

## Horizontal gene transfer of *Fhb7* from fungus underlies Fusarium Head Blight resistance in wheat

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Dec. 10, 2020

# OUTLINES

1	Introduction to Fusarium Head Blight and its effects on Wheat
2	Th. elongatum genome assembly and comparative Triticeae genome evolution
3	Map-based cloning of the <i>Fusarium</i> resistance gene <i>Fhb7</i>
4	Evolutionary history and molecular function of Fhb7
5	Application of Fhb7 in Fusarium resistance breeding

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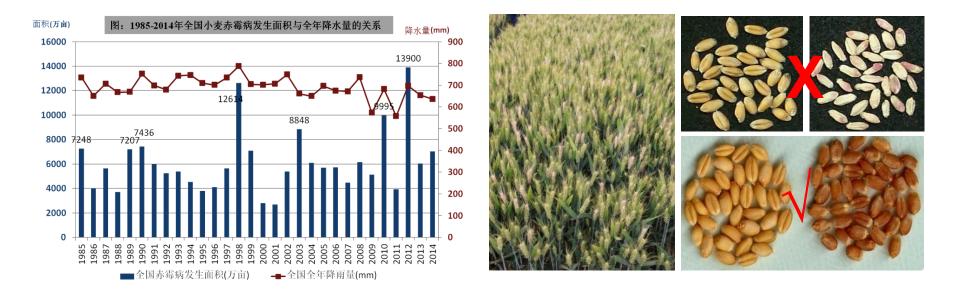
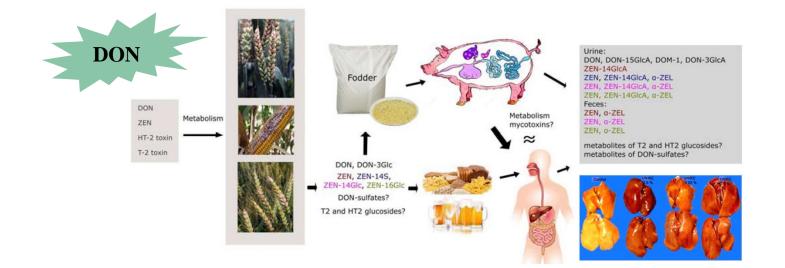
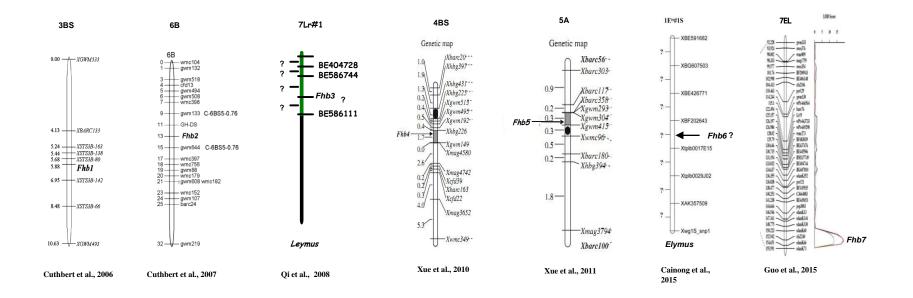


Fig.1 Wheat scab in China (Cheng et al., 2015)



**Fig.2** The grain contaminated by mycotoxins imposes health threats to humans and livestock

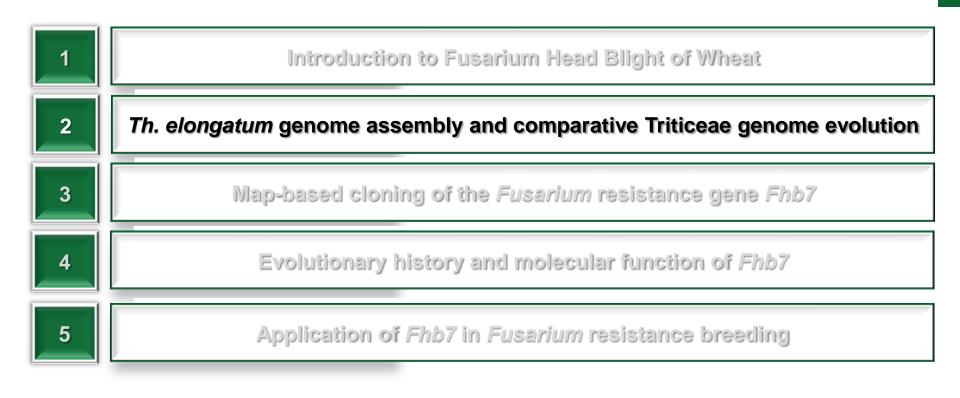


#### Fig.3 Seven loci resistant to FHB have been designated up to date

Disease	Genes	Chromosomes	Reference		
Stem rust	Sr26	T6AS.6AL-6Ae#1L	Knott 1961		
Stem rust	Lr24, Sr24	T3DS.3DL-3Ae#1L	Smith et al.,1968		
Leaf rust and	Sr25/Lr19	7el <sub>1</sub>	Knott 1968		
Stem rust			Xu et al.,2009		
Stem rust	Sr43	7el <sub>2</sub>	Liu et al.,2013		
Leaf rust	-	1St	Hu et al.,2011		
BYDV	Bdv2, Bdv3	7Ai	Ohm et al.,2009		
			Shen et al.,2004		
FHB	Fhb7	7el <sub>2</sub>	Zhang et al. 2011		
			Guo et al. 2015		
S. nodorum	SNB	?	Oliver et al.,2008		
Eyespot	-	4Ai#2	Li et al.,2004		
WSMV	Wms1		Baley et al.,2001		

Fig.5 Tall and intermediate wheatgrasses of the *Thinopyrum* genus carry resistant genes to different diseases including FHB

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	EE	CS-AA	CS-BB	CS-DD
Number of genes	44,474	35,345	35,643	34,212
Number of mRNA	44,474	43,697	44,220	42,828
Genes anchored to pseudo- chromosomes	44,144	35,345	35,643	34,212
Average mRNA length (bp)	3,243.4	3,400.4	3,509.6	3,419.1
Average mixivA length (op)	6	7	1	3
Average CDS length (bp)	1127.43	1,310.8	1,351.1	1,354.3
Average CDS length (bp)		5	5	2
Average exon number per gene	4.22	5.36	5.34	5.44
Average intron length (bp)	625	479.50	497.22	464.68

#### Table 1 Summary statistics for *Th. elongatum* genome assembly

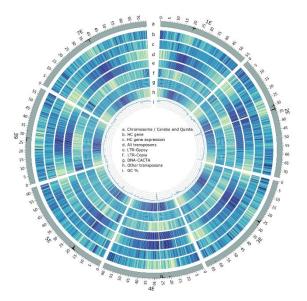
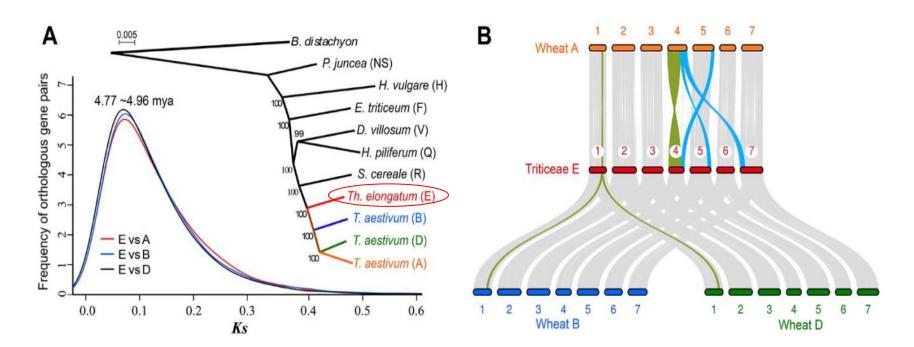


Fig.7 The landscape of *Th. elongatum* genome

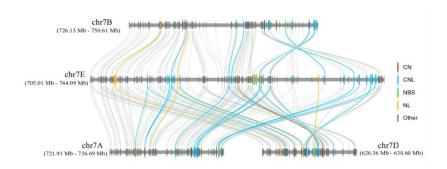
#### 2. Th. elongatum genome assembly and comparative Triticeae genome evolution



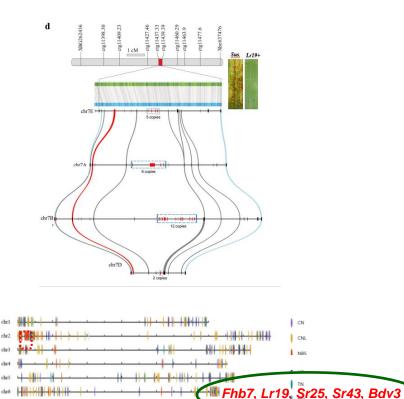
# Fig.8 NJ phylogenetic tree of the genomes of *Triticeae* species.

Fig.9 Syntenic blocks between the E genome and the three wheat sub-genomes

#### 2. Th. elongatum genome assembly and comparative Triticeae genome evolution



# Fig.10 Micro-synteny of Chr. 7 distal region between the *T. elongatum* and *T. aestivum* sub-genomes



400 450 500 550 600

750 'auto

650 700

Fig.11 Chromosome distribution of predicted RGAs in the T. elongatum genome

100 150 200 250 300 350

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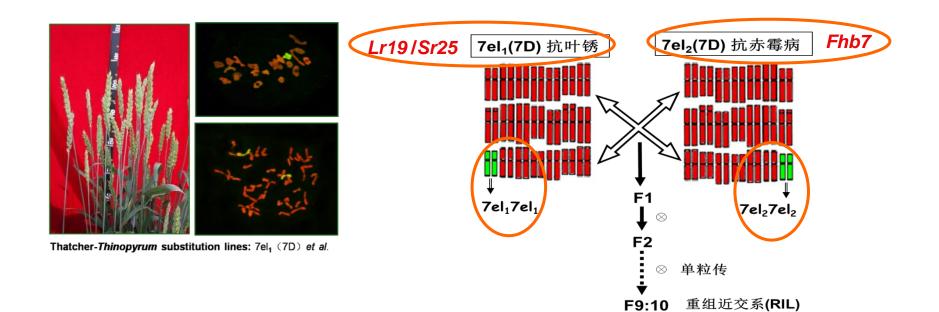


Fig.12 Recombinant Inbred Line (RIL) population is constructed using these two substitution lines, 7el1(7D) and 7el2(7D), as parents

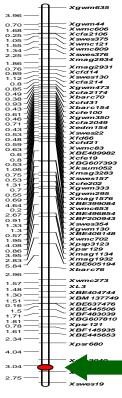


Fig.6 Fhb7 on Chr. 7E

Theor Appl Genet (2011) 122:263-270 DOI 10.1007/s00122-010-1441-3

ORIGINAL PAPER

A genetic map of *Lophopyrum ponticum* chromosome 7E, harboring resistance genes to Fusarium head blight and leaf rust

Xiuli Zhang · Xiaorong Shen · Yuanfeng Hao · Jinjin Cai · Herbert W. Ohm · Lingrang Kong

Received: 26 May 2010/Accepted: 25 August 2010/Published online: 10 September 2010 © Springer-Verlag 2010



Xiuli Zhang @ NWFU TAG, 2011



Jun Guo @ SAAS



Received: 3 April 2015 / Accepted: 16 July 2015 © Springer-Verlag Berlin Heidelberg 2015

TAG, 2015

Designated as *Fhb7* 

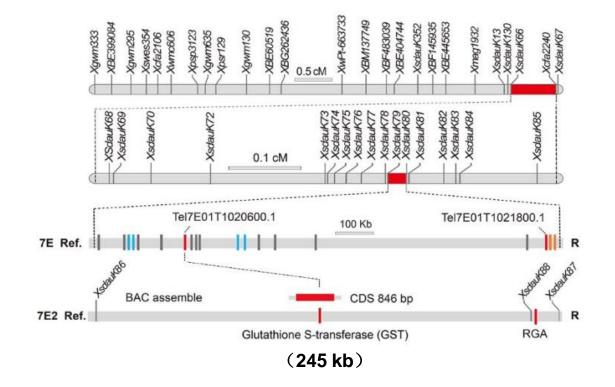


Fig.17 Map-based cloning of Fhb7 at the distal region of Chr. 7E

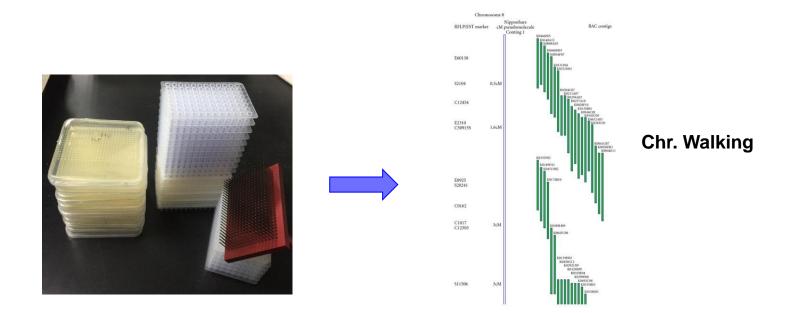
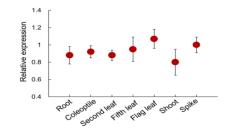
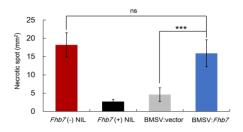


Fig.18 BAC (bacterial artificial chromosome) clones containing target gene were identified from the resistant donor



Tissue specific expression of *Fhb7* 



Functional validation of *Fhb7* by EMS mutants

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150A

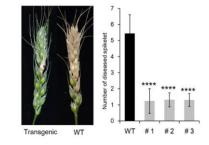
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ENDT L'I MIL ENDT LY MIL 31.79 21.54 



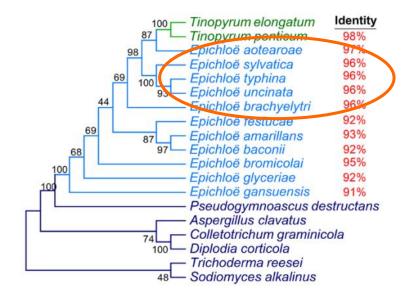
FHB was evaluated by VIGS

FHB was evaluated for wild-type and transgenic wheat

Fig.19 Map-based cloning of *Fhb7* at the distal region of Chr. 7E

# OUTLINES

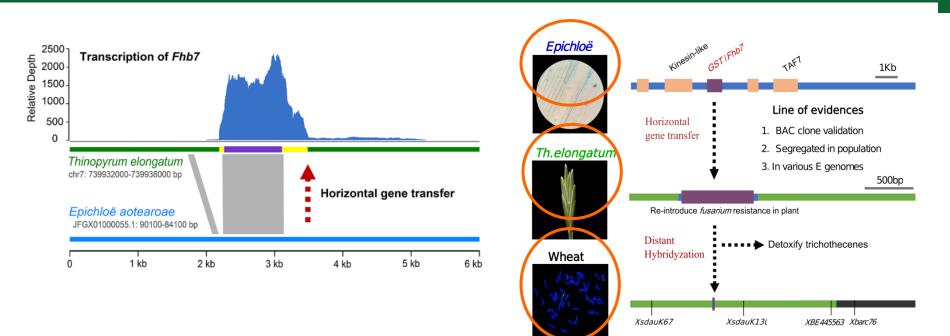
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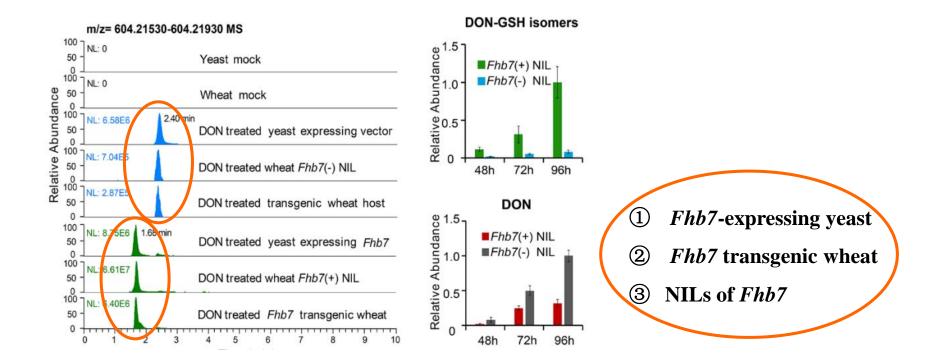
	Start
Thinopyrum elongatum	MATSTSTSTPIIFYDIAQRPPVAETCCAVNPWKSRLALNFKAVPYTTTWVKMPDISSVRASLNVPACRKFADGSDFNTLPIIHDPATDSLIGDS
Thinopyrum ponticum	MATSASTSTPTIFYDIAQRPPVAETCCAVNPWKSRLALNFKAVPYTTTWVKMPDISSVRASLNVPACRKFADGSDFNTLPIIHDPATDSLWGDS
Epichloë aotearoae	MATETSTSTPIIFYDIAQRPPVAETCCAVNPWKSRLALNFKAVPYTTTWVKMPDISSVRASLNVPACRKFADGSDFNTLPIMHDPATESLIGDSF
Epichloë svlvatica	<mark>M</mark> TSTSTSTSTPIIFYDIAQRPPVAETCCAVNPWKSRLALNFKAVPYKTTWVKMPDISSVRASLKVPACRKFADGSDFNTLPI <mark>M</mark> HOPATDSL <mark>L</mark> GDSF
Epichloë typhina	MATESTSTSTPTIFYDIAGRPPVAETCCAVNPWKSRLALNFKAVPYTTTWVKMPDISSVRASUNVPACRKFADGSDFNTUPIMHDPATDSLIGDSF
Epichloë uncinata	MATESTSTSTPILLEYDIAQRPPVAETCCAVNPWKSRLALNEKAVPYTTTWVKMPDISSVRASLNVPACRKEADGSDENTLPIMHDPATDSLIGDSE
Epichloë brachvelvtri	MATSTSTSTPIIFYDIAQRPPY ETCCAVNPWKSRLALNFKAVPYTTTWVKMPDISSVRASLNVPACRKFADGSDFNTLPIIHDPATDSLIGDSF
Epichloë bromicola	MATSTSTSTSTSTSTSTFTTFYDTAGRPPYTETCCAVNPWKSRLALNFKAVPYTTTWVKMPDTSSVRASLNVPACRKFADGSDFNTLPTTHDPATDSLVGDSF
Epichloë festucae	MATE TS TS TS TS TF I I FYD I AQRPPY E TC CAVNPWK RLALNFKAV YTT TWYKMPD I SEVRASLNYPACRKFADGEDFNTLPI I HOPATESLIGDSF
Epichloë amarillans	MATSTSTPIIFYDIAQRPPVTETCCAVNPWKSRLALNFKAVPYTTTWVKMPDISSVRASLNLPACRKFADGTDFDTLPIIHDPATOSLIGDSF
Epichloë baconii	MATSTETSTSTSTPTTFYDTAGRPPYTETCCAVNPWKSRLALNFKAVPYTTTWVKMPDTSSVRASINUPACRKFADGTDFNTUPTTHDPATGSLVGDSF
Epichloë alvceriae	WATSTPILFYDIAGRPPYAETCCAVNPWKSRLALNFKAVPYTTTWV MPDISSVRASLNVPACRKFADGSDFNTLPILHDPATOSLIGDSF
Epichloë gansuensis	MATE TSTSASTPILEYDIAGRPPVTETCCAVNPWKSRLALNFKAVPYTTTWVEWPDISSVRASLNUPACRKFADGSDFNTLPILHDPATOSLIGDSF
Thinopyrum elongatum	DIAAYLORTYPASGAGDLFPPOKLDYAVCRDMOLLEPLSETRAPELADYARFNSNVDAAFTAHVGLMVHGLPLDPATADVTKAEFVRRAGTSWDDTEMV
	DIAAYLQRTYPASGAGDLFPPQKLDYAVGRDMQLLIPLSETRAPELADYARFNSNVDAAFTAHVGLNVHGLPLDPATADVTKAEFVRRAG <mark>L</mark> SSWDDLEMV
Epichloë aotearoae	DIAAYLQRTYPASGAGDLFP QQKLDYAY ARD QLLIPLSETRAGELADYARFNSNVDAAFTAHVGLMVHGLPLDPATADVTKAEFVRRAGVSSWEDFEMV
Epichloë sylvatica	DIAAYLORTYPASGAGDLFPPOKLDYAVGRDMQLLIPLSE <mark>Y</mark> RAPELADYARFNSNVDAAFTAHVGLMVHGLPLDPATADVTKAEFVRRAGVSSWED <mark>L</mark> EMV
	DIAAYLORTYPASGAGDLFPPOKLDYAVGRDMQLLIPLSE <mark>Y</mark> RAPELADYARFNSNVDAAFTAHVGLMVHGLPLDPATADVTKAEFVRRAGVSSWEDFEMV
Epichloë uncinata	DIAAYLORTYPASGAGDUFPPOKUDYAVGRDMQUUIPUSE <mark>Y</mark> RAPELADYARFNSNVDAAFTAHVGUNVHGUPUDPATADVTKAEFVRRAGVSSWEDFEMV
	DIAAYLQRTYPASGAGDLFPPQKLDYAV RDMQLLIPLSEMRA ELADYARFNSNVDAAFTAHVGLMVHGLPLDPATADVTKAEFVRRAGVSSWEDFEMV
	DIAAYLORTYPASGAGDLFPPOKLDYAVGRDMQLLIPLSE RAPELADYARFNSNVDAAFTAHVGLNVHGLPLDPATADVTKAEFVRRAGVSSWEDFEMV
Epichloë festucae	DIAAYLORTYPASGAGHLFPPOKLDYAYGRDMQLLIPLSEYRABELADYARFNSNVDAAFTAHVGYMVHGLPLDPATADVTKAEFVRRAGVSSWEDFEMV
	DIAAYLQRTYPASGAGDLFPPQKLDYAAGRDIQLLIPLSEYRAPELADYARFNSNVDAAFTAHVGLNVHGLPLDPATADVTKAEFVRRAAVSSWDDLDWV
	DIAAYLORT
Epichloë glyceriae	DIAAHLORAYPASGAGDLFPPOELDYVVARDIRLLVPLSEIRASEFADYARFNSNVDAAFTAHVGLMVHGLPLDPATADVTKAEFVRRAGVSSWEDFELV
Epichloë gansuensis	DIAAYLORTYPASGADDLFPPOKLDYYYC <b>EHY</b> O <mark>RF</mark> IPLSDTRABEFADYARFNSNYDAAFTAHYGLMLHGLPLDPATADYTKAEFYRRAGYSSWEDFEMY
	end
	GEAR <mark>D</mark> KMMQSLRNMLGDLAALFR <mark>K</mark> DASGPFLLGQ <mark>R</mark> ATYAD <mark>M</mark> IVGGWLRMMRATLP <mark>V</mark> SEWQEARACHGAIFGQLHDALDKYAEVK*
Thinopyrum ponticum	GEAR <mark>D</mark> KMMQSLRNMLGDLAALFR <mark>K</mark> DASGPFLLGO <mark>R</mark> ATYAD <mark>M</mark> IVGGWLRMMRATLP <mark>V</mark> SEWQEARACHGAIFGQLHDALDKYAEVK*
Epichloë aotearoae	GEAREKMMQSLRNMLGDLAALFRRDASGPFLLGQRATYADLIVGGWLRMMRATLPASEWQEARACHGAIFGQLHDALDKYAEVK*
Epichloë svlvatica	GEAREKMMQSLRNMLGDLAALFRRDASGPFLLGORATYADLIVGGWLRMMRATLPASEWQEARACHGAIFGQLHDALDKYAEVK*
Epichloë typhina	GE <mark>V</mark> REKMMQSLRNMLGDLAALFRRDASGPFLLGQ <mark>R</mark> ATYADLIVGGWLRMMRATLPASEWQEARACHGAIFGQLHDALDKYAEVK*
Epichloë uncinata	GEVREKMMQSLRNMLGDLAALFRRDASGPFLLGORATYADLIVGGWLRMMRATLPASEWQEARACHGAIFGQLHDALDKYAEVK*
Epichloë brachvelvtri	GEAREKMMOSLRNMLGDLAALFRRDASGPFLLGOKATYADLIVGGWLRMMRATLPASEWQEVRAWHGAIFGOLHDALDKYAEVK*
Epichloë bromicola	GEAREKMMQSLRNMLGDLAALFRRDASGPFLLGQKATYADLIVGGWLRMMRATLPASEWQEVRACHGAVFGQLHDALDKYAEVK*
	GEAREKMMOSI RNMLGDLAALFRRDASGPFLLGOOATYADLIVGGWLRMMRATLPASEWOEVRAWHGAVFGRLHDALDKYAEVK*
	G DAR DKMMQSLRN DLCDLAALFREDASCPFLLGPKATYADLIVGGWLRMMRATLPESEWQAARAWHGAVFGQLHDALDKYAEVK
	GEAREKMMQSLERNILGDLAALFREDASGPFLLGRKATYADLIVGGWLEMMRATLPASEWQAARAWHGAVFGQLHDALDKYAEVK*
	GEAREKNINGSERNE GOLAALFREDASCPFLEGRATYADI IVGGWERNINGATERSEWGAAAHGAVFGGEHDALDKTAEVK*
	GEAREAMMOSERNYLÖDIAALFRRDASOFILGUNATTADIIVGGWLRMMRATLPASEWGEARANNGAVFGULHDALDKTAEVK
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Fig.20 ML phylogenentic tree of the closest homologs of *Fhb7* from plants and fungi

Fig.21 Alignments of *Fhb7* homologs in *Thinopyrum* and *Epichloë* species



#### Fig.22 Horizontal gene transfer of Fhb7 from fungus to Thinopyrum



**Fig.26 Extracted ion chromatograms (EICs) at m/z 604.2173 revealing the presence of two DON-glutathione adducts** 

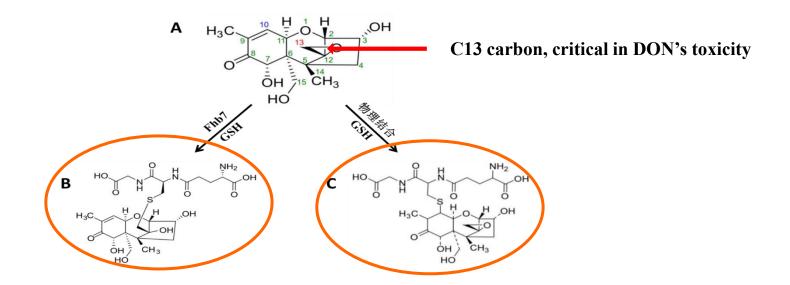
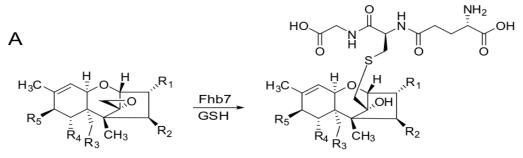


Fig.27 Molecular structure of the de-epoxidated DON-glutathione adduct catalyzed by the Fhb7



В

Trichothecene	Abbrev.	R1	R2	R3	R4	R5
Deoxynivalenol	DON	он	н	он	ОН	=0
3-Acetyl-deoxynivalenol	3-ADON	OCOCH₃	н	он	ОН	=O
15-Acetyl-deoxynivalenol	15-ADON	он	н	OCOCH₃	он	=O
Nivalenol	NIV	он	он	он	он	=0
Fusarenon X	Fus-X	он	OCOCH <sub>3</sub>	он	он	=O
T-2 Toxin	T-2	он	ососнз	OCOCH <sub>3</sub>	н	OCOCH <sub>2</sub> CH(CH <sub>3</sub> ) <sub>2</sub>
HT-2 Toxin	HT-2	он	он	OCOCH <sub>3</sub>	н	OCOCH <sub>2</sub> CH(CH <sub>3</sub> ) <sub>2</sub>
Diacetoxyscirpenol	DAS	он	OCOCH <sub>3</sub>	OCOCH₃	н	н

#### Fig.28 Illustration of the GSH adducts of trichothecenes catalyzed by Fhb7

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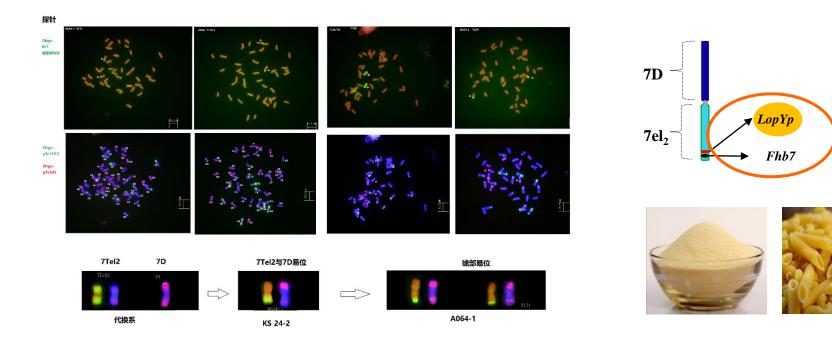
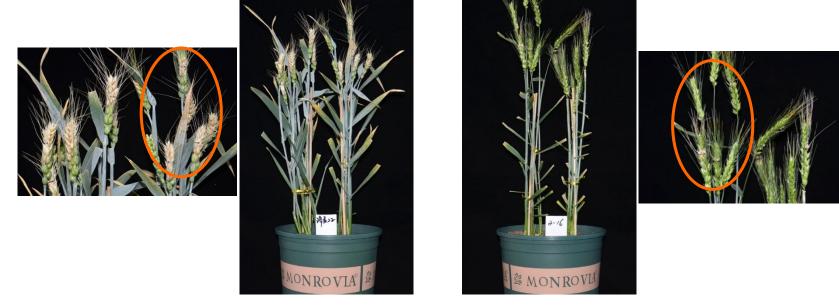


Fig. 33 The linkage with distance of about 18 Mb between Fhb7 and yellow pigment (Yp)

(Unpublished data)



LiangXing99

SN2-16 carrying Fhb7

Fig.35 The recombinants lines carrying *Fhb7* exhibited resistance to FHB using single floret inoculation

(Unpublished data)

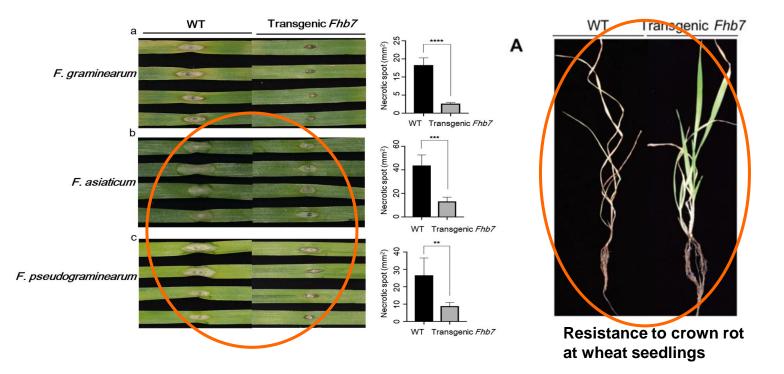


Fig.31 Images of *Fusarium* infected spikes (left panel) and crown rot (right panel) of 'LX99' NILs contrasting in *Fhb7* 



Fig.32 The cultivar carrying *Fhb7* exhibits crown rot resistance in the field in Taian, Shandong this year

## Summary of studies on *Fhb7* derived from wheatgrass

(i) A high-quality assembly of *Thinopyrum elongatum*;

(ii) *Fhb7* cloning supported by cytogenetic stocks, mutational genomics, and functional validation using virus-induced gene silencing (VIGS) and transgenics;
(iii) Demonstration of biochemical function of *Fhb7* and a novel mechanism of fungal disease resistance;

(iv) Field trials to demonstrate that there is no hit on wheat yield in stocks carrying *Fhb7*;

(v) *Fhb7* arose in plants through horizontal gene transfer (HGT) from a fungal endophyte.

# Deep thanks to my supervisor Prof. Herbert Ohm and colleagues at Purdue University



W. Lafayette, 2004

Taian, Shandong, 2009

# **Wheat Genetic Improvement and Genomics Lab**



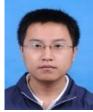




Prof. Af Li

Prof. HW Wang





Dr. SL Sun



Dr. Y Zhao

Dr. XQ Wang

#### Website for my lab : http://konglab.sdau.edu.cn











# Thank you!

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