Effects of Seven Plant Essential Oils on Mortalities of Chicken Lice (*Lipeurus caponis* L.) Adult

Jarongsak Pumnuan*, Ammorn Insung and Ampon Klompanya

Faculty of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand

Received: 9 August 2019, Revised: 16 October 2019, Accepted: 17 October 2019

Abstract

Chicken lice (*Lipeurus caponis* L.) are external parasite of chicken and farmers often use malathion and carbaryl insecticides to control this parasite. However, the use of chemical insecticides may result in direct toxicity to chicken or contamination in chicken meats. Thus, this study investigated the effect of seven plant essential oils (EOs) against adult chicken lice. Contact bioassay was performed by laying 10 adult chicken lice on treated filter paper added with EOs at concentrations of 0 (95% ethanol as a control), 0.079, 0.157, 0.236 and 0.314 $\mu l \cdot cm^{-2}$. Mortality percentages were observed at 3, 6 and 12 h intervals after the treatments. Clove, cinnamon, turmeric and star anise EOs were able to eliminate the lice completely (100% mortalities) at 12 h exposure which were higher than lemon grass, citronella grass and piper EOs. Clove EO was the most effective oil with LC_{50} of 0.132, 0.085 and 0.039 $\mu l \cdot cm^{-2}$ at 3, 6 and 12 h, respectively. Furthermore, clove EO at the 0.157 $\mu l \cdot cm^{-2}$ showed the highest mortalities with LT_{50} at 1.438 h. Our study suggests that clove EO could be used as an alternative medicinal insecticide to control chicken lice in farms.

Keywords: clove, cinnamon, star anise, contact method, insecticide, chicken lice
DOI 10.14456/cast.1477.5

1. Introduction

Poultry lice are important external parasite of poultry [1] that consume host tissues, secretions of quill feathers, etc. Their biting is usually irritating and painful and poultry will become restless resulting in decrease of feed intake [2]. Chicken lice (*Lipeurus caponis* L.), parasitic wing lice of chicken, may pierce the pulp of feathers or the skin which may be extremely dangerous especially to young poultry, even if they only feed by nibbling along the feather surface and/or eat epidermal debris [3]. Invasion of these lice are often found in many countries, including Bangladesh [4], Ethiopia [5], Malawi [6], Turkeys [7], Philippines [8], Nigeria [9], California [10] and Thailand [11].

In Thailand, the initial survey found that farmers often used malathion and carbaryl insecticides to control this parasite. Report from Turkey revealed that synthetic pyrethroid insecticides were applied for controlling chicken lice [12]. The use of organophosphate, pyrethroid and spinosyns insecticides to prevent lice and mite of poultry was recommended [13]. However, louse control can cause an intense growth of resistances against long-used insecticides [14]. The use of chemical pesticides may cause contamination in the chicken meats because animals intended for

* Corresponding author: Tel.: +66 02-329-8499 Fax: +66 02-329-8499
E-mail: jarongsak.pu@kmitl.ac.th

human food may absorb residual pesticides in their feed, water or during direct/indirect exposure in the course of pest control [15] and may cause direct toxic effect to chicken.

Nowadays, none of these methods are efficient for complete protection. Consequently, control method of high effectiveness against insects with non-toxic effect, non-residue toxicity in meat, environmentally friendly has focused on alternative bio-pesticides which specifically entails the property of natural degradability. Especially, essential oils (EOs) are good candidates for safer control agents that may provide good anti-lice activity and low levels of evolved resistance [16]. Essential oils were extensively studied and used against some insects and mites [17-20]. Plant EOs of clove, cinnamon, turmeric, star anise, black piper, citronella grass and lemon grass were previously reported as high potential against insect and mite pests [21].

The objective of this study was to evaluate the effectiveness of seven plant essential oils, namely clove (*Syzygium aromaticum*), cinnamon (*Cinnamomum bejolghota*), turmeric (*Curcuma longa*), star anise (*Illicium verum*), black piper (*Piper nigrum*), citronella grass (*Cymbopogon nardus*) and lemon grass (*Cymbopogon citratus*) against adult of chicken lice (*L. caponis*) by residue filter paper contact method in laboratory conditions.

2. Materials and Methods

2.1 Essential oil preparation

Essential oils from dried bud of clove (*S. aromaticum*), dried flower of star anise (*I. verum*), dried seed of black piper (*P. nigrum*), fresh rhizome of turmeric (*C. longa*), and fresh leaf of cinnamon (*C. bejolghota*), citronella grass (*C. nardus*) and lemon grass (*C. citratus*) which has been reported to contain insecticidal properties against adult of chicken lice (*L. caponis*) [22] are used in this study. All EOs were purchased from Thai-China Flavours and Fragrances Industry Co., Ltd., Bangkok, Thailand. The concentration of EOs at 0.1, 0.15 and 0.2% as well as the control group with the application of 0.2% of Tween-20 in water were applied.

2.2 Insect samples

An adult colony of chicken lice (*L. caponis*) was collected from native chickens at Learning Center and Management System Integrated with Urban Livestock Farm Learning, Faculty of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand.

2.3 Experimental treatments

The insecticidal activity test of the plant EOs against chicken lice was evaluated by using residue filter paper contact method. One ml of each plant EOs at concentrations of 0.2% in 95% ethanol was separately dropped on each filter paper (Whatman® No. 1) and placed onto Petri dish (with size of 90 mm in dia). By this application, the EO concentration was equal to 0.314 $\mu l \cdot cm^{-2}$. The treated filter papers were air-dried for 5 min and 10 chicken lice adults were put into the petri dish. Mortality observations were recorded at 6 and 12 h after treatment. The plant EOs showing high effectiveness against chicken lice were selected for further experiments.

For further insecticidal activity test, those EOs at the concentrations of 0.05, 0.10, 0.15, 0.20 and 0.25% in 95% ethanol or 0.079, 0.157, 0.236, 0.314 and 0.393 $\mu l \cdot cm^{-2}$, respectively were applied by using as the same method as described previously. Mortality observations were recorded at 2, 4, 6, 8, 10 and 12 h after treatment.

The experiment was replicated three times and statistically designed by completely randomized replication design (CRD). The actual death rates were calculated via Abbot's formula [23]. The data obtained were statistically analyzed by applying analysis of variance (ANOVA) and Duncan's multiple range tests (DMRT). Lethal concentrations of EOs needed to kill 50 and 90% of the insects (LC_{50} and LC_{90}, respectively) and lethal time of EOs needed to kill 50 of the insects (LT_{50}) were calculated via probit analysis.

3. Results and Discussion

The efficacy in terms of insecticidal properties of seven plant EOs against the adult of chicken lice (*L. caponis*) conducted by residue filter paper contact method in laboratory conditions showed that plant EOs of clove, turmeric, cinnamon and star anise were able to eliminate the lice completely (100% mortalities) at 12 h exposure which were higher than those of lemon grass, citronella grass and black piper EOs, respectively (Figure 1). At 6 h after treatment, the plant EO of clove showed to be the most effective insecticidal activity against the lice with completely 100% mortalities followed by turmeric and cinnamon EOs with mortality rate of 76.7 and 73.9%, respectively. The star anise EO caused only 39.5% mortality whereas plant EOs of black piper, lamon grass and citronella grass were the lowest group to control chicken lice with 1.7%, 6.1% and 11.9% mortality. Thus, the plant EOs with high effectiveness against the lice, including clove, turmeric and cinnamon were selected for further experiments to obtain the toxicity level. The insecticidal activity test by residue filter paper contact bioassay showed that clove EO was the most effective candidate with LC_{50} (at 3, 6 and 12 h) of 0.132, 0.085 and 0.039 $\mu l \cdot cm^{-2}$, respectively and LC_{90} of 0.168, 0.112 and 0.108 $\mu l \cdot cm^{-2}$ followed by EOs of cinnamon and turmeric with LC_{50} of 0.220, 0.090 and 0.038 $\mu l \cdot cm^{-2}$ and 0.256, 0.148 and 0.106 $\mu l \cdot cm^{-2}$, respectively (Table 1). Furthermore, clove EO at 0.157 $\mu l \cdot cm^{-2}$ showed the highest mortalities with LT_{50} at 1.438 h and was able to eliminate the lice completely (100% mortalities) at 4 h exposure (Table 2).

There were many reports regarding the effectiveness of extract and EO of plants against insect and mite pests of poultry. Aquatic and ethanolic leaf extracts of *Conocarpus erectus* had some toxic effects (acaricidal and repellent properties) on poultry red mite, *Dermanyssus gallinae* in Iran [24]. *Thuja occidentalis* arborvitae and *Juniper* spp. (Juniperus) leaf EOs were also found to be effective against the poultry red mite (*D. gallinae*) [25]. Lans and Turner [26] reported nineteen species of plants conducted for parasite control in poultry farm of British Columbia, Canada. Our study showed that EO of clove was effective to control chiken lice and this EO has been reported for insecticidal property against insect and mites pests, including fruit fly (*Ceratitis capitata*) [27], head louse (*Pediculus humanus capitis*) [28], maize weed (*Sitophilus zeamais*) [29], thrips (*Frankliniella schultzei*) [20], mealybug (*Pseudococcus jackbeardsleyi*) [20], rice weevil (*Sitophilus oryzae*) [30], pear psyllid (*Cacopsylla chinensis*) [31], aphid (*Aphid gossypii*), whitefly (*Bemisia tabaci*) [32], red spider mite (*Oligonychus coffeae*) [33], house dust mite (*Dermatophagoides farina* and *Dermatophagoides pteronyssinus*) [34]. Our study suggests that clove EO or maybe the combination of clove EO with cinnamon and turmeric EOs as mixture could be used as a new alternative medicinal insecticide to control chicken lice. Combination of EOs are a combination of chemical compounds in these EOs together, which will encourage the EOs mixture to be more effective in pest eradication. The combination of chemical compounds from plant were also reported to enhance EO efficacy. Koul *et al.* [35] reported that the combination of anethole and 1,8-cineole demonstrated reduction in the population of red flour beetle (*Tribolium castaneum*). Synergism or additive effects of monoterpenoid binary mixtures against tobacco cutworm larvae (*Spodoptera litura*) was also reported [36].

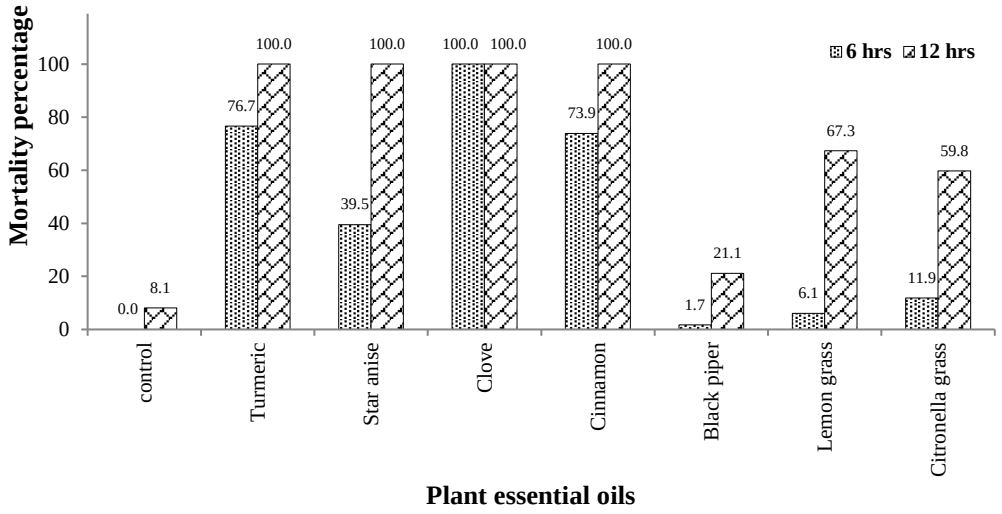

Figure 1. Mortality percentage of the adults of chicken lice (*Lipeurus caponis* L.) at 6 and 12 h after residue filter paper contact test with plant essential oils at the concentration of 0.314 µl·cm^{-2}

Table 1. Mortality percentage of the adults of chicken lice (*Lipeurus caponis* L.) at 6 and 12 h after residue filter paper contact test with plant essential oils at various concentrations

Plant essential oils	% Mortality[1/] (Means±S.D.) Concentration (µl·cm^{-2})						LC_{50} (µl·cm^{-2})	LC_{90} (µl·cm^{-2})
	control	0.079	0.157	0.236	0.314	0.393		
3 h								
Turmeric	0.0±0.0^{Db}	0.0±0.0^{Dd}	0.0±0.0^{Dd}	52.2±13.5^{Cb}	74.3±14.8^{Bb}	100.0±0.0^{Aa}	0.256	0.332
Cinnamon	0.0±0.0^{Db}	5.1±8.9^{CDd}	12.5±6.5^{Cd}	48.8±5.8^{Bb}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	0.220	0.299
Clove	0.0±0.0^{Cb}	3.3±5.8^{Cd}	81.2±17.1^{Bb}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	0.132	0.168
6 h								
Turmeric	0.0±0.0^{Cb}	8.3±9.2^{Cd}	51.6±13.2^{Bc}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	0.148	0.204
Cinnamon	0.0±0.0^{Db}	59.9±16.3^{Cb}	77.9±11.4^{Bb}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	0.090	0.166
Clove	0.0±0.0^{Cb}	38.8±10.2^{Bc}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	0.085	0.112
12 h								
Turmeric	8.6±2.4^{Da}	29.3±6.1^{Cc}	75.7±10.5^{Bb}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	0.106	0.189
Cinnamon	8.6±2.4^{Ba}	97.4±4.4^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	0.038	0.107
Clove	8.6±2.4^{Ba}	97.0±5.2^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	0.039	0.108

[1/] Means in each column followed by the same common letter and means in row followed by the same capital letter were not significantly different (P< 0.05) according to DMRT.

Table 2. Mortality percentage of the adults of chicken lice (*Lipeurus caponis* L.) at the various concentrations after residue filter paper contact test with plant essential oils at the 2-12 h

Plant essential oils	% Mortality[1/] (Means±S.D.) Times (h) 2	4	6	8	10	12	LT_{50} (h)	LT_{90} (h)
0.157 µl·cm^{-2}								
Turmeric	0.0±0.0^{De}	3.3±5.8^{Dd}	51.6±13.2^{Cc}	57.4±10.8^{BCc}	72.5±10.5^{ABb}	75.5±10.5^{Ab}	7.284	10.526
Cinnamon	2.8±4.8^{Dde}	21.8±4.8^{Cc}	77.9±11.4^{Bb}	80.9±10.5^{Bb}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	5.368	7.933
Clove	72.7±15.2^{Bb}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	1.438	2.663
0.236 µl·cm^{-2}								
Turmeric	12.2±6.7^{Cd}	72.8±16.7^{Bb}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	3.290	4.658
Cinnamon	0.0±0.0^{Ce}	67.2±19.5^{Bb}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	3.745	4.438
Clove	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	-	-
0.314 µl·cm^{-2}								
Turmeric	26.9±3.3^{Bc}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	2.337	3.036
Cinnamon	90.3±0.5^{Ba}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	0.661	1.986
Clove	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	100.0±0.0^{Aa}	-	-

[1/] Means in each column concentration followed by the same common letter and means in row followed by the same capital letter were not significantly different ($P< 0.05$) according to DMRT.

Non- toxic alternative options are hence needed for control of insect pest and natural products from plants especially EOs are good candidates for safer control agents that may provide good insecticidal activity and low levels of evolved resistance [15]. Our study suggests that clove EO could be used as an alternative medicinal insecticide to control chicken lice in the farm.

4. Conclusions

Insecticidal properties of plant EOs against the adult of chicken lice (*L. caponis*) by residue filter paper contact method in laboratory conditions revealed that clove EO was the most effective candidate with the LC_{50} at 3, 6 and 12 h of 0.132, 0.085 and 0.039 µl·cm^{-2}, respectively. Furthermore, the clove EO at 0.157 µl·cm^{-2} showed the highest mortalities of chicken lice with LT_{50} at 1.438 h, and this clove EO was able to eliminate the lice completely (100% mortalities) within 4 h exposure whlie the clove EO at the concentration of 0.236 µl·cm^{-2} was effective to kill the lice completely at 2 h. Our study suggests that clove EO or maybe the combination with cinnamon and turmeric EOs as the mixture could be used as an alternative medicinal insecticide to control chicken lice in farm.

References

[1] Khan, M.N., Nadeem, M., Iqbal, Zafar., Sajid, M.S., and Abbas, R.Z., 2003. Lice infestation in poultry. *International Journal of Agriculture & Biology*, 2, 213-216.

[2] Islam, M.K., Mondal, M.M.H., Rahman, M.M., Haque, A.K.M.F. and Chowdhury, M.A.A., 1999. Effects of *Lipeurus caponis*, Linnaeus, 1758, (*Mallophaga: Philopteridae*) on laying hens. *Veterinary Review Kathmandu*, 14, 32-33.

[3] Al-Quraishy, S., Abdel-Ghaffar, F., Al-Rasheid, K.A.S., Mehlhorn, J. and Mehlhorn, H., 2011. Effects of a neem seed extract (MiteStop®) on mallophages (featherlings) of chicken: *in vivo* and *in vitro* studies. *Parasitology Research*, 110, 617-622.

[4] Shanta, I.S., Begum, N., Anisuzzaman, A., Bari, A.S.M. and Karim, M.J., 2006. Prevalence and clinico-pathological effects of ectoparasites in backyard poultry. *Bangladesh Journal of Veterinary Medicine*, 4(1), 19-26.

[5] Firaol, T., Dagmawit, A., Askale, G., Solomon, S., Morka, D. and Waktole, T., 2014. Prevalence of ectoparasite infestation in chicken in and around ambo town, Ethiopia. *Journal of Veterinary Science and Technology*, 5(4). Doi:10.4172/2157-7579.1000189.

[6] Njunga, G.R. 2003. *Ecto and Haemoparasites of Chickens in Malawi with Emphasis on the Effect of Chicken Louse, Menacanthus cornutus*. Frederiksberg: The Royal Vertinary and Agriculture University, 173-195.

[7] Zarith, Z.M., Suhaila, A.H., Izzauddin, N. and Khadijah, S., 2017. Parasites prevalence in poultry: focusing on free range turkeys (*Meleagris gallopavo*). *Malaysian Journal of Veterinary Research*, 8(1), 1-9.

[8] Portugaliza, H.P and Bagot, M.A., 2015. Different species of lice (Phthiraptera), fleas (Siphonaptera) and ticks (Ixodida) collected from livestock, poultry, reptile and companion animal in Leyte Island, Philippines. *Livestock Research for Rural Development*, 27(8), 1-10.

[9] Lawal, J.R., Yusuf, Z.B., Dauda, J., Gazali, Y.A. and Biu, A.A., 2017. Ectoparasites infestation and its associated risk factors in village chickens (Gallus gallus domesticus) in and around Potiskum, Yobe State, Nigeria. *Journal of Animal Husbandry and Dairy Science*, 1(1), 8-19.

[10] Murillo, A.C. and Mullens, B.A., 2016. Diversity and prevalence of ectoparasites on backyard chicken flocks in California. *Journal of Medical Entomology*, 53(3), 707-711.

[11] Sangvaranond, A., 1992. Study on incidence and outbreak of ectoparasites of native chickens in Nanthaburi province Thailand. *KKU Veterinary Journal*. 1(2), 68-75. (in Thai)

[12] Diki, B., Erciyas-Yavuz, K. and Per, E., 2017. Chewing lice (Phthiraptera: Amblycera, Ischnocera) on birds in the Kızılırmak delta, Turkey. *Revue de Médecine Vétérinaire*, 167(1-2), 53-62.

[13] College of Agriculture, Food and Environment, University of Kentucky. 2017. *Common External Parasites of Poultry*. [Online] Available at: http://www2.ca.uky.edu/agcomm/pubs/asc/asc206/asc206.pdf.

[14] Kristensen, M., Knorr, M., Rasmussen, A.M. and Jespersen, J.B., 2006. Survey of permethrin and malathion resistance in human head lice populations from Denmark. *Journal of Medical Entomology*, 43, 533-538.

[15] Aulakh, R.S., Gill, J.P.S, Bedi, J.S., Sharma, J.K., Joia, B.S. and Ockerman, H.W., 2006. Organochlorine pesticide residues in poultry feed, chicken muscle and eggs at a poultry farm in Punjab, India. *Journal of the Science of Food and Agriculture*, 86, 741-744.

[16] Rossini, C., Castillo, L. and Gonzalez, A., 2008. Plant extracts and their components as potential control agents against human head lice. *Phytochemistry Reviews*, 7, 51-63.

[17] Ayvaz, A., Sagdic, O., Karaborklu, S. and Ozturk, I., 2008. Insecticidal activity of the essential oils from different plants against three stored-product insects. *Journal of Insect Science*, 10(21), 1-10.

[18] Pumnuan, J. and Insung, A., 2011. Effectiveness of essential oils of medicinal plants against stored product mite, *Suidasia pontifica* Oudemans. *ISHS Acta Horticulturae*, 945, 79-85.

[19] Benelli, G., Flamini, G., Canale, A., Cioni, P.L. and Conti, B., 2012. Toxicity of some essential oil formulations against the mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae). *Crop Protection*, 42, 223-229.

[20] Pumnuan, J. and Insung, A., 2016. Fumigant toxicity of plant essential oils in controlling thrips, *Frankliniella schultzei* (Thysanoptera: Thripidae) and mealybug, *Pseudococcus jackbeardsleyi* (Hemiptera: Pseudococcidae). *Journal of Entomological Research*, 40(1), 1-10.

[21] Pumnuan, J., Insung, A. and Chandrapatya, A., 2008. Acaricidal effects of herb extracts on the mushroom mites, *Luciaphorus perniciosus* Rack and *Formicomotes heteromorphus* Magowski. *Systematic & Applied Acarology,* 13(1), 33-38.

[22] Chantawee, A., Pumnuan, J. and Insung, A., 2012. Effectiveness of essential oils of medicinal plants against brown planthopper (*Nilaparvata lugens* (Stål)). *Proceedinds of the 10 th International Symposium on Biocontrol and Biotechnology*, Harbin Institute of Technology, Harbin, P.R. China, December 27-30, 2012. 54-58.

[23] Abbott, W.S., 1987. A method of computing the effectiveness of an insecticide. 1925. *Journal of the American Mosquito Control Association*. 3(2), 302-303.

[24] Rajabpour, A., Mashhadi, A. R. A. and Ghorbani, M. R., 2018. Acaricidal and repellent properties of some plant extracts against poultry red mite, *Dermanyssus gallinae* (Mesostigmata: Dermanyssidae). *Persian Journal of Acarology*, 7(1), 85–91.

[25] Maurer, V., Perler, E. and Heckendorn, F., 2009. *In vitro* efficacies of oils, silicas and plant preparations against the poultry red mite *Dermanyssus gallinae*. *Experimental and Applied Acarology*, 48, 31-41.

[26] Lans, C. and Turner, N., 2011. Organic parasite control for poultry and rabbits in British Columbia, Canada. *Journal of Ethnobiology and Ethnomedicine*, 7(1), 1-10.

[27] Arancibia, M., Rabossi, A., Bochicchio, P. A., Moreno, S., López- Caballero, M. E., Gómez-Guillén, M. C. and Montero, P., 2013. Biodegradable films containing clove or citronella essential oils against the Mediterranean fruit fly *Ceratitis capitata* (Diptera: Tephritidae). *Journal of Agricultural and Food Chemistry*, 3(3), 1-7.

[28] Choi, H. Y., Yang, Y. C., Lee, S. H., Clark, J. M. and Ahn, Y. J., 2010. Efficacy of spray formulations containing binary mixtures of clove and eucalyptus oils against susceptible and pyrethroid/malathion-resistant head lice (Anoplura: Pediculidae) . *Journal of Medical Entomology*, 47(3), 387-391.

[29] Pumnuan, J., Teerarak, M. and Insung, A., 2012. Fumigant toxicity of essential oils of medical plants against maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae). *Proceeding of 2nd International Symposium of Biopesticides and Ecotoxicology Network (2nd IS-BIOPEN)*. Bangkok, Thailand, September 24-26, 2012, 177-183.

[30] Ahmed, M. E. and Salam, A. E., 2010. Fumigant toxicity of seven essential oils against the cowpea weevil, *Callosobruch maculates* (F.) and the rice weevil, *Sitophilus oryzae* (L.). *Egyptian Academic Journal of Biological Sciences*, 2(1), 1-6.

[31] Tian, B., Liu, Q., Liu, Z., Li, P. and Wang, J., 2015. Insecticidal potential of clove essential oil and its constituents on *Cacopsylla chinensis* (Hemiptera: Psyllidae) in laboratory and field. *Journal of Economic Entomology*, 108(3), 957-961.

[32] Pumnuan, J., Khurnpoon, L. and Insung, A., 2017. Insecticidal activity of essential oil formulas and their physiological effects on eggplant. *Journal of Applied Horticulture*, 19(2), 152-158.

[33] Barua, A., Roy, S., Handique, G., Bora, F.R., Rahman, A., Pujari, D. and Muraleedharan, N., 2015. Clove oil efficacy on the red spider mite, *Oligonychus coffeae* Nietner (Acari: Tetranychidae) infesting tea plants. *Proceedings of the Zoological Society*, doi: 10.1007/s12595-015-0147-6.

[34] Kim, E. H., Kim, H. K. and Ahn, Y. J., 2003. Acaricidal activity of clove bud oil compounds against *Dermatophagoides farinae* and *Dermatophagoides pteronyssinus* (Acari: Pyroglyphidae). *Journal of Agricultural and Food Chemistry*, 51, 885-889.

[35] Koul, O., Walia, S. and Dhaliwal G. S., 2008. Essential oils as green pesticides: potential and constraints. *Biopesticides International*, 4(1), 63-84.

[36] Hummelbrunner, L.A. and Isman, M.B., 2001. Acute sublethal, antifeedant and synergistic effects of monoterpenoid essential oil compounds on the tobacco cutworm, *Spodoptera litura* (Lep., Noctuidae). *Journal of Agricultural and Food Chemistry*, 49(2), 715-720.