

Biological Control of Fall armyworm in Asia-Pacific, China as an example

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Outline



- FAW occurrence in China
- Natural enemies of FAW in China and application for FAW control
- Biopesticides application for FAW control in China
- Acknowledgements



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FAW occurrence in China

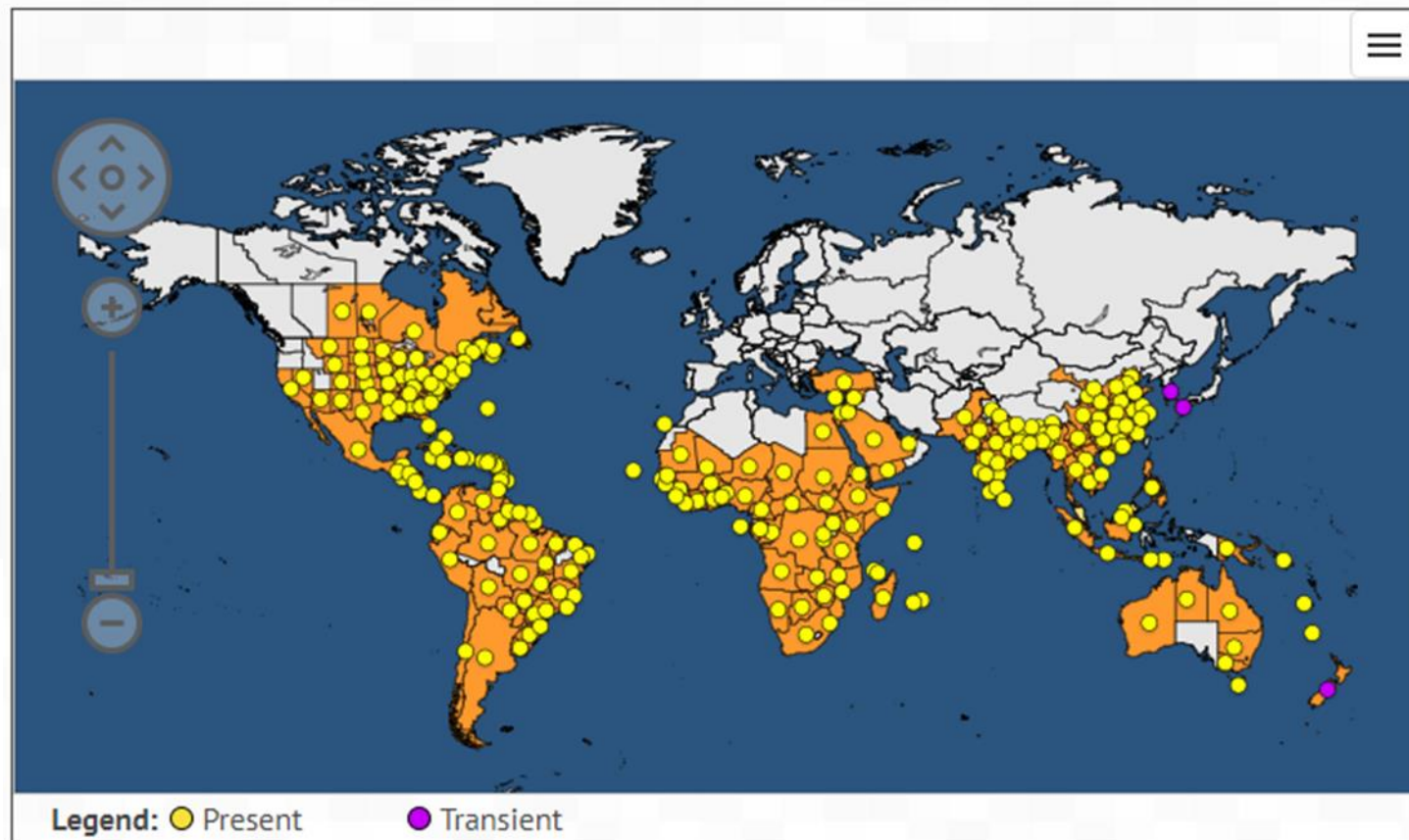
➤ FAW had distributed in 129 countries and regions till March 2023.

- ✓ Americas: 45
- ✓ Africa: 50
- ✓ **Asia: 26**
- ✓ Europe: 2
- ✓ Oceania: 6



Distribution

Last updated: 2023-03-02



<https://gd.eppo.int/taxon/LAPHFR/distribution>

FAW occurrence in China

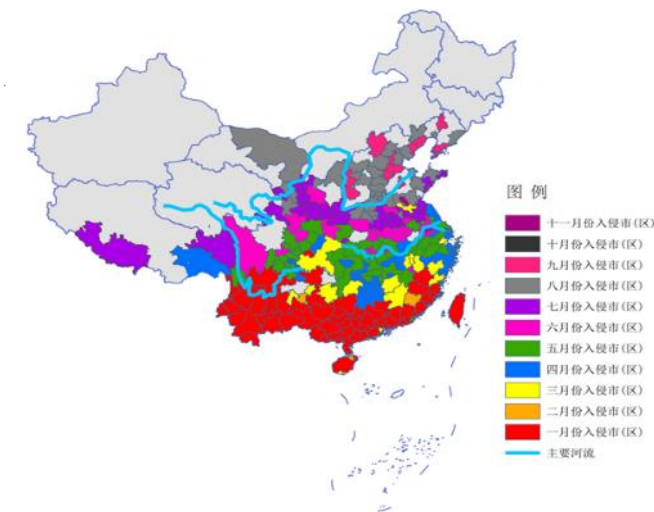


- FAW larvae were first observed in corn field in **Jiangcheng**, Puer, Yunnan, on **11 Jan. 2019**. It migrated to north Yunnan and adjacent provinces in April 2019, and then quickly dispersed in most provinces of mainland China.
- It was observed in 1518 counties in 26 provinces, among which 1438 counties in 22 provinces were found infestation with FAW in 2019.
- It has become one of the major corn insect pest in China.

Occurrence in 2019 in China



Occurrence in 2020 in China



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Natural enemies of FAW in China and application for FAW control



➤ Survey and identification of natural enemies of FAW

✓ Parasitoids

- 2 egg parasitoids , 1 egg-larval, 12 larval and 1 pupal parasitoids were identified.



Telenomus remus



Trichogramma chilonis



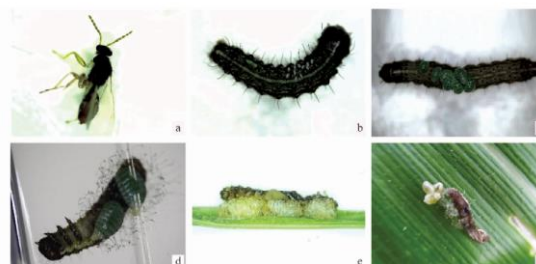
Microplitis pallidipes



Cotesia glomerata



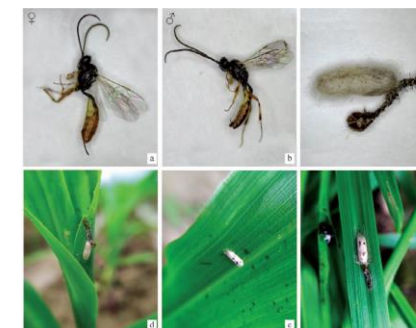
Microplitis similis



Euplectrus laphygmae



Tetrastichus howardi



Diadegma semiclausum



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Natural enemies of FAW in China and application for FAW control



➤ Survey and identification of natural enemies of FAW

✓ Predators

- 6 predatory bugs, 2 earwigs, 1 predatory carabid beetle, several ladybird beetles and lacewings were observed preying FAW larvae.



Picromerus lewisi



Arma chinensis



Synanus croceovittatus



Eocanthecona furcellata



Chlaenius bioculatus



Eurellia pallipes



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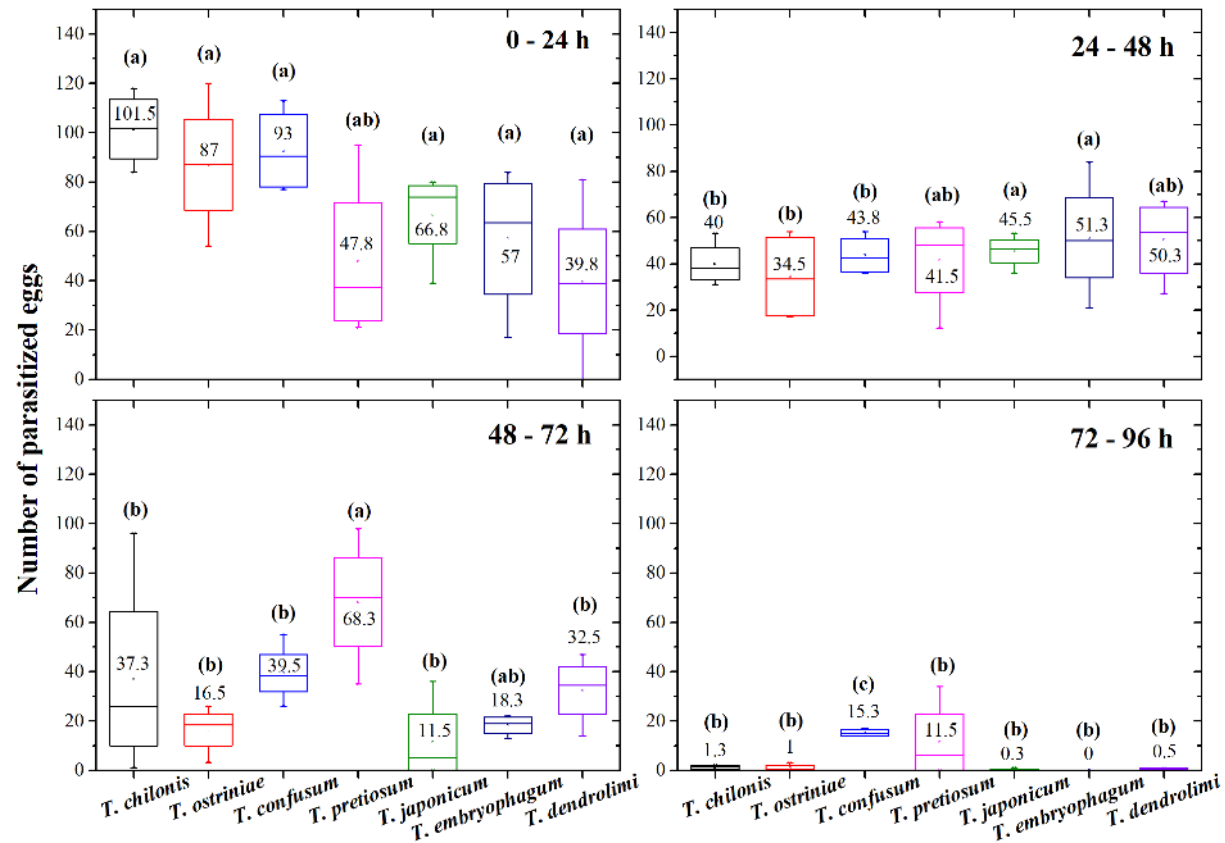


Natural enemies of FAW in China and application for FAW control



➤ Screening *Trichogramma* species for FAW control

Parasitization capacity of seven *Trichogramma* species



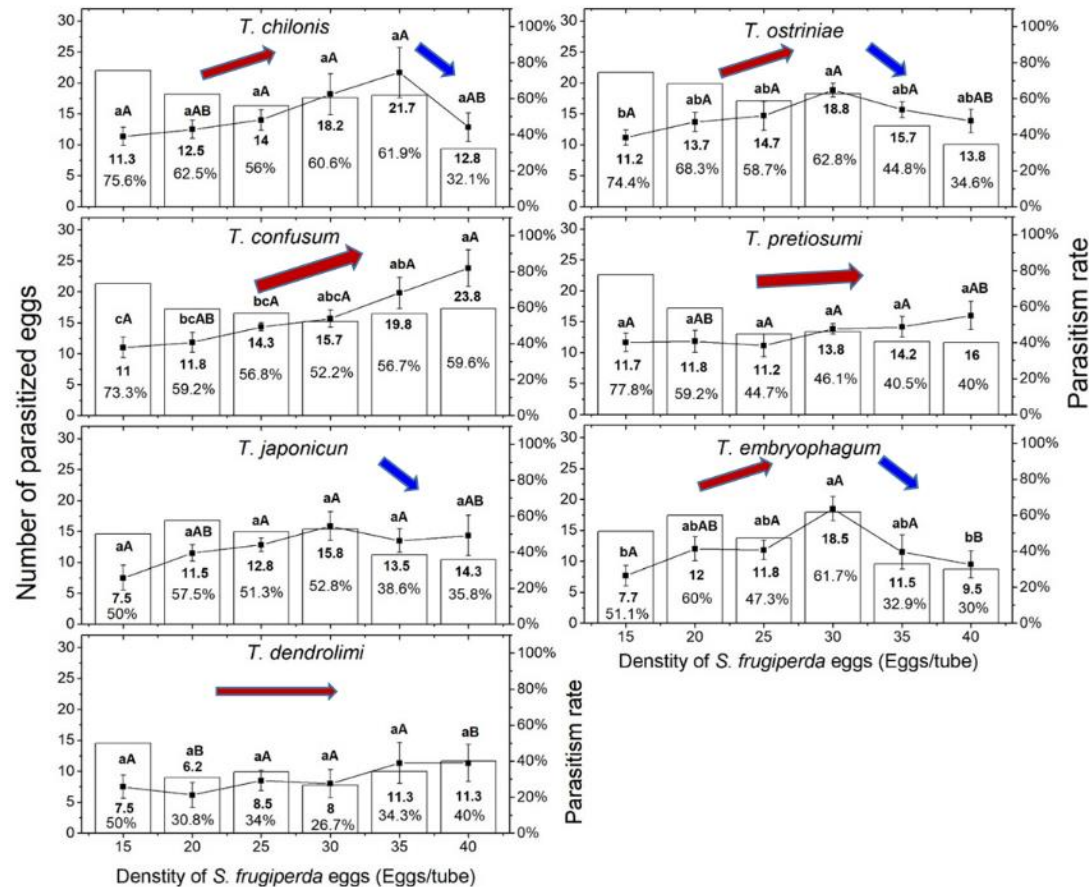
- ✓ At 0–24 h, the eggs parasitized by *T. chilonis*, *T. ostriniae* and *T. confusum* were 101.5, 87, and 93, respectively.
- ✓ The eggs parasitized by *T. pretiosum* at 0–24 h, 24–48 h, and 48–72 h were 47.8, 41.5, and 68.3, respectively.
- ✓ The total number of *S. frugiperda* eggs parasitized by 10 female *T. chilonis*, *T. ostriniae*, *T. confusum*, *T. pretiosum*, *T. japonicum*, *T. embryophagum*, and *T. dendrolimi* within 0–96 h were **180**, **139**, **191.3**, **169**, 124, 126.5 and 123.
- ✓ *T. chilonis*, *T. ostriniae*, *T. confusum*, *T. pretiosum*, have a **higher parasitization capacity** on *S. frugiperda* eggs.

Natural enemies of FAW in China and application for FAW control



➤ Screening *Trichogramma* species for FAW control

Parasitism rates on different densities FAW eggs



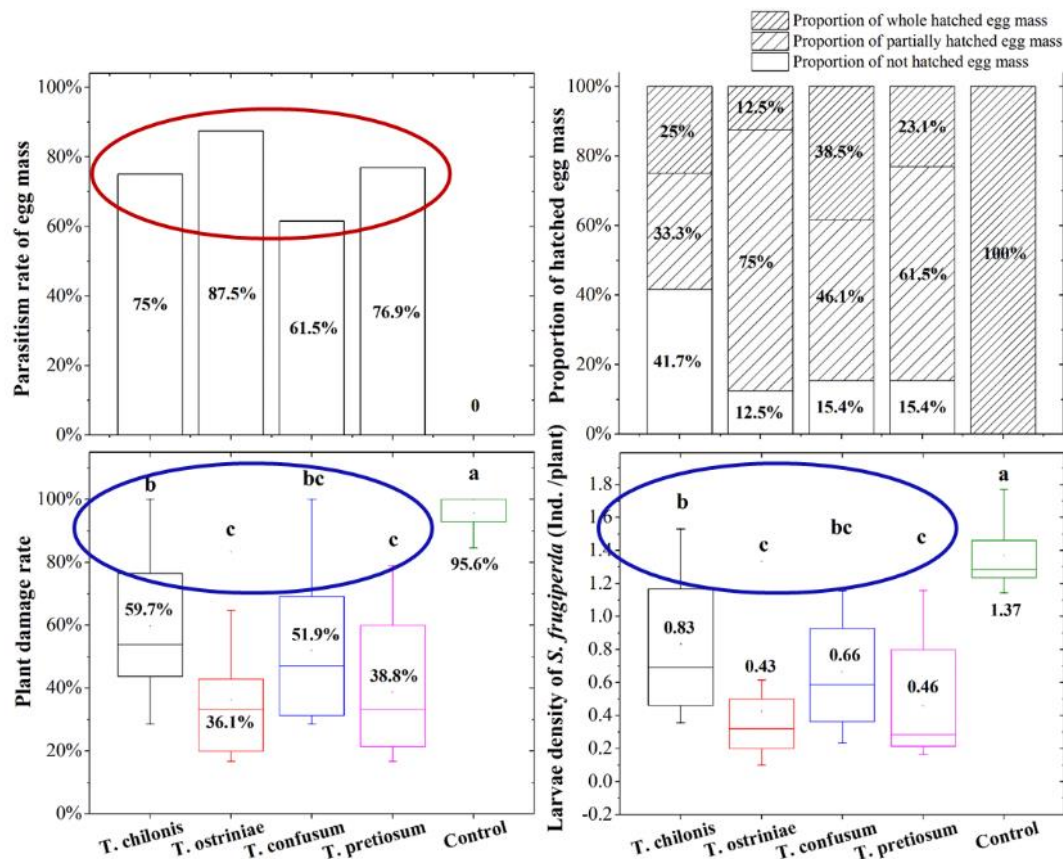
- ✓ The number of eggs parasitized by *T. chilonis*, *T. ostriniae*, and *T. confusum*, increased with an increasing density of host eggs.
- ✓ At the lowest egg density of 15 eggs/tube, the parasitism rate on FAW eggs by *T. chilonis*, *T. ostriniae*, *T. confusum*, *T. pretiosum*, and *T. dendrolimi* were the highest.
- ✓ *T. chilonis*, *T. ostriniae*, *T. confusum*, *T. pretiosum*, may as candidate parasitoids for FAW control.

Natural enemies of FAW in China and application for FAW control



➤ Screening *Trichogramma* species for FAW control

Field release of *Trichogramma* spp. to control FAW



- ✓ The parasitism rate on the egg masses ranged from **61.5 %** to **87.5 %**.
- ✓ Plant damage rates were **36.1 %**, **38.8 %**, **51.9 %**, and **59.7 %**, after the release of *T. ostriniae*, *T. pretiosum*, *T. confusum*, and *T. chilonis*, respectively. The unreleased control is **95.6 %**.
- ✓ FAW larval density ranged from **0.43** to **0.83** individuals/plant. The control treatment have **1.37** individuals/plant
- ✓ The field release of ***T. ostriniae***, ***T. pretiosum***, ***T. confusum***, and ***T. chilonis*** have positive result with noticeably reduced damage by FAW.

Natural enemies of FAW in China and application for FAW control



➤ Optimize the *Trichogramma* mass production line

- ✓ A production line covering an area of 300 m² was optimized in 2022 in Plant Protection Research Institute, Guangdong Academy of Agricultural Sciences
- ✓ It was equipped with air purification, temperature and humidity control fresh air system, intelligent feeding robot, and artificial feed all-in machine for rice moth.

Automated breeding workshop



Robot AGV automatic feeding



Automatic collection of moths



Automatic collection of eggs



Field application of *Trichogramma*



Trichogramma release cards



Breeding *Trichogramma*



Eggs of *C. cephalonica*



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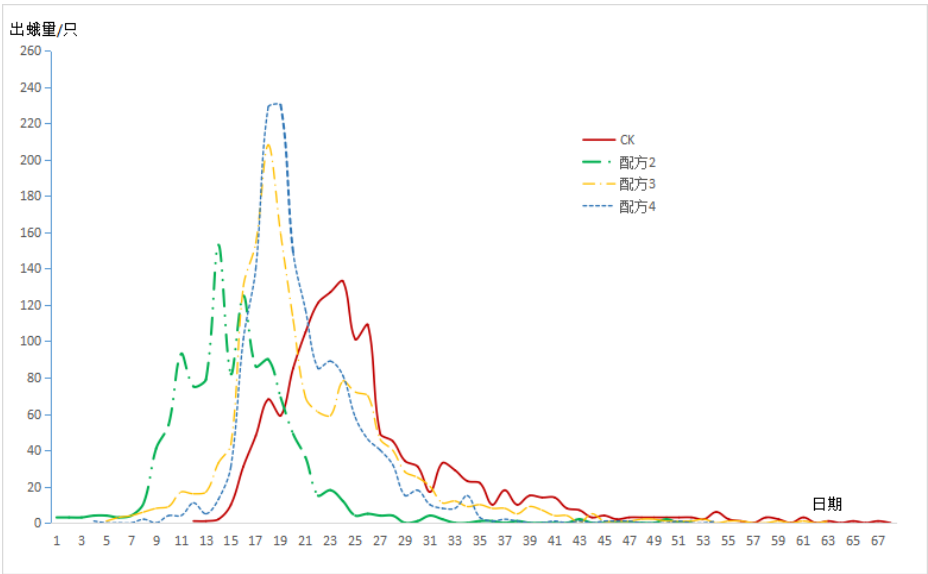
Natural enemies of FAW in China and application for FAW control



➤ Optimize the *Trichogramma* mass production line

- ✓ Annual production capacity is over 1 billion *Trichogramma* after the optimization of the mechanization level of the *Trichogramma* production line.

A new diet formula for rice moth larvae has been developed, the production cycle of *C. cephalonica* eggs shortened by 22.42%, which significantly improve the rice moth egg production efficiency.



Effects of different diets on production and sex ratio of *C. cephalonica*

Index	Treatment			
	CK	Diet 1	Diet 2	Diet 3
Average number moths harvested	285.8±18.57b	228.8±35.00a	319.4±10.11b	311.2±25.97b
Sex ratio	1.04±0.25a	1.43±0.23b	1.03±0.03a	1.02±0.13a
Average egg laid per female	660.4±45.96	652.4±26.03	656.4±17.76	679.2±39.42
Starting time of moth emergence	56.20±1.64	43.60±0.89	48.00±0.71	50.00±2.45
Emergence rate	64.22±4.17	68.17±7.37	67.24±2.13	65.51±5.47

Natural enemies of FAW in China and application for FAW control



➤ Production line of *Telenomus remus*

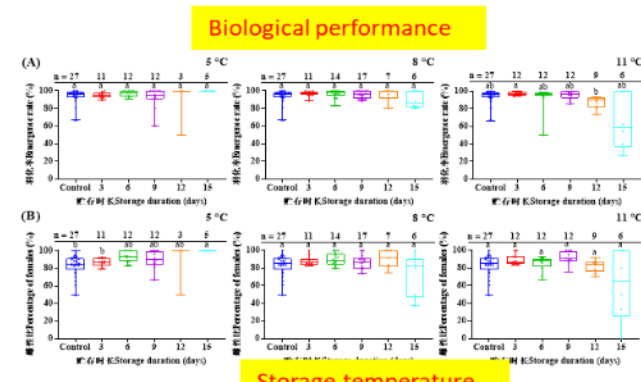
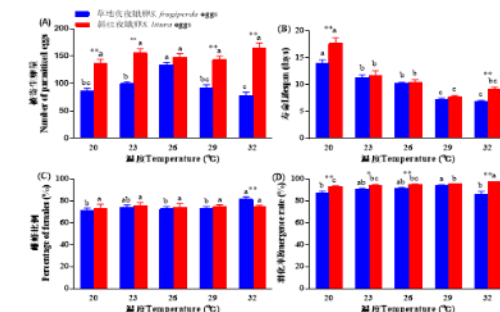
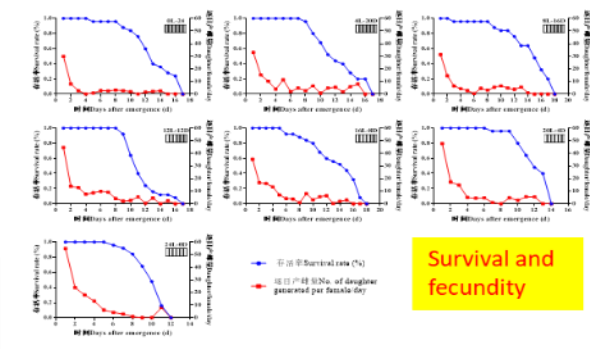
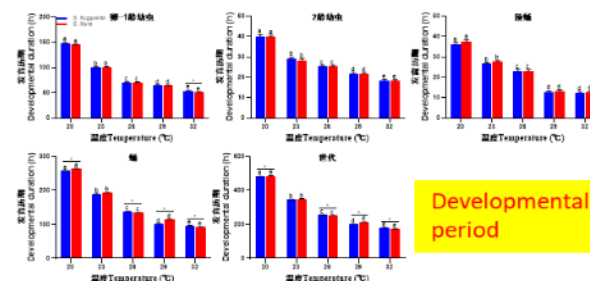
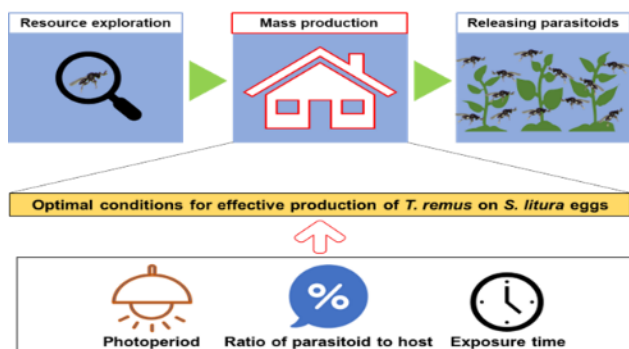
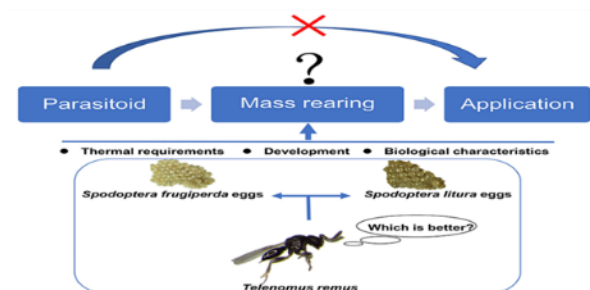
- ✓ Select alternative host eggs for *T. remus* (*Spodoptera litura* eggs is better).
- ✓ Mass production of *T. remus* by using *S. litura* eggs as host.
- ✓ Improve rearing and storage conditions for *T. remus*.



Spodoptera litura



Telenomus remus



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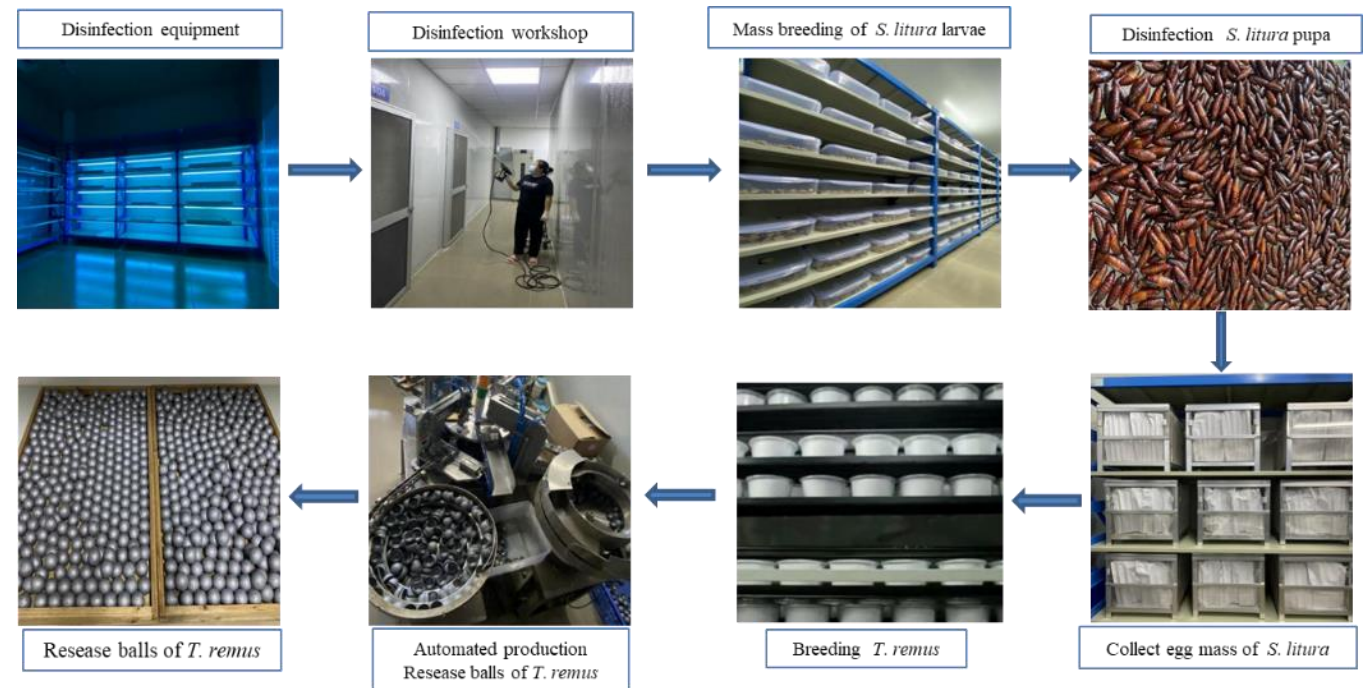


Natural enemies of FAW in China and application for FAW control



➤ Production line of *Telenomus remus*

- ✓ A mass production workshop for *Spodoptera litura* and *Telenomus remus* mass rearing established in 2022 in Plant Protection Research Institute, Guangdong Academy of Agricultural Sciences.



Natural enemies of FAW in China and application for FAW control



➤ Production line of *Telenomus remus*



Each rearing rack can accommodate 35 boxes,
and the production line is equipped with 15
rearing racks, which can expand to over 500
boxes per month.

100 female moths
produced per box

500 boxes per month

Production 50,000 female moths per month

One generation per month, 600,000 female moths annually

1000 eggs per female moth, production of 600 million
eggs per year

Parasitic rate is 80%, **annual production capacity is
over 480 million of *Telenomus remus*.**



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Natural enemies of FAW in China and application for FAW control



➤ Production line of *Telenomus remus*

- ✓ Disinfection techniques for mass rearing of *S. litura* to free from polyhedrosis virus and microsporidia

Disinfection techniques	Disinfection time	Disinfection object	Disinfection targets
Method 1	Everyday	Larval workshop	Microsporidia
Method 2	Egg stage	Overall environment of the workshop and surrounding areas	Polyhedrosis virus
Method 3	Egg and pupal stage	Eggs, pupae, all utensils and work clothes	Polyhedrosis virus
Method 4	Daily operations	Hand and desktop during operation	Polyhedrosis virus
Method 5	Periodicity	Ground	Degerming



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Natural enemies of FAW in China and application for FAW control

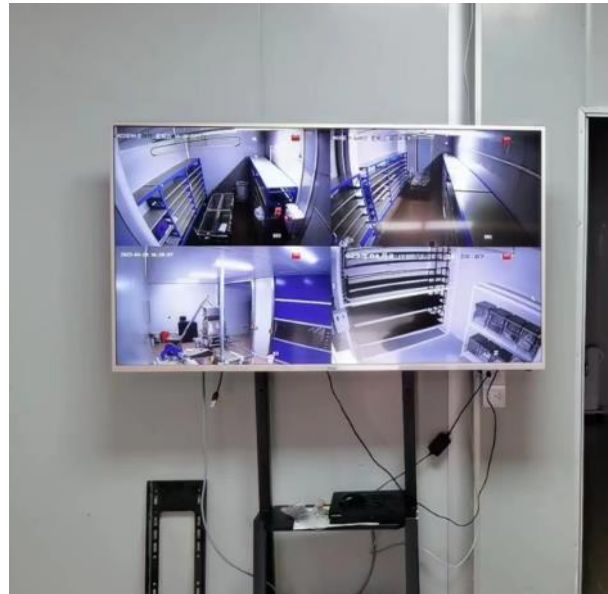


➤ Production line of *Telenomus remus*

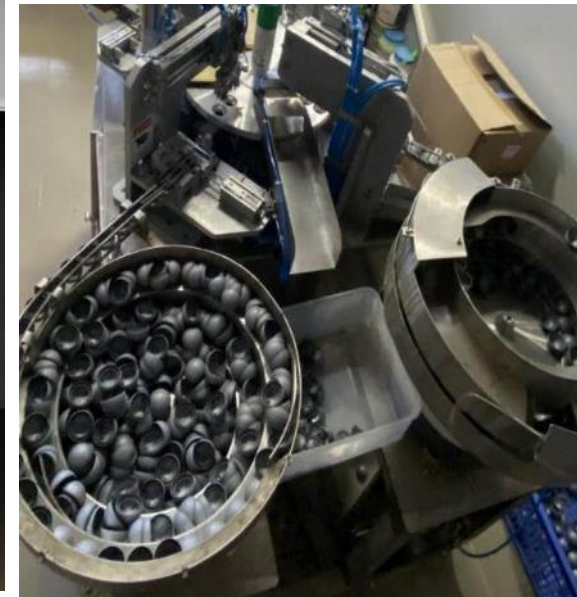
- ✓ Develop *T. remus* mass rearing equipment, parasitoid balls automatic production equipment, and remote control system to improve the mechanization level of production line.



Mechanized *T. remus* mass
rearing equipment



Remote control
equipment



Automatic production
equipment for parasitoid balls



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Natural enemies of FAW in China and application for FAW control



- Develop parasitoid products for controlling FAW: *T. remus*, *T. chilonis* and compound parasitoid balls for broadcasting by drone.



Egg card of *T. remus*



Egg card of *T. chilonis*



Compound parasitoid balls (*T. remus* + *T. chilonis*)



Natural enemies of FAW in China and application for FAW control



- Control effects on FAW by releasing *Trichogramma chilonis* and *Telenomus remus*
 - ✓ The field control effect of *T. chilonis* and *T. remus* to *S. frugiperda* was 50.50% and 71.86%, respectively.



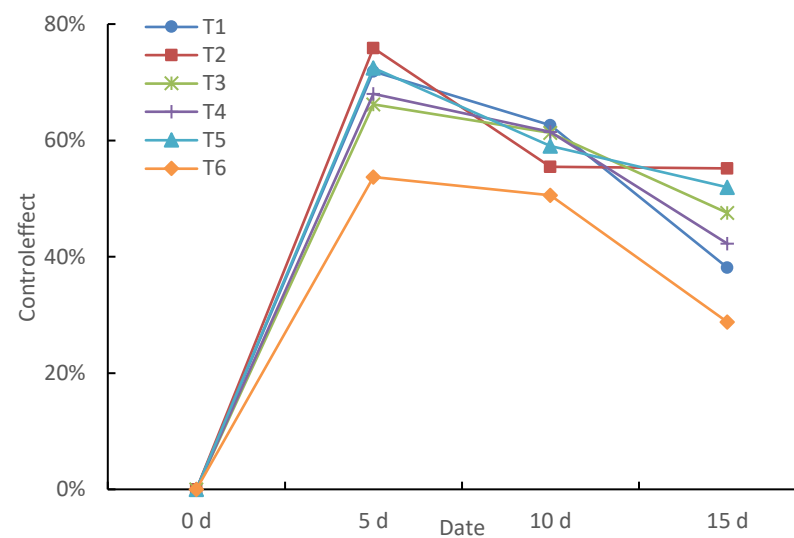
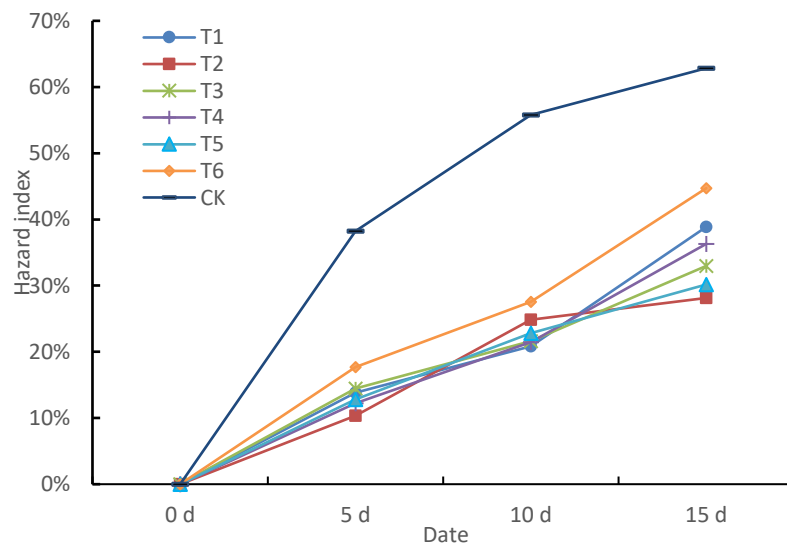
	Parasitism of FAW eggs (%)	7 d after release			
		FAW decreased rate (%)	Control effect for FAW (%)	Other Lepidopteran pest decreased rate (%)	Control effect for other Lepidopteran pest (%)
Release of <i>T. chilonis</i>	35.42 ± 5.80*	58.92 ± 2.33*	50.50 ± 1.47	43.25 ± 1.38*	38.14 ± 1.82
Un released plot	0.03 ± 0.03	9.72 ± 2.19	--	8.26 ± 1.97	--



Natural enemies of FAW in China and application for FAW control



- Control effects on FAW by releasing *Trichogramma chilonis* and *Telenomus remus*
 - ✓ Compound parasitoid ball: 20% *T. remus* + 80% *T. chilonis* could reduce the control cost, and the field control effect to *S. frugiperda* was 72.48%.

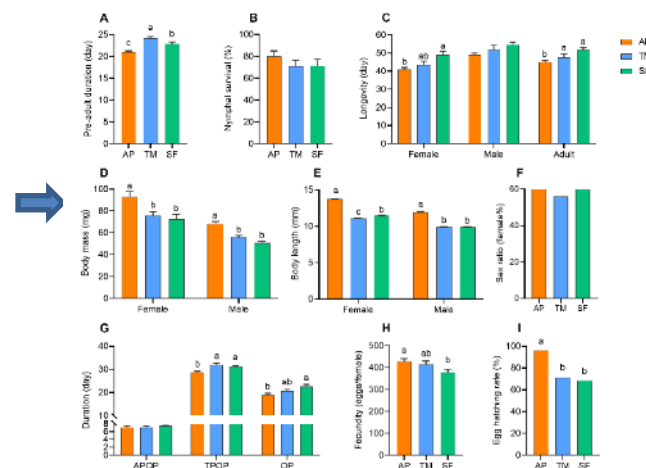
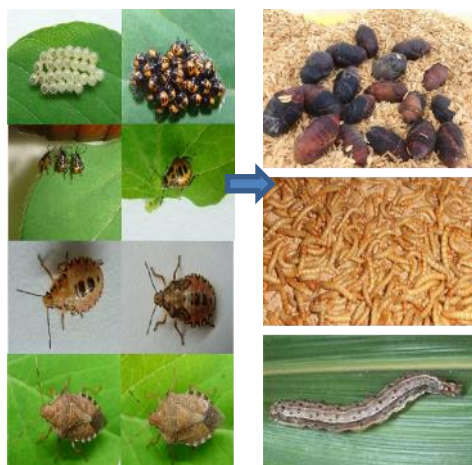


Natural enemies of FAW in China and application for FAW control



➤ Mass rearing of *Arma chinensis*, a predator for FAW larvae

- ✓ Institute of Plant Protection, Chinese Academy of Agricultural Sciences (IPP-CAAS), developed techniques for predatory bugs rearing
- ✓ Selected two alternative prey for rearing predator *A. chinensis*, *Tenebrio molitor* is better.
- ✓ Indicated the nutritional requirements of the predator.



Population parameters of *A. chinensis*

种群参数	AP		TM		SF		$F_{(DFn, DFd)}$	P-value
Population parameter	n	Mean \pm (SE)	n	Mean \pm (SE)	n	Mean \pm (SE)		
成虫产卵前期 (APOP)	26	7.12 \pm 0.34a	22	7.09 \pm 0.28a	20	7.45 \pm 0.21a	$F_{(2,65)}=0.4259$	0.6550
Adult pre-oviposition period								
总产卵前期 (TPOP)	26	28.81 \pm 0.34b	22	31.95 \pm 0.71a	20	31.20 \pm 0.42a	$F_{(2,65)}=11.29$	<0.0001
Total pre-oviposition period								
产卵时间	26	18.88 \pm 0.77b	22	20.59 \pm 0.80ab	20	22.65 \pm 0.78a	$F_{(2,65)}=5.727$	0.0051
Oviposition days								
单雌总产卵量	26	429.54 \pm 12.61a	22	415.14 \pm 16.06ab	20	379.80 \pm 13.45b	$F_{(2,65)}=3.207$	0.0469
Fecundity (total eggs/female)								

Natural enemies of FAW in China and application for FAW control



➤ Mass rearing of parasitoids and predator of FAW

- ✓ IPP-CAAS also set up mass rearing lines both for parasitoids and predators for FAW control
- ✓ It realizes intelligent full automation and can be controlled mobile APP.
- ✓ Produce a variety of alternative prey and natural enemy insects simultaneously.



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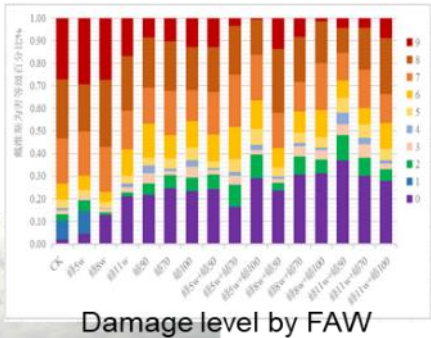
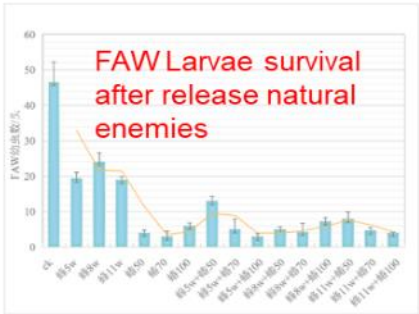
Natural enemies of FAW in China and application for FAW control



➤ Use “Predatory bugs + egg parasitoids” to control FAW, control effect >90%



序号	处理	被害株率	百株幼虫存活数	被害株减退率	防治效果
1	CK	98.29	49.8	----	----
2	蜂5w	95.53	16.6	2.49	66.67
3	蜂8w	87.00	23.5	10.79	52.81
4	蜂11w	79.25	17.3	19.24	65.26
5	蜡50	78.69	3.6	19.95	92.77
6	蜡70	75.49	2.7	22.75	94.58
7	蜡100	76.25	5.1	21.78	89.76
8	蜂5w+蜡50	75.80	11.2	22.55	77.51
9	蜂5w+蜡70	83.91	4.9	14.51	90.16
10	蜂5w+蜡100	71.58	2.7	27.62	94.58
11	蜂8w+蜡50	76.71	4.0	22.05	91.97
12	蜂8w+蜡70	69.72	3.4	29.32	93.17
13	蜂8w+蜡100	68.59	5.9	29.87	88.15
14	蜂11w+蜡50	63.27	7.4	35.74	85.14
15	蜂11w+蜡70	70.25	4.4	28.63	91.16
16	蜂11w+蜡100	71.57	2.5	26.27	94.98



Biopesticides application for FAW control in China

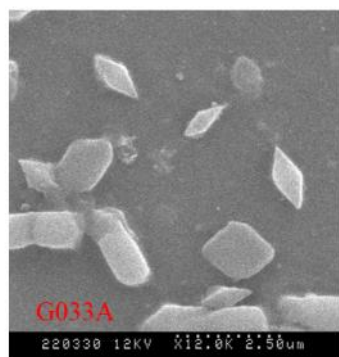


➤ *Bacillus thuringiensis* (Bt) formulations

- ✓ The genetically engineered strain G033A was constructed by introducing cry3Aa7 into wild Bt subsp. *aizawai* G03 by IPP-CAAS.

Bt G033A produced by Wuhan Kernel Bio-tech Co. Ltd

- ✓ PS3 was a new Bt wild strain.



Genes

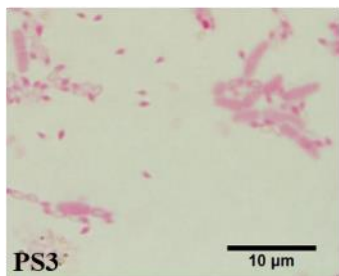
cry3Aa7
cry1Aa1
cry1Ca7
cry1Da1
cry1Ia10
cry2Ab1
cry9Ea1
vip3Aa11

Striped flea beetle
(*Phyllotreta vittata*)
Potato beetle
(*Leptinotarsa decemlineata*)
Fall armyworm (*S. frugiperda*)
Common cutworm (*S. litura*)
Cotton ballworm
(*Helicoverpa armigera*)
Diamondback moth
(*Plutella xylostella*)
Tomato leafminer
(*Tuta absoluta*)



Patent

Pesticide registration license



Genes

cry1Aa1
cry1Ca7
cry1Da1
cry1Ia10
cry2Ab1
cry9Ea1
vip3Aa11

Fall armyworm (*S. frugiperda*)
Common cutworm (*S. litura*)
Cotton ballworm
(*Helicoverpa armigera*)
Diamondback moth
(*Plutella xylostella*)
Tomato leafminer
(*Tuta absoluta*)



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Biopesticides application for FAW control in China



➤ *Bacillus thuringiensis* (Bt) formulations

- ✓ In the Year-round Breeding Region of FAW, FAW generations overlap seriously. FAW larvae density were over 100 larvae/100 plants, the proportion of 4th instar larvae was more than 50%, and the damage rate of corn was as high as 100% before Bt treatment.
- ✓ Control effect of Bt G033A was over 85% (7 days after Bt treatment)

Symptoms of corn damage before control



Jiangcheng, Yunnan

Plant recovery to normal after Bt application



7 days after Bt treatment

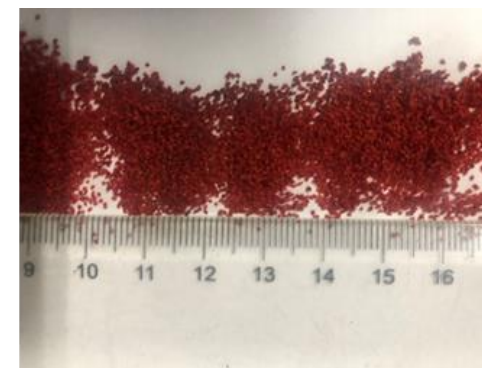
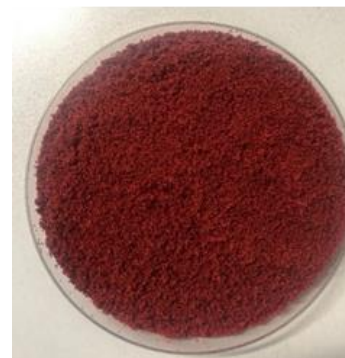


Biopesticides application for FAW control in China



➤ *Bacillus thuringiensis* (Bt) formulations

- ✓ Broadcasting of Bt tiny granules by **drone**



Tiny granules in the size range of 0.1 - 0.5 mm. The number of prepared granules was 8000-18000 granules g⁻¹

IPP-CAAS developed a new technique:
Preparation technique for tiny granules and
the broadcasting technique by drone



Research Article | [Full Access](#)

Broadcasting of tiny granules by drone to mimic liquid spraying for the control of fall armyworm (*Spodoptera frugiperda*)

Xiaojing Yan, Huizhu Yuan, Yixuan Chen, Xin Shi, Xiaohui Liu, Zhenying Wang, Yue Liu, Daibin Yang

First published: 17 August 2021 | <https://doi.org/10.1002/ps.6604>

Yan et al., (2021)



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Biopesticides application for FAW control in China

➤ *Bacillus thuringiensis* (Bt) formulations

- ✓ Control efficiency was **90%** using broadcast of Bt tiny granules by **drone**



Untreated Control



Biopesticides application for FAW control in China



➤ *Bacillus thuringiensis* (Bt) formulations

Control of Fall Armyworm in Field using Bt PS3 in Laos

Treatment	Dosage	Xaifongtai village		Xaifongneau village		Thakhaek village	
		7 days	14 days	7 days	14 days	7 days	14 days
PS3 wettable powder	3 kg/ha	78	100	82	100	86	99
PS3 tiny granules	30 kg/ha	87	96	80	98	82	100
Emamectin benzoate	20 mL/ha	98	98	90	100	98	100
Water (negative control)	--	0	0	0	0	0	0



Cooperated with Plant Protection Center, Laos, field demonstration showed that Bt PS3 had very good control effects on FAW, same as that of Emamectin benzoate spraying in January to March 2023.



Bt PS3



CK

Biopesticides application for FAW control in China



➤ Fungal pesticide *Metarhizium anisopliae* CQMa421

- ✓ Isolated by Chongqing University, a broad-spectrum fungal strain, infects 7 orders of insect pests
- ✓ CQMa421 and ZJU435(*Beauveria bassiana*) can reduce egg-hatching rate, and very effectively control the newly hatched larvae.

Impacts of insecticidal fungi on FAW egg-hatching and survival of neonates

Treatment	Egg-hatching rate (%)	Significance 5%	Survival rate of larvae 3 days after hatching (%)	Significance 5%
CQMa421	82.8 ± 6.3	b	20.8 ± 11.8	b
ZJU435	90.7 ± 5.5	b	0.0	c
Control	100	a	79.4 ± 8.3	a



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Biopesticides application for FAW control in China



➤ Fungal pesticide *Metarhizium anisopliae* CQMa421

- ✓ Mixed CQMa421 with Bt enhances the killing efficacy against FAW larvae

Synergism of CQMa421 + Bt on the FAW larvae

Instar	Treatment	Mortality %							
		3DAA		5DAA		7DAA		10DAA	
2nd	CQMa421	10.7±2.2	c	21.1±6.3	c	22.9±8.1	c	35.2±5.2	c
	Bt	54.7±4.8	b	65.5±5.0	b	66.8±6.1	b	70.3±4.5	b
	CQMa421+ Bt	70.9±5.1	a	82.6±6.1	a	88.1±3.7	a	92.3±3.1	a

The mixed application of CQMa421 and Bt(G033A) had obvious synergistic effect, which can effectively control the 2nd instar FAW larvae.

Peng et al., (2019)



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Biopesticides application for FAW control in China



➤ Fungal pesticide *Metarhizium anisopliae* CQMa421

Efficacy of CQMa421 and 4 chemical pesticides on FAW

Treatment	Control Efficacy (%)			
	1DAA	3DAA	5DAA	10DAA
Chlorantraniliprole (100%)	75.03%	92.57%	94.64%	79.88%
chlorantraniliprole (50%)	33.80%	40.00%	15.55%	50.00%
CQMa421+Chlorantraniliprole (50%)	27.59%	98.01%	85.60%	78.39%
5.6% Emamectin Benzoate (100%)	81.31%	98.26%	89.96%	77.42%
5.6%Emamectin Benzoate (50%)	78.43%	97.71%	90.07%	62.76%
CQMa421+5.6% Emamectin (50%)	82.62%	95.69%	92.22%	81.33%
60g/L Spinetoram (100%)	86.53%	100.00%	94.57%	97.29%
60g/L Spinetoram (50%)	60.00%	86.00%	75.11%	76.00%
CQMa421+60g/L Spinetoram (50%)	72.24%	98.21%	93.52%	82.78%
Chlorfenapyr (100%)	95.98%	98.50%	91.36%	35.18%
Chlorfenapyr (50%)	51.73%	82.05%	74.07%	-8.89%
CQMa421+Chlorfenapyr (50%)	93.97%	99.25%	97.84%	80.55%

The control efficacy of FAW by mixing CQMa421 with half dose chemicals (**Chlorantraniliprole, Emamectin Benzoate, Spinetoram, Chlorfenapyr**) was similar with that of full dose chemicals, had obvious synergistic and persistent effects to control FAW



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Biopesticides application for FAW control in China



➤ Fungal pesticide *Metarhizium anisopliae* CQMa421

- ✓ **Control efficacy of the combined application of CQMa421 + Chlorantraniliprole is above 95% on the 3rd day after application**

Location: Jianshan Village, Qianjiang, Chongqing.

Trial Size: 13,340M²

Trial date: Aug.-Sept. 2019



- **95% corn plants infested; Density: 4-5 larvae/plant**
- **Larval stage: 1st-3rd instar**



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Biopesticides application for FAW control in China



➤ Fungal pesticide *Metarhizium anisopliae* CQMa421

Location & size: Tuqiao Village, Puer, Yunnan, ~2600M²



Application of CQMa421+Chlorant. on 2 July with 70% plant infestation.



No newly infestation, on 13 July, observed after the application of CQMa421+ Chlorantraniliprole.

✓ **Fall armyworm was effectively controlled without newly infestation after only one application of the combination of CQMa421+ chlorantraniliprole on 2 July.**



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Biopesticides application for FAW control in China



➤ Fungal pesticide *Metarhizium anisopliae* CQMa421



Many mycosed FAW were found in surrounding fields after application of *M. anisopliae* CQMa421

Site: Puer, Yunnan (2020)

Insecticidal fungi have been applied for FAW control in China ~300,000 ha since 2020.



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Biopesticides application for FAW control in China



➤ Nuclear polyhedrosis virus

- ✓ *Mamestra brassicae* nuclear polyhedrosis virus has good control efficacy for FAW. The control effect of MbNPV 2×10^9 PIB/mL SC 50 g/666.7 m² was 90.42% and 91.78% at 7 days after application, in 2020 and 2021, respectively, in Yunnan province.



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Biopesticides application for FAW control in China



➤ Registered biopesticides for FAW control in China

- ✓ *Spodoptera frugiperda* NPV Hub1
- ✓ *Spodoptera litura* NPV
- ✓ *Mamestra brassicae* NPV
- ✓ *Autographa californica* NPV + Bt
- ✓ *Metarhizium anisopliae*
- ✓ *Metarhizium anisopliae* CQMa421
- ✓ *Beauveria bassiana*
- ✓ *Beauveria bassiana* ZJU435
- ✓ *Bacillus thuringiensis*
- ✓ *Bacillus thuringiensis* G033A



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