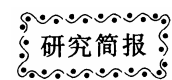


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## 非生物胁迫对玉米杂交种及其亲本自交系产量性状的影响

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**摘 要:** 以抗逆性较强玉米杂交种郑单 958 及其亲本(郑 58、昌 7-2)和抗逆性较差的杂交种陕单 902 及其亲本(K22、K12)为材料, 在不同种植密度(45 000 株  $\text{hm}^{-2}$  和 75 000 株  $\text{hm}^{-2}$ )、施氮量(112.5 kg  $\text{hm}^{-2}$  和 337.5 kg  $\text{hm}^{-2}$ )和灌水量(正常灌水和前期干旱控水)条件下, 分析了 2 个杂交种及其亲本产量及相关生理特性的变化规律。结果表明, 在非生物胁迫条件下(高密度、低氮和前期干旱控水), 与陕单 902 相比, 品种郑单 958 叶面积指数、SPAD 值、花后干物质积累量和产量的中亲优势值分别增加 18%、9%、28%和 22%; 与陕单 902 亲本(K22、K12)比, 郑单 958 亲本(郑 58、昌 7-2)叶面积指数、SPAD 值、花后干物质积累量和产量的中亲值分别增加 45%、36%、51%和 45%; 郑单 958 产量的中亲值和产量优势显著高于陕单 902, 且中亲值增幅高于杂种优势值。玉米杂交种郑单 958 较陕单 902 增产的同时, 增强了对非生物逆境适应的能力。玉米杂交种的抗逆性来自亲本自交系。玉米杂交种抗逆性强在于增强了花后叶片光合能力(较高的 LAI 和 SPAD 值), 促进了花后干物质积累。

**关键词:** 玉米; 杂交种; 自交系; 抗逆性; 产量

## Effects of Abiotic Stress on Yield Traits of Maize Hybrids and Their Parental Inbred Lines

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**Abstract:** The field experiments were conducted to study the changes of grain yield and concerned physiological traits in stress-tolerant maize variety Zhengdan 958 and its parental inbred lines (Zheng 58 and Chang 7-2), as well as stress-sensitive maize variety Shaandan 902 and its parental inbred lines (K22 and K12) under different treatments of density (45 000 and 75 000 plants  $\text{ha}^{-1}$ ), nitrogen application (112.5 and 337.5 kg  $\text{ha}^{-1}$ ), and irrigation (normal irrigation and controlling water at prophase). The results showed that there were little differences in yield, mean leaf area index after anthesis, mean SPAD after anthesis, post-anthesis dry matter accumulation and harvest index between Zhengdan 958 and Shaandan 902 under resource-replete conditions (low density, high nitrogen and normal irrigation). But there were great differences in all traits (besides harvest index) between Zhengdan 958 and Shaandan 902 under abiotic stress (high density, low nitrogen and drought stress), with much higher values in Zhengdan 958 than in Shaandan 902. Compared with Shaandan 902, mid-parent values of leaf area index, SPAD, post-anthesis dry matter accumulation and grain yield of Zhengdan 958 under abiotic stress (high density, low nitrogen and drought stress) increased by 45%, 36%, 51%, and 45%, respectively, and heterosis of Zhengdan 958 increased by 18%, 9%, 28%, and 22%, respectively. The mid-parent value of yield was much higher than heterosis of yield and both of them were higher in Zhengdan 958 than in Shaandan 902. So the maize variety Zhengdan 958 showed greater tolerance to abiotic stress which was mainly inherited from its parental inbred lines. Higher SPAD and LAI after anthesis contributed to post-anthesis dry matter accumulation, resulting in higher yield and higher stress tolerance.

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**Keywords:** Maize; Hybrids; Inbred lines; Stress tolerance; Grain yield

玉米杂交种被广泛应用以来,籽粒产量持续增长<sup>[1]</sup>。玉米产量增加的50%~60%归功于遗传增益,其余的归功于栽培管理的改进<sup>[2-3]</sup>。Tollenaar等<sup>[4]</sup>认为玉米产量改良依赖提高耐受胁迫能力和杂种优势。杂种优势对产量的贡献在不变或减少<sup>[5]</sup>。众多学者研究表明现代玉米品种产量增益来源于忍耐非生物胁迫能力的提高,特别是耐密性<sup>[6-8]</sup>。不同玉米在不同密度下的生理特性已有大量文献报道<sup>[9-12]</sup>,高密度下现代玉米品种能够截获更多的光能,生产的干物质有效地转运至籽粒<sup>[13-14]</sup>。干旱和低氮也是限制玉米产量两大非生物胁迫因素,导致叶片光合速率降低,叶片早衰,干物质积累与转运降低,粒重减少,造成减产<sup>[15-17]</sup>。一些育种工作者研究证明,产量杂种优势受到环境胁迫的影响,杂交种及其亲本产量在胁迫条件下较正常条件下降低<sup>[18]</sup>。而不同密度、施氮量和灌水量等综合环境下杂交种产量、亲本自交系产量和产量杂种优势是否有相同的变化规律,缺乏相关的研究报道。本文旨在阐明非生物胁迫条件下,杂交种及其亲本自交系的籽粒产量和产量杂种优势的变化规律,及其与相关生理性状的关系,为改良玉米品种的抗逆性提供理论依据。

## 1 材料与方法

### 1.1 供试材料

在前期试验基础上,选用抗逆性较强的玉米杂交种郑单958<sup>[19]</sup>及亲本自交系郑58(母本)和昌7-2(父本)和抗逆性较差的杂交种陕单902<sup>[19]</sup>及亲本自交系K22(母本)和K12(父本)为试材。

### 1.2 试验设计

试验于2010年在陕西杨凌西北农林科技大学农作物新品种示范园进行。前茬为玉米,地力均匀,肥力中等。0~20 cm耕层土壤含有机质1.06%、全氮0.0935%、速效氮55.2 mg kg<sup>-1</sup>、速效磷11.7 mg kg<sup>-1</sup>、速效钾314 mg kg<sup>-1</sup>。玉米生育期5月至9月降雨量为401.6 mm。

设密度、氮肥和水分3个独立试验。采用裂区设计,主区分别为密度、氮肥和水分,试验材料为副区,3次重复,6行区,行长5 m,行距0.6 m。小区间设置3 m的隔离带,以避免水分和施肥的影响。密度试验中,设45 000株hm<sup>-2</sup>和75 000株hm<sup>-2</sup>,施氮肥量为225 kg hm<sup>-2</sup>,进行正常灌水。氮肥试验中,施氮112.5 kg hm<sup>-2</sup>和337.5 kg hm<sup>-2</sup>,密度为60 000株hm<sup>-2</sup>,进行正常灌水。水分试验中,苗期、拔节期、吐丝期各灌水1次,灌水量分别为600、600和600 m<sup>3</sup> hm<sup>-2</sup>,干旱胁迫处理为苗期和拔节期控水,密度为60 000株hm<sup>-2</sup>,施氮量为225 kg hm<sup>-2</sup>。其他管理同一般大田。成熟后取中间4行收获计产。

### 1.3 测定项目与方法

1.3.1 叶绿素含量 分别于吐丝期、吐丝后25 d和成熟期从中间4行选取5株有代表性玉米,用SPAD-502叶

绿素仪测定穗位叶的SPAD值。

1.3.2 叶面积指数 分别于吐丝期、吐丝后25 d和成熟期选取5株有代表性植株测定叶面积,叶面积=长×宽×0.75,叶面积指数(LAI)=单株叶面积×单位土地面积内株数/单位土地面积。

1.3.3 干物质积累量 于吐丝期和成熟期选取5株有代表性的植株,将地上部分分为茎、叶、鞘、穗和轴5个部分,先称其鲜重,在105℃下杀青30 min,80℃下烘干,计算干物质积累量和收获指数。

中亲值(MP)为双亲的平均值,中亲优势(F<sub>1</sub>-MP)=杂种值-中亲值<sup>[1]</sup>。

## 2 结果与分析

### 2.1 不同密度、氮肥和水分条件下玉米杂交种及亲本产量的变化

资源供给充足条件下(低密度、高氮和正常灌水),郑单958与陕单902及其亲本之间产量差异较小;而资源供给匮乏的非生物逆境条件下(高密度、低氮和干旱),2个杂交种及其亲本之间产量差异较大,郑单958显著高于陕单902。从图1可知,在3种非生物逆境下,与陕单902相比,郑单958产量中亲值分别增加50%、43%和41%,郑单958产量中亲优势分别增加25%、19%和22%。说明郑单958在非生物逆境下产量的增进源于自交系产量的提高。

### 2.2 不同密度、氮肥和水分条件下玉米杂交种及亲本叶面积指数和SPAD值的变化

在资源供给充足条件下(低密度、高氮和正常灌水),郑单958与陕单902及其亲本之间花后叶面积指数的平均值差异较小。而资源供给匮乏的非生物逆境条件下(高密度、低氮和干旱),郑单958与陕单902及其亲本之间花后叶面积指数的差异增大,郑单958显著高于陕单902。从图2可知,在3种非生物逆境下,2个品种叶面积指数中亲值差异较大,郑单958比陕单902分别增加41%、48%和45%;2个品种叶面积指数中亲优势差异也较大,郑单958比陕单902分别增加15%、20%和17%。说明在非生物逆境下,郑单958及其亲本叶面积指数高于陕单902。

在资源供给充足条件下(低密度、高氮和正常灌水),郑单958与陕单902及其亲本之间花后SPAD平均值差异较小。而资源供给匮乏的非生物逆境条件下(高密度、低氮和干旱),郑单958与陕单902及其亲本之间花后SPAD平均值的差异增大,郑单958显著高于陕单902。从图3可知,在3种非生物逆境下,2个品种SPAD中亲值差异较大,郑单958比陕单902分别增加33%、32%和42%;2个品种SPAD中亲优势差异也较大,郑单958比陕单902分别增加7%、10%和9%。说明在非生物逆境下,郑单958及其亲本吐丝至成熟期SPAD平均值高于陕单902。

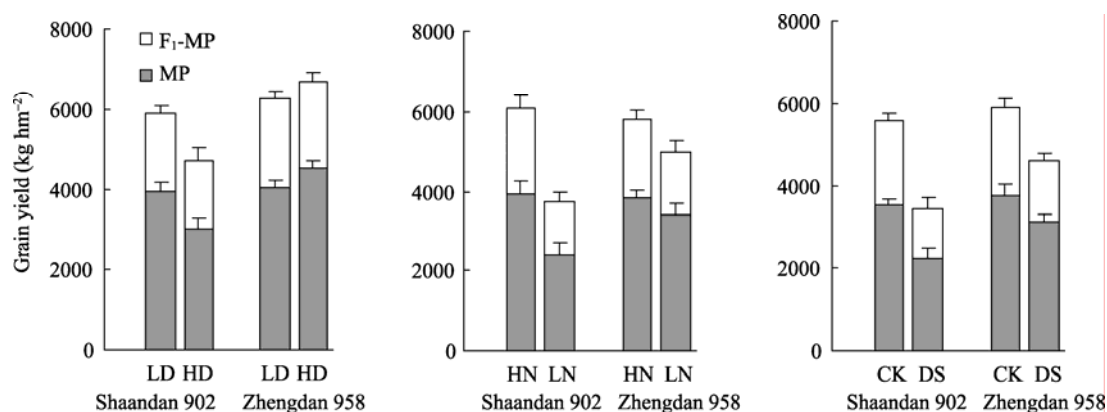


图 1 不同密度、氮肥和水分条件下玉米产量的杂种值、中亲值和中亲优势变化

**Fig. 1** Changes of heterosis, mid-parent value and mid-parent heterosis in yield under different density, nitrogen and water treatments  
 LD: 低密度; HD: 高密度; HN: 高氮; LN: 低氮; CK: 正常供水; DS: 干旱. MP 为中亲值, F<sub>1</sub>-MP (中亲优势) 为杂种值减去中亲值部分。  
 LD: low density; HD: high density; HN: high nitrogen; LN: low nitrogen; CK: normal irrigation; DS: drought stress. MP: mid-parent value;  
 F<sub>1</sub>-MP (heterosis): hybrid minus MP.

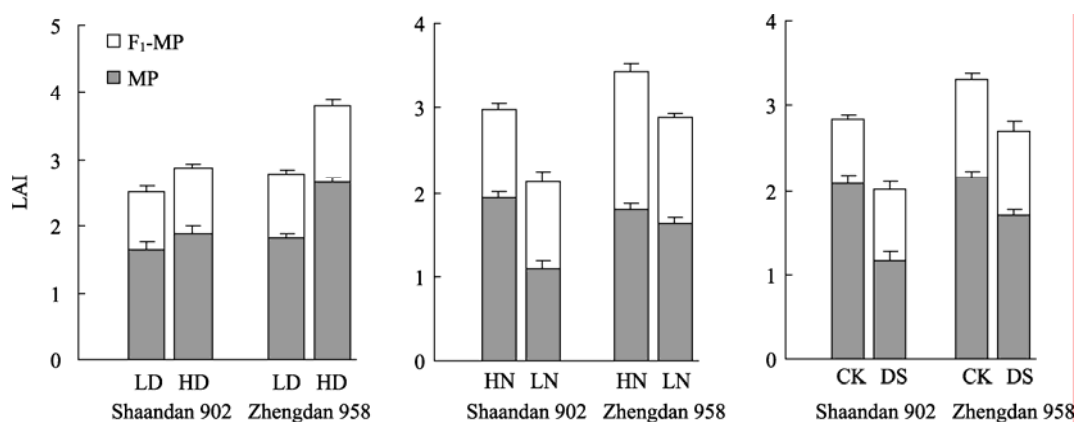


图 2 不同密度、氮肥和水分条件下玉米花后叶面积指数平均值的杂种值、中亲值和中亲优势变化

**Fig. 2** Changes of heterosis, mid-parent value and mid-parent heterosis in mean leaf area index after anthesis under different density, nitrogen, and water treatments  
 LD: 低密度; HD: 高密度; HN: 高氮; LN: 低氮; CK: 正常供水; DS: 干旱. MP 为中亲值, F<sub>1</sub>-MP (中亲优势) 为杂种值减去中亲值部分。  
 LD: low density; HD: high density; HN: high nitrogen; LN: low nitrogen; CK: normal irrigation; DS: drought stress. MP: mid-parent value;  
 F<sub>1</sub>-MP (heterosis): hybrid minus MP.

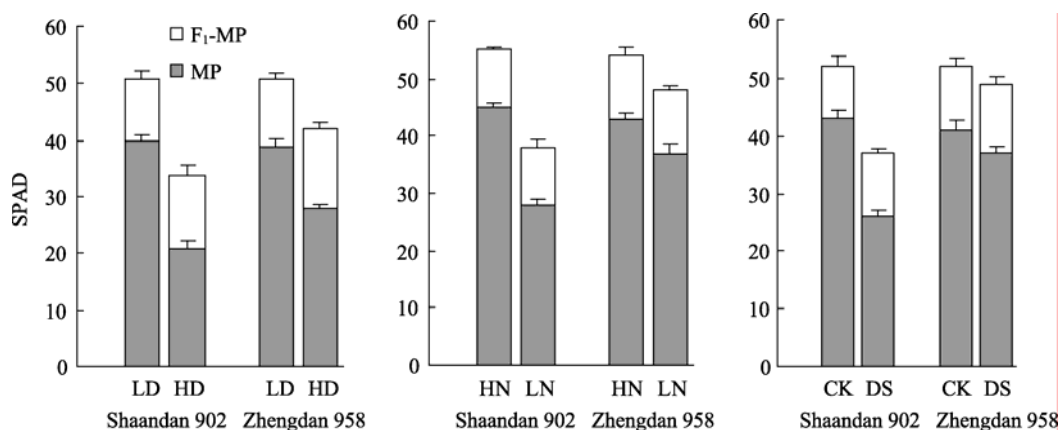


图 3 不同密度、氮肥和水分条件下玉米花后 SPAD 的平均值的杂种值、中亲值和中亲优势变化

**Fig. 3** Changes of heterosis, mid-parent value and mid-parent heterosis in mean SPAD after anthesis under different density, nitrogen, and water treatments  
 LD: 低密度; HD: 高密度; HN: 高氮; LN: 低氮; CK: 正常供水; DS: 干旱. MP 为中亲值, F<sub>1</sub>-MP (中亲优势) 为杂种值减去中亲值部分。  
 LD: low density; HD: high density; HN: high nitrogen; LN: low nitrogen; CK: normal irrigation; DS: drought stress. MP: mid-parent value;  
 F<sub>1</sub>-MP (heterosis): hybrid minus MP.

**2.3 不同密度、氮肥和水分条件下花后干物质积累量的变化**  
在资源供给充足条件下(低密度、高氮和正常灌水), 郑单 958 与陕单 902 及其亲本之间花后干物质积累量差异较小。而资源供给匮乏的非生物逆境条件下(高密度、低氮和干旱), 郑单 958 与陕单 902 及其亲本之间花后干物质积累量的差异增大, 郑单 958 显著高于陕单 902。从图 4 可知, 在 3 种非生物逆境下, 2 个品种花后干物质积累量中亲值差异较大, 郑单 958 比陕单 902 分别增加 58%、46% 和 47%; 2 个品种花后干物质积累量中亲优势差异也较大, 郑单 958 比陕单 902 分别增加 29%、28% 和 25%。说明在非生物逆境下, 郑单 958 及其亲本花后干物质积累量高于陕单 902。

**2.4 不同密度、氮肥和水分条件下玉米杂交种及亲本收获指数变化**

不论是在资源供给充足条件下(低密度、高氮和正常

灌水)还是在资源供给匮乏的非生物逆境条件下(高密度、低氮和干旱), 郑单 958 与陕单 902 及其亲本之间收获指数的差异都较小。从图 5 可知, 在 3 种非生物逆境下, 与陕单 902 相比, 郑单 958 的收获指数中亲值分别增加 11%、17% 和 15%, 郑单 958 收获指数中亲优势分别增加 11%、9% 和 8%, 品种间差异不显著。

### 3 讨论

Duvick<sup>[2,5]</sup>对过去 70 年美国玉米研究表明, 产量来自抗逆性。我国学者对中国玉米研究也表明玉米单株生产力并未发生变化, 玉米增产主要是由于耐非生物胁迫能力的提高, 特别是耐密性<sup>[3,6]</sup>。本研究, 在非生物逆境胁迫下(高密度、低氮和前期干旱), 郑单 958 的产量明显高于陕单 902。逆境胁迫对玉米的影响最终体现在产量上, 玉米抗逆性强弱与其在逆境胁迫下的产量表现有最直接的

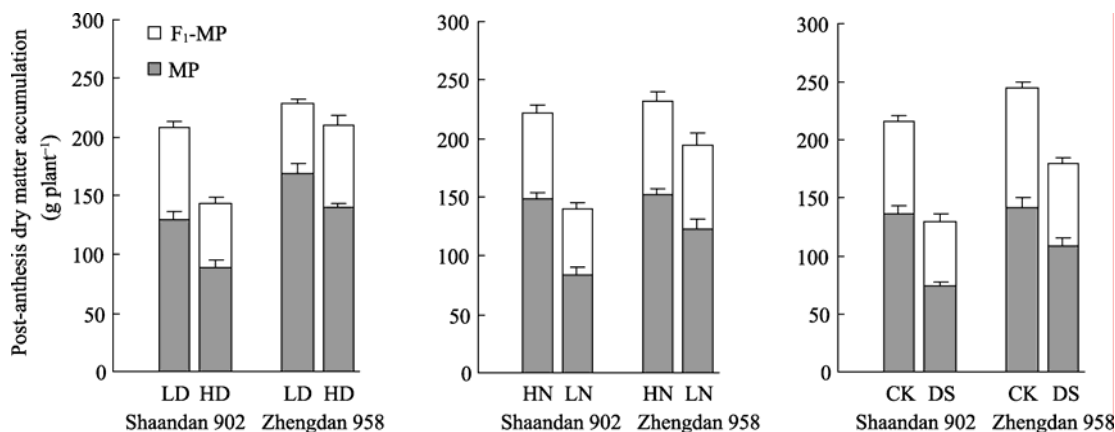


图 4 不同密度、氮肥和水分条件下玉米花后干物质积累量的杂种值、中亲值和中亲优势变化

**Fig. 4 Changes of heterosis, mid-parent value and mid-parent heterosis in post-anthesis dry matter accumulation under different density, nitrogen, and water treatments**

LD: 低密度; HD: 高密度; HN: 高氮; LN: 低氮; CK: 正常供水; DS: 干旱。MP 中亲值, F<sub>1</sub>-MP(中亲优势)为杂种值减去中亲值部分。

LD: low density; HD: high density; HN: high nitrogen; LN: low nitrogen; CK: normal irrigation; DS: drought stress.

MP: mid-parent value; F<sub>1</sub>-MP (heterosis): hybrid minus MP.

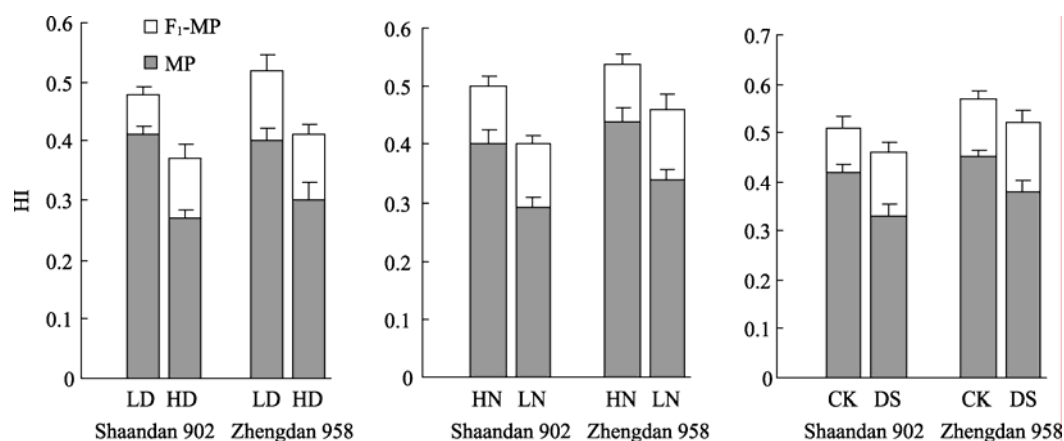


图 5 不同密度、氮肥和水分条件下玉米收获指数的杂种值、中亲值和中亲优势变化

**Fig. 5 Changes of heterosis, mid-parent value and mid-parent heterosis in harvest index under different density, nitrogen, and water treatments**

LD: 低密度; HD: 高密度; HN: 高氮; LN: 低氮; CK: 正常供水; DS: 干旱。MP 为中亲值, F<sub>1</sub>-MP(中亲优势)为杂种值减去中亲值部分。

LD: low density; HD: high density; HN: high nitrogen; LN: low nitrogen; CK: normal irrigation; DS: drought stress.

MP: mid-parent value; F<sub>1</sub>-MP (heterosis): hybrid minus MP.

关系<sup>[5,15]</sup>。本研究还发现郑单 958 亲本和陕单 902 亲本也显示出同样规律, 郑单 958 亲本自交系的抗逆性优于陕单 902 的亲本自交系。

玉米产量决定于成熟期地上部分的干物质积累量和收获指数<sup>[20]</sup>。干物质积累量与籽粒产量呈显著正相关, 干物质积累量越多产量越高<sup>[21]</sup>。花后干物质积累较多, 多用于籽粒形成<sup>[16]</sup>。本研究表明, 在非生物逆境胁迫下(高密度、低氮和前期干旱), 郑单 958 和陕单 902 花后干物质积累差异增大, 自交系的干物质积累量也表现出相同的变化趋势。非生物胁迫引起果穗秃尖, 降低了收获指数<sup>[6]</sup>。但在本研究中品种之间差异不显著。说明非生物胁迫下(高密度、低氮和前期干旱), 杂交种和亲本的产量主要受花后干物质积累量影响。

叶面积指数和 SPAD 反映玉米的光合能力。吐丝后较大的叶面积指数和 SPAD 值提高了叶片光合作用、干物质积累与转运, 有利于籽粒形成<sup>[15,22]</sup>。非生物逆境胁迫(高密度、低氮和前期干旱)增大了 2 个品种及其亲本之间叶面积指数和 SPAD 的差异。郑单 958 及其亲本吐丝后的光合能力明显强于陕单 902 及其亲本。

非生物胁迫下(高密度、低氮和前期干旱), 郑单 958 产量显著高于陕单 902, 这是郑单 958 产量中亲值和中亲优势高于陕单 902 所致。产量中亲值的增加幅度比中亲优势大得多, 说明非生物胁迫下杂交种抗逆性差异主要决定于亲本自交系抗逆性的差异。郑单 958 亲本自交系抗逆性强, 郑单 958 的抗逆性也强。进一步揭示了品种的抗逆性来源于其亲本自交系。本试验只对产量和主要生理指标性状进行了研究, 而抗逆性受多因素控制, 需要通过多年多点对多个品种及其亲本进行多因素试验, 综合分析杂交种和亲本自交系的产量及其性状指标与抗逆性的关系, 进一步阐明增强玉米抗逆性机制。

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