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不同基因型水稻苗期对 1,2,4-三氯苯胁迫的生理响应

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摘 要: 利用沙培试验, 研究了 6 种浓度(0、0.1、0.2、0.4、0.6、0.8 mmol kg⁻¹ 沙)的 1,2,4-三氯苯(TCB)对两水稻品种香粳 20-18(耐性基因型)和泗阳 1382(敏感基因型)种子发芽率、发芽指数、幼苗生物量以及叶片和根系的蛋白质含量、丙二醛含量(MDA)、超氧化物歧化酶(SOD)活性、过氧化物酶(POD)活性、过氧化氢酶(CAT)活性等生理指标的影响。结果表明, TCB 胁迫下, 水稻种子发芽率和发芽指数变化不明显, 幼苗的生物量显著下降, 香粳 20-18 下降幅度比泗阳 1382 小; 随 TCB 胁迫程度的增强, 香粳 20-18 叶片和根系可溶性蛋白质含量呈增加的趋势, 泗阳 1382 叶片蛋白质含量显著下降, 高浓度 TCB 胁迫下其根系蛋白质含量显著下降; 两个基因型叶片的 O₂⁻ 产生速率先降后升, 香粳 20-18 根系的 O₂⁻ 产生速率先降后升, 高浓度 TCB 胁迫下显著高于对照, 而泗阳 1382 与对照差异不显著; 香粳 20-18 叶片 SOD 活性随 TCB 胁迫程度的增强呈上升趋势, 低浓度 TCB 胁迫下就开始显著高于对照, 根系 SOD 活性显著增强, 而泗阳 1382 叶片和根系 SOD 活性与对照差异不显著; 香粳 20-18 叶片 POD 活性先升后降, 根系 POD 活性显著高于对照, 而泗阳 1382 叶片和根系 POD 活性均显著下降; 香粳 20-18 叶片 CAT 活性高于或显著高于对照, 泗阳 1382 低于或显著低于对照; 两个基因型叶片的 MDA 含量先降后升, 高浓度 TCB 胁迫下 MDA 含量显著高于对照, 根系 MDA 含量均随 TCB 胁迫程度的增强而显著增加。总之, 生物量降低幅度小、叶片和根系的蛋白质含量高、抗氧化酶系统清除活性氧的能力强、MDA 含量低是耐性基因型的主要生理特征。

关键词: 1,2,4-三氯苯; 水稻; 耐性基因型; 敏感基因型; 毒性; 抗氧化酶

Physiological Response to 1,2,4-Trichlorobenzene Stress of Different Rice Genotypes in Seedlings

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Abstract: 1,2,4-Trichlorobenzene (TCB) has pervaded in industrial and agricultural production. Because of a series of problems caused by its stableness and fatalness, TCB has been added into the environmental pollutant list. In order to know how TCB affects the rice seed germination, seedling growth and its physiological characteristics, the seed germination, seedling biomass, soluble protein, and malnodialdehyde (MDA) contents, as well as activities of superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT) in leaves and roots of seedlings treated with TCB were investigated in a sand culture experiment using rice cultivars, Xiangjing 20-18 (TCB tolerant genotype) and Siyang 1382 (TCB sensitive genotype). The results indicated that TCB had little effect on the seed germination rate and index, however caused the significant reduction of seedling biomass, with Xiangjing 20-18 being more affected than Siyang 1382. With TCB stress degree strengthening, soluble protein content of Xiangjing 20-18 leaves and roots presented an increasing tendency, while that of Siyang 1382 leaves decreased significantly, and that of its roots decreased too under treatment of high TCB concentration. O₂⁻ producing velocity of leaves in two genotypes decreased firstly, then increased with increasing TCB concentration. That of Xiangjing 20-18 roots presented the same tendency, and significantly higher than the control at TCB 0.6 mmol kg⁻¹, while that of Siyang 1382 roots had no significant difference with that of the control. SOD activity of Xiangjing 20-18 leaves increased, and that of roots increased significantly. After TCB 0.2 mmol kg⁻¹,

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SOD activity of Xiangjing 20-18 leaves was significantly higher than that of the control, that of Siyang 1382 leaves and roots was not significantly different with that of the control. POD activity of Xiangjing 20-18 leaves increased firstly, then decreased, and that of roots was significantly higher than the control, while that of Siyang 1382 leaves and roots decreased significantly. CAT activity of Xiangjing 20-18 leaves was higher or significantly higher than that of the control, and that of Siyang 1382 was contrary to the result of Xiangjing 20-18. MDA content of leaves decreased firstly, then increased, being significantly higher than that of the control at high TCB concentration, and that of roots increased significantly in two genotype. In conclusion, lower reduction of seedling biomass, high protein content of leaves and roots, the better active oxygen's elimination ability and lower MDA content in plants would be considered as the physiological traits in TCB-tolerant genotypes of rice.

Keywords: 1,2,4-trichlorobenzene; Rice; Tolerant genotype; Sensitive genotype; Toxicity; Antioxidant enzymes

氯苯类有机物(chlorobenzenes, CBs)在合成染料、芳香剂、农药、制药、油漆等工农业生产中有着广泛的用途,也是环境中存在的一类疏水性氯代有机污染物,美国环境保护局(EPA)已将其列入优先控制污染物名单^[1],中国也已将其列入水中优先控制污染物名单^[2]。CBs 中常见的有一氯苯、间二氯苯、对二氯苯、1,2,4-三氯苯(1,2,4-TCB)、四氯苯、六氯苯等化合物。周霞等^[3-4]于 2003 年 11 月在北京东南郊化工区取了 18 个土样、植物样及该区通惠河的 16 个断面水样、10 个断面表层沉积物样品,检测结果显示土壤(干重)中 CBs 的含量为 0.232~51.15 ng g⁻¹,植物(干重)中为 5.635~31.990 ng g⁻¹,水中为 0.093~6.638 μg L⁻¹,表层沉积物(干重)中为 95.3~1 827.7 ng g⁻¹。据 EPA^[1]统计,美国 2001 年向土壤中排放了 1,2,4-TCB 3 497 kg,累计已排放 53 023 kg。中国在珠三角、长三角、环渤海湾等地区 and 沈阳、兰州、西安等城市的污泥、土壤及地下水中均检测到了 1,2,4-TCB,在水中浓度可达 1.55 μg L⁻¹,污泥中含量高达 2.929 mg kg⁻¹干重^[5]。1,2,4-TCB 很难降解^[6]。污水灌溉以及用污泥制作肥料使用,均会导致农田中 1,2,4-TCB 的累积。He 等^[7]报道,水稻在 1,2,4-TCB 含量为 0~50 mg kg⁻¹干重的土中生长,稻谷和根中 1,2,4-TCB 的含量最高分别达 4.01 和 35.90 mg kg⁻¹干重。王泽港等^[8]也在稻米中检测 1,2,4-TCB 的浓度达 30~40 μg kg⁻¹干重,张建英等^[9]在叶菜类和根菜类蔬菜中也检测到了 1,2,4-TCB。Jan^[10]在人类的脂肪组织和乳液中均已检出 1,2,4-TCB。这说明环境中存在的 1,2,4-TCB 可能通过污水灌溉等方式积累在农产品中,进而通过食物链累积危害人类健康。

1,2,4-TCB 是一种毒性很高的化合物^[11-12],因此,国内外对其日益重视,迄今对其理化性质、生物学特性、生态毒理效应及在水生、陆生生态系统中的环境行为^[1-6,10-14]研究较多,但对高等植物的生态效应和毒性机理研究较少^[7-9,15-17]。水稻是中国的主要

粮食作物,也是消耗水分最多的作物,最易受到水体有机污染物的影响。特别是在工业较发达的长江和淮河流域地区,工业有机物污染已成为影响水稻生产安全的严重问题^[18-19]。以往的研究表明,水稻对 1,2,4-TCB 胁迫存在显著的基因型差异^[20],在此基础上,选择响应差异显著的 2 个水稻品种,在评价 1,2,4-TCB 对水稻种子萌发和幼苗生长影响的基础上,对其伤害机理以及 2 种水稻耐性差异的生理机制进行了初步探讨,以期水稻苗期的管理措施提供依据。

1 材料与方法

1.1 试验材料

水稻品种香粳 20-18(耐性品种)和泗阳 1382(敏感品种),为前期筛选出来的代表性品种;1,2,4-三氯苯(TCB),化学纯,纯度为 96%,购自中国医药集团上海化学试剂公司。

1.2 试验设计

在人工气候箱中进行沙培,每培养皿(90 mm × 10 mm)装沙 60 g,设置 0(对照)、0.1、0.2、0.4、0.6、0.8 mmol TCB kg⁻¹沙 6 个处理(0.3 mL 丙酮溶解),每处理 3 次重复,随机区组设计。选择健壮、饱满的水稻种子经消毒、浸种和催芽后分别播 30 粒于各培养皿中 30℃暗发芽,观察并记录种子发芽情况。发芽后培养条件为昼/夜温度 28℃/22℃,相对湿度 75%,每天光照 12 h,光照强度 50 μmol m⁻² s⁻¹,培养 2 周后水稻苗长至 2~3 叶时测定各指标。

1.3 测定项目及方法

1.3.1 发芽和生物量的测定 参照 OECD^[21]和 ISO^[22]方法进行种子发芽。发芽率=(7 d 内发芽种子数/供试种子数)×100%。发芽指数 $GI = \sum(Gt/Dt)$,式中 Gt 为不同时间的发芽种子数, Dt 为相应的发芽日数。生物量以 20 株幼苗干重的平均值表示,单位为 g 株⁻¹。

1.3.2 蛋白质含量的测定 采用考马斯亮蓝法测

定叶片和根系的蛋白质含量^[23], 以 $\text{mg g}^{-1}\text{FW}$ 为单位。

1.3.3 超氧阴离子自由基(O_2^-)产生速率的测定
根据王爱国和罗广华^[24]的方法, 略加修改。在每个处理每个重复中随机取若干植株, 取 0.5 g 叶片或根系加 pH 7.8 的 65 mmol L^{-1} 的磷酸缓冲液, 匀浆后 $2\,500 \times g$ 离心 10 min。取上清液 1 mL, 加 0.1 mL 羟胺氯化物(10 mmol L^{-1}), 25°C 反应 20 min。再加 1 mL 17 mmol L^{-1} 对氨基苯磺酸和 1 mL 7 mmol L^{-1} α -萘胺, 25°C 下再反应 20 min。

1.3.4 丙二醛(MDA)含量和抗氧化酶活性的测定
参照张宪政^[25]的方法测定丙二醛(MDA)含量。采用氮蓝四唑法^[26]测超氧化物歧化酶(SOD), 以抑

制 NBT 光还原相对百分率为 50% 的酶量作为一个酶活性单位(U), 酶活性以 $\text{U mg}^{-1}\text{Pro}$ 表示。采用愈创木酚法^[23]测过氧化物酶(POD), 酶活性以 $\Delta A_{470} \text{ min}^{-1} \text{ mg}^{-1}\text{Pro}$ 表示。采用紫外吸收法^[27]测过氧化氢酶(CAT), 以 1 min 内 A_{240} 减少 0.1 的酶量为 1 个酶活单位(U), 酶活性以 $\text{U min}^{-1} \text{ mg}^{-1}\text{Pro}$ 表示。

2 结果与分析

2.1 1,2,4-三氯苯胁迫对水稻种子发芽率和发芽指数的影响

在 1,2,4-TCB 胁迫下, 香粳 20-18 和泗阳 1382 的发芽率、发芽指数与对照差异均不显著(表 1), 说明水稻种子发芽期对 1,2,4-TCB 胁迫的反应不敏感。

表 1 1,2,4-TCB 浓度对水稻种子发芽率和发芽指数的影响
Table 1 Effect of 1,2,4-TCB on the germination rate and germination index of rice seed

1,2,4-TCB 浓度 1,2,4-TCB concentration	发芽率 Germination rate (%)		发芽指数 Germination index	
	香粳 20-18 Xiangjing 20-18	泗阳 1382 Siyang 1382	香粳 20-18 Xiangjing 20-18	泗阳 1382 Siyang 1382
0 mmol kg ⁻¹ (CK)	87.5±2.5 a	56.7±5.2 a	45.9±1.8 a	26.0±2.9 a
0.1 mmol kg ⁻¹	86.7±3.8 a	52.5±9.0 a	45.7±1.5 a	26.0±3.2 a
0.2 mmol kg ⁻¹	82.5±8.7 a	50.0±9.0 a	44.9±4.7 a	24.0±3.1 a
0.4 mmol kg ⁻¹	86.7±1.4 a	57.5±9.0 a	47.9±0.5 a	26.5±4.5 a
0.6 mmol kg ⁻¹	84.2±2.3 a	50.8±5.8 a	45.7±4.3 a	26.1±2.5 a
0.8 mmol kg ⁻¹	78.3±3.8 a	50.8±5.8 a	42.7±2.3 a	26.3±1.5 a

同列中标以不同字母的值在 0.05 水平上差异显著。
Values followed by a different letter within a column are significantly different at the 0.05 probability level.

2.2 1,2,4-三氯苯胁迫对水稻幼苗生物量的影响
两个水稻基因型苗期的生物量与 1,2,4-TCB 浓度之间均呈显著的负相关关系(表 2), 香粳 20-18 生物量(y)与 1,2,4-TCB 浓度(x)之间的线性方程为 $y = -0.0021x + 0.0121 (r = 0.9647^{**})$, 泗阳 1382 生物量(y)

与 1,2,4-TCB 浓度(x)之间的线性方程为 $y = -0.0025x + 0.011 (r = 0.9620^{**})$, 可见 1,2,4-TCB 胁迫使得水稻生长发育缓慢, 生物量下降。在 1,2,4-TCB 浓度为 0.8 mmol kg^{-1} 时, 香粳 20-18 和泗阳 1382 的生物量分别比对照下降 14.4% 和 21.1%, 耐性基因型香粳 20-18 下降幅度相对小些。

2.3 1,2,4-三氯苯胁迫对水稻叶片和根系可溶性蛋白质含量的影响

从图 1-A 可以看出, 1,2,4-TCB 胁迫下水稻叶片蛋白质含量基因型间存在着明显差异, 香粳 20-18 高于或显著高于对照; 泗阳 1382 显著低于对照。由图 1-B 可知, 根系蛋白质含量在中低浓度($0 \sim 0.4 \text{ mmol kg}^{-1}$) 1,2,4-TCB 胁迫下, 两个水稻基因型均随 1,2,4-TCB 浓度的增加先降低后升高, 当 1,2,4-TCB 浓度 $> 0.4 \text{ mmol kg}^{-1}$ 时表现出明显差异, 香粳 20-18 上升, 而泗阳 1382 显著下降。

表 2 1,2,4-TCB 浓度对水稻幼苗生物量的影响
Table 2 Effect of 1,2,4-TCB on the biomass of rice seedling (g plant⁻¹)

1,2,4-TCB 浓度 1,2,4-TCB concentration	香粳 20-18 Xiangjing 20-18	泗阳 1382 Siyang 1382
0 mmol kg ⁻¹ (CK)	0.0121 a	0.0111 a
0.1 mmol kg ⁻¹	0.0119 a	0.0104 b
0.2 mmol kg ⁻¹	0.0114 bc	0.0106 ab
0.4 mmol kg ⁻¹	0.0115 ab	0.0101 bc
0.6 mmol kg ⁻¹	0.0108 cd	0.0097 c
0.8 mmol kg ⁻¹	0.0103 d	0.0087 d

同列中标以不同字母的值在 0.05 水平上差异显著。
Values followed by a different letter within a column are significantly different at the 0.05 probability level.

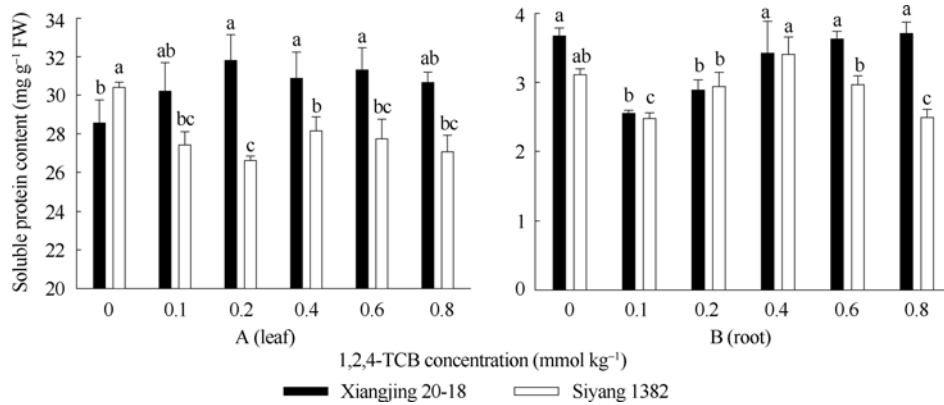


图 1 1,2,4-TCB 浓度对水稻叶片和根系可溶性蛋白质含量的影响

Fig. 1 Effect of 1,2,4-TCB on the soluble protein content in rice leaf and root

同品种不同字母表示在 0.05 水平上差异显著。

Bars superscripted by different letters within the same cultivar are significantly different at the 0.05 probability level.

2.4 1,2,4-三氯苯胁迫对水稻叶片和根系 O₂⁻ 产生速率的影响

在 1,2,4-TCB 胁迫下两个水稻基因型叶片的超氧阴离子(O₂⁻)产生速率先下降后上升(图 2-A)。香粳 20-18 在 1,2,4-TCB 浓度为 0.2 mmol kg⁻¹ 时, 其 O₂⁻ 产生速率显著低于对照, 其余处理与对照差异不显著; 泗阳 1382 在 1,2,4-TCB 浓度为 0.2 mmol kg⁻¹ 和 0.4 mmol kg⁻¹ 时, O₂⁻ 产生速率显著低于对照, 其余处理与对照无显著差异。从图 2-B 可以看出, 随着 1,2,4-TCB 浓度的升高, 香粳 20-18 根的 O₂⁻ 产生速率先降后升, 在低浓度(0.1 mmol kg⁻¹)时, O₂⁻ 产生速率显著低于对照, 当 1,2,4-TCB 浓度 0.6 mmol kg⁻¹ 时显著高于对照。而泗阳 1382 在中低浓度(0.1、0.2 和 0.4 mmol kg⁻¹)时 O₂⁻ 产生速率显著高于对照,

高浓度(0.6 mmol kg⁻¹)时与对照差异不显著。

2.5 1, 2, 4-三氯苯胁迫对水稻叶片和根系丙二醛含量的影响

两个水稻品种叶片 MDA 含量随着 1,2,4-TCB 浓度的增加先下降后上升, 高浓度 1,2,4-TCB 胁迫下显著高于对照; 随着 1,2,4-TCB 浓度的增加, 两品种根系 MDA 含量呈上升趋势, 说明根系比叶片更为敏感, 在低浓度 1,2,4-TCB 胁迫下膜脂过氧化程度开始加重(表 3)。

2.6 1, 2, 4-三氯苯胁迫对水稻叶片和根系抗氧化酶活性的影响

2.6.1 1,2,4-三氯苯胁迫对水稻叶片和根系 SOD 活性的影响 随着 1,2,4-TCB 浓度的增加, 香粳 20-18 叶片 SOD 活性呈上升趋势, 在 1,2,4-TCB 浓度

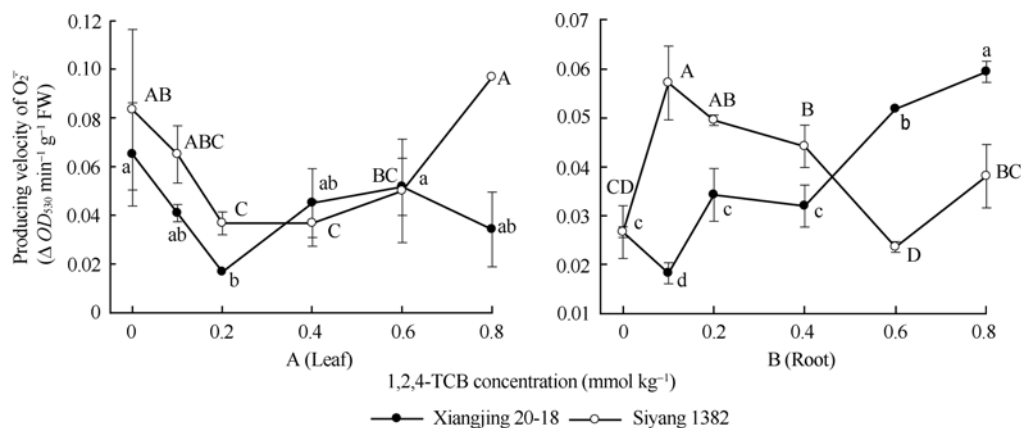


图 2 1,2,4-TCB 浓度对水稻叶片和根系 O₂⁻ 产生速率的影响

Fig. 2 Effect of 1,2,4-TCB on the producing velocity of O₂⁻ in rice leaf and root

同品种不同字母表示在 0.05 水平上差异显著。

Bars superscripted by different letters within the same cultivar are significantly different for producing velocity of O₂⁻ at the 0.05 probability level.

表 3 1,2,4-TCB 浓度对水稻幼苗丙二醛含量的影响
Table 3 Effect of 1,2,4-TCB on the MDA content in rice seedling (nmol g⁻¹ FW)

1,2,4-TCB 浓度 1,2,4-TCB concentration	叶片 MDA 含量 MDA content in leaf		根系 MDA 含量 MDA content in root	
	香粳 20-18 Xiangjing 20-18	泗阳 1382 Siyang 1382	香粳 20-18 Xiangjing 20-18	泗阳 1382 Siyang 1382
0 mmol kg ⁻¹ (CK)	10.34±0.23 c	11.63±0.26 b	2.15±0.26 d	5.80±0.13 e
0.1 mmol kg ⁻¹	8.24±0.36 d	9.87±1.03 c	3.49±0.04 c	6.31±0.13 d
0.2 mmol kg ⁻¹	6.71±0.51 e	7.64±0.30 d	2.48±0.01 d	7.16±0.27 c
0.4 mmol kg ⁻¹	7.02±0.47 e	7.98±0.79 d	4.83±0.70 b	7.69±0.23 b
0.6 mmol kg ⁻¹	11.73±1.33 b	12.00±0.72 b	4.38±0.31 b	7.64±0.33 b
0.8 mmol kg ⁻¹	13.26±0.47 a	14.11±0.52 a	6.21±0.67 a	8.62±0.17 a

同列中标以不同字母的值在 0.05 水平上差异显著。
Values followed by a different letter within a column are significantly different at the 0.05 probability level.

0.2 mmol kg⁻¹ 后显著高于对照; 泗阳 1382 叶片 SOD 活性与对照差异不显著。随着 1,2,4-TCB 浓度的增加, 香粳 20-18 根系 SOD 活性也呈上升趋势, 且显著高于对照; 泗阳 1382 各处理根系 SOD 活性与对照差异不显著(表 4)。

2.6.2 1, 2, 4-三氯苯胁迫对水稻叶片和根系 POD 活性的影响 随着 1,2,4-TCB 浓度的增加, 香粳 20-18 叶片的 POD 活性先升高后下降, 0.1 mmol kg⁻¹ 和 0.2 mmol kg⁻¹ 处理显著高于对照, 当 1,2,4-TCB

浓度 0.6 mmol kg⁻¹ 时显著低于对照; 而泗阳 1382 叶片的 POD 活性随 1,2,4-TCB 浓度的增加而显著下降。在 1,2,4-TCB 胁迫下香粳 20-18 根系的 POD 活性被激活, 各处理显著高于对照, 而泗阳 1382 根系的 POD 活性显著下降(表 5)。

2.6.3 1, 2, 4-三氯苯胁迫对水稻叶片 CAT 活性的影响 随着 1,2,4-TCB 浓度的增加, 香粳 20-18 叶片的 CAT 活性先上升后下降, 在中间浓度(0.2 mmol kg⁻¹ 和 0.4 mmol kg⁻¹)时显著高于对照, 其余处理与

表 4 1,2,4-TCB 浓度对水稻幼苗 SOD 活性的影响
Table 4 Effect of 1,2,4-TCB on the activity of SOD in rice seedling (U mg⁻¹ Pro)

1,2,4-TCB 浓度 1,2,4-TCB concentration	叶片 SOD 活性 Activity of SOD in leaf		根系 SOD 活性 Activity of SOD in root	
	香粳 20-18 Xiangjing 20-18	泗阳 1382 Siyang 1382	香粳 20-18 Xiangjing 20-18	泗阳 1382 Siyang 1382
0 mmol kg ⁻¹ (CK)	55.85±2.17 d	52.53±5.08 ab	131.82±3.14 e	192.21±11.56 ab
0.1 mmol kg ⁻¹	59.26±3.81 cd	55.50±5.85 ab	148.65±2.28 d	180.14±28.34 ab
0.2 mmol kg ⁻¹	65.87±2.74 b	52.81±5.45 ab	192.70±3.32 c	180.48±2.78 ab
0.4 mmol kg ⁻¹	63.31±5.31 bc	57.59±1.32 a	152.05±8.61 d	196.86±4.69 a
0.6 mmol kg ⁻¹	65.56±1.64 b	48.88±3.48 b	205.30±5.03 b	167.23±5.10 b
0.8 mmol kg ⁻¹	75.56±3.24 a	59.12±0.84 a	232.54±8.16 a	175.28±3.75 ab

同列中标以不同字母的值在 0.05 水平上差异显著。
Values followed by a different letter within a column are significantly different at the 0.05 probability level.

表 5 TCB 浓度对水稻幼苗 POD 活性的影响
Table 5 Effect of TCB on the activity of POD in rice seedling(A₄₇₀ min⁻¹ g⁻¹ Pro)

1,2,4-TCB 浓度 1,2,4-TCB concentration	叶片 POD 活性 Activity of POD in leaf		根系 POD 活性 Activity of POD in root	
	香粳 20-18 Xiangjing 20-18	泗阳 1382 Siyang 1382	香粳 20-18 Xiangjing 20-18	泗阳 1382 Siyang 1382
0 mmol kg ⁻¹ (CK)	4.17±0.02 b	4.14±0.10 a	64.80±2.97 d	78.58±1.12 a
0.1 mmol kg ⁻¹	4.36±0.12 a	3.85±0.04 b	68.78±3.47 cd	71.83±1.73 b
0.2 mmol kg ⁻¹	4.37±0.15 a	3.69±0.05 c	75.83±2.94 c	69.96±1.79 b
0.4 mmol kg ⁻¹	4.28±0.05 ab	3.60±0.02 c	90.39±0.97 a	64.77±2.73 c
0.6 mmol kg ⁻¹	3.61±0.11 c	3.28±0.05 d	86.09±4.00 b	56.23±0.41 d
0.8 mmol kg ⁻¹	3.60±0.05 c	3.40±0.11 d	79.05±4.47 c	43.64±0.69 e

同列中标以不同字母的值在 0.05 水平上差异显著
Values followed by a different letter within a column are significantly different at the 0.05 probability level.

对照无显著差异。泗阳 1382 叶片的 CAT 活性低于或显著低于对照(图 3)。

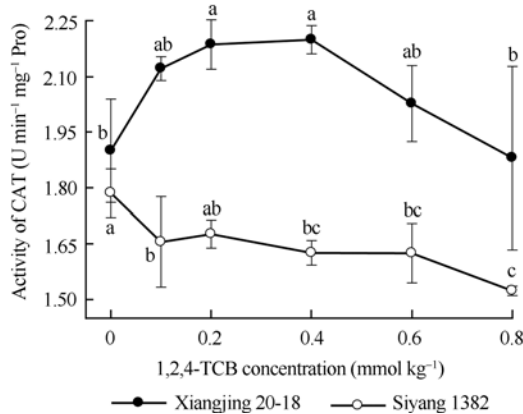


图 3 1,2,4-TCB 浓度对水稻叶片 CAT 活性的影响

Fig. 3 Effect of 1,2,4-TCB on the activity of CAT in rice leaf
同品种不同字母表示在 0.05 水平上差异显著。

Bars superscripted by different letters within the same cultivar are significantly different for CAT activity at the 0.05 probability level.

3 讨论

随着人民生活水平的提高,农产品质量和安全问题越来越受到关注,而农业上时常以污水灌溉及使用城市垃圾和污泥制作的肥料,均会导致农田中有机污染物的累积^[2,4,28],水稻最易受农田中有机污染物的影响。种子萌发是作物生长发育的起点。刘宛等^[15]研究表明,小麦种子发芽率对 1,2,4-TCB 胁迫是一个相对不敏感的指标。陈文军等^[20]以往收集了 50 个水稻品种,在 1,2,4-TCB 胁迫下,种子发芽势和发芽率不敏感,幼苗生物量降低且存在显著的基因型差异。本研究再次证明这一结果。泗阳 1382 生物量降低幅度比香粳 20-18 大,表现其对 TCB 的敏感性。

蛋白质是生物细胞中最重要的有机物质之一,生物的各种功能主要是通过蛋白质来实践的。生物体内蛋白质含量的变化是外界胁迫下生物生长发育受到影响的直接指示^[29]。杜青平等^[14]发现 1,2,4-TCB 使藻体内蛋白质含量降低,呈现一定的浓度效应。葛才林等^[29]发现 1,2,4-TCB 胁迫能诱导水稻品种矮籽占、汕优 63 根系内不同类型蛋白质的表达,认为诱导蛋白的差异表达可能是汕优 63 较矮籽占对 TCB 胁迫有较高耐性的机理之一。本研究表明,1,2,4-TCB 胁迫下,香粳 20-18 叶片可溶性蛋白质含量上升,泗阳 1382 显著下降。由于根系直接接触 TCB,低浓度 1,2,4-TCB 胁迫下两个水稻品种根系可溶性

蛋白质含量均下降,高浓度 1,2,4-TCB 胁迫下香粳 20-18 蛋白质含量升高,泗阳 1382 蛋白质含量下降。这说明 1,2,4-TCB 胁迫诱导了耐性基因型香粳 20-18 蛋白的表达,引起蛋白质含量上升;1,2,4-TCB 胁迫导致敏感基因型泗阳 1382 可溶性蛋白含量下降的原因可能是其进入水稻体内,和 DNA 共价结合或造成 DNA 损伤,进而影响基因活力,造成 mRNA 转录受阻,引起蛋白质合成的抑制或者是 1,2,4-TCB 诱导了水稻体内蛋白水解酶活性的增强,加速蛋白质水解的结果。

逆境下植物产生较多的活性氧,引起膜脂过氧化而导致膜系统受损,最终使组织受到破坏。SOD、POD 和 CAT 共同组成植物体内一个有效的活性氧清除系统,能够有效地清除植物体内的自由基和过氧化物。SOD 催化 O_2^- 形成 H_2O_2 , H_2O_2 仍然是活性氧一种存在形式,其最终被消除主要依赖于 CAT,此外 ASP、POD 等保护酶也清除部分 H_2O_2 ^[30]。丙二醛(MDA)是植物膜脂过氧化物作用的最终产物,具有细胞毒性,是膜系统受害的重要标志之一^[31]。本研究结果显示,两品种对 1,2,4-TCB 胁迫的响应存在明显的基因型差异,耐性基因型香粳 20-18 在 1,2,4-TCB 浓度较低时尚能通过提高 SOD、POD 和 CAT 的活性来清除多余的活性氧,在 1,2,4-TCB 浓度较高时 POD 和 CAT 活性才受到抑制,而敏感基因型泗阳 1382 叶片抗氧化酶清除活性氧的能力较弱,导致活性氧积累,积累的 O_2^- 和 H_2O_2 攻击生物膜,引起膜脂过氧化加剧,最终其 MDA 含量高于耐性基因型。对于根系,耐性基因型清除活性氧的能力较敏感基因型强,其 MDA 含量也低于敏感基因型。可以认为 1,2,4-TCB 对幼苗根系的伤害较叶片大。1,2,4-TCB 胁迫下水稻植株新合成逆境蛋白质多或者原有蛋白质降解少、抗氧化保护酶系统能力强、膜脂过氧化程度较轻是耐性基因型香粳 20-18 的重要生理特征。此外本试验是在水稻苗期进行的,未涉及后期对 1,2,4-TCB 胁迫的生理响应,在水稻高产栽培中选用耐性品种时,更要注意 1,2,4-TCB 积累部位,我们期望能够筛选出根、茎、叶积累多,籽粒积累少的品种,这样既修复了污染的环境,又符合安全稻米的生产要求。

4 结论

1,2,4-TCB 胁迫对水稻耐性基因型和敏感基因型的种子发芽率和发芽指数无明显影响,对幼苗根

系的伤害较叶片大, 能显著降低幼苗的生物量, 耐性基因型香粳 20-18 降低幅度相对较小。水稻叶片和根系的蛋白质含量高、抗氧化酶系统清除活性氧的能力强、膜脂过氧化程度轻是耐性基因型的主要生理特征。

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