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全膜覆土穴播对冬小麦旗叶光合和抗氧化酶活性的影响

温 健[1],郭振斌[1],郭天玲[1],王国宇[2],赵 刚[3],刘广才[4]

(1.甘肃省永登县农业技术推广中心,甘肃永登 730300;2.甘肃省兰州市农业科技研究推广中心,兰州 730070;3.甘肃省农业科学院 旱地农业研究所,兰州 730070;4.甘肃省农业技术推广总站,兰州 730000)

摘 要 采用田间试验的方法,以全膜不覆土穴播种植方式为对照,比较研究全膜覆土穴播对旱地冬小麦旗叶光合、抗氧化酶活性和膜脂过氧化水平的影响。结果表明,全膜覆土穴播处理提高了冬小麦灌浆中后期(花后20~35 d)旗叶净光合速率(P_n)和叶绿素SPAD值,P_n高值持续期(PAD)和叶绿素SPAD值缓降期(RSP)比对照分别增加6.5 d和5.8 d。全膜覆土穴播也提高了灌浆初期(花后0~15 d)旗叶蔗糖磷酸合成酶(SPS)活性,与对照相比提前5 d达到峰值,且在灌浆中期(花后10~20 d)依然能保持相对较高的蔗糖供应能力。全膜覆土穴播在灌浆中后期(10~35 d)超氧化物歧化酶(SOD)活性表现较强的诱导性,过氧化氢酶(CAT)活性也比对照提前5 d达到峰值,而过氧化物酶(POD)活性始终低于对照。2种处理丙二醛(MDA)质量摩尔浓度在开花15 d后急剧升高,但全膜覆土穴播处理的质量分数和变化幅度均低于对照。可见,全膜覆土穴播栽培的旱地冬小麦在灌浆期保持了较高的光合产物供应速率、较长的供应持续期、较低的活性氧产生速率和膜脂过氧化水平,因而后期产量和品质高于传统地膜栽培。

关键词 全膜覆土穴播;冬小麦;光合作用;抗氧化酶

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Effects of Whole Plastic-film Mulching Combined with Soil Overlying on Photosynthetic Characteristics and Antioxidant Enzyme Activities of Flag Leaves in Winter Wheat

WEN Jian[1], GUO Zhenbin[1], GUO Tianling[1], WANG Guoyu[2], ZHAO Gang[3] and LIU Guangcai[4]

(1. Yongdeng Agro-technical Extension Center Yongdeng, Gansu 730300, China; 2. Lanzhou Research Center for Agriculture Science, Lanzhou 730070, China; 3. Dryland Agriculture Institute, Gansu Academy of Agricultural Sciences, Lanzhou 730070 China; 4. Gansu Agro-technical Extension Station, Lanzhou 730000, China)

Abstract Comparative study on photosynthate supplying capability and antioxidant enzymes activities in winter wheat flag leaves was performed under the whole plastic-film mulching combined with soil overlying and whole film without overburden bunch. The results showed that dynamic changes of net photosynthetic rate (P_n) and SPAD contents of flag leaves were significantly increased during the middle and late grain filling period (20-35 days after anthesis) under the whole plastic-film mulching combined with soil overlying. Moreover, the extended steady phase of chlorophyll content (RSP) and the increased photosynthetic active duration (PAD) in flag leafves might reduce the aging of flag leaf, which could significantly increase in 6.5 days and 5.8 days. Compared with the control, both sucrose

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第一作者:温 健,男,农艺师,硕士,研究方向为农业技术推广。E-mail:iwenjian@163.com

通信作者:赵 刚,男,助理研究员,硕士,研究方向为旱地农业节水。E-mail:7635423@163.com

phosphate synthetase (SPS) activity and sucrose supplying capability of flag leaves in winter wheat were significantly increased during the early grain filling period (0—15 days after anthesis) and middle grain filling period (10—20 days after anthesis). The changes of SOD (Superoxide dismutase) activities suggested fluctuant trend. Compared with whole plastic-film mulching combined with soil overlying, the SOD and CAT activities were higher than that of whole film without overburden bunch during the early grain filling period (10—35 d), but the POD activities were much lower than that of whole film withoutt overburden bunch during the whole grain filling period. The MDA (Malondialdehyde) molality were in the trend of increase after anthesis (15—35 d). Therefore, the treatment can maintain a relatively higher photosynthate supplying rate, longer photosynthate supplying duration, lower reactive oxygen producing rate and lower lipid peroxidation level, which could be a key reason for a high quality and yield.

Key words Whole plastic-film mulching combined with soil overlying; Dry-land wheat; Photosynthesis; Antioxidant enzyme activity

小麦是甘肃第一大粮食作物，但干旱导致的生理代谢紊乱、植株早衰等使产量低而不稳[1]，其中主要原因是由自然降水与作物需水供需错位所导致的[2]，如何有效利用有限的降水资源、提高单产，保证省内小麦供需是该区农业可持续发展亟待解决的问题。全膜覆土穴播技术能够显著增加地温、降低课间蒸发、提高降水利用效率、调控土壤水分时空再分配，因而能有效减轻干旱和春季低温对作物的伤害，改善土壤水热状况，促进作物种子萌发和正常的生长发育，增加作物产量[3-4]，是中国旱作农业和旱地小麦栽培的重大创新和突破[1,5]，可使旱地小麦平均产量达到 4 500 kg/hm^{2}以上，平均较露地条播增产 1 500 kg/hm^{2}以上，增产幅度达到40%以上[5-6]。目前，关于全膜覆土穴播小麦栽培技术和增产效应，小麦光合作用、抗氧化酶活性和膜脂过氧化的研究已有较多报道[7-9]，但全膜覆土穴播对小麦旗叶光合作用、抗氧化酶活性和膜脂过氧化作用方面的研究，尚未见报道。旗叶光合效应和抗氧化酶活性的变化是作物对逆境反应机制研究的重要方面[8-9]。本研究以冬小麦京农 411 为试验材料，研究了采用全膜覆土穴播条件下小麦旗叶光合性能及抗氧化酶活性，为进一步探讨旱作区延缓小麦植株衰老和高产高效小麦栽培技术体系提供理论支撑。

1 材料与方法

1.1 试验区概况与试验设计

试验于 2013—2014 年在甘肃省永登县连城镇进行。该区海拔 1 940 m，无霜期 138 d，年平均气温 6.7 ℃，日照时数 3 288 h，≥10 ℃的有效积温 2 156 ℃，年太阳辐射总量 161 kJ/cm^2；年均降水量 356 mm，而年蒸发量 2 116 mm，是降水量的 6 倍。供试土壤为灰钙土，前茬为小麦。试验以冬小麦（*Triticumae stivum* L.）品种‘京农 411’为材料，采用全膜覆土穴播种植方式，以全膜不覆土穴播（传统地膜小麦）为对照，每处理 重复 3 次，小区面积 4.8 m×8.0 m。全膜覆土穴播为全地面、全生育期地膜覆盖，铺膜时首先用 1.2 m 的地膜全地面平铺，上面均匀撒一层 0.5～1.0 cm 的土（不开沟压膜，膜与膜之间紧靠对接不重叠，就地取土平整），然后用手动小麦穴播机播种，播种深度 3～5 cm，行距 16 cm，穴距 12 cm，每穴 9 粒，播种量为 520 万粒/hm^2；全膜不覆土穴播全地面、全生育期地膜覆盖，铺膜时首先用 1.2 m 的地膜全地面平铺，上面不覆土，播种方式同上。铺膜 1 d 后同时播种，施肥量为：N 150 kg/hm^2、P_2O_5 75 kg/hm^2、K_2O 45 kg/hm^2，肥料按小区称量，在播前作为底肥一次施入。2013-09-21 播种，2014-06-07 收获。

1.2 测定项目与方法

1.2.1 *净光合速率（P_n）和叶绿素 SPAD 值* 采用美国 LI-6400 型便携式光合仪测定，测定时间在开花期及花后每 5 d 9：00－11：00 晴朗时进行，测定时样本室 CO_2 摩尔分数为 380 μmol/mol，流速设为 400 μmol/(m^2 · s)，叶片温度为 25 ℃。每小区重复 3 次。叶绿素 SPAD 值采用日产 SPAD-502 型叶绿素计与 P_n 同时测定。每小区重复 9 次。

1.2.2 *蔗糖磷酸合成酶（SPS）活性和蔗糖质量分数* SPS 活性参照 Wardlaw 和 Douglas

等[10-11]的方法;蔗糖质量分数的测定采用间苯二酚法[12]。每小区重复 3 次。

1.2.3　抗氧化酶活性和(MDA)质量摩尔浓度

超氧化物歧化酶(SOD)活性的测定参照 Zhang 等[13]的方法,以抑制氮蓝四唑(NBT)光还原 50%为 1 个酶活力单位(U),用 U/g 表示。过氧化物酶(POD)活性的测定按 Omran[14]的方法,测定 470 nm 吸光度的变化,以每分钟内引起 470 nm 吸光度变化 0.01 的酶量为 1 个酶活力单位(U),用 U/g 表示。过氧化氢酶(CAT)活性的测定按照 Singh 等[15]的方法测定 240 nm 吸光度变化,以每分钟内使 240 nm 吸光度减少 0.1 的酶量为 1 个酶活力单位(U),用 U/(g · min)表示。丙二醛(MDA)质量摩尔浓度的测定参照硫代巴比妥酸法[12]。每小区重复 3 次。

1.3　数据分析

采用 Excel 2010 处理试验数据并绘图。

2　结果与分析

2.1　全膜覆土穴播对冬小麦旗叶 P_n 和叶绿素 SPAD 值的影响

由图 1 可见,随生育进程的延长,2 种处理小麦旗叶 P_n 呈下降趋势,花后 16 d 是分界线,前期不覆土穴播较高,后期覆土穴播栽培较高,整个生育进程覆土穴播栽培降低幅度明显小于不覆土穴播栽培。表明覆土穴播栽培的小麦在灌浆中后期(花后 20～35 d),旗叶能保持较高的 P_n。以开花期最高值为初始值,全膜覆土穴播的 P_n 高值持续期(PAD)[16]为 31.4 d,全膜不覆土穴播为 24.9 d。表明覆土穴播栽培的小麦旗叶 P_n 受生育后期干旱等因素的影响小,其高值持续期长。

2 种处理小麦旗叶叶绿素 SPAD 值也随生育进程延长而降低,花后 20～35 d 降幅增大,但覆土穴播栽培的始终高于不覆土穴播栽培。表明覆土穴播栽培的小麦也能保持较高的叶绿素 SPAD 值。以开花期最高值为初始值,全膜覆土穴播的叶绿素 SPAD 值缓降期(RSP)[16]为 28 d,全膜不覆土穴播为 22.3 d。表明,生育后期的干旱等因素明显促进小麦花后旗叶的衰老,但覆土穴播栽培的叶绿素 SPAD 值受影响小,其高值持续期长。

2.2　全膜覆土穴播对冬小麦旗叶 SPS 活性及蔗糖质量分数的影响

由图 2 可知,2 种处理小麦旗叶花后 SPS 活性均迅速升高,分别在第 10 天和第 15 天达到高峰,后期差异变小,但覆土穴播栽培的变化幅度较大,活性也高于不覆土穴播栽培。2 种处理小麦旗叶花后蔗糖质量分数在灌浆前期(0～15 d)均迅速降低,覆土穴播栽培变化幅度较大,但在花后 20 d 均有小幅回升,之后变化趋于一致并迅速降低至成熟。这可能是由于灌浆前期和中期促进旗叶蔗糖的合成,而在灌浆末期各处理旗叶均逐渐衰老,蔗糖合成能力亦减弱至丧失所致。

2.3　全膜覆土穴播对冬小麦旗叶抗氧化酶活性和 MDA 质量摩尔浓度的影响

由图 3 可见,2 种处理小麦旗叶花后 SOD 活性变化都表现为先降低后升高再降低的波动式变化。说明小麦旗叶抗氧化酶防御系统 SOD 具有较强的自动调节能力,覆土穴播栽培在灌浆中后期(10～35 d)对SOD活性诱导作用更强。2种处

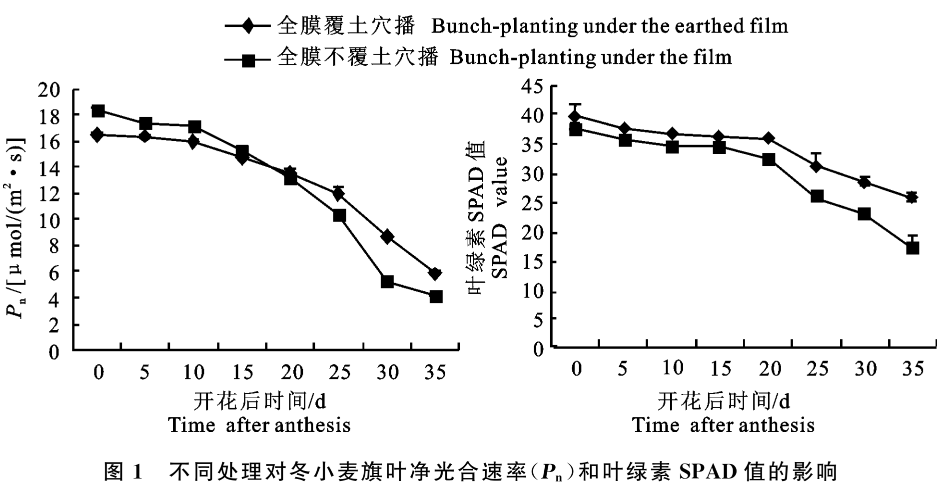

图 1　不同处理对冬小麦旗叶净光合速率(P_n)和叶绿素 SPAD 值的影响

Fig. 1　Effects of net photosynthesis rate(P_n) and chlorophyll SPAD value in the flag leaves of winter wheat under different treatments

理小麦旗叶 CAT 活性均呈单峰曲线变化,活性峰值分别出现在花后 5 d 和 10 d,这说明覆土穴播处理提前了 CAT 活性峰值,但高值维持时间较短。POD 活性变化也呈单峰曲线,峰值均出现在花后 15 d,而覆土穴播栽培 POD 活性在整个灌浆期均低于不覆土穴播栽培。MDA 质量摩尔浓度在整个灌浆期逐渐升高,花后 15 d 之后,MDA 质量摩尔浓度急剧升高,而覆土穴播栽培上升幅度明显低于不覆土穴播栽培,花后 20 d 后差异更显著。

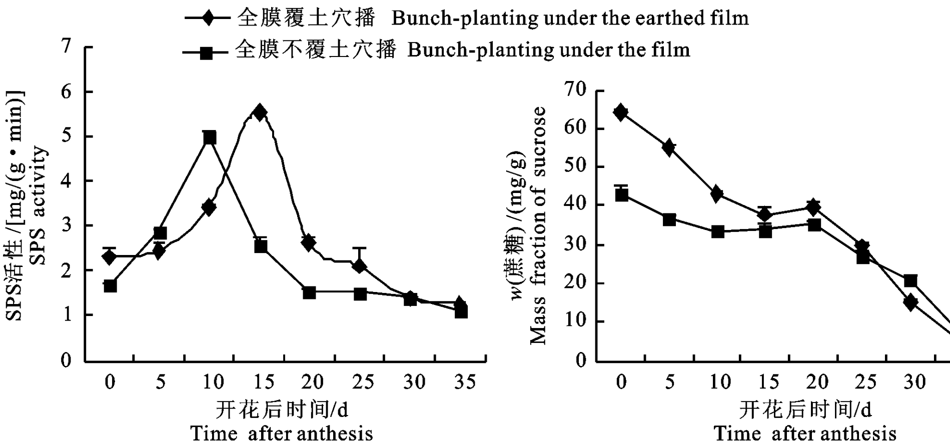

图 2 不同处理下冬小麦旗叶 SPS 活性和蔗糖质量分数

Fig. 2 Effects of sucrose phosphate synthetase (SPS) activities and sucrose mass fraction in the flag leaves of winter wheat under different treatments

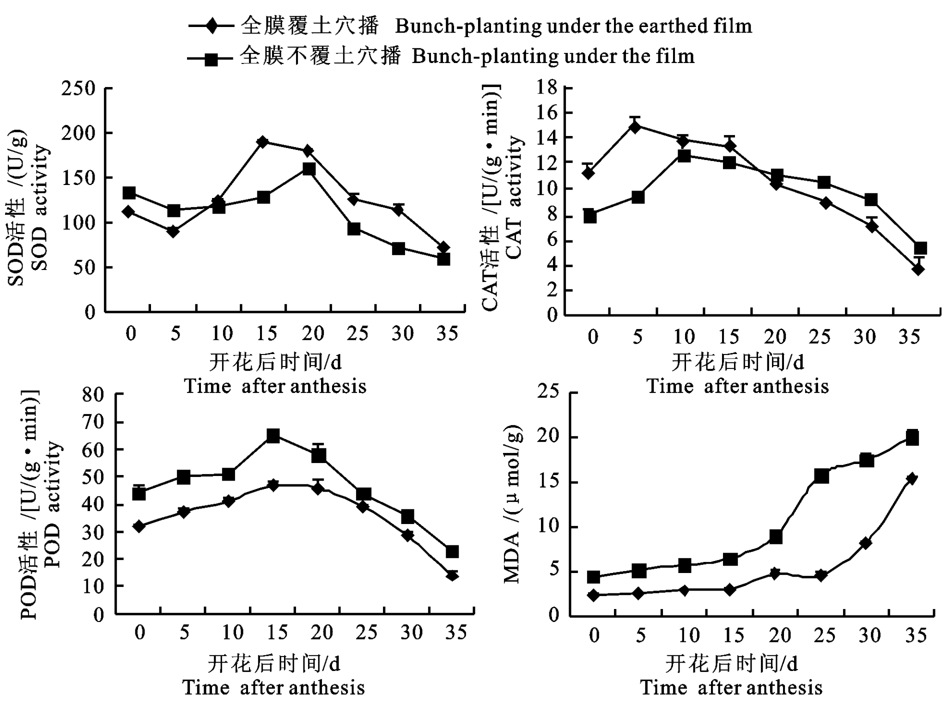

图 3 不同处理下冬小麦旗叶抗氧化酶活性和 MDA 质量摩尔浓度

Fig. 3 Effects of superoxide dismutase (SOD), peroxidase (POD), catalase (CAT) activities and malndialdehyde (MDA) molality in the flag leaves of winter wheat under different treatments

3 讨 论

全膜覆土穴播种植方式能使小麦旗叶在灌浆中后期(花后 15～35 d)保持相对较高的光合速率和叶绿素含量,与对照相比,光合速率持续期和叶绿素缓降期分别长 6.5 d 和 5.8 d。已有研究显示,小麦灌浆期籽粒碳水化合物的积累基础是冠层叶尤其是旗叶的光合作用,其对籽粒产量的贡

献率可达30%～50%[17],可见,覆土穴播栽培在灌浆期能维持相对较长的光合产物供应持续期,是后期籽粒产量较高的原因之一。造成这种结果的原因一方面是由于地膜覆盖改善了冬小麦的生育前期水热条件,有利于地上部分的生长,叶面积增长快,延长了叶的功能期;另一方面地膜表面覆土能够积蓄降水、提升深层水分、避免后期气温过高,保护了光合器官。全膜不覆土穴播种植(传统地膜小麦)由于灌浆期地面温度升高,旗叶忍耐力逐渐下降,光合能力减弱,进而影响小麦灌浆。

全膜覆土穴播种植方式亦显著提高了旗叶SPS活性,并在花后15 d达到高峰,而蔗糖质量分数在灌浆前期迅速降低后也在花后20 d达到小高峰,这和蔗糖与SPS活性呈显著正相关[18]的研究结论是一致的。因此,覆土穴播能够通过提高合成蔗糖的SPS活性来提高花后旗叶中蔗糖的合成能力,从而决定其具有较强的光合产物供应强度,提高了旗叶光合产物的供应和促进籽粒灌浆。已有研究表明,不同质地土壤中养分质量分数对小麦蔗糖代谢之间存在着相关作用[19],可见,全膜穴播栽培是通过改善农田微生态环境,促进钾等营养元素的吸收[2],进而提高籽粒中SPS活性,最终获得高产的。

2种处理冬小麦旗叶SOD活性呈现波浪式变化,这可能是小麦对逆境的适应性反应,但覆土穴播栽培表现较强的调节性。2种处理CAT活性都于灌浆前期升高,覆土穴播栽培提前5 d达到峰值。而MDA质量摩尔浓度、POD活性全膜覆土穴播的旱地冬小麦均低于对照。有研究表明SOD、CAT活性少量增加就能及时清除过氧化物体和叶绿体内活性氧自由基的积累[20],而POD亦可在逆境或衰老后期表达,参与活性氧的产生、叶绿素的降解[9]。这说明生育后期,全膜覆土穴播小麦膜系统抗氧化代谢维持在较高水平,保证了光合器官功能的正常进行,而全膜不覆土穴播小麦膜脂过氧化加剧,引起生物膜结构和功能的破坏,光合能力相应降低,影响了小麦产量。

4　结论

与传统地膜小麦种植方式相比,全膜覆土穴播种植方式的旱地冬小麦在灌浆期可维持较高的光合产物供应速率、较长的供应持续期、较低的活性氧产生速率和膜脂过氧化水平。光合产物的供应速率(强度)和供应持续期决定光合产物的供应总量,抗氧化酶系统延缓了生物膜结构和功能的破坏,因而全膜覆土穴播栽培在后期产量和品质高于传统地膜栽培。

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