新三板上市公司
股票名称：汉和生物
股票代码：839724

汉和生物 Harworld®
农业价值创造者

γ-氨基丁酸在农业上的应用

一、γ-氨基丁酸的介绍及在植物上的应用研究

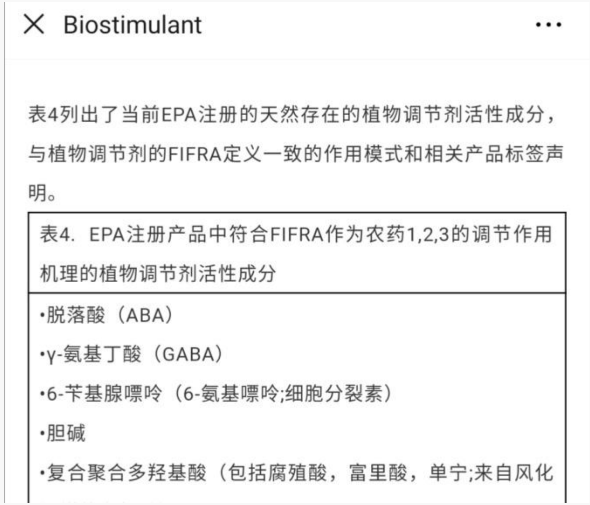
- 1、γ-氨基丁酸的促生作用研究
- 2、γ-氨基丁酸的抗逆作用研究

二、汉和生物对γ-氨基丁酸的应用试验报告

三、汉和生物γ-氨基丁酸的技术先进性

γ-氨基丁酸 (GABA)

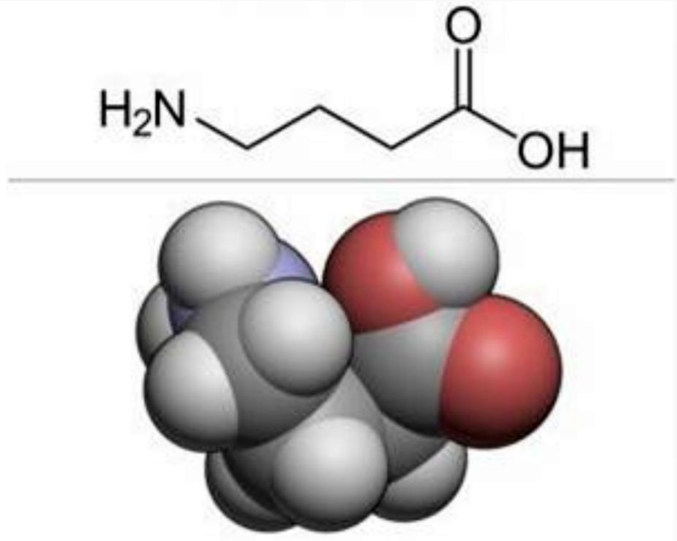
γ-aminobutyric acid



Biostimulant

表4列出了当前EPA注册的天然存在的植物调节剂活性成分，与植物调节剂的FIFRA定义一致的作用模式和相关产品标签声明。

表4. EPA注册产品中符合FIFRA作为农药1,2,3的调节作用机理的植物调节剂活性成分
•脱落酸（ABA） •γ-氨基丁酸（GABA） •6-苄基腺嘌呤（6-氨基嘌呤;细胞分裂素） •胆碱 •复合聚合多羟基酸（包括腐殖酸，富里酸，单宁;来自风化



1883年被人工合成，1949 年 Steward 首次发现 γ-氨基丁酸存在于植物中。

γ-氨基丁酸(GABA)是一种以自由态存在于各种生物中的四碳非蛋白质氨基酸。

1、目前研究，GABA 在医疗保健中的生理活性主要表现在以下几方面：

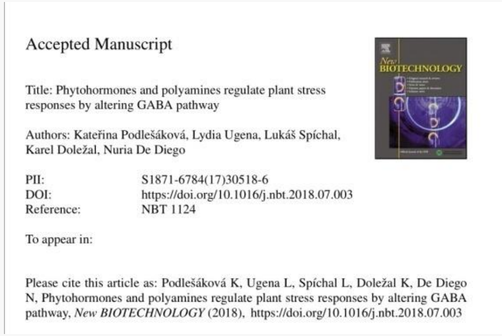
(1)镇静神经、抗焦虑；(2) 调节血压；(3) 消除疲劳；

(4) 稳定血糖；(5) 提高脑活力；

2、在食品工业中，GABA 被用于开发功能性乳制品，烘焙食品等。

3、近年来，**GABA 逐渐被应用到调控植物生长上**，特别是在逆境条件下的生长。

GABA在植物上的生理作用


Accepted Manuscript

Title: Phytohormones and polyamines regulate plant stress responses by altering GABA pathway

Authors: Kateřina Podlešáková, Lydia Ugena, Lukáš Spíchal, Karel Doležal, Nuria De Diego

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一、γ-氨基丁酸的介绍及在植物上的应用研究

- 1、γ-氨基丁酸的促生作用研究
- 2、γ-氨基丁酸的抗逆作用研究

1、 GABA具有促进营养生长的作用

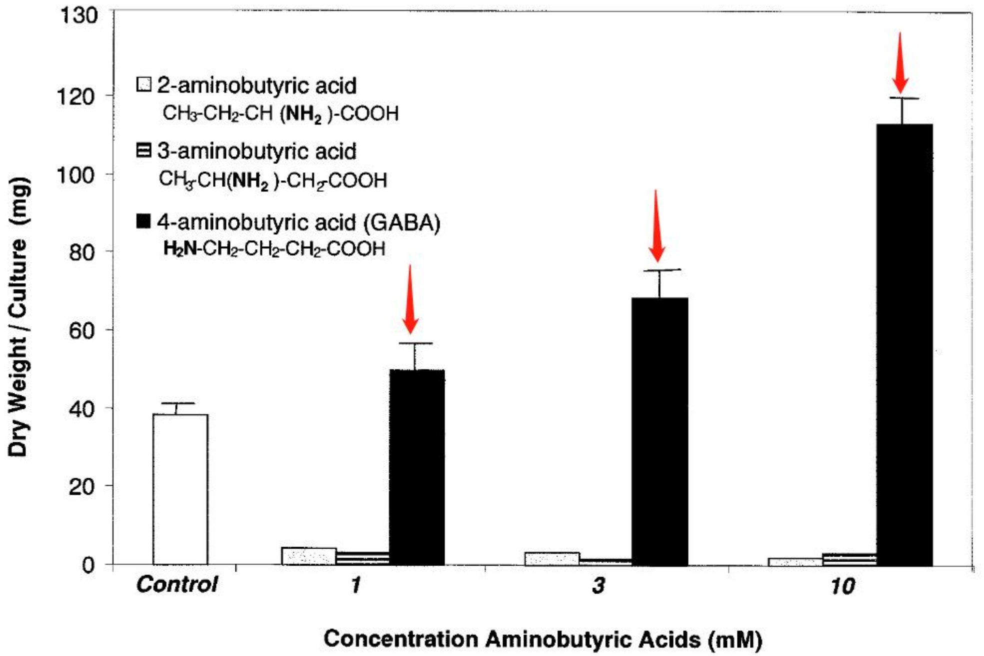


Figure 2. Effect of GABA, 3AB and 2AB on *Lemna* growth. *Lemna* was grown in liquid culture media containing different molar amounts of GABA, 3-AB and 2-AB. Plants were harvested after the culture period and dry weights determined.

GABA 具有促进浮萍生长的作用，10mmol/L 的 GABA对浮萍进行处理后，能够使其生长量增加二到三倍。

Receptor modifiers indicate that 4-aminobutyric acid (GABA) is a potential modulator of ion transport in plants.(Alan M. Kinnersley, Fang Lin. 2000)

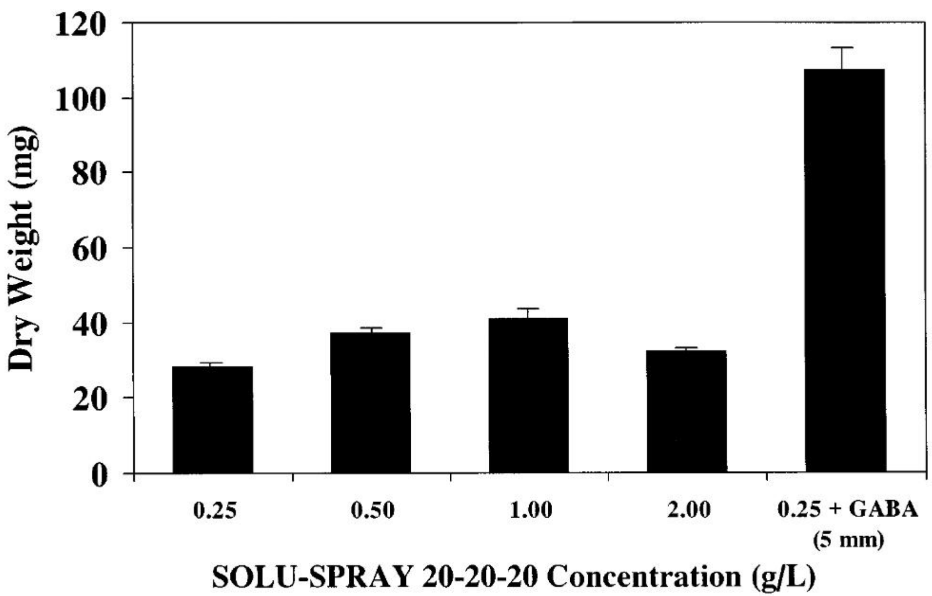


Figure 4. Effect of GABA on biomass of *Lemna minor* grown in reduced nutrients *Lemna* was grown in culture media containing 0.25–2.0 g/L SOLU-SPRAY 20-20-20 fertilizer, and in medium containing 0.25 g/L SOLU-SPRAY 20-20-20 plus 5 mM GABA. Following culture period plants, cultures were harvested and dry weights determined.

GABA 对浮萍的生长不但具有促进作用，并且还能够增加其对矿质元素的吸收量。

Receptor modifiers indicate that 4-aminobutyric acid (GABA) is a potential modulator of ion transport in plants.(Alan M. Kinnersley, Fang Lin. 2000)

Table 3. Mineral composition of *Lemna* grown in optimal (1.0 g/L) levels of nutrients and in sub-optimal (0.25 g/L) levels of nutrients with and without 5 mM GABA (Dry weights of these treatments are shown in Figure 4.)

20-20-20

	1.0 g/L	0.25 g/L	0.25 g/L + GABA 5 mM	% change 0.25 g/L + GABA/ 0.25 g/L – GABA
Mineral composition				
N%	6.26	4.11	4.9	19
P%	1.28	0.70	0.88	26
K%	3.11	1.30	2.89	22
Ca%	0.35	0.28	0.47	68
Mg%	0.11	0.07	0.11	57
Na%	0.09	0.06	0.13	17
S%	0.32	0.31	0.35	13
Zn ppm	335	86	122	42
Fe ppm	294	263	122	–54
Mn ppm	59	27	58	15
B ppm	22	17	28	65
Cu ppm	96	66	70	–27

N	19%
P	26%
K	22%
Ca	68%
Mg	57%
Na	17%
Zn	13%
Fe	-54%
Mn	15%
B	65%
Cu	-27%

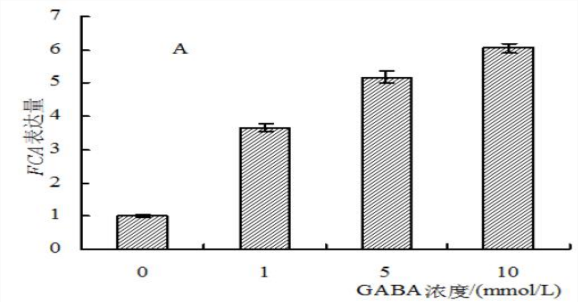
…mM GABA on dry weight and mineral composition of *Lemna* grown in

…L	1.0 g/L + 4AB 1 mM%	% change	1.0 g/L + 4AB 10 mM	% change
…4.2	63 ± 2.7	23	139 ± 7.5	172
	6.02	1	7.14	20
	1.11	4	1.48	38
	3.26	7	5.20	72
	0.27	8	0.51	104
	0.07	0	0.13	86
	0.10	11	0.07	–23
	0.36	6	0.36	6
	227	–4	298	26
	280	–12	111	–65
	59	5	122	118
	34	–3	41	17
	49	–6	47	–10

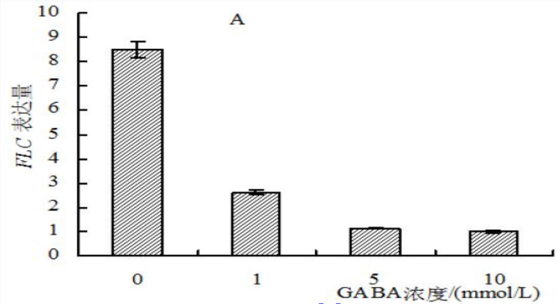
GABA 对浮萍的生长不但具有促进作用，并且还能够增加其对矿质元素的吸收量。

Receptor modifiers indicate that 4-aminobutyric acid (GABA) is a potential modulator of ion transport in plants.(Alan M. Kinnersley, Fang Lin. 2000)

2、 GABA具有促进生殖生长的作用



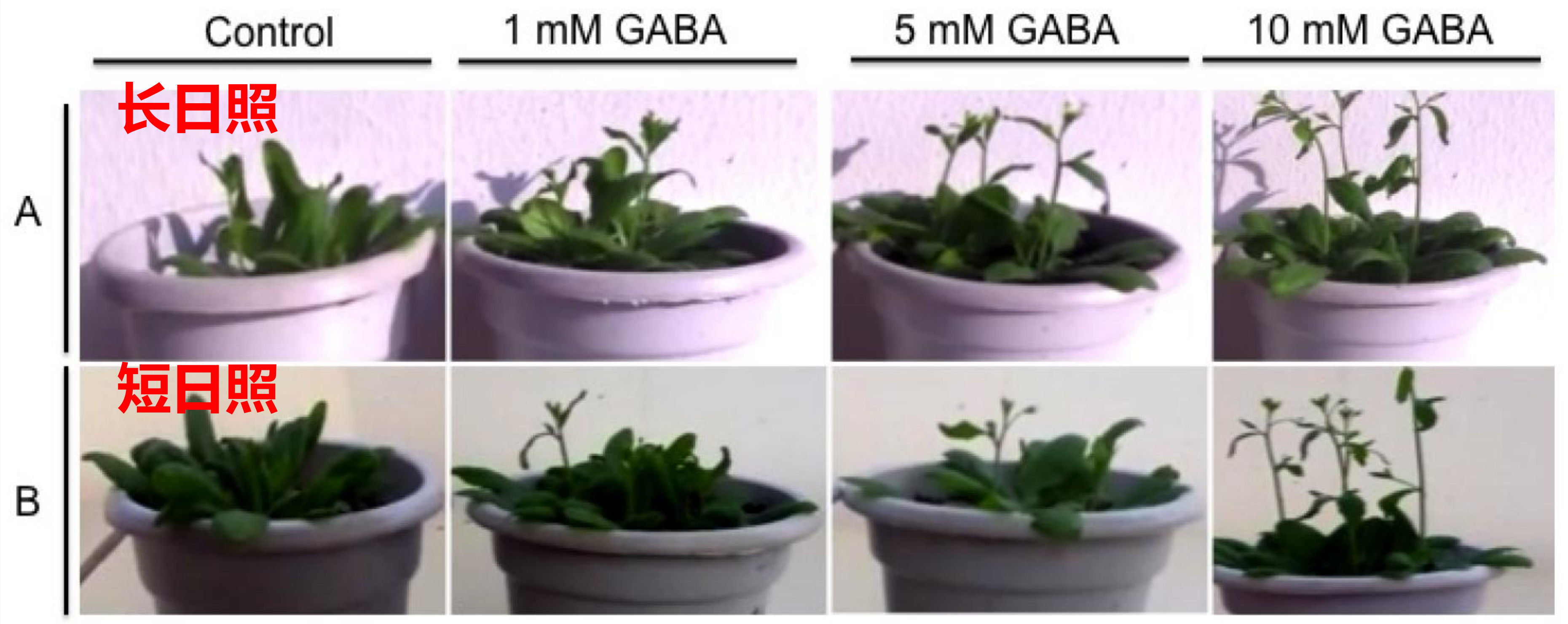
FCA 基因



*FLC*基因

外源GABA 处理拟南芥，有效调控自主开花途径基因*FCA* 基因的上调表达，同时下调表达开花抑制因子*FLC*基因，进而促进拟南芥早开花3-5天。

γ-氨基丁酸促进拟南芥开花的机理研究。（张瑞琦，2012）



无论长日照和短日照条件下，GABA 均能不同程度地促进拟南芥早开花2-5 天。

γ-氨基丁酸促进拟南芥开花的机理研究。（张瑞琦，2012）

二、GABA具有提高植物抗逆的作用

植物体内GABA积累的逆境胁迫应激动力学研究

TABLE 1
Stress-Related Kinetics of GABA Accumulation in Plants

Plant	Stress	GABA[a] % of Control	Time	Ref.
Asparagus cells	Acidosis	300	15 s	Crawford et al., 1994
Soybean leaves	Mechanical damage	1800	1 min	Ramputh and Bown, 1996
Soybean leaves	Mechanical damage	2700	5 min	Wallace et al., 1984
Soybean leaves	Cold (6°C)	2000	5 min	Wallace et al., 1984
Asparagus cells	Cold (10°C)	200	15 min	Cholewa et al., 1996
Radish leaves	Anoxia	10,000	4 h	Streeter and Thompson, 1972
Tea leaves	Anoxia	4,000	12 h.	Tsushida and Murai, 1987
Rice root	Anoxia	750	24 h	Aurisano et al., 1995
Rice shoot	Anoxia	1,000	24 h.	Aurisano et al., 1995
Cowpea cells	Heat	1,800	24 h.	Mayer et al., 1990
Bean leaves	Drought	200	3 d	Raggi, 1994
Turnip leaves	Drought	1000	3 d	Thompson et al., 1996
Tomato root	Salt	200	4 d	Bolarin et al., 1995
Tomato leaves	Salt	300	5 d	Bolarin et al., 1995
Tomato leaves	Viral	130	13 d	Cooper and Selman, 1974

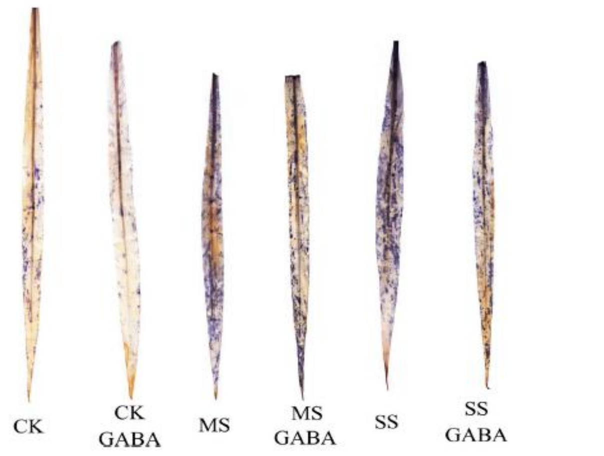
[a] For each stress the time to reach the greatest reported GABA accumulation relative to unstressed controls has been shown.

Gamma Aminobutyric Acid (GABA) and Plant Responses to Stress. Alan M. Kinnersley & Frank J. Turano.

（一）、抗盐害胁迫

正常培养　　中度盐害胁迫　　重度盐害胁迫

Figure 3. Phenotypes of maize with or without GABA treatment under salt stress.



玉米幼苗中超氧根离子组织化学定位

盐胁迫严重损害玉米幼苗细胞功能，抑制光合作用，尤其是高盐害下。外源施用GABA可以减轻有害物质超氧阴离子(O_2^{-})和丙二醛(MDA)造成的氧化损伤，帮助维持细胞形态，改善光合作用和叶绿素荧光参数。这些作用可以减轻盐胁迫对光合系统的损害，从而增强了玉米幼苗的耐盐性。

γ-Aminobutyric Acid Imparts Partial Protection from Salt Stress Injury to Maize Seedlings by Improving Photosynthesis and Upregulating Osmoprotectants and Antioxidants. (Yongchao Wang, Wanrong Gu, Yao Meng, Tenglong Xie, Lijie Li, Jing Li & Shi Wei. 2017)

Treatment	Plant height (cm)	Leaf area per plant (cm^2)	Leaf fresh weight per plant (g)	Leaf dry weight per plant (g)
0 mM NaCl	29.3 ± 1.1ab	44.75 ± 2.41ab	0.993 ± 0.102a	0.082 ± 0.005b
150 mM NaCl	21.5 ± 1.8c	33.28 ± 1.95c	0.568 ± 0.069c	0.052 ± 0.005c
300 mM NaCl	15.7 ± 1.4d	24.16 ± 2.94d	0.375 ± 0.018d	0.039 ± 0.006c
0 mM NaCl + 0.5 mM GABA	31.6 ± 1.5a	48.32 ± 3.33a	1.124 ± 0.127a	0.097 ± 0.013a
150 mM NaCl + 0.5 mM GABA	26.9 ± 2.6b	43.14 ± 2.73b	0.857 ± 0.026b	0.079 ± 0.006b
300 mM NaCl + 0.5 mM GABA	18.6 ± 1.5 cd	30.97 ± 2.83c	0.517 ± 0.016c	0.047 ± 0.006c

Table 2. Plant height, leaf area, leaf fresh weight and leaf dry weight per plant for plants grown at varying salt stress for 48 h that were treated with 0.5 mM γ- aminobutyric acid (GABA) or left untreated. Values are mean ± SE. Values with the same letters in a column are not significantly different at P = 0.05 (LSD test).

外源GABA的应用分别使中度和重度盐胁迫下玉米幼苗株高提高了25%和18%，叶面积分别增加30%和28%。使中度盐胁迫下玉米叶片鲜重和干重分别增加51%和52%。

GABA能降低盐胁迫下植物细胞膜损伤，提高叶片含水量，并降低对线粒体和叶绿体功能的损伤。

Treatment	Membrane damage (%)	SPAD value	Relative leaf water content (%)	Cellular reduction ability (OD 485/50 mg FW)
0 mM NaCl	21.4 ± 0.76d	14.2 ± 1.17a	96.54 ± 1.05a	0.41 ± 0.04a
150 mM NaCl	27.9 ± 4.91ab	11.1 ± 0.66b	84.91 ± 4.54c	0.35 ± 0.04b
300 mM NaCl	30.3 ± 1.23a	8.5 ± 1.59c	73.03 ± 0.75d	0.24 ± 0.03c
0 mM NaCl + 0.5 mM GABA	22.4 ± 2.41 cd	14.7 ± 1.91a	94.82 ± 1.31a	0.44 ± 0.01a
150 mM NaCl + 0.5 mM GABA	23.6 ± 1.88 cd	13.1 ± 0.5a	89.02 ± 0.87b	0.41 ± 0.02a
300 mM NaCl + 0.5 mM GABA	25.7 ± 1.45bc	9.7 ± 0.75bc	75.75 ± 0.51d	0.26 ± 0.03c

Table 3. Membrane damage, SPAD, relative leaf water content and cellular reduction ability for plants grown at varying salt stress for 48 h treated with 0.5 mM γ- aminobutyric acid (GABA) or left untreated. Values are mean ± SE. Values with the same letters in a column are not significantly different at P = 0.05 (LSD test).

γ-Aminobutyric Acid Imparts Partial Protection from Salt Stress Injury to Maize Seedlings by Improving Photosynthesis and Upregulating Osmoprotectants and Antioxidants. (Yongchao Wang, Wanrong Gu, Yao Meng, Tenglong Xie, Lijie Li, Jing Li & Shi Wei. 2017)

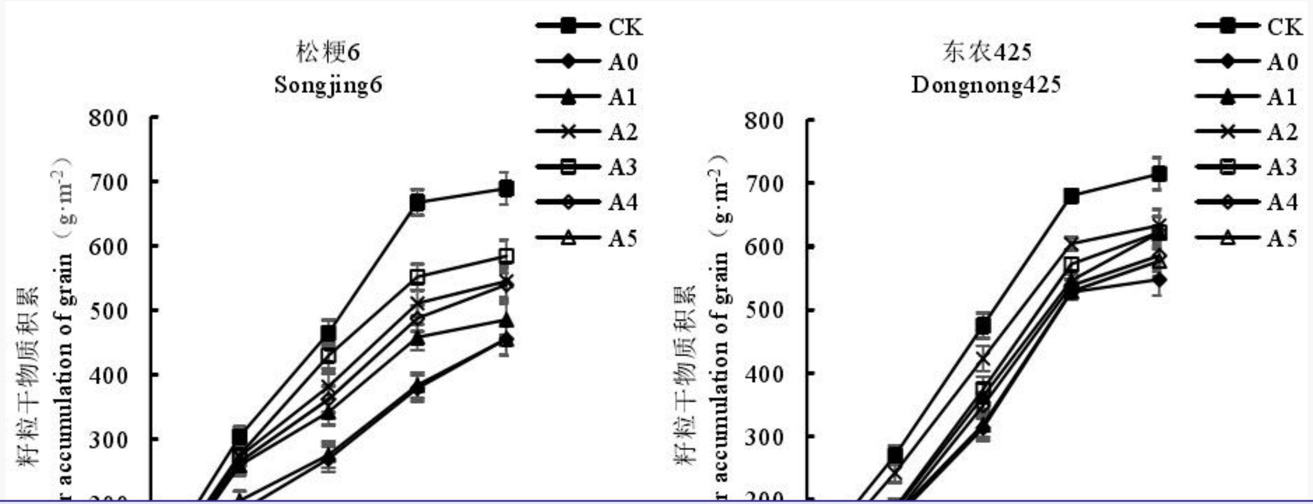
Treatment	SOD超氧化物歧化酶 Superoxide dismutase ($U \cdot g^{-1}$)	过氧化物酶 Peroxidase ($U \cdot g^{-1} \cdot min^{-1}$)	过氧化氢酶 Catalase ($U \cdot g^{-1} \cdot min^{-1}$)	抗坏血酸过氧化物酶 Ascorbate peroxidase ($U \cdot g^{-1} \cdot min^{-1}$)
0 mM NaCl	52.14 ± 1.94c	13.02 ± 0.77cd	15.11 ± 0.55b	20.47 ± 1.92c
150 mM NaCl	125.25 ± 4.38b	19.79 ± 2.04b	17.36 ± 0.79b	32.14 ± 2.67b
300 mM NaCl	31.47 ± 1.75e	8.41 ± 0.45e	10.74 ± 0.67d	10.34 ± 1.85e
0 mM NaCl + 0.5 mM GABA	54.57 ± 1.49c	14.12 ± 2.55c	14.74 ± 0.84bc	21.24 ± 1.76c
150 mM NaCl + 0.5 mMGABA	144.32 ± 3.58a	27.54 ± 1.88a	21.21 ± 1.76a	45.96 ± 2.44a
300 mM NaCl + 0.5 mMGABA	41.39 ± 2.01d	10.21 ± 1.15de	12.29 ± 0.63 cd	15.88 ± 1.20d

Table 4. Activity of enzymatic antioxidants in leaves of plants grown at varying salt stress for 48 h that were treated with 0.5 mM γ- aminobutyric acid (GABA) or left untreated. Values are mean ± SE. Values with the same letters in a column are not significantly different at P = 0.05 (LSD test).

经GABA处理的中度和重度盐胁迫下玉米幼苗的抗氧化酶活性明显高于未经处理的对照组，进而增强玉米幼苗的耐盐性。

γ-Aminobutyric Acid Imparts Partial Protection from Salt Stress Injury to Maize Seedlings by Improving Photosynthesis and Upregulating Osmoprotectants and Antioxidants. (Yongchao Wang, Wanrong Gu, Yao Meng, Tenglong Xie, Lijie Li, Jing Li & Shi Wei. 2017)

（二）、抗干旱胁迫



处理	GABA浓度
CK	正常灌溉
A0	0 mM
A1	0.25 mM
A2	0.5 mM

与干旱胁迫相比，喷施 GABA 提高两品种籽粒干物质积累量。
在一定范围内，随着喷施 GABA 浓度的增加，籽粒干物质积累量上升，达到一定浓度后下降，在齐穗后第 35 天，松粳 6 与东农 425 籽粒干物质积累量分别在 A3 和 A2 处理下增幅最大，其增幅分别为 32.80%和 27.67%，分别恢复到正常灌溉的 84.79%和 88.62%。

外源-氨基丁酸对孕穗期干旱胁迫下寒地粳稻氮代谢及产量的调控效应。谷海涛，2018

品种 Variety	处理 Treatments	氮素转运量 Nitrogen operation（kg·hm-2）		氮素转运率 Nitrogen transport rate（%）		茎叶氮素贡献率 Stem and leaf Nitrogen contribution rate（%）
		叶 Leaf	茎 Stem	叶 Leaf	茎 Stem	
松粳 6 Songjing6	CK	37.05a	27.53a	54.72ab	59.14a	84.79a
	A0	21.93f	16.00e	48.55d	53.12c	64.64c
	A1	28.70d	18.56c	54.04b	53.98bc	77.28ab
	A2	35.08b	22.04b	53.88b	54.55b	85.29a
	A3	36.67ab	24.17ab	56.28a	56.50ab	83.11a
	A4	32.04c	19.79c	55.62ab	52.83cd	80.86a
	A5	25.53e	16.71d	51.65c	52.01d	69.77b

外源-氨基丁酸对孕穗期干旱胁迫下寒地粳稻氮代谢及产量的调控效应。谷海涛，2018

品种 Variety	处理 Treatments	氮素转运量 Nitrogen operation（kg·hm^{-2}） 叶 Leaf	 茎 Stem	氮素转运率 Nitrogen transport rate（%） 叶 Leaf	 茎 Stem	茎叶氮素贡献率 Stem and leaf Nitrogen contribution rate（%）
东农425 Dongnong 425	CK	37.64a	28.45a	53.46a	59.34a	81.68ab
	A0	24.44d	18.77d	47.45c	53.27d	64.51d
	A1	33.68b	25.62b	53.47a	58.63a	83.25ab
	A2	37.62a	27.16ab	55.11a	58.83a	84.63a
	A3	37.07ab	26.09b	54.85a	58.23b	85.35a
	A4	28.48c	22.75c	49.65b	55.70c	73.80b

与干旱胁迫相比，喷施 GABA 提高两品种氮素转运量、氮素转运率、氮素贡献率。

外源-氨基丁酸对孕穗期干旱胁迫下寒地粳稻氮代谢及产量的调控效应。谷海涛，2018

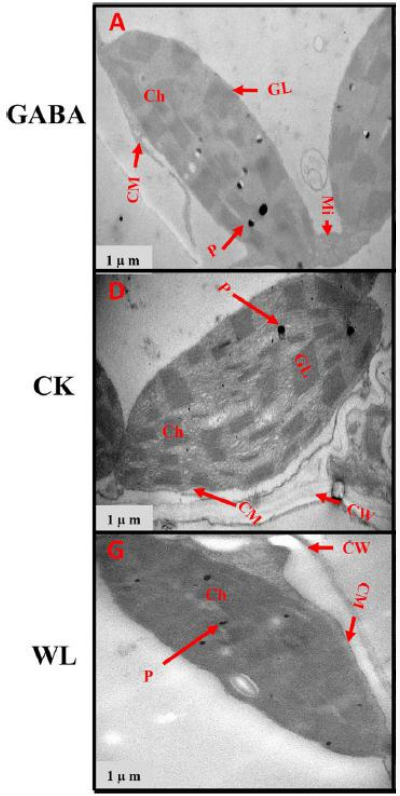
（三）、抗水渍胁迫

Varieties	Treatments	V3 stage 3叶期 PH (cm) 株高	GLA (cm^2 $plant^{-1}$) 绿叶面积	Aboveground DM (g $plant^{-1}$) 地上部干重	Root DM (g $plant^{-1}$) 根干重	V5 stage 5叶期 PH (cm) 株高	GLA (cm^2 $plant^{-1}$) 绿叶面积	Aboveground DM (g $plant^{-1}$) 地上部干重	Root DM (g $plant^{-1}$) 根干重
2016	处理								
XK-6	GABA	44.5 b	55.4 c	1.39 c	0.56 d	73.9 b	107.3 b	4.21 c	1.06 b
	CK	54.8 a	93.4 b	2.53 a	1.79 a	86.9 a	171.0 a	7.93 a	2.77 a
	WL	37.3 c	47.4 de	1.04 d	0.38 e	65.0 cd	91.1 c	3.50 d	0.72 c
ZD-958	GABA	39.4 c	51.7 cd	0.93 c	0.62 c	69.2 bc	99.1 bc	3.62 d	1.46 b
	CK	55.9 a	116.5 a	1.81 b	1.49 b	83.0 a	159.4 a	6.80 b	2.42 a
	WL	33.8 c	42.7 e	0.82 d	0.39 e	61.3 d	85.5 c	3.08 e	0.62 c
2017									
XK-6	GABA	56.7 b	77.7 bc	1.94 b	0.74 c	72.3 c	112.6 d	5.75 d	1.49 b
	CK	75.6 a	128.8 a	4.69 a	2.00 a	98.3 a	179.7 b	9.15 b	2.87 a
	WL	45.6 c	63.4 c	1.56 c	0.48 d	64.3 c	85.5 f	4.98 f	1.02 c
ZD-958	GABA	58.6 b	83.3 b	1.92 b	0.93 b	87.0 b	122.4 c	6.20 c	1.59 b
	CK	79.2 a	120.9 a	4.85 a	1.90 a	93.7 ab	196.1 a	9.38 a	2.70 a
	WL	50.2 bc	67.0 bc	1.57 c	0.45 d	66.4 c	103.3 e	5.22 e	0.95 c

与淹水处理相比，GABA处理显著提高了玉米地上部和根干物质含量，分别为19.0%和61.0%，促进了光合速率和叶绿素含量，分别为19.8%和36.0%，增加了每个叶绿体中基粒的数量36.0%。

GABA改善淹水玉米幼苗的叶绿体超微结构、提高抗氧化能力，促生长

Figure 8.（右图） Chloroplast ultrastructure in leaves of ZD-958 maize cultivars under different treatments. Chloroplast ultrastructure under GABA application for waterlogging maize seedlings (GABA) at 14 d after treatment initiated **at third leaf (V3) in 2016**. Ch: chloroplast, **GL: grana lamella,** P: particles, CM: chloroplast envelope membrane, CW: cell wall, Mi: mitochondria, BS: bundle sheath.



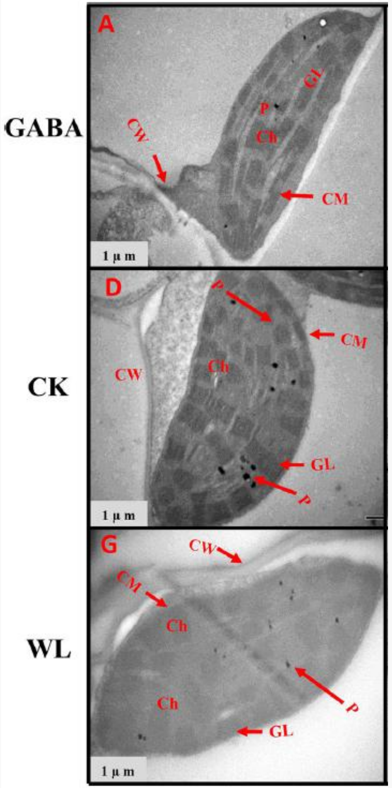


Figure 10.（左图） Chloroplast ultrastructure in leaves of ZD-958 maize cultivars under different treatments. Chloroplast ultrastructure under GABA application for waterlogging maize seedlings (GABA) at 14 d after treatment initiated **at five leaf (V5) stage in 2016**. Ch: chloroplast, **GL: grana lamella**, P: particles, CM: chloroplast envelope membrane, CW: cell wall, Mi: mitochondria, BS: bundle sheath.

γ-Aminobutyric Acid Promotes Chloroplast Ultrastructure, Antioxidant Capacity, and Growth of Waterlogged Maize Seedlings. Akram Salah, Ming Zhan, Cougui Cao, Yuling Han, Lin Ling, Zhihui Liu, Ping Li, Miao Ye & Yang Jiang. 2019.

（四）、抗高/低温胁迫

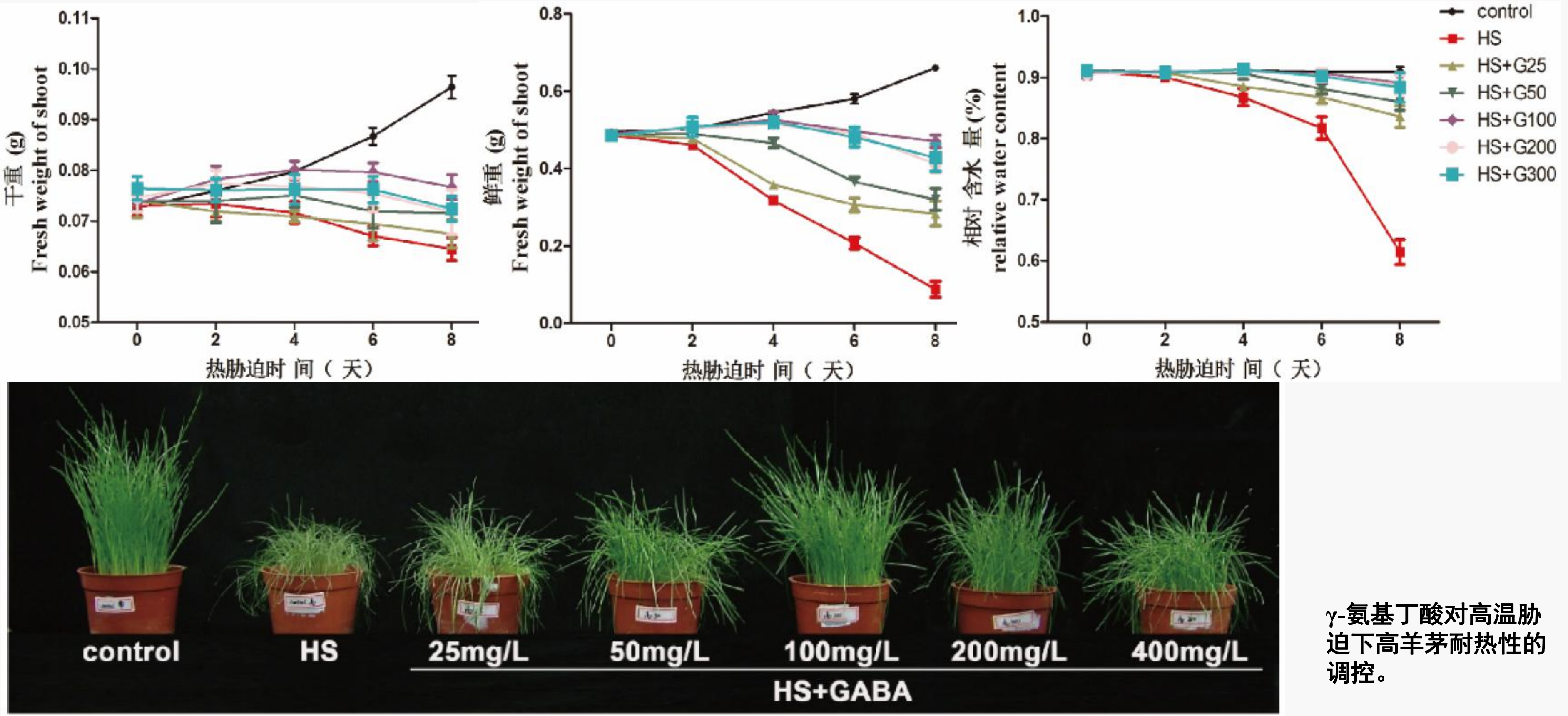


图 1 GABA 对高温胁迫下高羊茅生长的影响

γ-氨基丁酸对高温胁迫下高羊茅耐热性的调控。

夏倩倩，2018.

植物生长调节剂对逆境条件下小麦产量、品质及其生理代谢的影响

解备涛（段留生课题组），2003

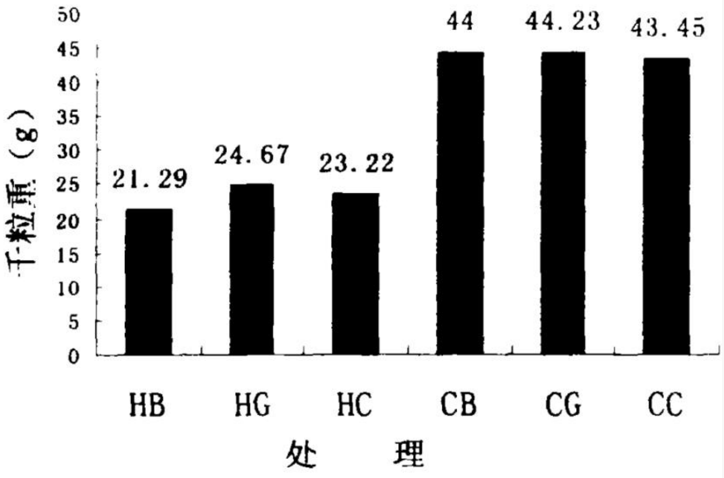


图1-3 高温对对农大189千粒重的影响

HB：高温+芸苔素内酯（BR）
HG：高温+GABA
HC：高温+对照

CB：常温+芸苔素内酯（BR）
CG：常温+GABA
CC：常温+对照

由图 1-3 可以看出，小麦生育后期高温严重影响了小麦的千粒重，高温逆境与常温条件下相比，千粒重下降了 50%左右。在常温条件下，调节剂对农大 189 千粒重没有显著影响 BR 和 GABA 处理分别比对照增加 1．27%和 1．80%。而在高温逆境条件下 BR 和 GABA 处理分别比对照降低 8．31%和增加 6．24%。由此可以看出，对于农大 189 而言，GABA 能够提高其抗高温能力，而 BR 没有表现出其功能。

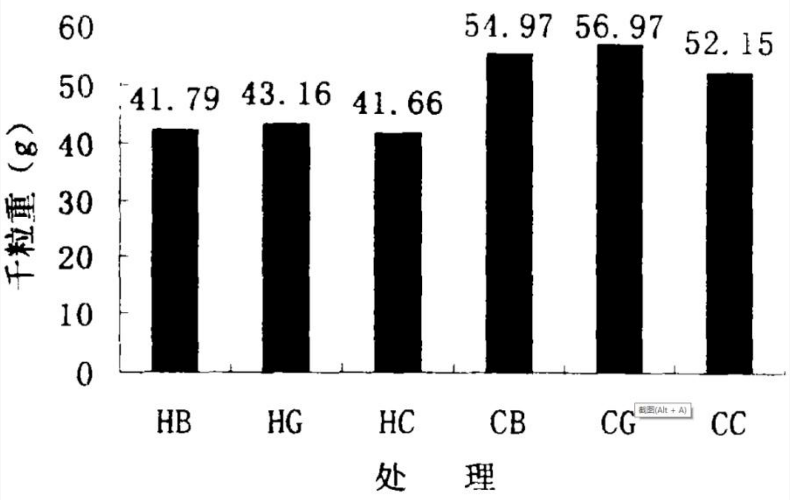


图1-4高温条件下9507的千粒重

HB：高温+芸苔素内酯(BR)
HG：高温+GABA
HC：高温+对照

CB：常温+芸苔素内酯（BR）
CG：常温+GABA
CC：常温+对照

由图 1-4 可以看出，对小麦品种中优 9507 而言，该品种有较强的抗旱能力，在逆境条件下，其千粒重比在常温条件下减少了 20%左右。这说明中优 9507 在高温逆境条件下，能保持较高的光合作用和同化物的运输能力。而 GABA 能在常温条件下和高温逆境条件下增强这种能力，其在这两种条件下分别比对照的千粒重增加 9．24%和 3．6%。而 BR 的作用不太明显，分别为 5．4%和 0．3%。

（五）、提高植物对重金属的耐受性

Accumulation				
Treatments	As		GABA	
	Shoot	Root	Shoot	Root
C	—	—	241.84 ± 11.82[a]	116.03 ± 10.36[a]
GABA(L) (Long term)	—	—	275.35 ± 8.49[b]	269.24 ± 13.98[c]
GABA(H) (Long term)	—	—	405.98 ± 8.04[f]	479.80 ± 41.72[e]
GABA(L) (Short term)	—	—	259.18 ± 9.97[ab]	191.94 ± 14.41[b]
GABA(H) (Short term)	—	—	308.31 ± 2.85[c]	250.54 ± 8.15[c]
As(III)	19.04 ± 1.02[d]	166.31 ± 4.32[d]	375.18 ± 6.48[e]	167.88 ± 15.16[ab]
As(III) + GABA(L) (Long term)	8.65 ± 0.56[a]	54.16 ± 3.75[a]	324.60 ± 8.49[cd]	144.68 ± 17.08[ab]
As(III) + GABA(H) (Long term)	10.27 ± 0.45[ab]	53.82 ± 5.59[a]	332.34 ± 2.83[d]	173.40 ± 18.47[ab]
As(III) + GABA(L) (Short term)	14.36 ± 0.33[c]	84.93 ± 2.72[b]	268.66 ± 3.28[b]	260.62 ± 8.09[c]
As(III) + GABA(H) (Short term)	16.59 ± 1.49[cd]	100.55 ± 4.43[bc]	437.54 ± 10.65[g]	392.27 ± 53.37[d]

外源GABA的提高了植物体内GABA的含量，降低了植物体内金属的积累。在目前的研究中，外源施用GABA (50和100μg/ml)能提高植物内源性GABA水平，同时降低了水稻幼苗中砷的积累。

GABA accretion reduces Lsi-1 and Lsi-2 gene expressions and modulates physiological responses in *Oryza sativa to provide tolerance* towards arsenic. Navin Kumar , Arvind Kumar Dubey等，2017

（六）、其他（机械损伤、酸中毒、生物胁迫等）

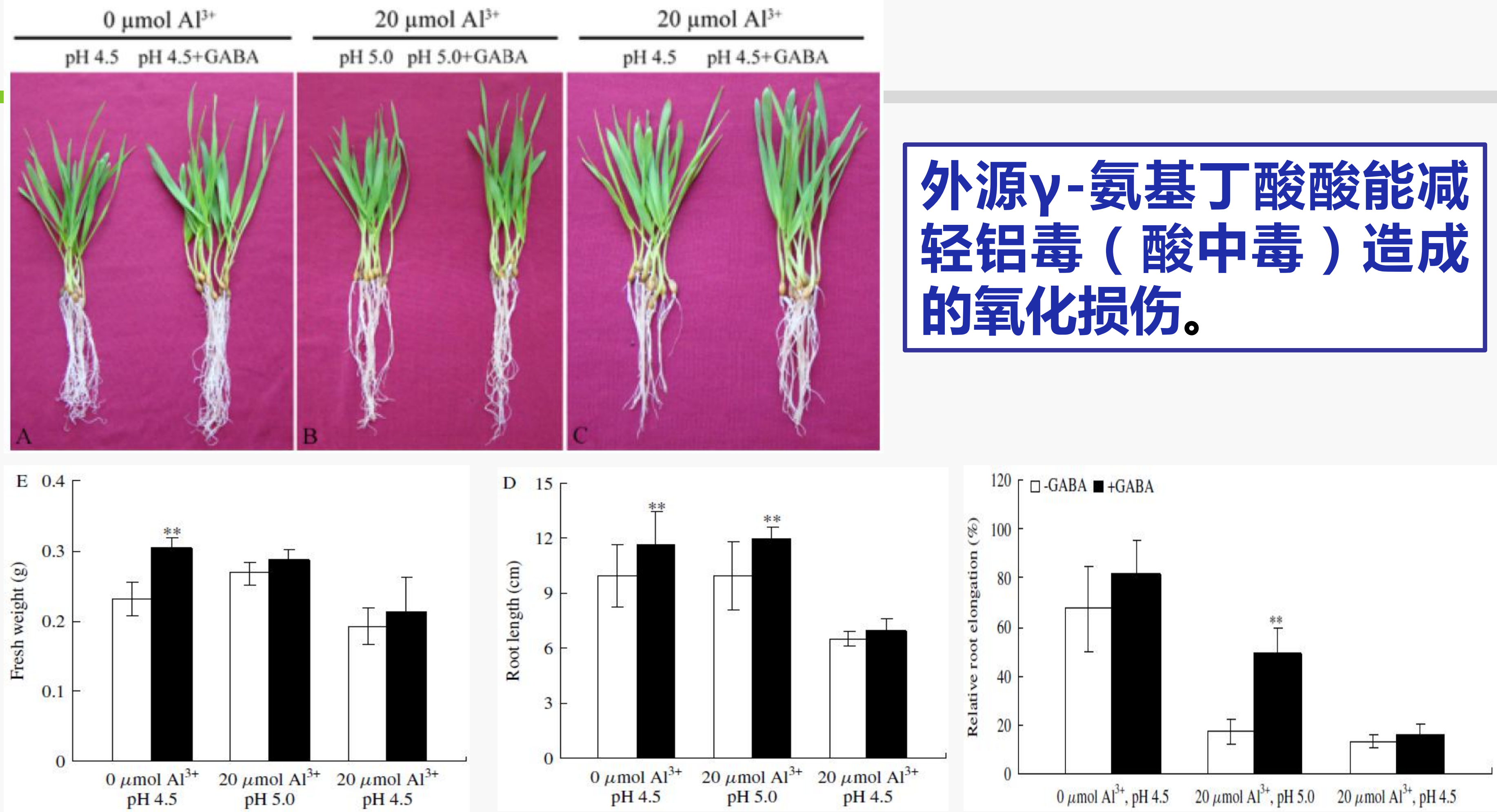
TABLE 1
Stress-Related Kinetics of GABA Accumulation in Plants

植物体内GABA积累的逆境胁迫应激动力学研究

Plant	Stress	GABA[a] % of Control	Time	Ref.
Asparagus cells	Acidosis	300	15 s	Crawford et al., 1994
Soybean leaves	Mechanical damage	1800	1 min	Ramputh and Bown, 1996
Soybean leaves	Mechanical damage	2700	5 min	Wallace et al., 1984
Soybean leaves	Cold (6°C)	2000	5 min	Wallace et al., 1984
Asparagus cells	Cold (10°C)	200	15 min	Cholewa et al., 1996
Radish leaves	Anoxia	10,000	4 h	Streeter and Thompson, 1972
Tea leaves	Anoxia	4,000	12 h.	Tsushida and Murai, 1987
Rice root	Anoxia	750	24 h	Aurisano et al., 1995
Rice shoot	Anoxia	1,000	24 h.	Aurisano et al., 1995
Cowpea cells	Heat	1,800	24 h.	Mayer et al., 1990
Bean leaves	Drought	200	3 d	Raggi, 1994
Turnip leaves	Drought	1000	3 d	Thompson et al., 1996
Tomato root	Salt	200	4 d	Bolarin et al., 1995
Tomato leaves	Salt	300	5 d	Bolarin et al., 1995
Tomato leaves	Viral	130	13 d	Cooper and Selman, 1974

[a] For each stress the time to reach the greatest reported GABA accumulation relative to unstressed controls has been shown.

Gamma Aminobutyric Acid (GABA) and Plant Responses to Stress. Alan M. Kinnersley & Frank J. Turano.



外源γ-氨基丁酸酸能减轻铝毒（酸中毒）造成的氧化损伤。

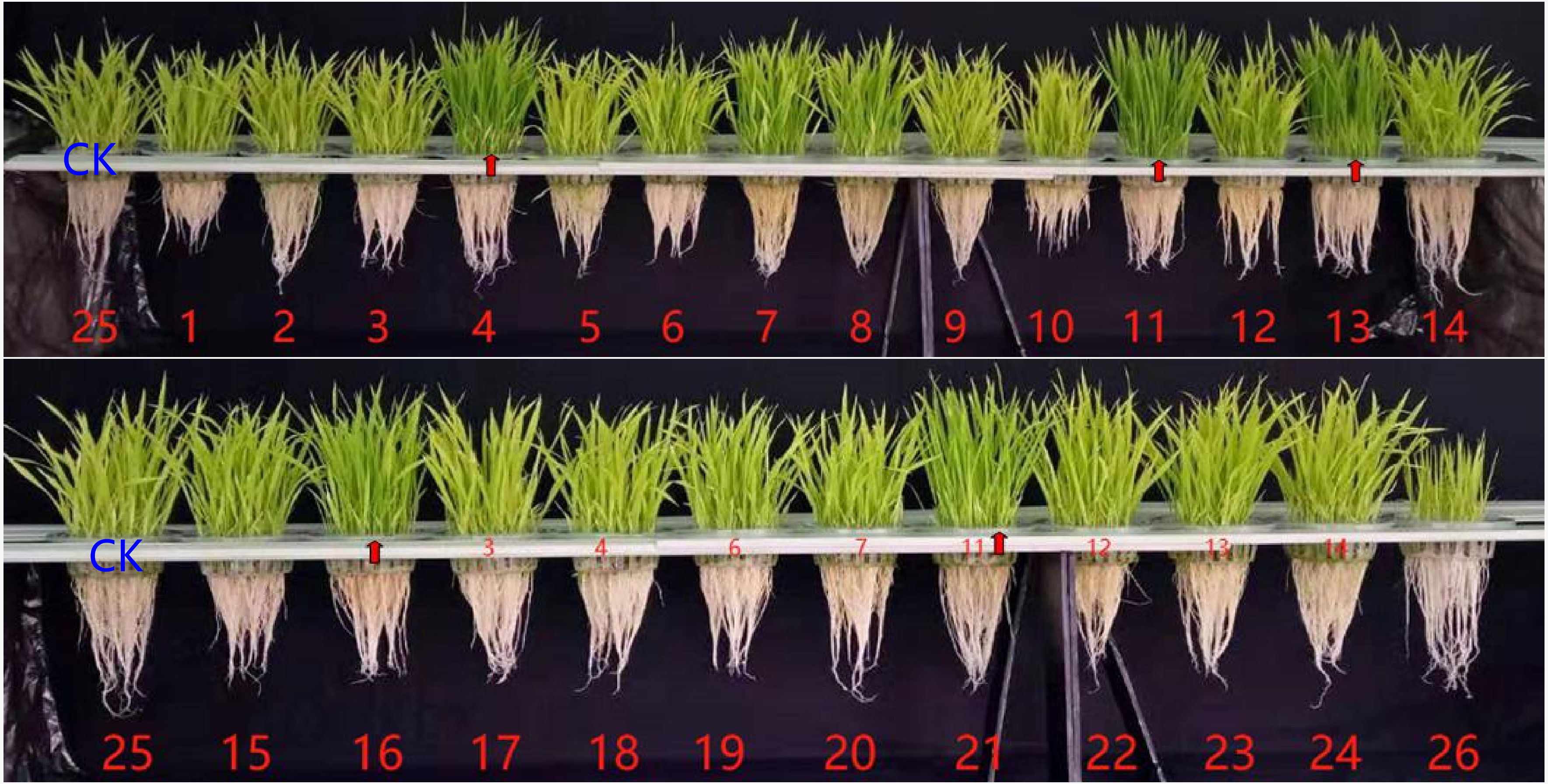
Exogenous *γ -aminobutyric acid alleviates* oxidative damage caused by aluminium and proton stresses on barley seedlings. Hongmiao Song等，2010

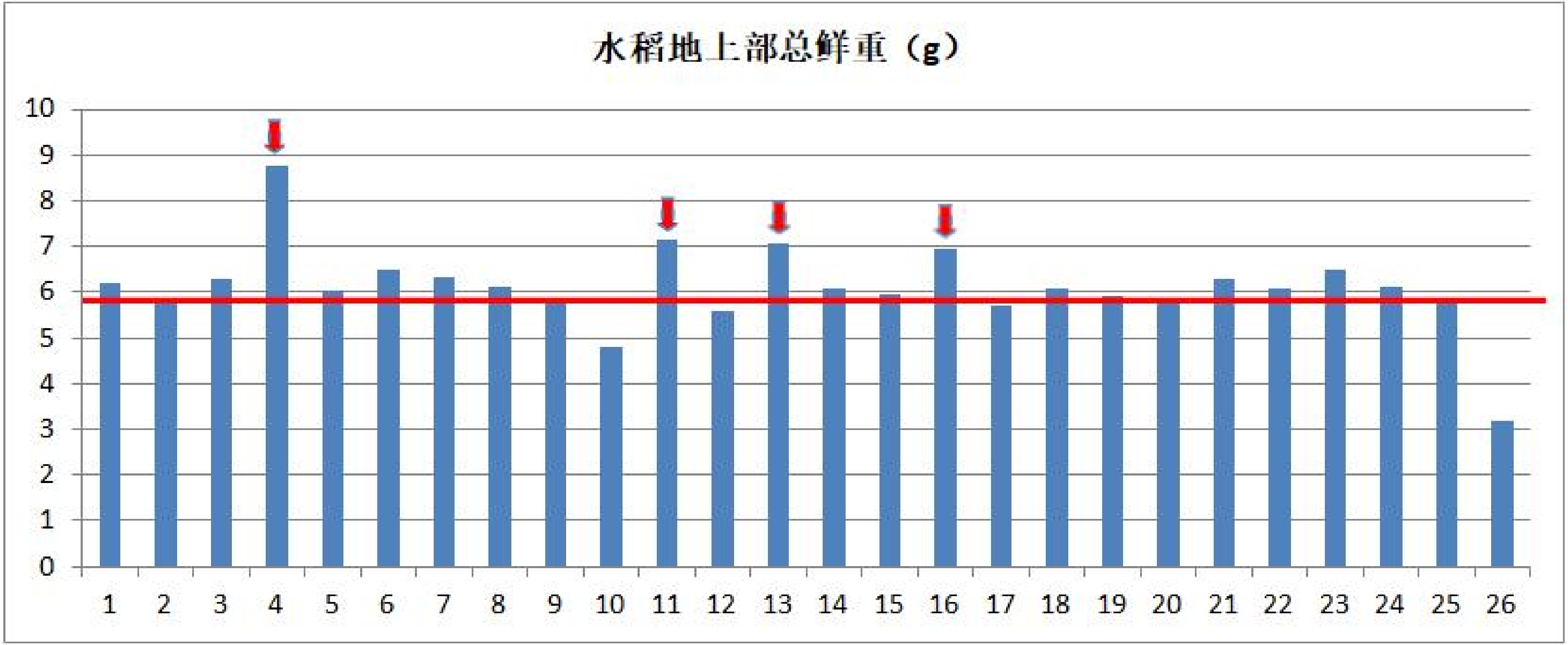
二、γ-氨基丁酸的应用试验报告

1、GABA促进植物生长实验

2、GABA提高上海青耐旱性实验

1、GABA促进水稻幼苗生长实验




水稻地上部总鲜重（g）
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
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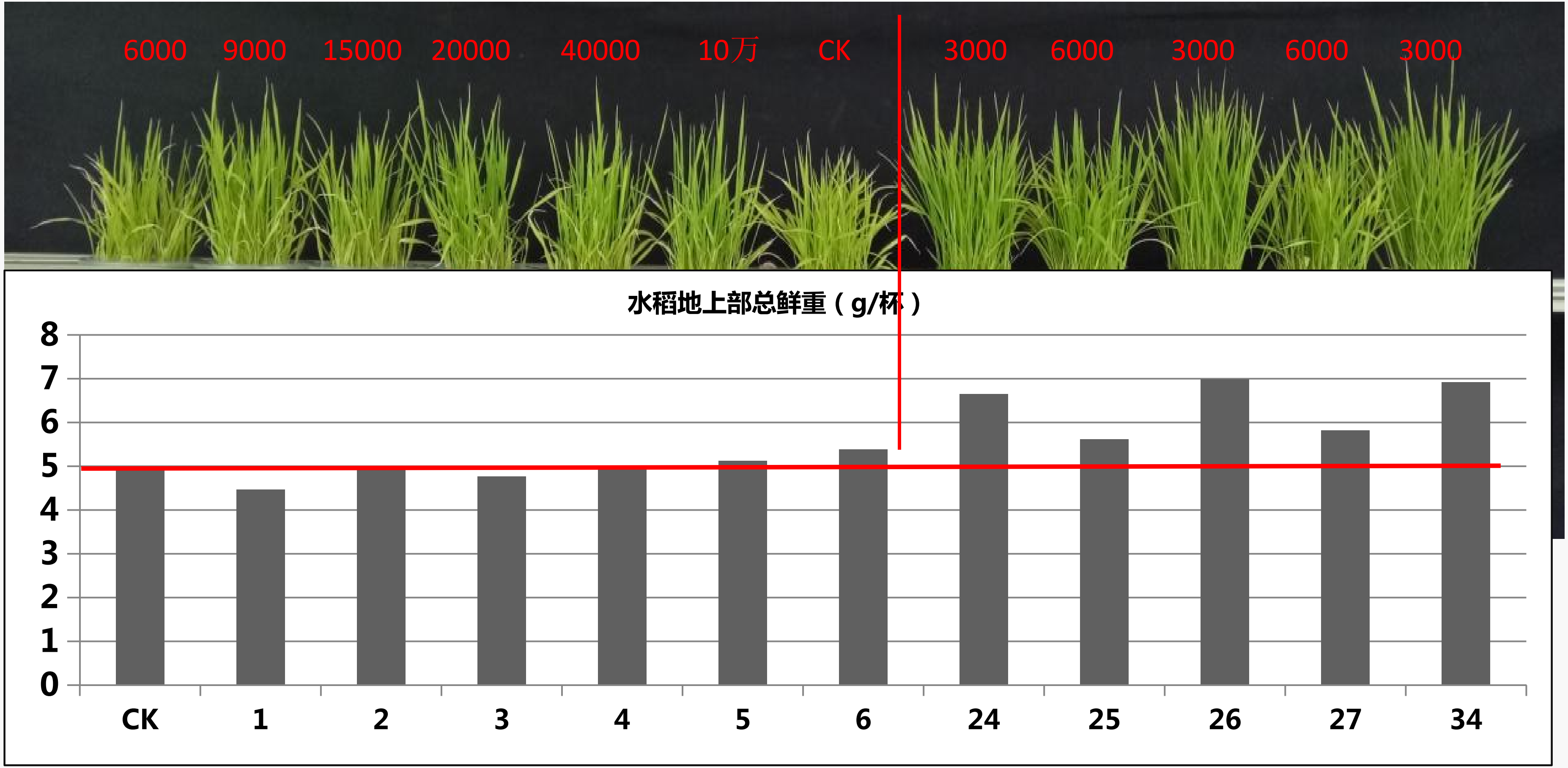
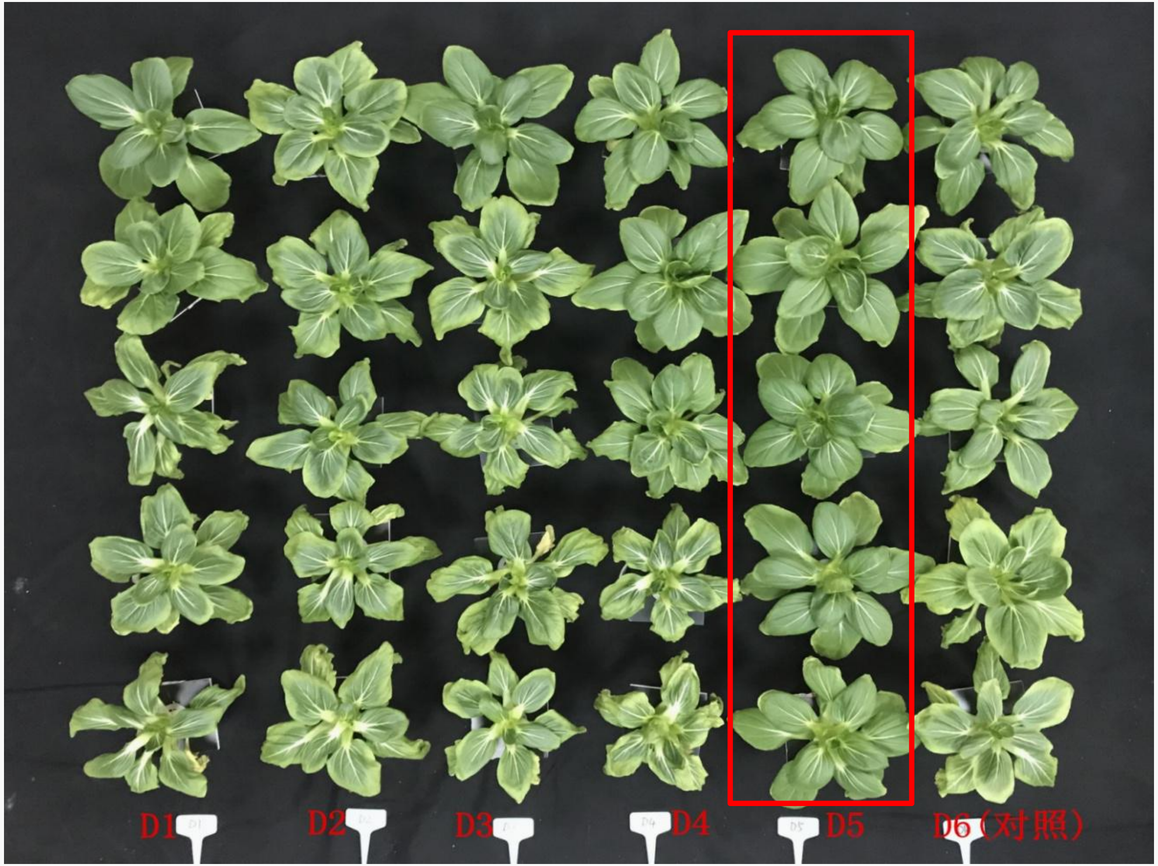
21
22
23
24
25
26

1、GABA促进水稻幼苗生长实验



GABA促进拟南芥开花实验

2、GABA提高上海青耐旱性实验

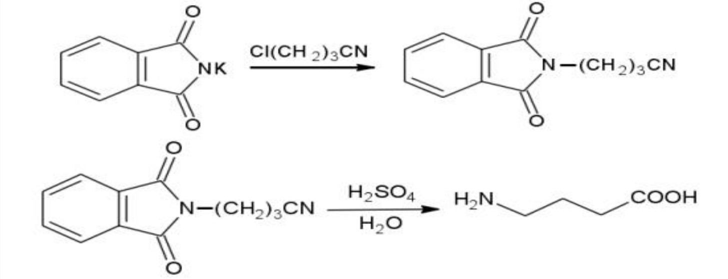


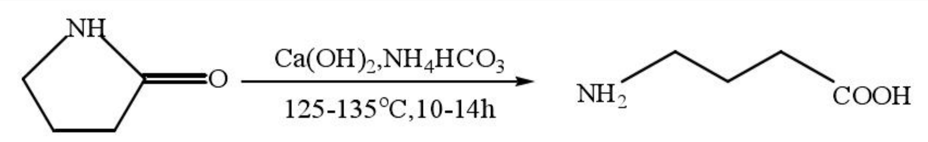
处理编号	叶片相对含水量%	较对照%
D1	83.95 bc	0.14
D2	80.23 c	-4.29
D3	80.33 c	-4.18
D4	86.53 ab	3.21
D5	91.91 a	11.09
D6 (对照)	83.83 bc	0.00

三、γ-氨基丁酸的生产方法

GABA生产方法

1、化学合成法





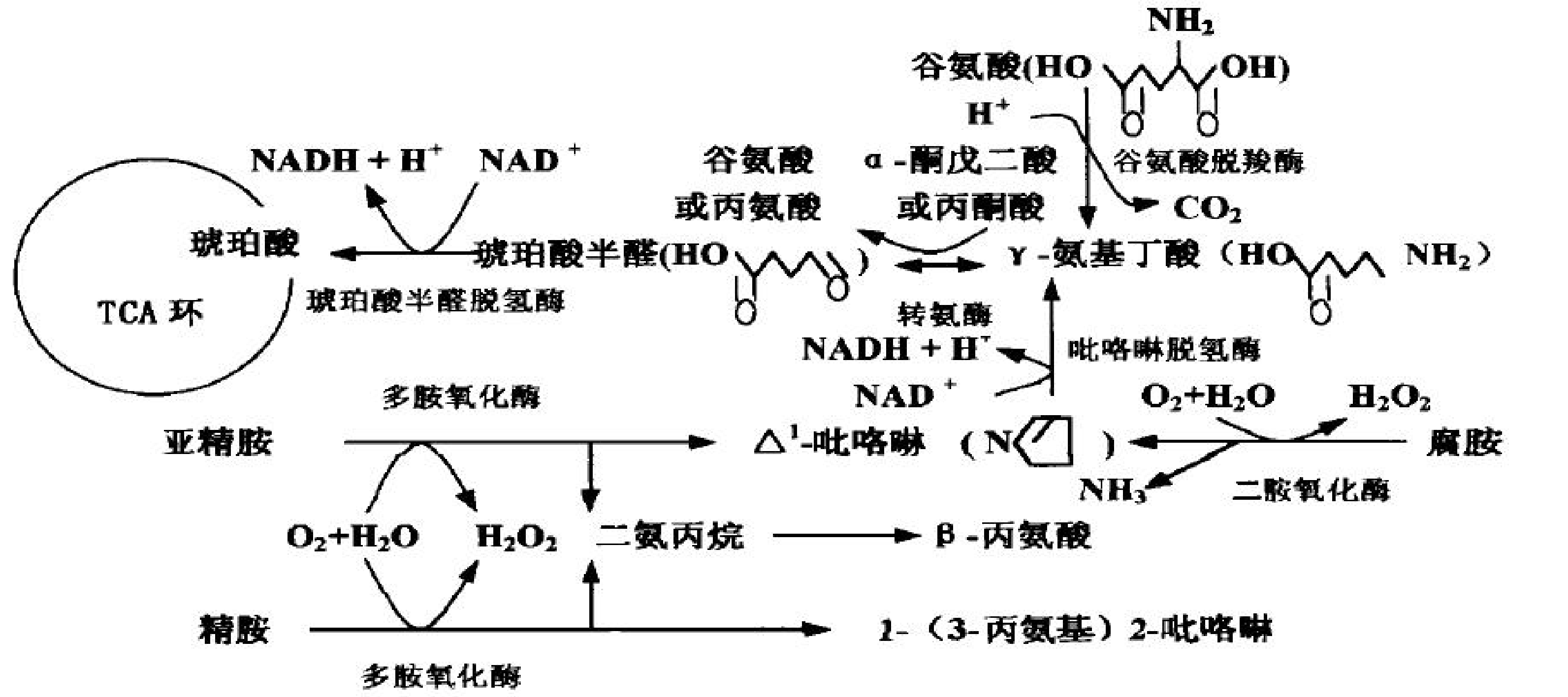
邻苯二甲酰亚胺钾和 一 氯丁氰在强烈条件下反应，然后产 物与浓硫酸水解得到；

吡咯烷酮经氢氧化钙 、碳酸氢铵水解开环制得 。

化学法 反应速度快，但脱除产品中有毒成分比较复杂，成本较 高，安全性差 。

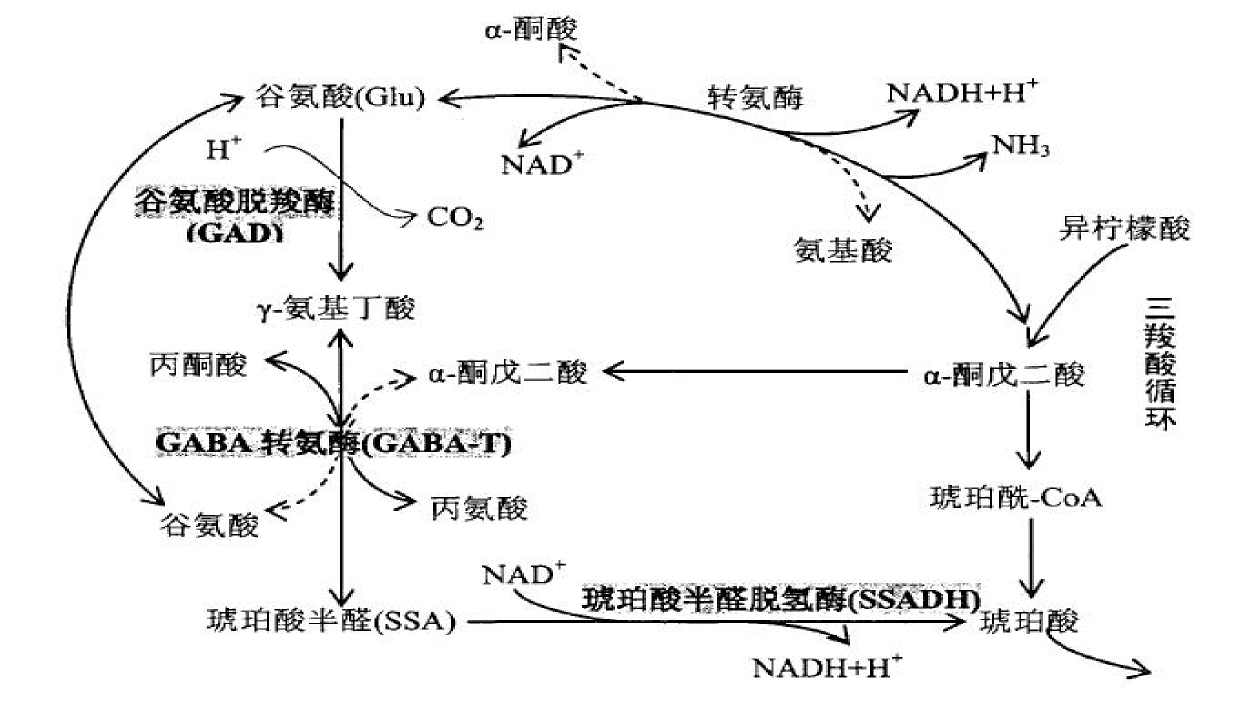
GABA生产方法

2、植物富集法



GABA生产方法

3、微生物发酵法



技术路线

全基因合成技术开发

- 二步法（AOE）

合成脱羧酶基因

- 核酸序列设计
- 合成

高效基因工程菌

- 优化表达原件
- 高效表达载体
- 新型宿主细胞
- 高通量筛选

小试发酵工艺优化

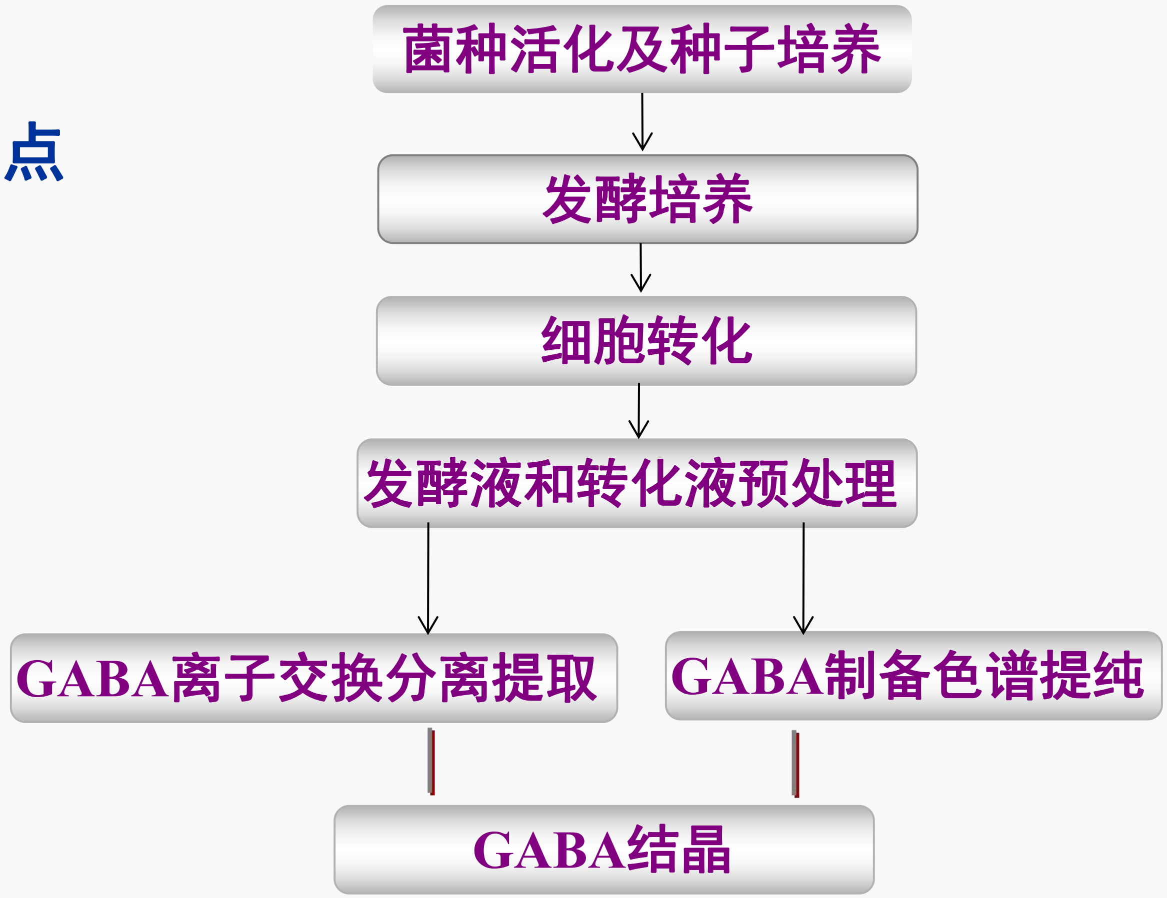
- 过程参数优化
- 后处理技术

中试发酵工艺优化

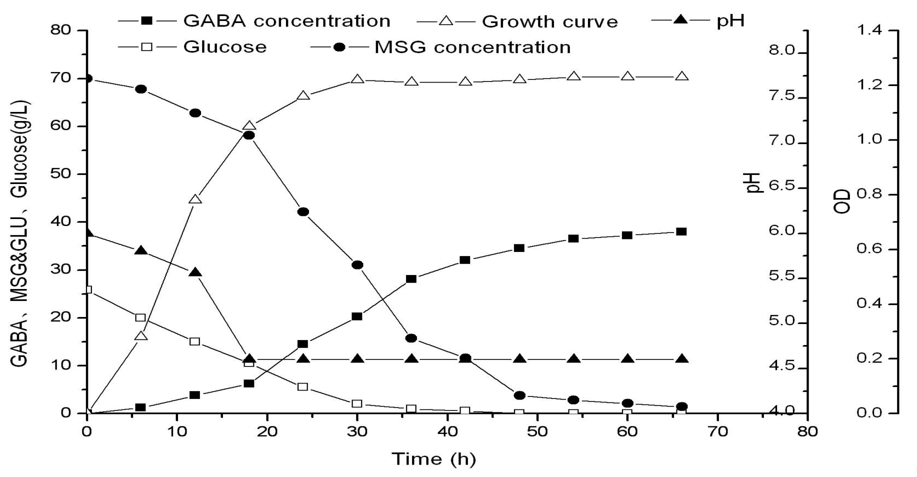
- 过程参数优化
- 后处理技术

GABA产业化

过程控制点


菌种活化及种子培养
发酵培养
细胞转化
发酵液和转化液预处理
GABA离子交换分离提取
GABA制备色谱提纯
GABA结晶

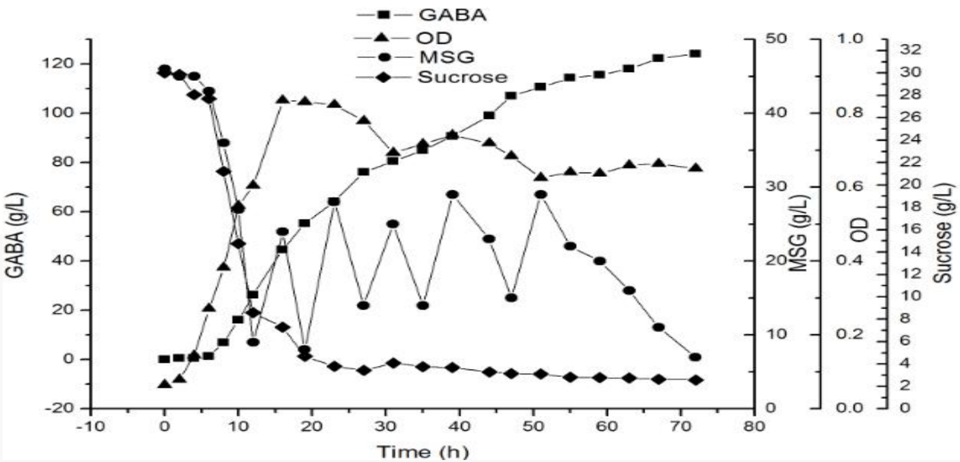
发酵过程控制生产GABA



发酵罐补料发酵曲线

GABA产量≥450g/L

分阶段pH控制发酵过程曲线



微生物 Microorganism	生产方法 Production mode	GABA含量 GABA concentration	参考文献 References
大肠杆菌 *Escherichia coli*	固定化细胞	10 g/L	赵景联
乳酸乳球菌 *Lactococcus lactis*	奶酪生产	0.38 g/kg	M. Nomura
乳酸乳球菌 *Lactococcus lactis* SYSFS 1.009	深层发酵	2.5 g/L	许建军
副干酪乳杆菌 *Lactobacillus paracasei*	深层发酵	31.15 g/L	Komatsuzaki
短乳杆菌 *Lactobacillus brevis* OPY-1	深层发酵	8003.28 nmol/mL	Park & Oh
Lactobacillus brevis IFO12005	酒糟发酵	10.18 mmol/L	Yokoyama
短乳杆菌 *Lactobacillus brevis* hjxj-01	深层发酵	107.5 g/L	夏江
植物乳杆菌 *Lactobacillus plantarum*	深层发酵	4 g/L	蒋冬花
戊糖乳杆菌 *Lactobacillus pentosus*	深层发酵	1 g/L	宋伟
屎肠球菌 *Enterococcus faecium*	细胞转化	38 g/L	李云
戊糖片球菌 *Pediococcus pentosaceus*	细胞转化	39 g/L	李云
酿酒酵母 *Saccharomyces cerevisiae*	深层发酵	0.42 mmol/L	Takahashi
葡萄汁酵母 *Saccharomyces uvarum*	深层发酵	3. 653 g/L	徐晓波
红曲菌 *Monascus pilosus* IFO 4520	制作Koji	120 mg/kg	Kono
乳酸菌球菌 *Lactococcus lactis*	细胞转化	450-500g/L	汉和生物

谢谢您的关注！