Journal of Advances in Microbiology

5(4): 1-7, 2017; Article no.JAMB.35927
ISSN: 2456-7116

Baculoviruses: Emerging Frontiers for Viral Biocontrol of Insect Pests of Agricultural Importance

O. I. Afolami[1*] and M. K. Oladunmoye[1]

[1]Department of Microbiology, Federal University of Technology, Akure, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. Author OIA designed the study, performed the statistical analysis, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Author MKO supervised the study. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAMB/2017/35927
Editor(s):
(1) Niranjala Perera, Department of Food Science & Technology, Wayamba University of Sri Lanka, Sri Lanka.
Reviewers:
(1) Pablo Daniel Ghiringhelli, Universidad Nacional de Quilmes, Argentina.
(2) Bakli Mahfoud, University Center of Ain Temouchent, Algeria.
(3) A. C. Wada, National Cereals Research Institute, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/21167

Review Article

Received 3rd August 2017
Accepted 30th August 2017
Published 27th September 2017

ABSTRACT

Accumulated evidences gathered over recent decades demonstrated that Baculoviruses (Occlusion body forming nucleopolyhedroviruses and the host specific granuloviruses) have proven Biocontrol activities on insect and pests of agricultural importance while being non-pathogenic to humans. These studies have laid the foundations for the launch of several trials phases using Baculoviruses on specific insect pests for their efficacy as viral Biocontrol agents. After a brief overview of the biology of Baculoviruses, this review focuses on the studies which unraveled the Biocontrol properties of these agents and supported their use as biopesticides of insect pests resistant to chemical pesticides. Furthermore, this review emphasizes the development of more complex Baculovirus treatment strategies aimed at enhancing formation of occlusion bodies, accelerated virus replication of infective budded forms in insect hosts and improvement of direct lethal effects in several insect developmental forms as necessary tools for increased efficacy in viral Biocontrol of insect pests of agricultural importance. However, the review also addressed the key challenges that

**Corresponding author: E-mail: afolamiolufemiifeoluwa@gmail.com;*

remain towards a more efficient use of Baculoviruses as biopesticides, and discuss how a better understanding of the virus life-cycle of and the cellular factors involved in virus infection, replication and cytotoxicity may promote further development of integrated pest management involving viral biopesticides and chemical insecticides to open up new prospects for treatment of plant diseases of economic importance.

Keywords: Baculoviruses; viral biocontrol; occlusion bodies; integrated pest management; insect pests.

1. INTRODUCTION

Baculoviruses (Baculoviridae) are a large group of host-specific viruses with double stranded circular DNA genome ranging from 80 to 180 kilo base pairs (kbp) that infect arthropods chiefly insects; Baculoviruses sustains high levels of environmental stability due to their formation of thick protein shell around their nucleocapsid know as occlusion bodies (OBs) [1-3]. Baculoviridae has two genera, the Nucleopolyhedroviruses (NPVs) and the Granuloviruses (GVs); the NPVs have a single occlusion body (OB) formed by the viral polyhedrin protein which contains multiple nucleocapsids packed singly or in groups while GVs have their OBs with single nucleocapsid formed by the viral granulin proteins [2-4]. The OBs have a carbohydrate-rich coat that helps to protect them from degradation, particularly if eaten by larger animals [5,6]. Baculoviruses develop non-occluded forms referred to as the Budded form; this is formed during infection of insect hosts, in which budded form spreads infection within insect host tissues [2,7].

Recently, Baculoviruses have been subdivided into four genera these include the Alpha Baculoviruses (the Lepidopteran specific Nucleopolyhedroviruses), Beta Baculoviruses (the Lepidopteran specific Granuloviruses), Gamma Baculoviruses (the Hymnopteran specific Nucleopolyhedroviruses), and Delta Baculoviruses (the Dipteran specific Nucleopolyhedroviruses) [2,5,8]. Baculoviruses predominantly infect the immature (larval) forms of moth species but they also infect sawflies, mosquitoes, and shrimps [3,9-11]. The viruses have been known to be capable of entering mammalian cells but they do not replicate in vertebrate animal tissues [5-7].

Baculoviruses require a capsid glycoprotein (gp64) to be able to spread systemic infection as infective budded forms [5,12,13]. The Gp64 is essential for efficient budding of the virion and for the cell-to-cell transmission during the infection cycle as well as enhancing viral trophism and endosome-mediated uptake to the cells [12-14]. The capsid glycoprotein (Gp64) also functions in the pH-mediated envelope fusion of virus and host cell endosomes [3,12-14]. The autographa californica multicapsid nucleo-polyhedroviruses (AcMNPV) originally isolated from the *Alfalfa looper* (a Lepidopteran) has been the most widely studied of the Baculoviruses [2,3,8,11]. AcMNPV contains a 134-kbp genome with 154 open reading frames (ORF) [6,11,15,16].

2. BIOLOGICAL CONTROL OF INSECTS AND PEST OF AGRICULTURAL IMPORTANCE

The use of organisms to control damaging pests is broadly known as biological control or Biocontrol [2,3,17]. There are four basic approaches of Biocontrol of insect pests, these include: Predators, which prey on the target species; Parasites or parasitoids; Pathogens, which cause disease in the target species and competing species (antagonists) [17-19]. Viruses over the years have been employed increasingly for the control of multiple species of insects and also for the control of rabbits [5,11 20].

Viral Biocontrol agents have also been recognized as inherently less toxic environmentally than conventional chemical pesticides [21-23]. Hence, their use as biological pest control agents have been greatly encouraged given their comparative advantage as fastidious host-specific organisms [23-25]. However, there have been some setbacks that have been encountered in the use of viral biopesticides and these include: High host specificity which limits the range of insects that can be controlled; relatively slow effects compared to chemical agents and low environmental stability particularly in sunlight [2, 3,5,21].

3. BACULOVIRUSES AND BIOCONTROL OF INSECT PESTS OF AGRICULTURAL IMPORTANCE

The mechanism of action of Baculoviruses against wide arrays of insect pest is due to their ability to multiply and replicate rapidly in different developmental forms of insects (larva or adult form) and cause multiple cytotoxic effects in their hosts [5,26,27]. They are ingested by insects as occlusion body (OB) forms and then spread in insect guts via the budded forms infecting the connective tissues and are transported across internal organs where the initiate multiple tissue necrosis [19,28-30]. As part of their infectious cycle, Baculoviruses are eaten by insect larvae. They then infect the cells of the gut and grow there. From these cells, the virus can then spread throughout the body of the insect, destroying it and releasing a new generation of the occluded body forms of the virus from the liquefied remains of the killed insect forms [2,3, 31-34].

In contrast to the resistance to chemical insecticides developed by insects, insect forms rarely develop resistance to viral biopesticides [2, 3,5,35]. Insects generally acquire increasing resistance as they mature in development to insecticides in a process known as developmental resistance, this ability is not necessarily transmitted to the next filial generation of insect larvae forms, hence, resistance is not inheritable [2,4,20,26,33].

4. BACULOVIRUSES AND INTEGRATED PEST MANAGEMENT

The term integrated pest management (IPM) approach refers to the use of multiple insect pest control methods together in synergy to reduce pest numbers to acceptable levels [17,24,35-37]. Biological control agents are often used as part of an IPM strategy and this may include introducing or maintaining habitats for natural enemies, such as hedgerows or suitable plants, along with reducing the conditions that will favor the survival of targeted pest organisms [10,13 20,24,38]. Chemical pesticides can also be used in synergy with other approaches, including viral biological agents of which Baculoviruses hold a huge comparative advantage [2,5,6,34-38]. However, the chemical pesticide to be employed in synergy must have no or low toxic effect on the performance of the biological agent used [5-8,37-39].

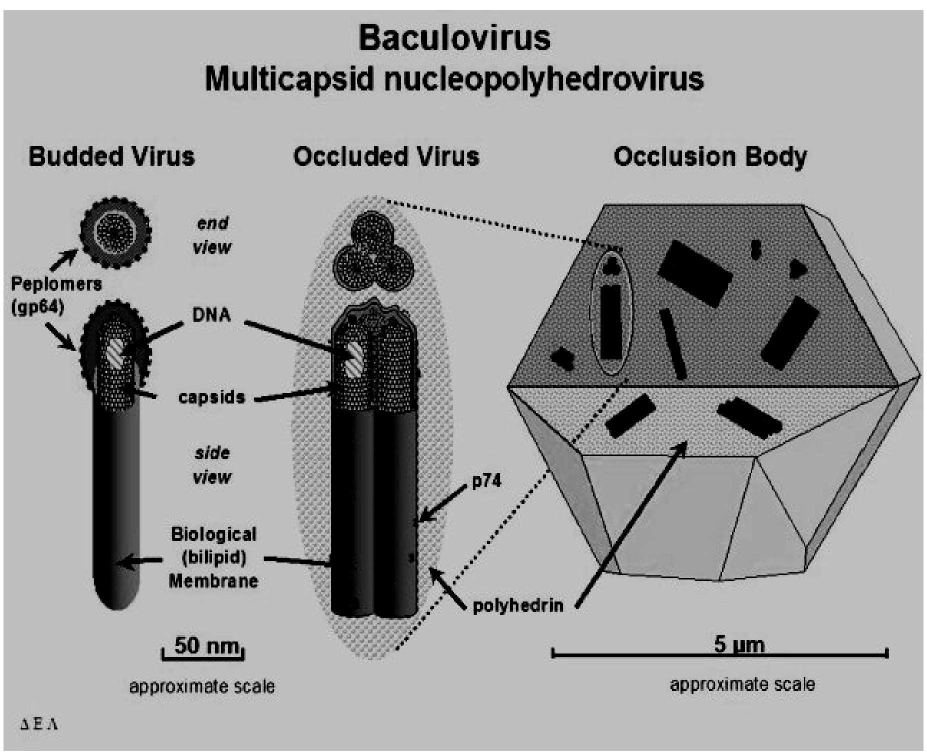

Fig. 1. The baculovirus multicapsid of a nucleopolyhedrovirus [6,13,17]

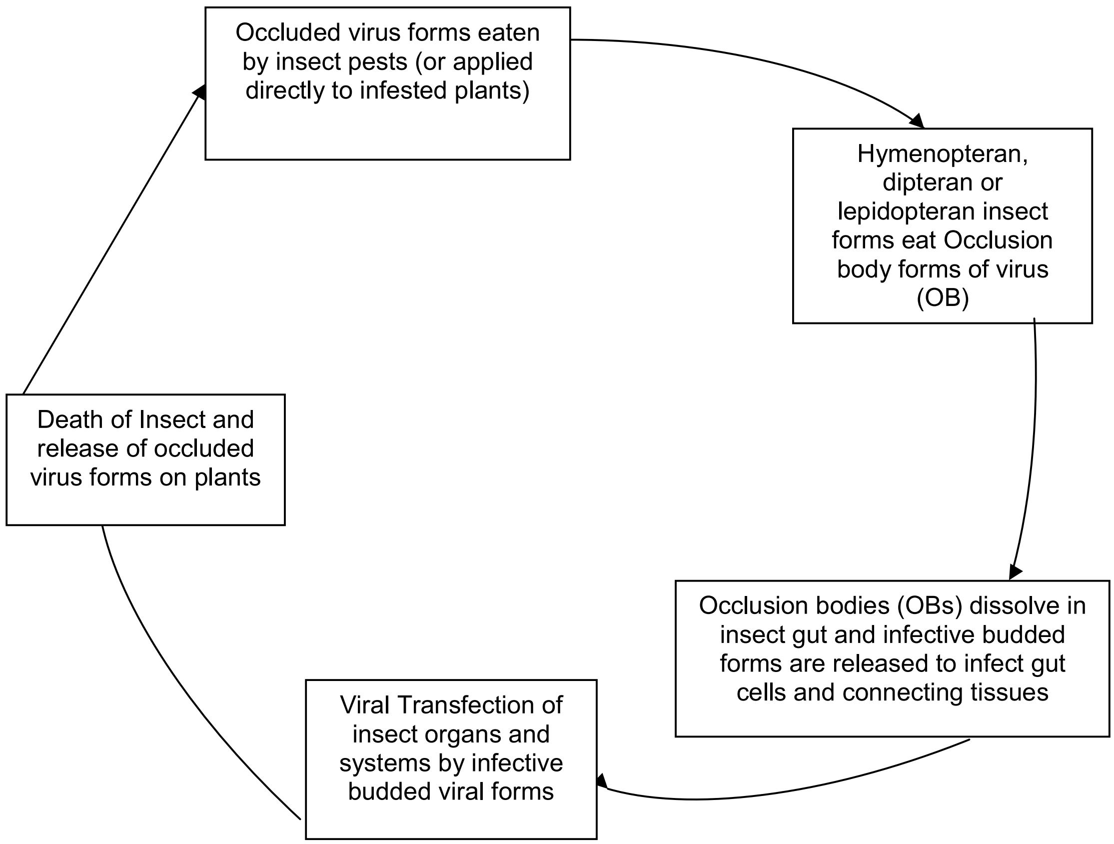

Fig. 2. Generalized infection cycle/ mechanism of action of baculoviruses on insect hosts

Table 1. Some selected baculoviruses used as viral biopesticides [3,13,14,21]

Selected baculovirus strain	Trade names	Target insects
Anagrapha falcifera NPV	CLV LC	Celery looper
Codling moth GV	Carpovirusine, Cyd-X, Madex	Codling moth
Helicoverpa zea NPV	(Biotrol VHZ), Gemstar LC	Cotton bollworm, tobacco budworm, tomato fruit worm
Heliothis armigera NPV	Ness-A	Old world bollworm
Lymantria dispar NPV	Gypchek, Gypsy moth NPV	Gypsy moth
Neodiprion lecontei NPV	Lecontvirus	Redheaded pine sawfly
Orgyia pseudotsugata NPV	TM Biocontrol 1, Virtuss	Douglas fir tussock moth
Plodia interpunctella NPV	Nutguard-V, Fruitguard-V	Indian meal moth

N.B. Strain names follow the naming conventions for Baculoviruses, where each virus is named for the target insect followed by general type (genus) of the infecting Baculoviruses; Nucleopolyhedroviruses (NPV) or Granuloviruses (GV)

Viruses are generally impermeable to chemical agents and relatively unaffected by the chemical treatments, thus they are well suited for synergistic uses with other in an IPM approach [20,21,24,35,39]. Some Baculoviruses are also known to have additive effects on the efficacy of chemical treatments on yam beetles and they helped in quick exertion of controlling effects [14, 33,39-40].

5. BACULOVIRUS BIOCONTROL OF INSECT PESTS AND THE FUTURE

The use of viruses in Biocontrol of insect pests and worms of agricultural importance is gaining momentum as emerging frontiers of environmental Biocontrol agents [2,3,40-42]. For the full potential of these viral biopesticides to be exploited, the development of more effective treatment strategies aimed at enhancing formation of occlusion bodies and development of infective budded forms of the viruses in insect developmental forms will be necessary [4,5,13, 18]. Furthermore, the varying susceptibility of some adult insect pest forms to ingested occlusion bodies and budded infective virus forms should be researched [3,20,23,24]. Researchers should also be encouraged to study the host specific barriers of Baculoviruses in different demonstration models for further optimization of Baculovirus-based therapy of plant diseases whose vectors are insect pests [2, 24,26,43]. More importantly, the efficacy of synergistic chemical treatments of insect pests with Baculoviruses can be further researched as a frontier in integrated pest management of insect pests of agricultural importance [3-8,17, 37,40-42].

6. CONCLUSION

The use of Baculoviruses as viral Biopesticides presents a relatively cheap, practicable, environmental friendly and potent tool for Biocontrol of insect pests of agricultural importance of farm crops and stored products.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Altmann F, Staudacher E, Wilson I, März L. Insect cells as hosts for the expression of recombinant glycoproteins. Glycoconjugate Journal. 1999;16(2):109–23.
   PMID 10612411
   DOI: 10.1023/A:1026488408951
2. Rohrmann G. Baculovirus Molecular Biology Third Edition (3rd ed.). Bethesda, MD: NCBI, U.S.A. 2013;46-57.
3. Jeremy A, Bryong C, Robert H. Expression, delivery and function of insecticidal proteins expressed by recombinant Baculoviruses. Viruses. 2015;7:422-455.
4. Herniou E, Arif B, Becnel J, Blissard G, Bonning B, Harrison R, Jehle J, Theilmann D, Vlak J. Baculoviridae. In virus taxonomy: Ninth Report of the International Committee on Taxonomy of Viruses; King, A.M.Q., Adams, M.J., Carstens, E.B., Lefkowitz, E.J., Eds.; Elsevier: Oxford, UK. 2013;163–174.
5. Theze J, Bezier A, Periquet G, Drezen J, Herniou A. Paleozoic origin of insect large dsDNA viruses. Proceedings of the National Academy of Sciences. 2011; 108(38):15931–5.
   DOI: 10.1073/pnas.1105580108
6. Xue J, Qiao N, Zhang W, Cheng R, Bao Y, Xu Y, Gu L, Han J. Dynamic interactions between Bombyx mori nucleo-polyhedro virus and its host cells revealed by transcriptome analysis. J. Virol. 2012;86:7345–7359.
7. Burand J, Hunter B. RNAi: Future in insect management. J. Invertebr. Pathol. 2013; 112(Suppl. S68–S74): 142.
8. Di Lelio I, Varricchio P, Di Prisco G, Marinelli A, Lasco V, Caccia S, Casartelli M, Giordana B, Rao R, Gigliotti S. Functional analysis of an immune gene of *Spodoptera littoralis* by RNAi. J. Insect Physiol. 2014;64:90–97.
9. Ignoffo M, Conch T. The nucleo-polyhedrasis virus of *Heliothis* species as a microbial insecticide. Academic Press, London. 1981;92-94.
10. Jehle J, Blissard G, Bonning B, Cory J, Herniou E, Rohrmann G, Theilmann D, Thiem S, Vlak J. On the classification and nomenclature of baculoviruses: A proposal for revision. Journal of Virology. 2006; 151(7):1257–1266.
    PMID 16648963.
    DOI: 10.1007/s00705-006-0763-6
11. Templeton N. Gene and cell therapy: Therapeutic mechanisms and strategies, 3rd ed. CRC Press, Boca Raton. 2008; 1267-89.
12. De Barjac H, Frachon E. Classificatoin of Bacillus thuringiensis strains. Journal of Entomophaga. 1990;35(2):1-8.
13. El-Menofy W, Osman G, Assaeedi A, Salama M. A novel recombinant baculovirus over expressing a *Bacillus thuringiensis* Cry1AB toxin enhances insecticidal activity. Biol. Proced. 2014;16-27.
14. Harper D, Kutter E. Therapeutic use of bacteriophages. In Encyclopedia of Life Sciences. John Wiley & Sons, Chichester. New York, U.S.A. 2008;12-17.
    Available:http://www.els.net/
15. Burges H, Thompson M. Standardization and assay of microbial insecticides. In: Microbial control on insects and mites, Academic Press, London. 1971;56-61.

16. Hofmann C, Sandig V, Jennings G, Rudolph M, Schlag P, Strauss M. Efficient gene transfer into human hepatocytes by baculovirus vectors. Proceedings of the National Academy of Sciences. 1995; 92(22):10099–10103.
DOI: 10.1073/pnas.92.22.10099
17. Lacey L, Kaya H. Field manual of techniques in invertebrate pathology: Application and evaluation of pathogens for control of insects and other invertebrate pests. Springer, Netherlands. 2007;10-15.
18. Nguyen Q, Nielsen L, Reid S. Genome scale transcriptomics of baculovirus-insect interactions. Viruses. 2013;5:2721–2747.
19. Tang X, Sun L, Pu G, Wang W, Zhang C, Zhu J. Expression of a neurotoxin gene improves the insecticidal activity of *Spodoptera litura* nucleo-polyhedro virus (SpltNPV). Virus Res. 2011;159:51–56.
20. Hynes R. The evolution of metazoan extracellular matrix. J. Cell Biol. 2012;196: 671–679.
21. Lackner A, Genta K, Koppensteiner H, Herbacek I, Holzmann K, Spiegl-Kreinecker S, Berger W, Grusch M. A bicistronic baculovirus vector for transient and stable protein expression in mammalian cells. Journal of Analytical Biochemistry. 2008;380(1):146–8.
PMID 18541133.
DOI: 10.1016/j.ab.2008.05.020
22. Hegedus D, Erlandson M, Gillott C, Toprak U. New insights into peritrophic matrix synthesis, architecture and function. Annu. Rev. Entomol. 2009;54:285–302.
23. Gramkow A, Perecmanis S, Sousa R, Noronha E, Felix C, Nagata T, Ribeiro B. Insecticidal activity of two proteases against *Spodoptera frugiperda* larvae infected with recombinant baculoviruses. Virol. J. 2010;7:143.
24. Madeo M, Carrisi C, Iacopetta D, Capobianco L, Cappello A, Bucci C, Palmieri F, Mazzeo G, Montalto, A. Abundant expression and purification of biologically active mitochondrial citrate carrier in baculovirus-infected insect cells. Journal of Bioenergetics and Biomembranes. 2009;41 (3):289–297.
ISSN: 0145-479X.
DOI: 10.1007/s10863-009-9226-6
25. Terenius O, Papanicolaou A, Garbutt J, Eleftherianos I, Huvenne H, Kanginakudru, S, Albrechtsen, Barthel A. RNA interference in lepidoptera: An overview of successful and unsuccessful studies and implications for experimental design. J. Insect Physiol. 2011;57:231–245.
26. Wright A, Hawkins H, Änggård E, Harper D. A controlled clinical trial of a therapeutic bacteriophage preparation in chronic otitis due to antibiotic-resistant Pseudomonas aeruginosa; a preliminary report of efficacy. Clinical Otolaryngol. 2009;34: 349–357.
27. Harrison RL, Hoover K. Baculoviruses and other occluded insect viruses. Academic Press: Boston, MA, USA. 2012;73–131.
28. Maramorosh K, Sherman K. Viral insecticides for biological control. Academic Press, Orlando. Florida. 1985; 223-234.
29. Häusler T. Viruses vs. superbugs: A solution to the antibiotics crisis? Macmillan, London, United Kingdom. 2006;175-183.
30. Sun X, Wua D, Sun X, Jin L, Mab Y, Bonning B, Peng H, Hu Z. Impact of *Helicoverpa armigera* nucleo polyhedron viruses expressing a cathepsin l-like protease on target and nontarget insect species on cotton. Biol. Control. 2009;49: 77–83.
31. Federici B, Granados R. The biology of baculoviruses. CRC Press, Inc. Boca Raton, Florida. 1986;49-52.
32. Sun X, Chen X, Zhang Z, Wang H, Bianchi F, Peng H, Vlak J, Hu Z. Bollworm responses to release of genetically modified *Helicoverpa armigera* nucleo polyhedron viruses in cotton. J. Invertebr. Pathol. 2002;81:63–69.
33. Betting D, Mu X, Kafi K, McDonnel D, Rosas F, Gold D, Timmerman, J. Enhanced immune stimulation by a therapeutic lymphoma tumor antigen vaccine produced in insect cells involves mannose receptor targeting to antigen presenting cells. Journal of Vaccines. 2009;27(2):250–9.
34. Kamita S, Kang K, Hammock B, Inceoglu, A. Addendum: Genetically modified baculoviruses for pest insect control. In Insect Control: Biological and Synthetic Agents; Gilbert, L.I., Gill, S.S., Eds.; Academic Press: London, UK. 2010;383–386.
35. Harrison R, Bonning B. Use of proteases to improve the insecticidal activity of baculoviruses. Biol. Control. 2001;20:199–209.
36. Tuan S, Hou R, Lee C, Chao Y. High level production of polyhedra in a scorpion toxin

containing recombinant Baculovirus for better control of insect pests. Bot. Stud. 2007;48:273–281.

37. Passarelli A. Barriers to success: How baculoviruses establish efficient systemic infections. Virology. 2011;411:383–392. 96.
38. Fan X, Zheng B, Fu Y, Sun Y, Liang A. Baculovirus-mediated expression of a chinese scorpion neurotoxin improves insecticidal efficacy. Chin. Sci. Bull. 2008; 53:1855–1860.
39. Hong-Lian S, Du-Juan D, Jin-Dong H, Jin-Xin W, Xiao-Fan Z. Construction of the recombinant baculovirus AcMNPV with cathepsin B-like proteinase and its insecticidal activity against *Helicoverpa armigera.* Pestic. Biochem. Physiol. 2008; 91:141–146.
40. Means J, Passarelli A. Viral fibroblast growth factor, matrix metalloproteases, and caspases are associated with enhancing systemic infection by baculoviruses. Proc. Natl. Acad. Sci. USA. 2010;107:9825–9830.
41. Georgievska L, Joosten N, Hoover K, Cory J, Vlak J, van der Werf W. Effects of single and mixed infections with wild type and genetically modified *Helicoverpa armigera* nucleo polyhedrovirus on movement behaviour of cotton bollworm larvae. Entomol. Exp. Appl., 2010;135:56–67.
42. Kang L, Shi H, Liu X, Zhang C, Yao Q, Wang Y, Chang C, Shi J, Cao J, Kong J. Arginine kinase is highly expressed in a resistant strain of silkworm (*Bombyx mori*, lepidoptera): Implication of its role in resistance to *Bombyx mori* nucleo-polyhedrovirus. Comp. Biochem. Physiol. B Biochem. Mol. Biol. 2011;158:230–234. 136.
43. Regev A, Rivkin H, Gurevitz M, Chejanovsky N. New measures of insecticidal efficacy and safety obtained with the 39k promoter of a recombinant baculovirus. FEBS Lett. 2006;580:6777–6782.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/21167