小麦花后弱光引起籽粒淀粉的粒度分布及组分含量的变化

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摘要：在籽粒灌浆阶段（花后 1～30 d）对小麦进行光强为自然光照 45% 的弱光处理，研究了小麦籽粒淀粉粒度分布和组分含量的变化。结果表明，小麦籽粒淀粉粒体积分布呈双峰曲线，峰值分别在 5.1～6.1 μm 和 20.7～24.9 μm，两峰值间的低谷出现在 9.9 μm 左右。表面积分布和数目分布分别表现为双峰和单峰曲线。小麦花后弱光显著降低 2.8～9.9 μm 淀粉粒体积百分比，增加 22.8～42.8 μm 淀粉粒体积百分比。同时花后弱光显著降低 <0.8 μm 和 2.8～9.8 μm 淀粉粒表面积百分比，增加 0.8～2.8 μm 和 >9.9 μm 淀粉粒表面积百分比。可见灌浆期弱光显著降低籽粒 B 型（<9.9 μm）淀粉粒体积和表面积百分比，而 A 型（>9.9 μm）淀粉粒比例相对增加。与 A 型淀粉粒相比，B 型淀粉粒对弱光的反映更敏感。小麦弱光处理籽粒淀粉及其组分含量显著低于对照，但其直/支比较对照高。相关分析表明，籽粒直/支比与 2.8～9.9 μm 淀粉粒体积百分比呈显著负相关，而与 22.8～42.8 μm 淀粉粒体积百分比呈显著正相关。花后不同阶段弱光显著增加 A 型淀粉粒体积百分比、降低 B 型淀粉粒体积百分比，其中灌浆中、后期弱光影响程度较前期大。表明，弱光条件下小麦籽粒淀粉合成底物优先供应淀粉粒的生长，而非形成更多的淀粉粒。

关键词：小麦；弱光；淀粉；淀粉粒；粒度分布
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Starch granule size distribution and starch component content in wheat grain in relation to shading stress after anthesis

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Abstract: Starch, the main carbohydrate in the endosperm of wheat grain, is an important determinant of the textural and processing properties of many foods. Starch is deposited in the endosperm as discrete semi-crystalline aggregates known as starch granules during grain development. Various authors have demonstrated that the starch granules in wheat grain endosperm exist in two contrasting types, a large, A- (>9.9 μm) and a little, B-type (<9.9 μm) starch granules, which are different significantly in their physical, chemical and functional properties. It was generally accepted that the starch granule size distribution had a close association with the usage in industrial food and nonfood applications. Low light intensity as a result of cloudy or rainy days, and densely planting population often occurs during the grain filling of winter wheat. However, there is little knowledge about the effect of low light intensity after anthesis on starch granule size distribution in wheat grain.

The field experiments were carried out at Tai'an Experimental Station of Shandong Agricultural University in two

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growing seasons from October 2005 to June 2006 and from October 2006 to June 2007. Two winter wheat (*Triticum aestivum* L.) cultivars, SN12 and SN1391, were chosen in this study. The field was shaded by the black nets with 55% shading over the plants during grain filling (1－30 d after anthesis, SH) in this study. And the black nets were also over the wheat canopy to reduce light intensity to 10% in the early (6－9 d after anthesis, S1), middle (16－19 d after anthesis, S2) and late (26－29 d after anthesis, S3) grain filling stages. The treatments were arranged in a randomized complete design with three replications. Effect of shading during grain filling in field on starch granule size distribution and starch component content was examined in wheat grain at maturity.

The results showed that volume distribution showed the typical two populations of starch granules with peak values in the ranges of 5.1－6.1 μm and 20.7－24.9 μm, respectively. The limit between the two populations was defined as the minimum of the curves that occurred at 9.9 μm. Surface area distribution of starch granules also was the two populations of starch granules, and number distribution of starch granules exhibited a single peak curve. The volume % of 2.8－9.9 μm starch granules was significantly decreased, and that of 22.8－42.8 μm starch granules was significantly increased under shading stress. The surface area % of starch granules in shading stress with the ranges of <0.8 μm and 2.8－9.9 μm were lower, and that of the ranges of 0.8－2.8 μm and >9.9 μm were higher than those of control. These observations suggest that shading stress led to a significant decline in volume % and surface area % of B-type starch granules (<9.9 μm) and increase in those of A-type starch granules (>9.9 μm), respectively. B-type starch granules were more sensitive to shading stress than A-type starch granules in wheat grain. There was significant effect of shading stress after anthesis on starch and starch component content. Shading stress remarkably reduced starch and starch component content at the maturity. However, the ratio of amylose and amylopectin of shading stress was higher than that of control in grain. The ratio of amylose to amylopectin was negatively correlated with volume % of 2.8－9.9 μm starch granules, and positively correlated with volume % of starch granules of 22.8－42.8 μm. It was found that the volume % of A-type starch granule was significantly increased and that of B-type starch granule was significantly decreased due to shading stress at different grain filling stages, especially at middle and late grain filling stages. Based on results here we consider that under dim light condition, the limited substrate for starch accumulation was mainly partitioned for growing starch granules, not for producing more starch granules.

Key Words: winter wheat (*Triticum aestivum* L.); shading; starch; starch granule; granule size distribution

淀粉是小麦籽粒的主要贮藏物质。淀粉粒是小麦籽粒胚乳中淀粉的存在形式,淀粉粒度分布是籽粒品质的重要决定因素[1~3]。光照强度是影响小麦籽粒产量和品质的重要环境因子之一[4]。由于天气状况或小麦过高种植密度,造成小麦群体光照条件变劣,这使其籽粒发育和物质充实受到严重影响,制约了籽粒产量和品质的形成。小麦籽粒灌浆阶段遮光使籽粒淀粉含量有下降的趋势[5],但小麦花后较低的光照强度对籽粒淀粉组分及直/支比的影响,目前研究较少。

研究认为,小麦籽粒胚乳主要含有 A、B 两种类型的淀粉粒[6,7]。其中 A 型淀粉粒呈椭圆双凸透镜状,平均直径 10~35 μm,而 B 型淀粉粒体积较小,呈球形状,直径 1~10 μm[8]。淀粉粒是由支链淀粉、直链淀粉和少量的蛋白质和脂类组成[9]。A、B 型淀粉粒的物理、化学和功能特性显著不同。B 型淀粉粒体积小,表面积相对较大,从而可以结合更多的蛋白质、脂类和水分。B 型淀粉粒的比例大,面团吸水率提高[10,11]。因此,两种类型淀粉粒对食品或非食品加工的应用不同。

小麦籽粒胚乳不同类型淀粉粒的形成与籽粒的发育进程密切相关。研究表明,在小麦籽粒胚乳细胞分裂期所形成的淀粉粒核大部分发育为 A 型淀粉粒,而小部分发育为 B 型淀粉粒;在小麦籽粒胚乳细胞膨大期至籽粒成熟期间所形成的淀粉粒核则发育为 B 型淀粉粒[12,13]。小麦籽粒发育进程中,环境条件,尤其是光照条件的变化,不仅影响小麦籽粒淀粉的形成与积累,而且对籽粒淀粉粒度分布亦应具有调节效应。然而,关于这

方面的研究报道尚少。本试验在田间条件下对小麦进行弱光照处理,研究并分析小麦花后弱光对籽粒胚乳淀粉的粒度分布及组分含量的影响,进而明确弱光条件下小麦籽粒淀粉的粒度分布与组成之间的关系。

1 材料与方法

1.1 种植方式

试验于2005年10月至2007年6月在山东农业大学农学试验农场进行。试验地耕层(0~20 cm)土壤含有机质1.23%、全氮0.091%、碱解氮87.2 mg·kg^{-1}、速效磷18.6 mg·kg^{-1}、速效钾57.5 mg·kg^{-1}。供试小麦品种为山农12(SN12)和山农1391(SN1391)。播种期为2005年10月15日和2006年10月10日,收获期为2006年6月10日和2007年6月8日,其中开花到成熟的时间均为35 d。种植密度180万株·hm^{-2}。小区面积为3 m × 3 m =9 m^2。播种前施入基肥纯氮120 kg·hm^{-2}、P_2O_5 75 kg·hm^{-2}、K_2O 120 kg·hm^{-2},拔节期追施纯氮120 kg·hm^{-2}。其他田间管理同一般高产田。

1.2 试验设计

试验设籽粒灌浆阶段(花后1~30 d,SH)弱光处理和对照(自然照光,CK)处理,随机排列,3次重复,利用透光率为45%黑色遮阳网进行弱光处理。同时,试验设籽粒灌浆前期(花后6~9 d,S1)、中期(花后16~19 d,S2)、后期(花后26~29 d,S3)弱光处理,随机区组排列,3次重复,利用透光率为10%黑色遮阳网进行弱光处理。遮阳网距小麦群体表面保持60 cm左右,以不影响群体内通风状况。弱光处理对小麦群体小气候的影响见表1,其中光照强度是用Lx-101照度计距小麦群体表层的测定值;CO_2浓度、温度和湿度分别用便携式CO_2分析仪测定和DWHJ-2温湿两用计测定。数据均于每天11:00测定。

表1 弱光处理对田间小气候的影响

Table 1 Effect of shading treatment on field microclimate

处理 Treatment	光照强度 Light intensity(μmol·m^{-2}·s^{-1})	CO_2浓度 CO_2 Concentration(μmol·mol^{-1})	温度 Air temperature(℃)	湿度 Humidity(%)
CK	904.8 ±10.2 a	355.9 ±1.1 a	25.5 ±2.9 a	18.9 ±0.3 a
SH	407.2 ±8.4 b	356.4 ±0.9 a	25.2 ±2.7 a	19.2 ±0.4 a
CK	966.4 ±7.3 a	356.2 ±0.5 a	23.1 ±0.5 a	17.9 ±0.2 a
S1	98.7 ±0.9 b	357.4 ±0.8 a	22.6 ±0.4 a	18.5 ±0.3 a
CK	994.1 ±8.5 a	355.9 ±0.6 a	25.2 ±0.4 a	17.2 ±0.2 a
S2	101.5 ±1.1b	356.4 ±0.9 a	24.8 ±0.4 a	17.6 ±0.2 a
CK	1012.1 ±9.6 a	356.5 ±0.5 a	26.8 ±0.5 a	19.1 ±0.1 a
S3	102.4 ±0.8 b	356.0 ±0.4 a	26.5 ±0.3 a	19.2 ±0.1 a

表中数据为所测平均值±标准偏差;SH处理数据为花后1~30 d测定的平均值;S1、S2、S3处理数据为花后6~9、16~19、26~29 d处理4 d的平均值;同一列不同小写字母表示5%水平下差异显著 Values in the table are means ± SD; Data of SH treatment was the means from 1 to 30 d after anthesis. Data of S1 treatment were the means for 4 days (from 6 to 9 days after anthesis); The field microclimate between the treatments from 16 to 19 days, and 26 to 29 days after anthesis was similar to those of 6~9 days after anthesis. Data within columns followed by different letter are significantly different at $P < 0.05$

1.3 测定项目与方法

1.3.1 淀粉粒

淀粉粒提取参照Peng等[14]的方法进行。取2g小麦籽粒在蒸馏水中浸泡24 h,在研钵中研磨,匀浆用200目筛布过滤。淀粉匀浆在1700×g离心10min,去掉上清液,加入5ml 2mol/L NaCl,旋涡混合,匀浆离心,重复3次。同样方法用0.2% NaOH、2% SDS和蒸馏水清洗。最后用丙酮清洗3次,风干,贮存于-20℃处。利用美国Beckman Coulter公司LS13320衍射粒度分析仪进行粒径分析。

1.3.2 淀粉

参照双波长比色法[15]测定淀粉含量。

1.4　数据统计与分析

均值差异性比较采用 *t*-test。统计分析在 Microsoft Excel 2003 和 DPS 3.01(Data Processing System)下完成。

2　结果与分析

2.1　淀粉粒体积分布

小麦籽粒淀粉粒体积分布呈双峰曲线(图1),峰值分别在5.1~6.1 μm和20.7~24.9 μm,两峰值间的低谷出现在9.9 μm左右。<42.8 μm淀粉粒体积约占总体积的99%,>42.8 μm淀粉粒体积约仅占总体积的1%。B型(<9.9 μm)淀粉粒体积百分比为32.6%~40.7%,A型(>9.9 μm)淀粉粒体积百分比为58.5%~66.3%。

花后弱光对籽粒淀粉粒体积分布具有显著影响。B型淀粉粒的体积百分比因弱光显著降低,而A型淀粉粒的体积百分比增加(图1)。由表2结果进一步看出,花后弱光显著降低两品种2.8~9.9 μm淀粉粒体积百分比,增加22.8~42.8 μm淀粉粒体积百分比;<2.8 μm和9.9~22.8 μm淀粉粒体积百分比未因弱光而显著变化。

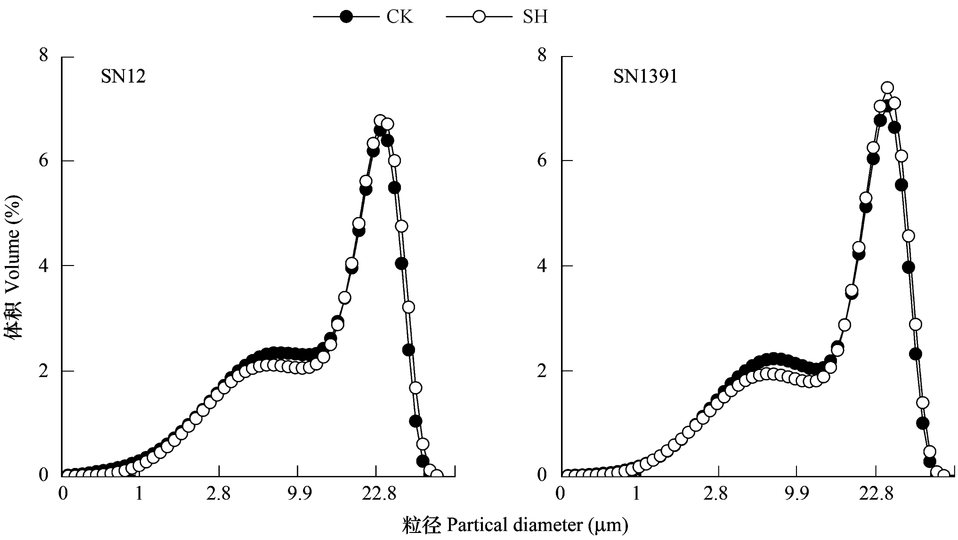

图1　小麦籽粒淀粉粒体积分布

Fig.1　Volume distribution of starch granules in grain

Data were charted in growing season 2005—2006; The same below

表2　花后弱光对籽粒淀粉粒体积分布的影响(%)

Table 2　Effect of shading after anthesis on volume distribution of starch granules in grain (%)

年份 Season	品种 Cultivar	处理 Treatment	淀粉粒径 Partical diameter of starch granule (μm)					
			<2.8	2.8~5.6	5.6~9.9	<9.9	9.9~22.8	22.8~42.8
2005~2006	山农12	CK	9.69 a	15.91 a	14.2 a	39.8 a	34.1 a	25.4 b
	SN12	SH	9.56 a	14.04 b	12.7 b	36.3 b	34 a	28.9 a
	山农1391	CK	8.21 a	14.59 a	13.2 a	36 a	30.5 a	32.7 b
	SN1391	SH	8.19 a	12.91 b	11.5 b	32.6 b	30.5 a	35.8 a
2006~2007	山农12	CK	9.97 a	16.13 a	14.6 a	40.7 a	33.7 a	24.8 b
	SN12	SH	9.94 b	13.66 b	12.6 b	36.3 b	34.3 a	28.6 a
	山农1391	CK	8.35 a	14.45 a	13.2 a	36 a	30.5 a	32.6 b
	SN1391	SH	8.48 a	13.22 b	11.7 b	33.4 b	31.1 a	34.3 a

同一列品种内不同小写字母表示5%水平差异显著　Means within cultivar followed by different letter are significantly different at $P < 0.05$

2.2　淀粉粒数目分布

小麦淀粉粒的数目分布呈单峰曲线(图2),峰值在0.54~1.05 μm,其中<2.8 μm和<9.9 μm的颗粒百

分比范围为89.8% ~94.6%和99.6% ~99.8%,表明小麦籽粒中的淀粉粒绝大多数为 B 型淀粉粒,且多为 <2.8 μm淀粉粒。

花后弱光使两小麦品种籽粒 B 型淀粉粒数目百分比较对照略有降低,A 型淀粉粒数目百分比略有提高。在 B 型淀粉粒中,弱光对 <2.8 μm 淀粉粒数目分布影响较大,即弱光显著降低 <0.8 μm 淀粉粒数目百分比,而增加了 0.8 ~2.8 μm 淀粉粒数目百分比(表 3)。

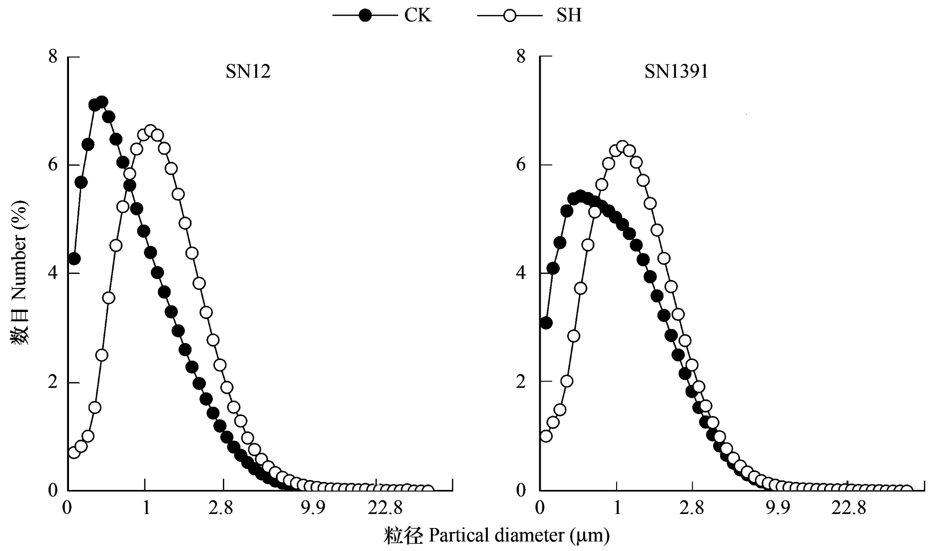

图 2　小麦籽粒淀粉粒数目分布

Fig. 2　Number distribution of starch granules in grain

表 3　花后弱光对籽粒淀粉粒数目分布的影响(%)

Table 3　Effect of shading after anthesis on number distribution of starch granules in grain (%)

年份 Season	品种 Cultivar	处理 Treatment	淀粉粒径 Partical diameter of starch granule (μm)				
			<0.8	0.8 ~2.8	2.8 ~9.9	<9.9	9.9 ~42.8
2005 ~2006	山农 12	CK	46.5 a	48.1 b	5.2 b	99.8 a	0.2 a
	SN12	SH	16.8 b	73.2 a	9.6 a	99.7 a	0.3 a
	山农 1391	CK	35.3 a	56.3 b	8.1 b	99.7 a	0.3 a
	SN1391	SH	19 b	70.8 a	9.8 a	99.6 a	0.4 a
2006 ~2007	山农 12	CK	45.6 a	48.7 b	5.5 b	99.8 a	0.2 a
	SN12	SH	27.6 b	64.6 a	7.5 a	99.7 a	0.3 a
	山农 1391	CK	34.6 a	57.3 b	7.8 b	99.7 a	0.3 a
	SN1391	SH	26.5 b	64.7 a	8.5 a	99.7 a	0.3 a

同一列品种内不同小写字母表示 5% 水平差异显著　Means within cultivar followed by different letter are significantly different at $P < 0.05$

2.3　淀粉粒表面积分布

小麦淀粉粒的表面积分布呈双峰曲线(图 3),峰值分别在 2.4 ~3.2 μm 和 20.7 ~24.9 μm,两峰值间的低谷出现在 9.9 μm 左右。B 型淀粉粒的表面积占总数的 74.9% ~80.4%,A 型淀粉粒占 20% ~25%。花后弱光显著降低两品种 <0.8 μm、2.8 ~9.8 μm 和 <9.9 μm 淀粉粒表面积百分比,显著增加 0.8 ~2.8 μm 和 >9.9 μm 淀粉粒表面积百分比。表明小麦花后弱光增加了 A 型淀粉粒表面积百分比,降低了 B 型淀粉粒表面积百分比。

2.4　淀粉组分含量及与淀粉粒分布的关系

花后弱光显著降低籽粒淀粉及其组分的含量,但直/支比却显著增加(表 5)。随着籽粒直/支比的提高,2.8 ~9.9 μm(图 4B)淀粉粒体积百分比显著降低($P < 0.05$),22.8 ~42.8 μm(图 4D)淀粉粒体积百分比显著增加($P < 0.05$)。<2.8 μm(图 4A)和 9.9 ~22.8 μm(图 4C)淀粉粒体积百分比与籽粒直/支比间相关均未

达显著水平($P > 0.05$)。

表 4　花后弱光对籽粒淀粉粒表面积分布的影响

Table 4　Effect of shading after anthesis on surface area distribution of starch granules in grain (%)

年份 Season	品种 Cultivar	处理 Treatment	淀粉粒径 Partical diameter of starch granule (μm)					
			<0.8	0.8~2.8	2.8~9.9	<9.9	9.9~22.8	22.8~42.8
2005~2006	山农 12	CK	10.6 a	28.3 b	41.2 a	80.1 a	13.9 b	5.98 b
	SN12	SH	4.6 b	33.6 a	38.8 b	77 b	15.4 a	7.56 a
	山农 1391	CK	6.4 a	30.5 b	41.9 a	78.8 a	14.2 b	8.5 b
	SN1391	SH	4.5 b	32.1 a	38.5 b	75.1 b	15.9 a	9.8 a
2006~2007	山农 12	CK	5.37 a	36.93 b	38.1 a	80.4 a	13.6 b	5.99 b
	SN12	SH	2.59 b	37.71 a	37 b	77.3 b	15.6 a	7 a
	山农 1391	CK	2.95 a	33.65 b	40.5 a	77.1 a	14.3 b	8.5 b
	SN1391	SH	2.24 b	35.56 a	37.1 b	74.9 b	15.8 a	9.2 a

同一列品种内不同小写字母表示 5% 水平差异显著　Means within cultivar followed by different letter are significantly different at $P < 0.05$

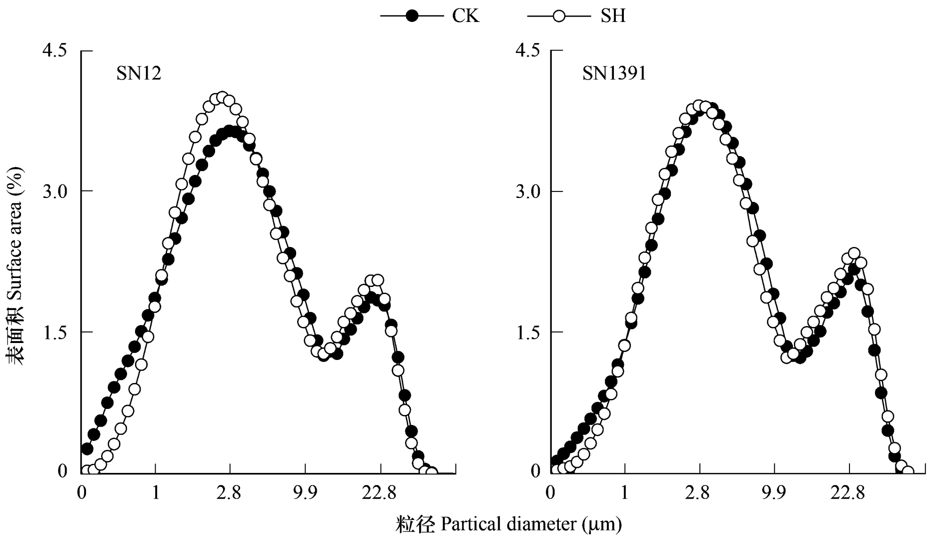

图 3　小麦籽粒淀粉粒表面积分布

Fig. 3　Surface area distribution of starch granules in grain

表 5　花后弱光对籽粒淀粉组分含量的影响

Table 5　Effect of shading after anthesis on starch component content in wheat grain

年份 Year	品种 Cultivar	处理 Treatment	淀粉 ST (%)	直链淀粉 AM (%)	支链淀粉 AP (%)	直/支比 AM/AP
2005~2006	山农 12	CK	63.2 a	15.9 a	47.3 a	0.336 b
	SN12	SH	54.3 b	14.1 b	40.2 b	0.351 a
	山农 1391	CK	65.2 a	17.1 a	48.1 a	0.356 b
	SN1391	SH	57.9 b	15.4 b	42.5 b	0.362 a
2006~2007	山农 12	CK	63.3 a	16.4 a	46.9 a	0.349 b
	SN12	SH	54.2 b	14.3 b	39.9 b	0.358 a
	山农 1391	CK	66.4 a	17.8 a	48.6 a	0.366 b
	SN1391	SH	57.8 b	15.9 b	41.9 b	0.38 a

ST: Starch; AM: Amylose; AP: Amylopectin; AM/AP: Amylose/Amylopectin

2.5　籽粒和淀粉产量

花后弱光显著降低小麦籽粒产量和淀粉产量,降幅分别为 38.2% ~44.4% 和 46.2% ~52.3%(图 5)。

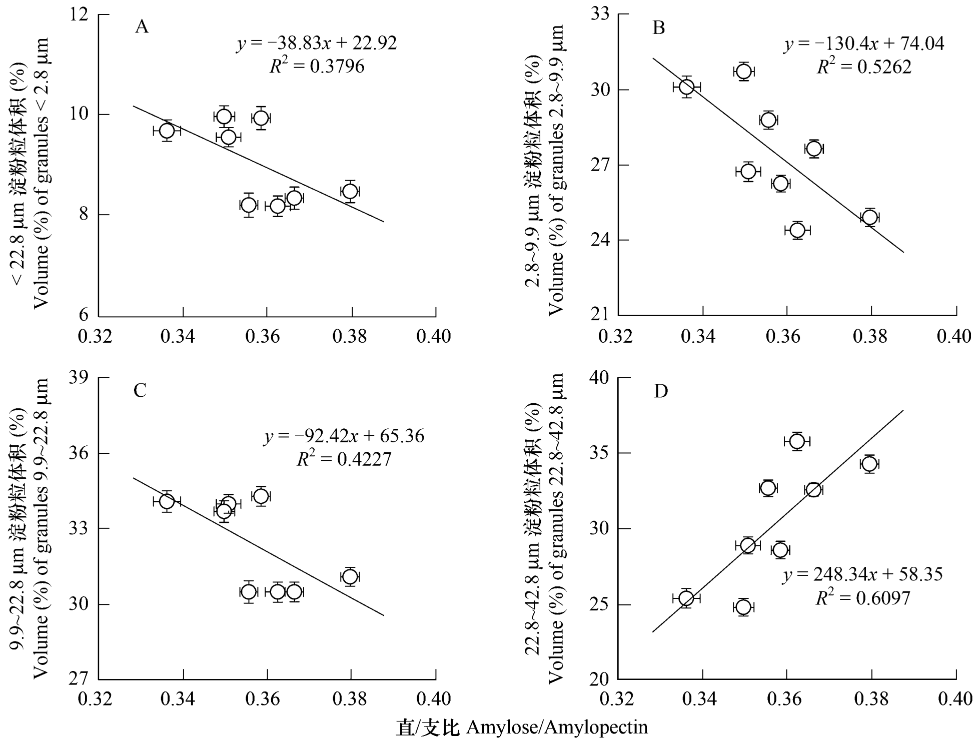

图 4 籽粒直/支比与淀粉粒体积分布的关系

Fig. 4 The relationship between the ratio of amylose to amylopectin and volume distribution of starch granules in grain

Values in the figure are means ± SD

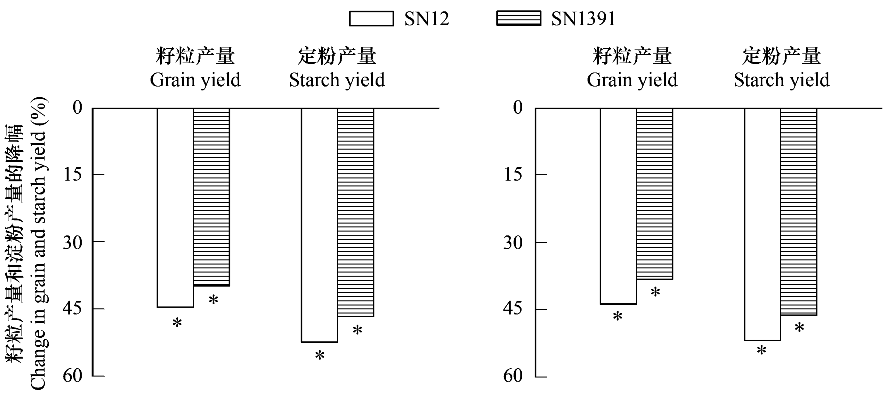

图 5 花后弱光对籽粒产量、淀粉产量的影响

Fig. 5 Effect of shading after anthesis on grain yield and starch yield in growing seasons 2005 ~ 2006 (left) and 2006 ~ 2007 (right)

* means significantly different between shading treatment and control for a cultivar at $P < 0.05$

2.6 花后不同阶段弱光对淀粉粒度分布的影响

表 6 显示了小麦花后不同阶段弱光对籽粒 A(9.9 ~ 42.8 μm)、B(< 9.9 μm)型淀粉粒的体积、数目分布的影响。弱光显著降低 B 型淀粉粒体积百分比、增加 A 型淀粉粒体积百分比。同时弱光降低了 B 型淀粉粒数目百分比、增加了 A 型淀粉粒数目百分比,但处理间差异较小。不同时期弱光对籽粒淀粉粒分布的影响程度不同,灌浆中、后期弱光影响程度较前期大。

3 讨论

小麦籽粒淀粉粒分布是淀粉品质的重要决定因素之一。Park 等[16] 利用 B 型淀粉粒含量不同(0 ~ 82%)

的重组面粉制作面包时发现,随着重组面粉 B 型淀粉粒增加,面包的货架时间延长。最近,Soh 等[17]研究亦发现,小麦籽粒 B 型淀粉粒含量的提高,有利于改善意大利面条品质。而环境条件显著影响小麦籽粒淀粉粒度分布。研究表明,不同生长环境下,小麦 A、B 型淀粉粒体积百分比显著不同[18]。灌浆期高温使籽粒 B 型淀粉粒数目减少,A 型淀粉粒数目增加[19]。同时,本课题组研究表明,小麦花后高温显著降低籽粒 B 型淀粉粒体积、数目及表面积百分比,增加 A 型淀粉粒体积、数目及表面积百分比。B 型淀粉粒对高温胁迫的反映比 A 型淀粉粒更敏感[20]。本研究表明,花后弱光显著改变小麦籽粒 A、B 型淀粉粒的体积和表面积分布。B 型(<9.9 μm)淀粉粒的体积和表面积百分比因花后弱光而显著降低,A 型(>9.9 μm)淀粉粒比例则相对增加。花后弱光对籽粒 A、B 型淀粉粒的数目百分比无明显影响,这可能是 <2.8 μm 淀粉粒数目较多(89.8% ~94.6%)的缘故。

表 6　花后不同阶段弱光对淀粉粒度分布的影响(2005 ~ 2006)

Table 6　Effect of shading at different grain filling stages on starch granule distribution in grain (2005 ~ 2006)

品种 Cultivar	处理 Treatment	体积 Volume (%)		数目 Number (%)	
		<9.9 μm	9.9 ~ 42.8 μm	<9.9 μm	9.9 ~ 42.8 μm
山农 12 SN12	CK	39.8 a	59.5 d	99.8 a	0.2 a
	S1	37.6 b	61.6 c	99.8 a	0.2 a
	S2	33.5 d	65.6 a	99.7 a	0.3 a
	S3	35.6 c	63.6 b	99.7 a	0.3 a
山农 1391 SN1391	CK	36 a	63.2 d	99.7 a	0.3 b
	S1	32.3 b	66.8 c	99.6 ab	0.4 ab
	S2	28.4 c	70.6 b	99.55 b	0.45 a
	S3	24.6 d	74.2 a	99.5 b	0.5 a

小麦花后弱光显著降低成熟期籽粒淀粉产量(图 5),表明籽粒淀粉粒(淀粉的存在形式)的积累量显著降低。弱光条件下 B 型淀粉粒降低、A 型淀粉粒增加为本试验所用仪器测定的 A、B 型淀粉粒分布的相对变化。出现这一结果的原因可能是小麦籽粒小淀粉粒是由大淀粉粒分化而来,而小淀粉粒在养分充足的情况下方可正常分化生长[21]。本研究的花后不同阶段弱光试验结果与之趋势一致,即弱光降低了 B 型淀粉粒体积百分比、提高 A 型淀粉粒体积百分比(表 4)。这进一步说明,弱光条件下小麦籽粒淀粉合成底物优先供应淀粉粒的生长,而非形成更多的淀粉粒,因而,B 型淀粉粒的产生及所占比例显著降低。

小麦籽粒淀粉粒的主要成分为支链淀粉和直链淀粉[9]。直/支比影响着淀粉的理化特性,与面条等食品的质地和表观性状密切相关[22,23]。前人关于弱光影响籽粒直链淀粉含量的结果不一。本研究认为,小麦花后弱光可显著降低籽粒支、直链淀粉含量,但籽粒直/支比提高。Raeker 等[24]在研究软质小麦淀粉粒分布时认为,9.9 ~ 18.5μm 的淀粉粒体积百分比与直链淀粉含量呈显著正相关,18.5 ~ 42.8 μm 的淀粉粒体积百分比与直链淀粉含量呈显著负相关。本试验的相关性分析表明,籽粒直/支比与 2.8 ~ 9.9 μm 淀粉粒体积百分比呈显著负相关,但与 22.8 ~ 42.8 μm 淀粉粒体积百分比呈显著正相关(图 4)。说明弱光环境下小麦籽粒 22.8 ~ 42.8 μm 淀粉粒的比例提高可能与直/支比的提高有关。

籽粒灌浆期弱光引起籽粒品质的不一致和不稳定一直是制约优质小麦生产的重要问题。因此如何根据各地的光照特点,通过选用耐弱光品种、采用适宜群体和合理栽培措施以降低弱光逆境的危害,是值得进一步研究的重要问题。

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