effort was made to examine the management measures in Nepal and outside country.

Respondents ranking index, $I_{imp} = \Sigma (S_i \times f_i / N)$

Where, I_{imp} = Index of importance, S_i= Scale value, N= No. of respondents, f_i= Frequency of importance given by respondents

Results and Discussion

Status of citrus production in Nepal

From 2006/07 to 2020/21, the total production and productive area of citrus fruit has increased to almost double. However, while looking into the productive area (%) it stagnated around 64% whereas productivity has declined to 9.67 from 11.30 mt/ha. This information shows that something unwanted is happening in our citrus orchard that we are not obtaining the realized production per unit area. There could be some reasons which need to be explored and this paper is trying to find what is going on in our declining citrus orchards.

Table 1. Total area, productive area, % productive area, production and productivity of citrus fruit in Nepal from 2006/07 to 2020/21

Year	Total area (ha)	Productive area (ha)	% Productive area	Production (mt)	Productivity (mt/ha)
2006/07	27,980	15,832	56.58	1,71,875	10.86
2007/08	30,790	19,915	64.68	2,26,404	11.37
2008/09	32,322	22,482	69.56	2,53,766	11.29
2009/10	33,898	22,903	67.56	2,59,191	11.30
2010/11	35,578	23,609	66.36	2,63,710	11.20
2011/12	37,565	24,089	64.13	2,40,793	10.00
2012/13	36,975	23,645	63.95	2,16,188	9.14
2013/14	38,988	25,497	65.40	2,24,357	8.80

Year	Total area (ha)	Productive area (ha)	% Productive area	Production (mt)	Productivity (mt/ha)
2014/15	39,035	25,261	64.71	2,22,790	8.82
2015/16	40,554	24,854	61.29	2,18,447	8.82
2016/17	46,328	26,759	57.76	2,39,773	8.96
2017/18	44,424	25,946	58.41	2,45,176	9.44
2018/19	46,411	28,406	61.21	2,71,908	9.57
2019/20	46,715	27,339	58.52	2,74,140	10.03
2020/21	50,235	32,188	64.07	3,11,188	9.67

(Source: MoALD, 2022)

Citrus decline in Nepal

Among the different causes of citrus decline, diseases related problems ranked highest score (27.93%) followed by orchard establishment and management related problems (24.48%), soil and nutrition related problems (24.14%) and insect pests related problems (23.45%) (Figure 1). For citrus growers in Nepal, citrus decline has been a major impediment (Poudel, Pandey, Oli, & Regmi, 2022). Abiotic (soil, water, nutrition and management) and biotic (diseases and insect pests) factors all play a part in citrus decline, which is a complex problem (Acharya & Adhikari, 2022).

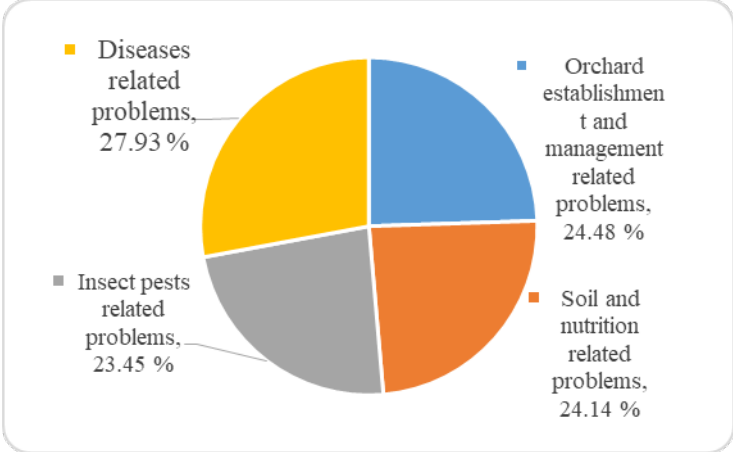

Fig 1. *Causes of the major causes of citrus decline in Nepal*

Major Diseases of citrus in Nepal

The present online survey with agriculture technician of Nepal showed that citrus greening (3.59) as number one threat to citrus production followed by Phythopthora root rot (3.30), citrus tresteza virus (3.00), sooty mold (3.00) and powdery mildew (2.70) (Figure 2). The major diseases of citrus cultivation and their recommendation for management are presented in Table 3. Other significant diseases in Nepal are citrus canker, felt disease, pink disease and blue mold.

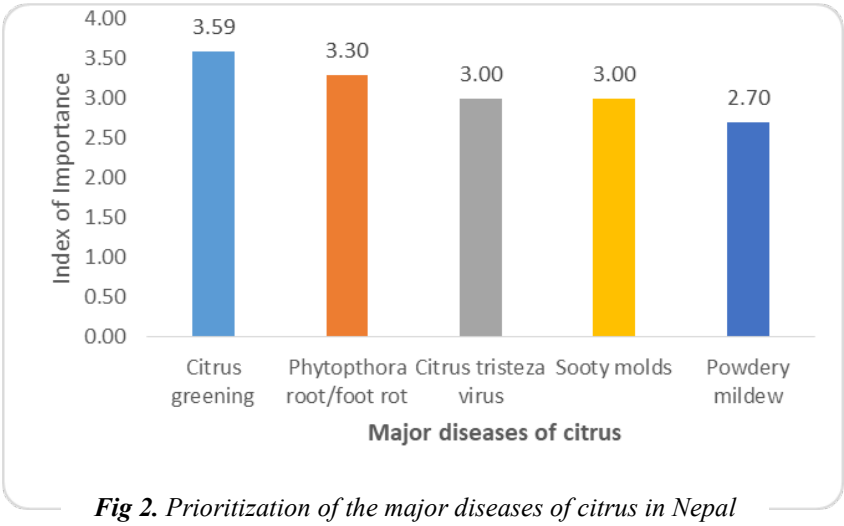

Fig 2. *Prioritization of the major diseases of citrus in Nepal*

Citrus greening (*Candidatus* Liberibacter asiaticus) is an important disease of citrus. In many parts of the world, citrus production has been affected by the citrus greening disease. Since there is no curative treatment for HLB, it is important to rely on management techniques to minimize the disease spread on citrus orchard. Citrus tristeza virus (CTV) genus *Closterovirus* is responsible for the citrus disease that has the worst economic impact (Yokomi, Sisterson, & Hajeri, 2020; Moreno & Garnsey, 2010). Depending on the viral strain, the citrus variety and the scion-rootstock combination, the CTV affects citrus plants with different symptoms such as quick decline or tristeza disease, seedling yellows, stem pitting disease etc. Aphid species that transmit CTV include *Toxoptera citricida*, *Aphis gossypii* (FFTC, 2001). Phytopthora caused root/foot rot and gummosis is important diseases that have considerable impact on citrus production in the world (Chaudhary et al., 2020). Lower portion of tree foot and root became rotten, with symptoms including yellowing of leaves, bark cracking and surface gumming (Rajeev, 2012). A fungal illness caused by *Capnodium citri* called sooty molds develops on leaves and other surfaces that have been covered in the sticky honeydew that some insects produce (Doy, 2021). Since sooty mould don't feed on agricultural plants and fungal growth development can be easily removed. However, sooty molds limit the leaf's capacity for photosynthesis, which can cause a decline in the quantity and quality of the fruit. Powdery mildew in citrus is caused by *Acrosporium tingitaninum* shows symptoms of white 'powdery' spores develop mostly on the upper leaf surface also in twig and fruit, those leaves turn a pale whitish-grey-green, defoliation, young shoots die back, premature drop of infected fruit (Adhikari, 2018).

Citrus greening

Citrus greening, also known as huanglongbing (HLB), is a devastating disease that has destroyed several citrus plantations all over the world (Acharya & Adhikari, 2022; Pokhrel, Pandey, Ghimire, & Kandel, 2021). *Candidatus* Liberibacter asiaticus, *Candidatus* Liberibacter africanus and *Candidatus* Liberibacter americanus are phloem-restricted bacteria related to the disease. Among them *Candidatus* Liberibacter asiaticus bacterium that is the most commonly found in Nepal and is spread by the vector insect, Asian citrus psyllid (*Diaphorina citri*). There is a substantial yield loss as a result of this disease in citrus orchards of Nepal. In order to maintain citrus health and production whenever HLB is prevalent, many management techniques are used worldwide. Several management measures are both economically viable and environmentally sound, despite the fact that some management tools need huge financial investment and are not appropriate for small rural farmers. It is crucial to explore for appropriate HLB-vector control measures and effective HLB management practices in order to revive Nepal's citrus production.

Incidence of citrus greening

Table 2 shows the detection of citrus greening disease in different 14 districts of Nepal performed by National Fruit Development Centre (NFDC), Kirtipur, Kathmandu from FY 2076/77 to 2079/80. The highest citrus greening incidence (%) was reported from Gulmi (91.67), followed by Palpa (81.69), Gorkha (28.63), Dailekh (26.47), Ramechhap (20.97), Sindhuli (15.68), Myagdi (8.51) and Syangia (1.19).

Table 2. Detection of citrus greening in different district of Nepal from FY 2076/77 to 2079/80

SN	District	No. of sample taken	PCR +ve detected	% incidence	Years of test
1	Syangja	84	1	1.19	2076/077, 2079/080
2	Lamjung	38	0	0.00	2076/077, 2077/078
3	Kavre	17	0	0.00	2076/077
4	Nawalparasi	21	0	0.00	2076/077
5	Tanahau	18	0	0.00	2076/077
6	Myagdi	47	4	8.51	2076/077, 2077/078
7	Palpa	71	58	81.69	2076/077, 2077/078, 2078/079, 2079/080
8	Ramechap	124	26	20.97	2077/078, 2079/080
9	Sindhuli	370	58	15.68	2077/078, 2078/079, 2079/080
10	Gorkha	262	75	28.63	2077/078, 2078/079, 2079/080
11	Parbat	19	0	0.00	2077/078
12	Gulmi	60	55	91.67	2077/078, 2078/079
13	Salyan	60	0	0.00	2079/080
14	Dailekh	34	9	26.47	2079/080
		1225	286	23.35	

(Source: NCFD, 2023)

Table 3. Major diseases of citrus cultivation and their recommendation for management

S N	Major diseases	Management recommendations in Nepal		Management recommendations in other countries		Way forward
		Non-chemical measures	Chemical pesticides	Non-chemical measures	Chemical pesticides	
1	Citrus greening *Candidatus Liberobacter asiaticus*	• Destruction of infected trees • Plantation of disease free planting materials • Quarantine measure, vector insect management (AITC, 2022) • Intercropping with white flesh guava (NCRP, 2020) • Mother plant management under screen house • Regular PCR testing of mother plants, remove positive mother plants from screen house • Sapling production under screen house • Citrus bud wood certification program	• Insecticide for vector insect (ACP) control: Diamethoate (AITC, 2022)	• For propagation, use certified pathogen-free bud wood (Satyagopal et al., 2014).	• Foliar spray of Copperoxychloride 50 % WP + Streptomycin sulphate 2.5 g/l • 2-Bromo-2-Nitro-1, 3-Propanediol (Bronopol)+ Copperoxychloride 50 % 2.5 g / l, • 0.5% Zinc sulphate + 0.3 % Neem oil (CHES, 2017)	▪ Surveillance of disease. ▪ Nursery management ▪ Bud wood certification ▪ Quarantine measures. ▪ Technical awareness. ▪ Clean Plant Centre.
2	Citrus tristeza virus CTV	• Destruction of infected trees • Application of resistant rootstock (Trifoliate etc.) (AITC, 2022) • Mother plant management under screen house • Regular PCR testing of mother plants, remove PCR positive mother plants from screen house. • Sapling production under screen house • Citrus bud wood certification program	• Insecticide for vector (aphids) control: Diamethoate, (AITC, 2022)	• Use CTV-free certified budwood • Use tolerant rootstock (Satyagopal et al., 2014) • Enact strong quarantine regulations • Make use of healthy and certified planting materials (Gohel, Prajapati, & Srivastava, 2022) • Whenever and wherever the disease appears, remove all infected trees (Gohel, Prajapati, & Srivastava, 2022; Satyagopal et al., 2014).	• Diamethoate 30 % EC +0.3 % Neem oil 1.5+3 ml/l, • Imidachloprid 17.8% SL 0.25 ml / l, • Thiamethoxam 25 % WG+0.3 % Neem oil 0.25+3 g/l, • Acetamiprid 20 SP + 0.3 % Neem oil 0.3+3 ml/l (CHES, 2017) • Insecticidal sprays like dimethoate to control aphids from spreading the disease further (Gohel, Prajapati, & Srivastava, 2022).	▪ Surveillance of disease. ▪ Bud wood certification program ▪ Nursery management ▪ Quarantine measures. ▪ Technical awareness. ▪ Clean Plant Centre. ▪ Virus elimination program ▪ Adoption of shoot tip grafting technology

S N	Major diseases	Management recommendations in Nepal		Management recommendations in other countries		Way forward
		Non-chemical measures	Chemical pesticides	Non-chemical measures	Chemical pesticides	
3	Phytopthora root/foot rot and gumosis *Phytophthora parasitica, P. citrophthora and P. palmivora*	• Proper drainage • Grafting in trifoliate (AITC, 2022) • *Trichoderma viride, Pseudomonas fluorescens* • Nechugi (NCRP, 2020)	• Bordeaux mixture and paste or copperoxychloride (AITC, 2022) • Carbendazim (Bavistin) (NCRP 2020)	• *Trichoderma viride, Pseudomonas fluorescens* (Gade & Lad, 2018)	• Fenamidon 10 % + Mancozeb 50 % WDG 1+2 gm / l, Fendminod 4.44% + Fosetyl-Al 66.66% WDG 1+2 gm/l, Famoxadone 16.6%+Cymoxanil 22.1 % SC 1.5+2.0 g/l foliar spray and soil dreanching and 10%Borodeopaste (CHES, 2017)	▪ Encourage grafted (trifoliate) sapling. ▪
4	Sooty mold *Capnodium citri*	• Pruning of diseased plant parts (AITC, 2022) • Horticultural oil spray (NCRP, 2020)	• Spray Diamethoate to control of sucking insect pests • Spray ATSO Fungicide Mancozeb to manage disease (AITC, 2022)	• Pruning of diseased plant parts	• 1 % Sodium bicarbionate (10 g / l) foliar spray (CHES, 2017)	▪ Research on the integrated management.
5	Powdery mildew *Acrosporium tingitaninum*	• Pruning and destruction of infected plant parts (AITC, 2022)	• Sulphur fungicide, or Dinocap, or Carbendazim, or Bordeaux mixture (AITC, 2022)	• Fertilizers containing nitrogen should be applied at precise rates since they encourage dense leaf growth favorable for disease (Satyagopal et al., 2014)	• Carbendazim 50 % WP 1 g/l, or Hexaconazol 5EC 0.5 ml/l, or Sulfex 80% WP 2.5 g/l (CHES, 2017)	▪ Research on the alternative fungicide.

Major Insect Pests of citrus in Nepal

While ranking citrus insects through online survey forum agricultural technicians believed that citrus fruit fly (3.19) and Asian Citrus Psylla (3.19) as number one threat followed by scale insect (2.93) (Figure 3). Both technician and farmers need to focus on management of these insects. The major insect pests of citrus cultivation and their recommendation for management are presented in Table 5. In Nepal, bugs, leaf miners, aphids, stem borer and mealy bug are also significant insect pests of citrus.

The damage caused by fruit flies, *Bactrocera spp.* (Chinese citrus fly (*Bactrocera minax*) and Oriental fruit fly (*Bactrocera dorsalis*)) which are common pests of fruit production, is mostly due to the fruit pulp that the larvae consume, causing the fruits loss (McCoy, Samson, Boucias, Osborne, Pena, & Buss, 2009). Chinese citrus fly, *Bactrocera minax* is the major species of fruit flies affecting the citrus fruit in Nepal (Acharya & Adhikari, 2019) and area wide control program (AWCP) consisted of spot application of protein bait and

sanitation measures have been recommended (Adhikari, Thapa, Joshi, Liang, & Du, 2020). Asian citrus psyllid (ACP) is an important insect pest of citrus. Both nymphs and adults of citrus psylla, *Diaphorina citri* are responsible for the damage, which results in the curling of leaves, defoliation and drying of twigs by sucking the cell sap from the leaves, tender shoots and flowers. Nymphs release whitish, crystalline honey dew that encourages the growth of fungus and impairs the photosynthesis of citrus psylla on leaves (Ahuja & Chattopadhyay, 2015). The pathogen that causes citrus greening is also spread by this insect (Dhakal et al., 2022). Similarly, fruit sucking moths, *Ophiusa coronata* and *Eudocima fulllonia* have long been considered significant pests in tropical and subtropical regions, has recently gained importance (Leroy, Christian, & Bruno, 2021). Scale insects: red scale (*Aonidiella aurantii*), brown soft scale (*Coccus hesperidium*) and purple scale (*Lepidosaphes beckii*) suck on the sap from tree and produce honeydew (Adhikari, Adhikari, & Thapa, 2018). Mites cause the problem in citrus cultivation in Nepal. Brown-reddish black dots on the fruit's surface indicate mite infestation. Citrus rust mites, infestation cause damage on twigs, leaves and fruit which is term as rusting (ACES, 2016; Ahuja & Chattopadhyay, 2015).

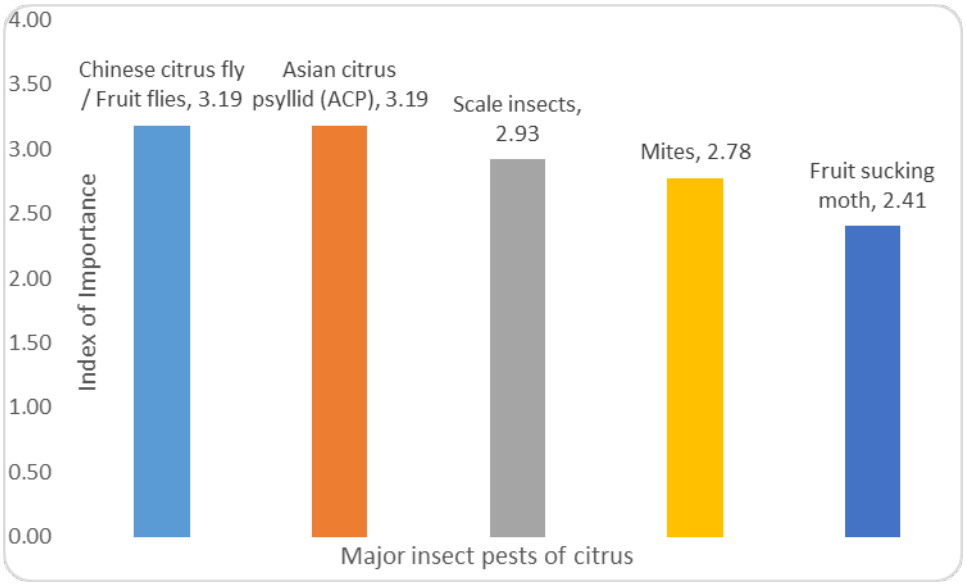

Fig 3. *Prioritization of the major insect pests of citrus in Nepal*

Presence of citrus psylla

The citrus psylla has been reported from east to west citrus growing districts from 954 to 1162 masl (Table 4). The photographs are presented below Table 4.

Table 4. Incidence of citrus psylla, Diaphorina citri in different districts of Nepal

SN	Location of citrus orchard	Citrus type	Altitude (masl)	Latitude (North)	Longitude (East)
1	Rawabeshi-3, Lamidanda, Khotang	Mandarin	1162	$27^0$25.226' N	$86^0$67.625' E
2	Golanjor-5, Nayakharka, Sindhuli	Sweet orange	1067	$27^0$27.385' N	$86^0$00.393' E
3	Chure-3, Bhaktapur, Kailali	Mandarin	954	$29^0$01.590' N	$80^0$66.862' E

Major Insect pest of citrus in Nepal

Table 5. Major insect pests of citrus cultivation and their recommendation for management

SN	Major insect pests	Management recommendations in Nepal		Management recommendations in other countries		Way forward
		Non-chemical measures	Chemical pesticides	Non-chemical measures	Chemical pesticides	
1	Fruit flies *Bactrocera spp.*	• Maintain proper sanitation to prevent pupation (Adhikari, 2020)	• Malathion, malathion bait with sugar, spot application protein bait as per protocol of area wide control program (AWCP) (Adhikari, 2020) • Protein bait spray (NCRP, 2017)	• Sanitation,		▪ Technical support to the growers. ▪ Research on production of protein bait in Nepal. ▪ Facilitation on implementation of AWCP in larger scale.
2	Asian citrus psyllid (ACP) *Diaphorina citri*	• Yellow sticky trap, Light trap (NCRP, 2022)	• Dimethoate (AITC, 2022)	• Application of parasitoid (*Tamaraxia radiata*),	• Fenvalerate 20 % EC 1 ml/l, ▪ Phosalone 35%EC 1.5-2.0 ml/l (CHES, 2017), ▪ Thiamethoxam 70 % WS 0.2 ml/l (CHES, 2017; Satyagopal et al., 2014).	▪ Monitoring and surveillance of ACP. ▪ Research on parasitoid application. ▪ Research for the recommendation of appropriate chemical insecticides.
3	Fruit sucking moth *Ophiusa coronata*	• Sanitation, fumigation, light trap, food bait, bagging (Adhikari, 2020)	• Malathion (AITC, 2022) ▪ Sweet orange juice+ Deltametrin/ Malthion (Joshi and Adhikari, 2020)	• Bagging of the fruits	• Cyantraniloprole 10.26% OD 0.5 / lit, Flubendiamide 39.35 % SC 0.25 ml/l (CHES, 2017)	▪ Technical support to the growers. ▪ Research on the integrated management of pest.
4	Scale insects	• Use insect free planting materials. Spray kerosene and soap solution (AITC, 2022)	• Dimethoate, ATSO (AITC, 2022)	• Spray garlic and pepper solution (Satyagopal et al., 2014).		▪ Technical support to the growers. ▪ Research on the integrated management of pest.
5	Mites Citrus rust mite (*Phyllocoptruta oleivora*)		• Proparzite (AITC, 2022) ▪ Sulfur containing pesticide spray in winter (NCRP, 2017)	• Water stress frequently makes the mite problem worse. Make sure the trees are properly irrigated, especially when they are under stress in the late summer (Satyagopal et al., 2014).		▪ Technical support to the growers. ▪ Research on the integrated management of pest.

Conclusion

Citrus greening, phytophthora root rot, citrus tristeza virus, sooty mold and powdery mildew are the main diseases of citrus orchards. Chinese citrus fly, fruit sucking moth, scale insects and mites are now the primary causes behind significant fruit losses. The research and development institutions working for citrus fruit crops need to test new and less poisonous chemical and cultural options to deal with the emerging threats. The biological management measures of the citrus insect pests and diseases should be taken under study and recommend for application by the growers. The citrus fruit industry is desperately seeking new alternatives as previously recommended chemicals are banded for commercial use. Quarantine measures need to be strictly followed while introducing planting materials from neighboring districts and abroad. Fruit nursery regulation and citrus bud wood certification system (at least for CTV and CGD free) should immediately be adopted for quality and clean planting material production and distribution to farmers. Additionally, the establishment of clean plant center would be very helpful for quality planting material production within the country. Further, the pest surveillance system need to be strengthened as present capacity is not enough to deal with these emerging threats.

Acknowledgements

Authors are thankful to the respondents participated in the survey and grateful to Dr. Samudra Lal Joshi for sharing this valuable information regarding citrus insect pests.

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