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PAC配施氮肥对高粱花后叶片抗氧化特性及产量的调控效应

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摘　要:[目的]东北地区全基施施肥方式易造成高粱生育期内营养供应失衡,导致生育后期缺氮早衰。探究全基施背景下聚天门冬氨酸和脱乙酰甲壳素对东北地区高粱花粒期叶片衰老与产量的调控效应,有助建立全基施施肥背景下高粱防衰增产生产技术。[方法]2021—2022年在中国农业科学院作物科学研究所公主岭试验基地进行大田试验,试验材料为龙杂25号和吉杂127号,设置氮肥处理与化控处理(聚天门冬氨酸和脱乙酰甲壳素复配剂,polyaspartic acid—chitosan,PAC),测定分析PAC配施氮肥下高粱叶片衰老程度、抗氧化特性和产量差异。[结果]花期到成熟期,随施氮水平增加,可显著增加2高粱品种单株叶面积,提高旗叶叶绿素相对含量与抗氧化酶活性,降低丙二醛(MDA)含量,上述指标在2品种间存在差异。PAC处理可显著提高各施氮水平下2高粱品种旗叶超氧化物歧化酶、过氧化氢酶和过氧化物酶活性以及叶绿素相对含量,显著降低MDA含量;显著抑制单株叶面积下降,延缓植株衰老进程。PAC处理后,各施氮水平下,龙杂25号和吉杂127号较各自常规施氮处理分别平均增产2.26%～9.11%和3.51%～15.76%;2高粱品种均在施氮量为150 kg·hm^{-2}时显著增产,2年平均增幅分别为9.11%和15.76%。[结论]PAC配施氮素全基施可作为一项防衰增产增效的栽培技术应用于吉林省中西部高粱产区。

关键词:聚天门冬氨酸和脱乙酰甲壳素复配剂; 全基施; 高粱; 抗氧化特性; 产量
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高粱(*Sorghum bicolor*),是我国重要的经济作物,可分为食用、糖用、帚用等用途[1];其抗旱性强、适应性广,在我国广泛栽植,以华北、东北地区为主[2]。高粱作为我国北方主要的杂粮之一,在我国种植业结构调整、农业产业发展、绿色生产和保障粮食安全等方面具有重要意义[3-5]。在大田生产中,普遍通过施加氮肥来促进作物生长发育和实现增产稳产目标[6]。研究表明,在实际农业生产实践中,由于当代农村劳动力的减少和人力成本的增加,农民常常采用一次性全基施的施肥方式来应对作物的需肥要求[7]。但由于作物早期需氮量少,多余氮素易挥发流失,导致生育前期"烧苗"、后期缺氮,从而引起植株叶片早衰,产量降低[8-9];同时,早期流失的氮肥也会造成一系列负效应,如农业资源和经济的双重浪费、水土污染以及花房效应等[10-14]。研究发现,全基施氮肥处理相较于分次追施氮肥会使作物花后叶片的叶绿素含量与抗逆能力显著降低,植株衰老过程显著加快[15-16]。此外,氮肥全基施处理还会导致活性氧代谢失衡和膜脂过氧化程度升高,降低抗逆能力,从而影响作物产量的形成;若在作物产量形成的关键时期内同时缺少氮肥供应,则进一步推进植株衰老,影响植株正常代谢。在叶片衰老过程中,活性氧代谢失调,加剧不饱和脂肪酸的降解,促进膜脂过氧化

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产物不断积累,推进细胞程序性死亡过程。植物体内含有应对膜脂过氧化的酶促防御系统,该系统具有各种保护酶,如超氧化物歧化酶(SOD)、过氧化物酶(POD)和过氧化氢酶(CAT)[17]。SOD能清除自由基,产生歧化产物过氧化氢(H_2O_2),维持细胞内的氧化还原平衡,被视作植物抗氧化系统的第一道防线;POD和CAT则能酶促降解H_2O_2等高氧化物,避免有害活性氧积累损伤细胞,延缓植株衰老[18-20]。然而研究表明,合理施加氮肥可以增强作物的抗氧化酶活性,减少膜脂过氧化产物,提高植株抗逆防衰能力,延长叶片持绿期,促进干物质积累与转运[21-23]。因此,保证高粱花后氮素供应,提高叶片保护酶活性,降低丙二醛(MDA)含量,延缓叶片衰老,将为全基施背景下防止高粱早衰和增产提供有利基础。

肥料增效剂PAC(polyaspartic acid-chitosan),由聚天门冬氨酸(PASP)和脱乙酰甲壳素(CTS)复配而成。其中,PASP是一种天然存在软体动物壳内的氨基酸类聚合物,内含丰富的酰胺键、羧基等活性基团,极易被完全降解为CO_2和H_2O,具有螯合分散、生物降解以及环境友好等多种性能[24];在农业领域方面,多作为增效剂和缓释剂与肥料配施,可富集大量营养元素,改善土壤质量,促进氮素吸收与转运,提高干物质积累量和产量等[25-28],达到根深叶茂、改善品质的效果。CTS是甲壳素脱部分乙酰后的天然多糖类聚合物,又称壳聚糖,具有无毒抑菌、增强免疫等多种生理功能[29-30],被誉为"人类第六大生命要素";因其具有良好的缓释性与自然降解性,在农业上常与农药、肥料一起使用,可实现改善土壤性能,减缓营养元素释放速率,促进植物生长代谢与渗透调节,加强植株抗逆能力,提高产量和改善品质等目的[31-34]。东北春谷试验[35-39]表明,PAC能有效解决全基施施肥造成的谷子生育后期氮素供应不足的问题,降低氮肥损失,促进氮素吸收和积累,增强抗氧化酶活性,延缓叶片衰老,提高氮肥利用效率和产量。因此,本试验旨在研究全基施背景下PAC配施氮肥对东北地区高粱花后叶片抗氧化特性与产量的影响,以期实现缓解全基施施肥方式引起的高粱花粒期叶片缺氮早衰现象,为建立东北地区高粱的全基施绿色增产栽培技术提供理论依据和技术支撑。

1 材料与方法

1.1 试验地概况

大田试验于2021-2022年在中国农业科学院作物科学研究所公主岭试验基地(43°29′55″N,124°48′43″E)进行。试验地5-9月内有效积温约3000 ℃,日均气温20.1 ℃,降水量约580 mm。试验地耕作层土壤情况见表1。

表1 试验地耕作层土壤情况

Table 1 Soil conditions of the plough layer in the experimental site

指标 Indices	结果 Results
土壤类型	黑土
全氮含量/(g·kg^{-1})	1.4
速效氮含量/(mg·kg^{-1})	155.3
速效磷含量/(mg·kg^{-1})	34.4
速效钾含量/(mg·kg^{-1})	184.2
有机质含量/(g·kg^{-1})	26.7
pH值	5.8

1.2 试验材料与设计

本试验以龙杂25号(Longza 25,简称LZ)和吉杂127号(Jiza 127,简称JZ)为材料,采用裂区试验设计,主区为PAC处理,PASP含量为3‰,CTS含量为0.45‰,拌入基肥一同施入,以常规氮肥处理为对照;副区为氮肥梯度,设置4个水平分别为:N0、N1、N2和N3,各处理PAC用量和施氮量见表2(CN为常规氮肥处理,PN为PAC配施氮肥处理)。每小区施加同等剂量的磷肥和钾肥(P_2O_5 75.0 kg·hm^{-2}和K_2O 75.0 kg·hm^{-2}),并与氮肥(缓释尿素)全部作为基肥施入,后期不追肥。试验小区长6.0 m、宽4.2 m,每个处理设3次重复。高粱种植密度为11.25万株·hm^{-2},等行距起垄播种,行距为0.6 m。田间中耕、除草、植保等管理措施与当地大田生产相同。2021年5月14日播种,LZ于9月10日收获,JZ于9月18日收获;2022年5月12日播种,LZ于9月8日收获,JZ于9月18日收获。

1.3 测定指标与方法

1.3.1 单株绿叶面积和叶面积降幅

在各小区中选择6株固定的代表植株,于开花之日起,每隔10 d采用长宽系数法测定叶面积(叶面积=叶长×叶宽×0.75);按照Tollenaar等[40]的方法,以一段时间内前后2次测得的绿叶面积降幅表征叶片的衰老程度,即叶面积降幅=(LA2−

LA1)/LA1×100%。其中,LA1和LA2分别代表前后2次测得的单株绿叶面积。

1.3.2　叶绿素相对含量

在各小区中选择6株固定的代表植株,于开花之日起,每隔10 d采用手持式SPAD-502型叶绿素计(Soil-plant Analysis Development Section, Minolta Camera Co.,日本)测定旗叶叶绿素相对含量(SPAD值)。

1.3.4　SOD、CAT、POD活性及MDA含量

于开花之日起,每隔10 d的上午10点,在每小区选取2~3株长势相同的单株剪其旗叶,去掉叶脉、叶缘、叶基和叶端,液氮速冻后储存于-20 ℃冰箱。参照王永军等[41]的方法测定SOD、CAT、POD活性以及MDA含量。

1.3.5　产量及其构成因素

收获测产于成熟期在每小区选取约2 m×6 m大小区域的长势相同的高粱植株,经晾晒至一定程度后进行脱粒称重,并折算出公顷产量。

表2　CN和PN处理的氮肥与PAC用量

Table 2　Nitrogen fertilizer and PAC application amounts in CN and PN treatments　**单位:**kg·hm^{-2}

处理 Treatment	施氮水平 Nitrogen application level	氮肥用量 Nitrogen fertilizer application amount	PASP用量 PASP application amount	CTS用量 CTS application amount
CN	N0	0	0	0
	N1	75	0	0
	N2	150	0	0
	N3	225	0	0
PN	N0	0	0	0
	N1	75	0.937 5	1.5
	N2	150	1.875 0	3.0
	N3	225	2.812 5	4.5

1.4　统计分析

整理数据及作图采用Microsoft Excel 2016软件,统计分析采用IBM SPSS Statistics 22软件,检验平均数间的差异显著性采用Duncan法及成对法T检验($P<0.05$)。2年试验结果呈现出的趋势基本一致,因此本文中采用2022年的数据。

2　结果与分析

2.1　施用PAC后高粱叶片衰老进程

如图1所示,花粒期2高粱品种单株绿叶面积随施氮量增加而增加;品种间LZ高于JZ。N0~N3施氮水平下,2高粱品种花后每隔15 d叶面积呈降低趋势,LZ降幅分别为6.27%~12.45%、5.58%~11.97%、4.23%~11.80%和2.79%~11.69%,JZ降幅分别为4.61%~12.05%、4.42%~10.41%、3.60%~11.65%和2.24%~9.07%。PAC处理可显著降低2高粱品种叶面积降幅。N1~N3施氮水平下,LZ-PN花后每隔15 d降幅较LZ-CN分别减小13.03%~20.81%、1.25%~20.60%和5.93%~22.32%;JZ-PN较JZ-CN分别减小12.31%~30.02%、6.58%~42.46%和6.35%~31.87%。

2.2　施用PAC后高粱旗叶SPAD值

如图2所示,花粒期2高粱品种旗叶SPAD值随施氮量增加而增加;品种间LZ高于JZ。PAC处理后,N1~N3施氮水平下,2高粱品种旗叶SPAD值均有提高,花后10~40 d时较CN达显著水平。N1~N3施氮水平下,LZ-PN较LZ-CN增幅分别为5.47%~8.34%、5.46%~8.41%和5.25%~8.41%;JZ-PN较JZ-CN增幅分别为5.35%~6.38%、3.78%~10.64%和5.18%~10.41%。

2.3　施用PAC后高粱旗叶抗氧化酶活性

2.3.1　施用PAC后高粱旗叶SOD活性

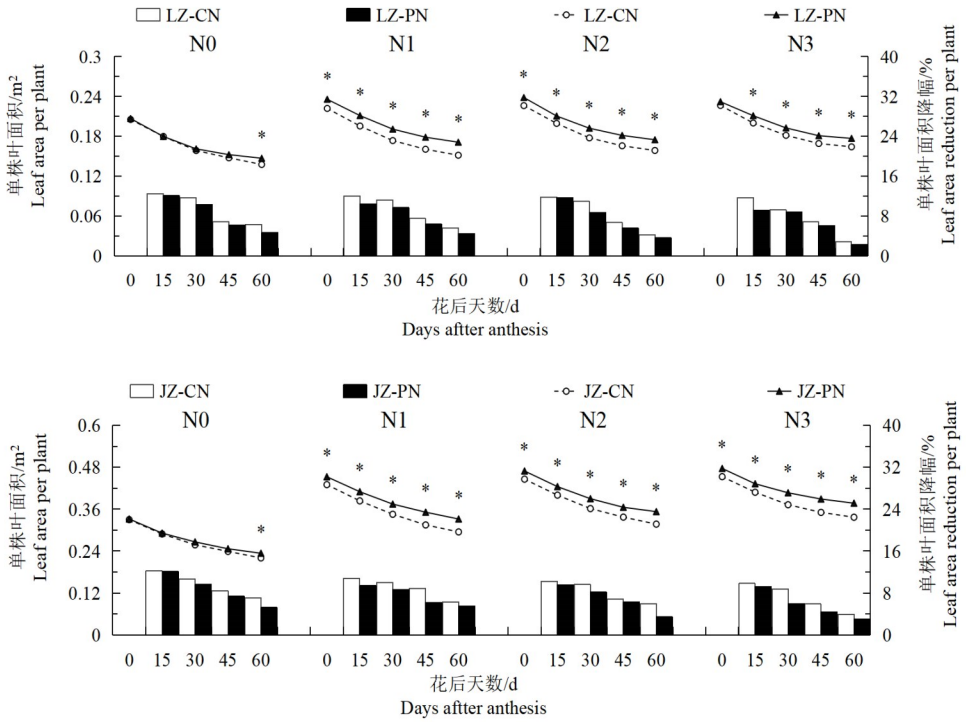
如图3所示,花粒期2高粱品种旗叶SOD活性随施氮量增加呈先升后降趋势,品种间LZ高于JZ。PAC处理后,N1~N3施氮水平下2高粱品种SOD活性显著提高,LZ-PN较LZ-CN分别显著增加13.72%、14.31%和10.93%;JZ-PN较JZ-CN分别显著增加17.51%、15.76%和11.63%。

2.3.2　施用PAC后高粱旗叶POD活性

如图4所示,花粒期2高粱品种旗叶POD活性随施氮量增加呈先升后降趋势;品种间LZ高于JZ,且LZ花后0~20 d增幅显著高于JZ。PAC处理后,N1~N3施氮水平下2高粱品种旗叶POD活性显著提高,LZ-PN较LZ-CN分别显著增加14.80%、19.84%和21.49%;JZ-PN较JZ-CN分别显著增加10.00%、18.12%和18.55%。

2.3.3　施用PAC后高粱旗叶CAT活性

如图5所示,随施氮量增加,2高粱品种的旗叶CAT活性呈先升后降趋势;品种间LZ在N2、N3水平下显著高于JZ。PAC处理后,N1~N3施氮水平下2高粱品种旗叶CAT活性显著提高,LZ-PN



*表示同一施氮水平下同个品种不同处理间差异显著($P<0.05$)

* indicate significant difference at $P<0.05$ between different treatments of the same variety under the same nitrogen application level

图1 各施氮水平下高粱单株绿叶面积及其降幅对PAC的响应

Fig. 1 Response of green leaf area per sorghum plant and its reduction to PAC under different nitrogen application levels

较LZ-CN分别显著增加13.46%、11.93%和13.76%;JZ-PN较JZ-CN分别显著增加9.94%、18.13%和11.43%。

2.4 施用PAC后高粱旗叶MDA含量

如图6所示,花粒期2高粱品种的旗叶MDA含量随施氮量增加呈先降后升趋势;品种间JZ显著高于LZ。PAC处理后,N1~N3施氮水平下2高粱品种旗叶MDA含量显著降低,LZ-PN较LZ-CN分别显著降低13.02%、10.54%和11.50%;JZ-PN较JZ-CN分别显著降低9.20%、9.18%和10.46%。

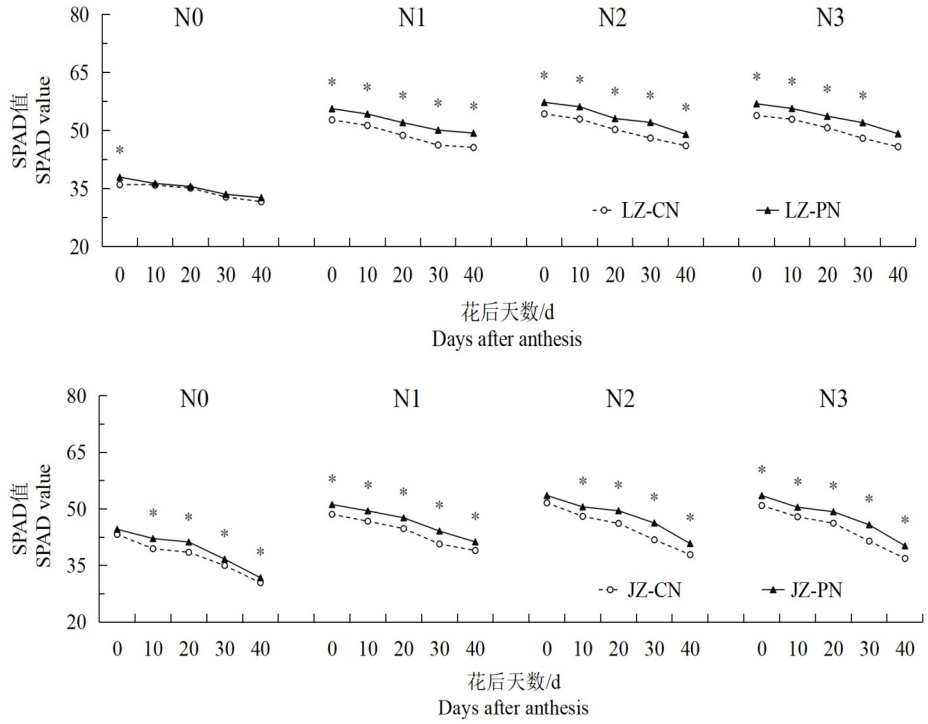
2.5 施用PAC后高粱产量

如图7所示,LZ与JZ的产量均随施氮水平增加呈现先增后减趋势,N2施氮水平下达到最大值;JZ产量显著高于LZ。LZ在N2水平下比N0显著增产33.11%,比N1和N3分别增产3.57%和0.34%;JZ在N2水平下比N0显著增产77.70%,比N1和N3分别增产1.29%和1.14%。PAC处理后,2高粱品种在N1~N3水平下较常规施氮处理均达显著水平。N0~N3施氮水平下,LZ-PN较LZ-CN分别增加3.43%、10.10%、10.03%和7.05%;JZ-PN较JZ-CN分别增加3.40%、22.45%、23.19%和15.58%。

如表3所示,N0~N3施氮水平下,2高粱品种千粒重均随施氮量增加而升高,品种间表现为JZ显著高于LZ;PAC处理后,LZ-PN较LZ-CN提高1.26%~3.12%,JZ-PN较JZ-CN提高1.12%~4.85%。N0~N3施氮水平下,2高粱品种有效穗数随施氮量增加而升高,品种间JZ显著高于LZ;PAC处理后,LZ-PN较LZ-CN提高1.83%~6.89%,JZ-PN较JZ-CN提高4.72%~6.50%。2高粱品种单穗粒数在N1~N3施氮水平下随施氮量增加而降低,品种间JZ显著高于LZ;PAC处理后,LZ-PN较LZ-CN提高5.17%~13.07%,JZ-PN较JZ-CN提高1.91%~10.86%。

3 讨论

花粒期是影响作物籽粒灌浆与产量形成的关键时期,随着时间的推移,叶片叶绿素与无机物含量逐渐降低,光合效率与各种代谢速率逐渐减退,植株开始进入衰老失绿阶段。施加适量氮肥可以增加单株叶面积,提高叶绿素相对含量,提高光合

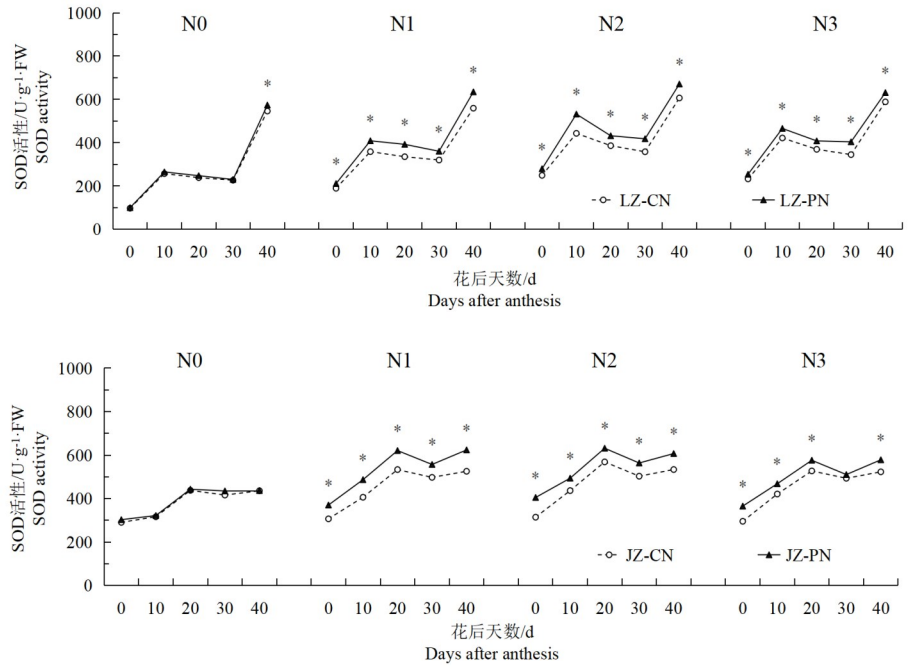


*表示同一施氮水平下同个品种不同处理间差异显著($P<0.05$)

* indicate significant difference at $P<0.05$ between different treatments of the same variety under the same nitrogen application level

图2　各施氮水平下高粱旗叶SPAD值对PAC的响应

Fig.2　Response of SPAD value of sorghum flag-leaf to PAC under different nitrogen application levels

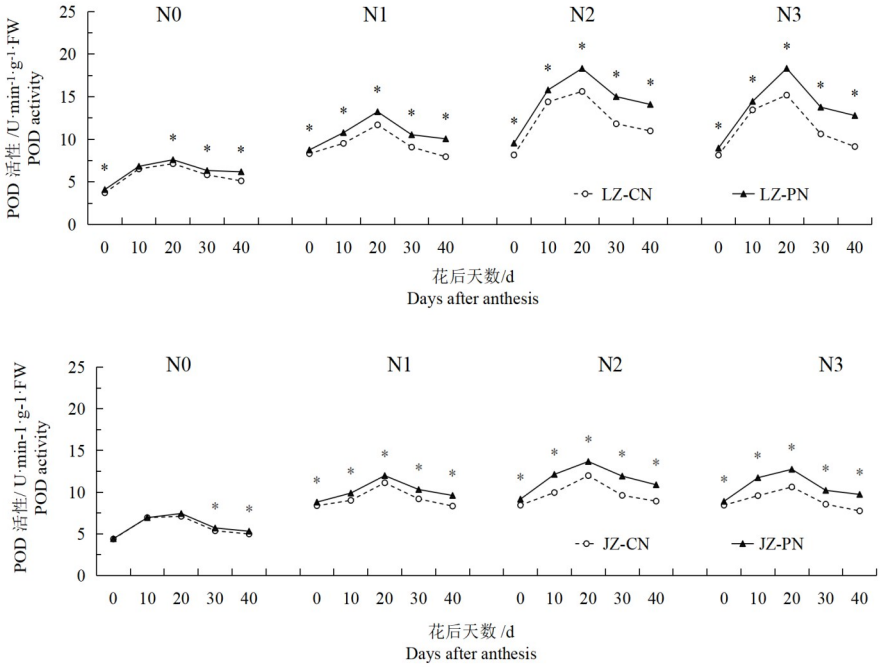


*表示同一施氮水平下同个品种不同处理间差异显著($P<0.05$)

* indicate significant difference at $P<0.05$ between different treatments of the same variety under the same nitrogen application level

图3　各施氮水平下高粱旗叶SOD活性对PAC的响应

Fig. 3　Response of SOD activity of sorghum flag-leaf to PAC under different nitrogen application levels

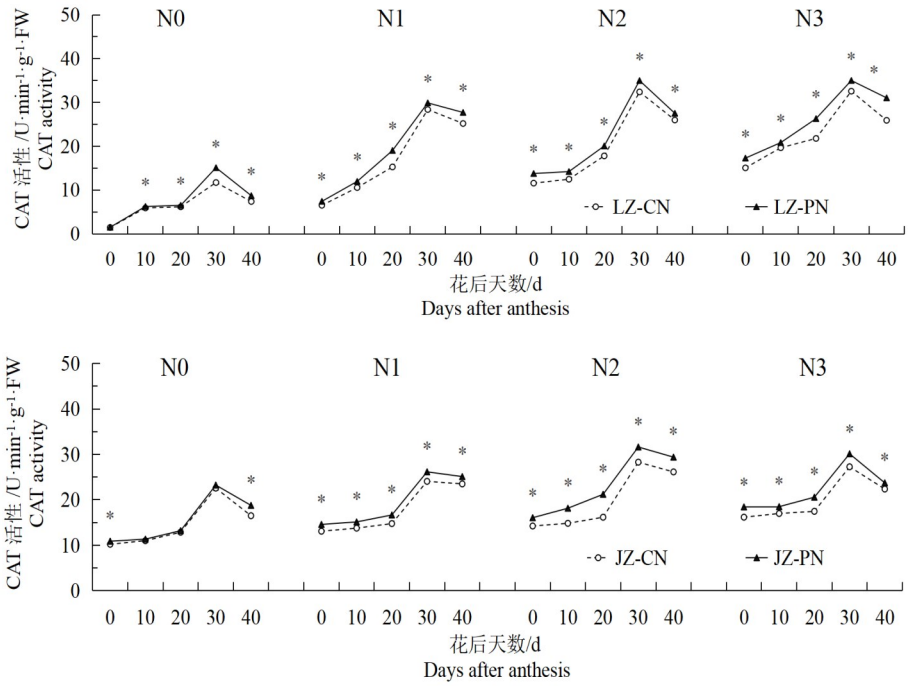


*表示同一施氮水平下同个品种不同处理间差异显著($P<0.05$)

* indicate significant difference at $P<0.05$ between different treatments of the same variety under the same nitrogen application level

图4 各施氮水平下高粱旗叶POD活性对PAC的响应

Fig. 4 Response of POD activity of sorghum flag-leaf to PAC under different nitrogen application levels

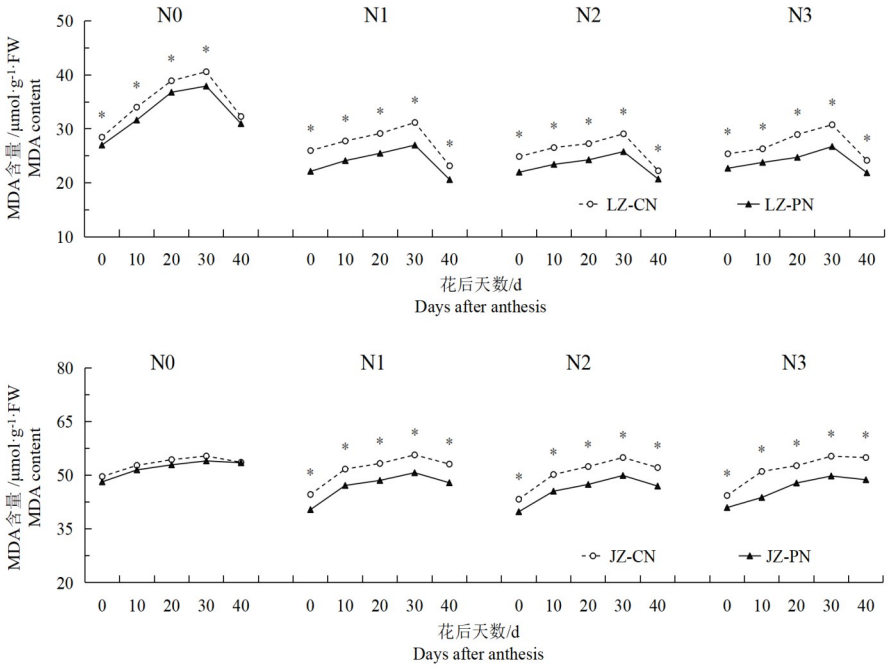


*表示同一施氮水平下同个品种不同处理间差异显著($P<0.05$)

* indicate significant difference at $P<0.05$ between different treatments of the same variety under the same nitrogen application level

图5 各施氮水平下高粱旗叶CAT活性对PAC的响应

Fig. 5 Response of CAT activity of sorghum flag-leaf to PAC under different nitrogen application levels

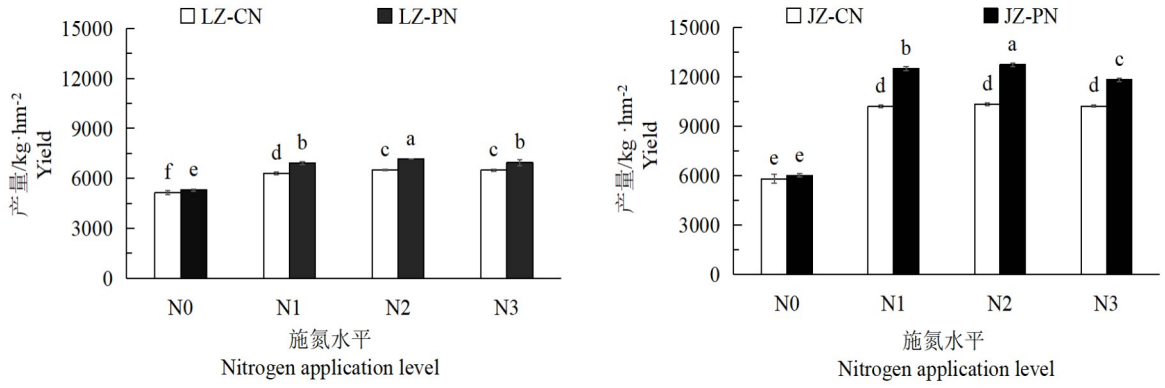


*表示同一施氮水平下同个品种不同处理间差异显著($P<0.05$)

* indicate significant difference at $P<0.05$ between different treatments of the same variety under the same nitrogen application level

图6　各施氮水平下高粱旗叶MDA含量对PAC的响应

Fig. 6　Response of MDA content of sorghum flag-leaf to PAC under different nitrogen application levels



不同小写字母表示同一品种下各处理间差异显著($P<0.05$)

Values followed by different lowercase letters are significant difference at $P<0.05$ among different treatments in the same variety

图7　各施氮水平下高粱产量对PAC的响应

Fig. 7　Response of sorghum yield to PAC under different nitrogen application levels

效率;然而全基施则会引起生育早期氮肥流失,后期氮素亏缺,加速叶片衰老,降低产量[8-9]。因此,延缓叶片衰老,保持较高的光合有效期,有利于促进籽粒灌浆,提高最终产量[42]。本研究结果显示,随着施氮水平增加,2高粱品种的单株叶面积与SPAD值均呈升高趋势,单株叶面积降幅则呈降低趋势,花后30~45 d时降幅最高,且LZ降幅低于JZ。PAC处理可减小2高粱品种单株叶面积降幅,延缓叶片衰老,提高SPAD值,尤其在中低氮肥条件下(75 kg·hm^{-2}和150 kg·hm^{-2})极显著。因此,全基施下配施PAC可提高叶绿素相对含量,延缓植株叶片衰老,为增产提供有利条件。

叶片衰老与活性氧代谢呈正相关[43],而SOD、POD、CAT等抗氧化酶可以降低MDA含量,清除过量毒害物质,调节活性氧代谢平衡,提高抗逆能力[17]。研究表明,氮肥可有效延缓植株衰老,稳定

表3 各施氮水平下高粱产量构成因素对PAC的响应

Table 3 Response of yield components of sorghum to PAC under different nitrogen application levels

品种 Variety	施氮水平 Nitrogen application level	处理 Treatment	千粒重/g 1000-kernel weight	穗数/($\times10^4$ ears·hm^{-2}) Ear numbers	穗粒数 Kernels per ear
LZ	N0	CN	25.63±0.18f	5.90±0.18ab	1 695.15±25.37f
		PN	27.11±0.06c	5.67±0.18bc	2 360.44±26.64d
	N1	CN	25.96±0.13e	6.11±0.19a	1 782.86±23.32e
		PN	27.45±0.19b	6.07±0.02a	2 668.87±34.03a
	N2	CN	25.94±0.24e	5.76±0.11bc	2 520.86±36.15c
		PN	27.42±0.16b	5.62±0.08c	2 347.75±45.10d
	N3	CN	26.75±0.24d	6.09±0.02a	2 716.64±48.02a
		PN	28.04±0.13a	5.73±0.16bc	2 598.94±8.65b
JZ	N0	CN	24.56±0.14f	6.25±0.19bc	1 745.43±29.06e
		PN	30.01±0.10c	6.00±0.02e	3 044.65±25.61d
	N1	CN	25.75±0.09e	6.56±0.08a	1 778.76±25.32e
		PN	30.79±0.20a	6.31±0.01b	3 375.33±65.44b
	N2	CN	29.68±0.14d	6.13±0.06d	3 259.42±24.69c
		PN	30.49±0.06b	5.90±0.05cd	3 020.55±46.77d
	N3	CN	30.33±0.16b	6.53±0.01a	3 486.12±76.85a
		PN	30.83±0.18a	6.18±0.01cd	3 267.91±25.12c

注:同列不同小写字母表示同一品种各处理间差异显著($P<0.05$)

Note: Values within the same column followed by different lowercase letters are significant difference at $P<0.05$ among different treatmentsin the same variety

活性氧自由基代谢平衡,而氮素养分缺乏或过量均会降低叶片保护酶活性,加剧衰老过程[44-46]。本研究结果显示,在N0~N2(0~150 kg·hm^{-2})施氮水平下,SOD、POD、CAT活性随施氮量增加而增强,MDA含量随施氮量增加而降低;超过该施氮水平范围,抗氧化酶活性开始降低,MDA含量则开始升高。PAC处理后,N1~N3(75~225 kg·hm^{-2})施氮水平下,较常规施氮处理,抗氧化酶活性显著增强,MDA含量显著降低。因而,PAC处理配施氮肥可提高中低氮水平下叶片抗氧化酶活性,降低MDA含量,增强植株抗逆能力,保障正常代谢活动。

氮肥与作物生长发育以及产量形成密切相关,其对最终产量的形成贡献高达40%,甚至50%[47-48]。研究表明,施加适量的氮肥可以促进植株氮素代谢,改善农艺性状,从而提高产量[49];超过最佳施氮水平范围时,养分供过于求,不仅浪费农业资源,加剧土壤酸碱失衡、水体污染以及温室效应等现象,而且会加剧叶茎徒长,降低植株光合功能,同时抑制其它元素吸收,最终导致减产[50]。本研究结果显示,N0~N3(0~225 kg·hm^{-2})施氮水平下,千粒重随施氮量增加呈升高趋势,单位面积内有效穗数与穗粒数随施氮量增加呈降低趋势,作物产量随施氮量增加呈先升后降趋势,施氮水平为N2(150 kg·hm^{-2})时达到最高产量。PAC处理显著提高各施氮水平下2高粱品种的千粒重、穗粒数及有效穗数,在中低氮肥条件下(75 kg·hm^{-2}和150 kg·hm^{-2})增产极显著。因此,氮肥全基施背景下施加PAC可改善个体生理功能,优化产量构成因素,在结构性与功能性上实现最终增产目的。

进一步分析,我们可以得到如下氮肥全基施背景下配施PAC处理增强高粱抗逆能力以及延缓植株衰老的原因。第一,PAC主成分PASP可作保水剂和缓释剂,促进氮素积累转运,提高干物质积累量[25-28],为作物增产提供有利基础;CTS可提高叶绿素含量,增强植株抗逆性能,提高产量和改善品质[31-34]。第二,本课题组前期研究结果表明,PAC处理能够提高作物NR、GS、GPT、GOT等酶活性,促进氮素代谢的正常进行,提高氮素利用效率,促进花后干物质的积累与转运,提高氮肥偏生产力与农学效率,最终提高产量[39]。第三,本研究结果表明,PAC处理可提高高粱叶绿素相对含量与抗氧化酶活性,减少绿叶面积降幅,延缓叶片衰

老,维持植株正常的代谢活动,进而提高产量。

4　结论

综上所述,增施氮肥可提高龙杂25与吉杂127的花粒期单株绿叶面积、旗叶SPAD值以及抗氧化能力,降低单株绿叶面积降幅与MDA含量;PAC处理则能显著提高中低氮肥条件下(75和150 kg·hm^{-2})2高粱品种旗叶SPAD值和抗氧化酶活性,显著降低MDA含量,减小叶面积降幅,延缓叶片衰老程度,提高产量。因此,在施氮量为150 kg·hm^{-2}时配施PAC(PASP为1.875 kg·hm^{-2},CTS为3 kg·hm^{-2})可减缓全基施背景下高粱花后叶片衰老,维持正常的代谢活动,改善产量构成因素,并减少氮肥浪费,最终实现绿色高产目的。

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Regulatory effects of PAC combined with nitrogen fertilizer on leaf antioxidant characteristics and yield of sorghum after anthesis

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Abstract: [Objective] In the northeastern region of China, the full basal application of fertilizers often leads to imbalanced nutrient supplies during the growth period of sorghum, resulting in nitrogen deficiency and premature senescence in the later growth stages. This study aimed to explore the regulatory effects of polyaspartic acid-chitosan (PAC) on leaf senescence and yield of sorghum during the flowering to grain-filling stage under the background of full basal application of fertilizers, therefore assisting in the establishment of an anti-aging and yield-increasing technologies for sorghum under full basal application of fertilizers. [Methods] Field experiments were conducted at the Gongzhuling Experimental Station of Chinese Academy of Agricultural Sciences (43°29′55" N, 124°48′43" E) from 2020 and 2021, Two varieties, Longza 25 and Jiza 127, were selected as experimental materials. Different nitrogen fertilizer treatments and chemical control treatment (PAC) were setup, and the degree of leaf senescence, antioxidant characteristics, and yield differences of sorghum under PAC combined with nitrogen fertilizer were measured and analyzed. [Results] From flowering to maturity, increasing nitrogen levels significantly increased the leaf area (LA) per plant of the two sorghum varieties, increased the relative content of chlorophyll in flag leaves, enhanced the activity of antioxidant enzymes, and decreased malondialdehyde (MDA) content, with differences observed between the two varieties. PAC treatment significantly increased the activity of superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), as well as the relative content of chlorophyll in flag leaves of both sorghum varieties at various nitrogen levels. It significantly inhibited the decrease in leaf area per plant and delayed the aging process of plants. After PAC treatment, both varieties showed average yield increase of 2.26%～9.11% for Longza 25 and 3.51%～15.76% for Jiza127 compared to their respective conventional nitrogen treatments. Both varieties showed significant yield increases at a nitrogen application rate at 150 kg·hm^{-2}, with average increases of 9.11% and 15.76% over two years. [Conclusion] The combined application of PAC and nitrogen fertilizer under full basal application can be used as a cultivation technology to effectively prevent aging and increase yield in the central and western sorghum-producing area of Jilin Province, China.

Keywords: Polyaspartic acid-chitosan, One-time basic fertilizer application, Sorghum, Lantioxidant characteristics, Yield

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