Environmental Microbiology

Expression of cry1Ab gene from a novel Bacillus thuringiensis strain SY49-1 active on pest insects

Ugur Azizoglu a,*, Abdurrahman Ayvaz b, Semih Yılmaz c, Salih Karabörkül d, Ridvan Temizgül b

a Erciyes University, Department of Crop and Animal Production, Kayseri, Turkey
b Erciyes University, Department of Biology, Kayseri, Turkey
c Erciyes University, Department of Agricultural Biotechnology, Kayseri, Turkey
d Düzce University, Department of Field Crops, Düzce, Turkey

ARTICLE INFO

Article history:
Received 5 June 2015
Accepted 24 November 2015
Available online 20 April 2016
Associate Editor: Lucy Seldin

Keywords:
Bt SY49-1
Gene cloning
Recombinant Cry1Ab
Insecticidal activity

ABSTRACT

In this study, the cry1Ab gene of previously characterized and Lepidoptera-, Diptera-, and Coleoptera-active Bacillus thuringiensis SY49-1 strain was cloned, expressed and individually tested on Ephesia kuehniella (Lepidoptera: Pyralidae) and Plodia interpunctella (Lepidoptera: Pyralidae) larvae. pET-cry1Ab plasmids were constructed by ligating the cry1Ab into pET28a (+) expression vector. Constructed plasmids were transferred to an Escherichia coli BL21 (DE3) strain rendered competent with CaCl₂. Isopropyl β-D-1-thiogalactopyranoside was used to induce the expression of cry1Ab in E. coli BL21 (DE3), and consequently, ∼130 kDa of Cry1Ab was obtained. Bioassay results indicated that recombinant Cry1Ab at a dose of 1000 μg·g⁻¹ caused 40% and 64% mortality on P. interpunctella and E. kuehniella larvae, respectively. However, the mortality rates of Bt SY49-1 strains’ spore–crystal mixture at the same dose were observed to be 70% on P. interpunctella and 90% on E. kuehniella larvae. The results indicated that cry1Ab may be considered as a good candidate in transgenic crop production and as an alternative biocontrol agent in controlling stored product moths.

© 2016 Sociedade Brasileira de Microbiologia. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

Bacillus thuringiensis (Bt) is a Gram-positive aerobic or facultative aerobic spore-forming entomopathogenic bacterium that can easily be isolated from a variety of environmental sources.¹ It has specific toxicity against target insects and is safe to non-target organisms. Cry1 toxins are the most common crystal proteins characterized so far in Bt strains and have specific insecticidal activity against lepidopteran insects.² They form typical bipyramidal parasporal inclusions with 130 kDa molecular weight.² Biotechnological developments in agriculture have caused scientists to seek new solutions to insect pest problems. Transgenic technology, involving a wide range of pesticidal genes from Bt, dominates the scenario of agricultural biotechnology. The improvement of broader spectrum biopesticides using novel Bt strains against target insects is an important aspect for improving their persistence.

* Corresponding author.
E-mails: azizoglugur@hotmail.com, azizoglu@erciyes.edu.tr (U. Azizoglu).
http://dx.doi.org/10.1016/j.bjm.2016.04.011
1517-8382/© 2016 Sociedade Brasileira de Microbiologia. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
on plants. The pyralid moths Ephesia kuehniella (Lepidoptera: Pyralidae) and Plodia interpunctella (Lepidoptera: Pyralidae) are global pests, particularly of stored grains, legumes, dried fruits, nuts, dates, and cocoa beans, and they are the most commonly reported pests of stored grains. Larvae can cause extensive damage to crops and a variety of processed foods. The presence of live insects and insect parts can result in the depreciation of the grain when sold. Chemical insecticides are commonly used in controlling these important pest insects worldwide. However, due to the risks of chemical pest control to the environment and human health, the cloning and expression of cry genes with activity to lepidopteran pests is an important issue concerning species-specific control. In the current study, we amplified and cloned the cry1Ab gene of a novel Bt SY49-1 strain. The strain had insecticidal activity to a variety of lepidopteran, dipteran and coleopteran pests, and we desired to improve the efficiency through transforming the cry1Ab gene into E. coli BL21 (DE3). Expression of the cry1Ab gene and its insecticidal activity against the serious stored product pests E. kuehniella and P. interpunctella were investigated. The results will reveal useful information for stored product pest control by providing Cry proteins from novel strains.

Materials and methods

Strains and plasmids

The Bt SY49-1 was isolated from a soil sample collected from Adana, Turkey in 2008 using sodium acetate enriched medium. The strains B. thuringiensis SY49-1, Escherichia coli DH5α (kindly supplied by Middle East Technical University, METU, Molecular Biology Laboratory), cloning vector pGEMT-Easy, expression vector pET28a (+) and E. coli BL21(DE3) were used in experimental procedures. Bt and E. coli were cultured in Luria Bertani (LB, 10 g/L Triptone, 5 g/L yeast extract, 5 g/L NaCl) medium at 30 ℃ and 37 ℃, respectively.

Electron microscopy

For electron microscopy, a Bt SY49-1 spore–crystal mixture was suspended in dH2O on a microscope slide and fixed after air drying at room temperature. The sample was sputter-coated with 10 nm Au/Pd using a SC7620 Mini-sputter coater and viewed using a scanning electron microscope (LEO440) at 20 kV beam current.

Insect cultures

The larvae of E. kuehniella were reared on a diet containing a mixture of wheat flour, wheat bran and glycerol, and the Indian meal moth P. interpunctella larvae were obtained from naturally infested dried apricot in Kayseri province. The larvae of P. interpunctella were maintained continuously on a diet containing 10% glycerol, 50% dried apricot and 40% wheat flour–wheat bran mixture. Throughout the experiments, insect cultures were maintained at constant temperature (27 ± 1 ℃), photoperiod (14L:10D) and relative humidity (60 ± 5%).

Amplification of cry1Ab gene from Bt SY49-1

Total DNA of Bt SY49-1 was extracted according to the method of Bravo et al. and used as template for polymerase chain reactions (PCR). The cry1Ab gene was amplified using the primer pairs F-5’-GGATTCATATGGGCTGGTGGGCTG-3’; R- 5’-GCTGACTTCTTTGGCTGACGATTCG-3’. BamHI and Sall restriction enzyme recognition sequences were added to the 5’ end of the forward and reverse primers, respectively. PCR mixes contained the reagents at a final concentration of 2.3 mM MgCl2, 1 × Taq buffer, 0.2 mM dNTP mix, 0.3 pmol of each primer, 0.5 U MaxTaq DNA polymerase (Vivantis, PL2201), and 30–100 ng template DNA. The PCR amplification was performed under the following conditions: Initial denaturation at 95 ℃ for 5 min, followed by 30 cycles at 94 ℃ for 1 min, 52 ℃ for 1 min, 72 ℃ for 3.5 min, and a final extension step at 72 ℃ for 10 min. Adenine was added to the 3’ end of the PCR products after amplification for the TA cloning process.

Transfer of cry1Ab gene into pGEM-T Easy cloning vector

To construct the pGEM-cry1Ab, PCR products (~3.5 kb) were purified and ligated into pGEM-T Easy vector. The ligation procedure was conducted according to the manufacturer’s protocol (Promega, vector system I), and then ligate was transformed into CaCl2-rendered competent E. coli DH5α.

Expression of cry1Ab gene in E. coli

BamHI and Sall restriction enzyme recognition sequences were added to the manufacturer’s protocol (PET manual system). The pET-cry1Ab was transferred into E. coli BL21(DE3) cells rendered competent with CaCl2. The positive clones were selected using the PCR method and incubated at 37 ℃ until reaching OD600 = 0.5–1 in 100 mL of LB medium containing 30 μg/mL kanamycin. The 50 mL of culture was induced by 1 mM IPTG for 4 h and followed by centrifuging at 4 ℃ and 5000 rpm for 5 min. The pellet was solubilized in 12 mL of 20 mM Tris–HCl (pH 7.5) and centrifuged as described above. The remaining pellet was solubilized in 5 mL of 20 mM Tris–Cl (pH 7.5) containing 50 μL lysozyme (10 mg/mL) and incubated for 15 min at 30 ℃. The cells were then sonicated for 1 min to release proteins from lysate. Subsequently, it was centrifuged at 4 ℃ and 14,000 rpm for 10 min, and the pellet was resuspended in 2 mL of 20 mM Tris–HCl (pH 7.5) for SDS-PAGE analysis. The same procedure was applied for isolating the proteins from E. coli BL21(DE3) and Bt SY49-1. Total protein quantitation was determined according to the Bradford method.

Cry1Ab protein quantification

The SDS-PAGE image of the approximately 130 kDa Cry1Ab band was used for determining the quantities. Cry protein concentrations were calculated by the following formula: Cry protein concentration (μg/mL) = (μg/mL total protein) × (proportion of Cry protein to total protein). The proportion of Cry protein to total protein was determined
using the Biorad Chemi Doc MP Imaging System Image Lab version 5.1 (Biorad).

**Insecticidal activity of Cry1Ab**

Lyophilized samples of Bt SY49-1, E. coli carrying pET-cry1Ab, and plasmid-free E. coli BL21(DE3) were applied to 10 third-instar larvae of *P. interpunctella* and *E. kuehniella* at doses of 10, 25, 50, 100, 250, 500 and 1000 μg g⁻¹ supplied in the diet. Bioassay experiments on *P. interpunctella* and *E. kuehniella* were performed according to the method of Obeidat et al. Experiments were carried out as three replicates. The data from the experiments were subjected to analysis of variance (ANOVA), and means were separated at the 5% significance level by using the Tukey HSD post hoc test. LC₅₀ were estimated by probit analysis.

**Results**

**Amplification of cry1Ab gene**

The total DNA of the Bt SY49-1 strain was screened by the PCR method using the cry1Ab-specific primer pairs for amplifying the full-length gene region (Fig. 1).

**Spore-crystal mixture and electron microscopy**

Bt SY49-1 was incubated in T3 sporulation medium at 30 °C for 4 days to obtain a spore-crystal mixture. Investigations of the mixture indicated that bipyramidal crystals were compatible with the presence of cry1 gene products. Spherical, cubic and irregularly shaped crystals were also observed via electron micrograph (Fig. 2).

**Cry1Ab gene TA cloning**

PCR product corresponding to the open reading frame of cry1Ab gene (~3.5 kb) was amplified and inserted into the pGEM-T Easy vector system to preserve the gene for further use. The resulting combination was transferred into E. coli DH5α. Subsequently, pGEM-cry1Ab from a positive clone of

![Image 1](image1.png)

**Fig. 1** – cry1Ab gene amplicon, Marker (Fermentas, SM 0331).

![Image 2](image2.png)

**Fig. 2** – Spore-crystal morphology of Bt SY49-1 strain. B, bipyramidal; C, cubic; S, spherical; I, irregularly shaped spherical; Sp, spore.

E. coli DH5α was digested with EcoRI to validate the ligation (Fig. 3).

**Expression of cry1Ab in E. coli BL21(DE3)**

The cry1Ab gene excised with BamHI and SalI was inserted into expression vector pET28a (+) for obtaining pET-cry1Ab. The resulting pET-cry1Ab was transformed into the E. coli BL21(DE3) strain, and positive clones were validated by colony PCR (Fig. 4). A positive clone, E. coli BL21 (DE3) pET-cry1Ab, was cultured in kanamycin containing LB medium until OD₆₀₀ = 0.5–1 was achieved and subsequently induced with IPTG. The expression of recombinant products was analyzed by SDS-PAGE, verifying the presence of a 130 kDa protein band (Fig. 5).

**Cry1Ab quantification**

The protein concentration was calculated according to the following formula: Cry1Ab concentration (μg/ml) = (μg/ml total protein) × (% proportion of Cry1Ab to total protein). Here, the total protein was 7.63 μg/ml, the proportion of Cry1Ab to total

![Image 3](image3.png)

**Fig. 3** – Validation of recombinant pGEM-cry1Ab by restriction digestion with EcoRI, Marker (Fermentas, SM 0331).
protein was 2.58 μg/mL, and the proportion of Cry1Ab to total protein was 33.82%.

Toxicity of pET-cry1Ab, Bt SY49-1 and plasmid-free E. coli BL21(DE3)

The LC₅₀ values of recombinant Cry1Ab on third-instar larvae of E. kuehniella and P. interpunctella were found to be 685.67 and 1320.84 μg·g⁻¹, respectively. The toxicity of the source strain SY49-1 was higher compared with recombinant protein (LC₅₀ = 365.17 μg·g⁻¹ for E. kuehniella and 582.179 μg·g⁻¹ for P. interpunctella). Plasmid-free E. coli BL21(DE3) did not exert significant activity on both pest larvae. The mortality rates are supplied in Figs. 6 and 7. (A) \( F = 7.710; \) \( df = 7; \) \( P \leq 0.0001 \); (B) \( F = 22.136; \) \( df = 7; \) \( P \leq 0.0001 \); (C) \( F = 0.635; \) \( df = 7; \) \( P = 0.721 \); Fig. 7: (A) \( F = 4.082; \) \( df = 4; \) \( P \leq 0.037 \); (B) \( F = 8.799; \) \( df = 4; \) \( P \leq 0.003 \); (C) \( F = 0.474; \) \( df = 4; \) \( P = 0.754 \).

Discussion

Bt SY49-1 is a novel strain, and the toxicity of its wettable spore–crystal powder was previously determined against insect pests from different orders.⁴ E. kuehniella and P. interpunctella are two troublesome pests posing serious problems in stored products worldwide. In the present study, the cry1Ab gene (~3.5 kb) of a previously characterized Bt SY49-1 strain was used thorough cloning and expression in E. coli BL21(DE3). It is well known that cry1A genes have specific insecticidal activity against lepidopteran pests.¹⁴,¹⁵ Bt SY49-1 produces a 130–140 kDa Cry1 band corresponding to the bipyramidal crystal structure (Fig. 2). Cry1Ab (~130 kDa) was overexpressed in IPTG-induced E. coli BL21 (DE3), and its bioactivity was tested on E. kuehniella and P. interpunctella. The results indicated that recombinant Cry1Ab exhibited considerable mortality on pest larvae. However, increasing doses of Cry1Ab from 50 to 500 μg·g⁻¹ had little additional toxicity on the larvae when compared with the spore–crystal mixture of source organism. Similar trends were reported with the recombinant Cry3Aa on Hypothemus hampei,¹⁶ Zhang et al.¹⁷ also reported that the activity of recombinant cry8Ab1 has lower toxicity compared with the source organism, suggesting that this phenomenon may originate from less Cry8Ab1 expression in the host organism and more than one type of differently sized crystals being expressed in wild-type Bt. Comparatively lower toxicity was
Fig. 6 – Toxicity on *E. kuehniella* larvae. (A) pET-cry1Ab; (B) Bt SY49-1 spore–crystal mixture; (C) *E. coli* BL21(DE3) total protein.

Fig. 7 – Toxicity on *P. interpunctella* larvae. (A) pET-cry1Ab; (B) Bt SY49-1 spore–crystal mixture; (C) *E. coli* BL21(DE3) total protein.
also reported by some other researchers on *K. kuehniella* using Cry1Aa, Cry1Ac, and Cry2Aa \(^{18}\) and on *Chironomus tepperi* using Cry11A and Cry4B. \(^{19}\) On the other hand, Park et al. \(^{20}\) reported similar toxicity to the parent strain against Culex mosquitoes with Cry11B from *B. thuringiensis* subsp., *jegathasan*. Similarly, *Bt* SY49-1 harbors cry1, cry2, cry4, cry5 and cry9 genes, and its higher activity may possibly result from the combined activity of these gene-corresponding products. Therefore, this study was intended to determine the effectiveness of Cry1Ab, independent of other genes encoding insecticidal proteins.

In the present study, the individual toxicity of Cry1Ab (expressed in *E. coli*) was evaluated on *K. kuehniella* and *P. interpunctella* to avoid potential synergistic interactions between spores and crystals. \(^{21}\) As far as we know, this is the first report evaluating the toxicity of *E. coli* BL21(DE3) pET-cry1Ab on *E. kuehniella* and *P. interpunctella*. Significant differences were not observed with respect to toxicity between *E. coli* BL21 (DE3) and water control. The individual toxicity of recombinant Cry1Ab on the third-instar larvae of these two stored product pests was precisely estimated.

In conclusion, the cry1Ab gene of the *Bt* SY49-1 strain was successfully cloned, expressed and tested on *E. kuehniella* and *P. interpunctella* larvae. The results indicated that cry1Ab may be considered as a good source in transgenic crop production and as an alternative biocontrol agent in controlling stored product moths.

**Ethical statement**

The authors declare that the experiments complied with the current laws of the country in which they were performed.

**Conflict of interest**

The authors declare that they have no conflict of interest.

**Acknowledgements**

The authors thank Dr. Mikail Akbulut and Zehra Büşra Atciyurt for their valuable assistance. Special thanks to METU Molecular Biology Laboratory for supplying *E. coli* DH5α. This project was funded by the Erciyes University Scientific Project Unit under the codes of FBD11-3634 and ÖNAP-3638 and also funded by Bilim, Sanayi ve Teknoloji Bakanlığı Türkiye (TGSD-0802).

**REFERENCES**

1. Federici BA. *Bacillus thuringiensis* in biological control. In: Bellows TS, Gordh G, Fisher TW, eds. Handbook of biological control. New York, San Diego: Academic Press; 1999 [Chapter 21].
2. Nariman AH. PCR detection of cry genes in local *Bacillus thuringiensis* isolates. A/BAS. 2007:1:461–466.
3. Wasano N, Saitoh H, Maeda M, Ohgushi A, Mizuki E, Ohba M. Cloning and characterization of a novel gene cry9Ec1 encoding lepidopteran-specific parasporal inclusion protein from a *Bacillus thuringiensis* serovar galleriae strain. Can J Microbiol. 2005;51:988–995.
4. Yılmaz S, Ayvaz A, Akbulut M, Azzizoglu U, Karabörkli S. A Novel *Bacillus thuringiensis* strain and its pathogenicity against three important pest insects. J Stored Prod Res. 2012:51:33–40.
5. Travers RS, Martin PAW, Rechelderfer CF. Selective process for efficient isolation of soil *Bacillus* sp. Appl Environ Microbiol. 1987;53:1263–1266.
6. Ayvaz A, Albayrak S, Tuncbilek AS. Inherited sterility in Mediterranean flour moth *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae): effect of gamma radiation doses on insect fecundity fertility and developmental period. J Stored Prod Res. 2007;43:234–239.
7. Ayvaz A, Albayrak S, Karabörkli S. Gamma radiation sensitivity of the eggs, larvae and pupae of Indian meal moth *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae). Pest Manag Sci. 2008;64:505–512.
8. Bravo A, Sarabia S, Lopez L, et al. Characterization of cry genes in a Mexican *Bacillus thuringiensis* strain collection. Appl Environ Microbiol. 1998;64:4965–4972.
9. Stobdan T, Kaur S, Singh A. Cloning and nucleotide sequence of a novel cry gene from *Bacillus thuringiensis*. Biotechnol Lett. 2004;26:1153–1156.
10. Bradford MM. Rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Anal Biochem. 1976;72:248–254.
11. Li H, Bouwer G. Evaluation of the synergistic activities of *Bacillus thuringiensis* Cry proteins against Helicoverpa armigera (Lepidoptera: Noctuidae). J Invertebr Pathol. 2014;12:7–13.
12. Obeidat M, Hassawi D, Ghabesh I. Characterization of *Bacillus thuringiensis* strains from Jordan and their toxicity to the *Lepidoptera, Ephestia kuehniella* Zeller. Afr J Biotechnol. 2004;3:622–626.
13. SPSS Version 10. Illinois: SPSS Inc; 2001.
14. Bravo A, Gill SS, Soberon M. Mode of action of *Bacillus thuringiensis* Cry and Cyt toxins and their potential for insect control. Toxicon. 2007;49:423–435.
15. Darsi S, Prakash GD, Udayasursyian V. Cloning and characterization of truncated cry1Ab gene from a new indigenous isolate of *Bacillus thuringiensis*. Biotechnol Lett. 2010;32:1311–1315.
16. López-Pazos SA, Gómez JEC, Cry1B SAC. Cry3A are active against *Hypothenemus hampei* Ferrari (Coleoptera: Scolytidae). J Invertebr Pathol. 2009;101:242–245.
17. Zhang Y, Zheng C, Tan B, Li C, Chenga L. Cloning and characterization of a novel cry9Ab1 gene from *Bacillus thuringiensis* strain B-JX with specific toxicity to *Scaraeidae* (Coleoptera: Scarabaeidae) larvae. Microbiol Res. 2013;168:512–517.
18. Tounsi S, Dammak M, Rebai A, Jaoua S. Response of larval *Ephestia kuehniella* (Lepidoptera: Pyralidae) to individual *Bacillus thuringiensis* kurstaki toxins and toxin mixtures. Biol Control. 2005;35:27–33.
19. Hughes PA, Stevens MM, Park HW, Federici BA, Dennis ES, Akhurst R. Response of larval *Chloromonas tepperi* (Diptera:Chironomidae) to individual *Bacillus thuringiensis* var. *israelensis* toxins and toxin mixtures. J Invertebr Pathol. 2005;88:34–39.
20. Park HW, Bideshi DK, Federici BA. Recombinant strain of *Bacillus thuringiensis* producing Cyt1A, Cry1B, and the *Bacillus sphaericus* binary toxin. Appl Environ Microbiol. 2003;69:1331–1334.
21. Johnson DE, Oppert B, McGaughy WH. Spore coat protein synergizes *Bacillus thuringiensis* crystal toxicity for the Indian meal Moth (*Plodia interpunctella*). Curr Microbiol. 1998;36:278–282.