小麦干物质、果聚糖和氮的积累分配及其与籽粒产量和品质的关系*

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[摘 要] 在 200 kg/hm² 施N 条件下, 对 17 个澳大利亚小麦品种的干物质、果聚糖、氮的积累分配及其与籽粒产量(GY)、籽粒氮产量(GNY)及籽粒氮含量(GNC)的关系进行了研究。结果表明, 干物质、果聚糖和氮积累的模式相似, 在叶片、茎秆和植株中分别于开花期、乳熟期和成熟期积累到最大值。在开花前, 茎秆是贮存果聚糖的主要器官, 叶片是氮的主要贮存器官, 而在花期后, 籽粒成为贮存果聚糖和氮最多的器官, 其次为茎秆。从乳熟期至成熟期, 随着干物质、果聚糖和氮在营养器官中积累的降低, GY、GNY 和籽粒果聚糖积累快速增加。在多数取样期, 植株干物质积累和果聚糖积累与 GY 和 GNY 呈极显著正相关, 与 GNC 呈负相关; 成熟期植株氮积累与 GY 呈显著负相关, 与 GNC 显著正相关; 在花期后, 叶片和茎秆氮积累与 GY 和 GNY 呈显著负相关。

[关键词] 小麦; 干物质; 果聚糖; 氮积累与分配; 籽粒氮产量; 籽粒氮含量
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提高籽粒产量和蛋白质含量是小麦育种工作的主要目标, 由于籽粒产量和蛋白质含量之间的负相关关系[1~4], 通过直接选择同时提高籽粒产量和蛋白质含量是很困难的。籽粒产量和蛋白质含量与小麦植株生长发育过程中碳水化合物和氮素的同化、积累以及其在籽粒灌浆期向籽粒的转运有关[5~10], 而果聚糖是小麦最主要的非结构性碳水化合物的贮存形式[8,9], 其积累与转运水平是籽粒产量的主要来源[11~13]。研究表明, 小麦的氮积累、氮含量在不同时期存在基因型差异[1,2,14], 花期前氮同化量为成熟期的 80% 以上[15,16]。迄今为止, 有关氮积累、干物质积累与籽粒产量和蛋白质相关性的报道较多[5~10,17~19], 但结论并不一致; 且有关果聚糖在此方面的研究报道较少[6]。针对这一现状, 本研究对小麦干物质、果聚糖、氮的积累分配及其与籽粒产量和籽粒氮的关系进行了分析, 以期为小麦的高产优质育种和栽培提供理论依据。

1 材料与方法

1.1 试验材料与设计

田间试验在澳大利亚悉尼大学植物育种研究所(Narrabri)进行, 随机区组设计, 2 次重复, 施氮量 200 kg/hm², 分别于小麦拔节期和孕穗期各施 50%。7 行区, 行长 10 m, 行距 0.25 m, 相邻区间距 0.5 m。试验材料为 17 个小麦品种, 分别为 CH35, CH51, APOLLO, GEMINI, MERCURY, METEOR, CUNNINGHAM, CURRAWONG, JANZ, SUNBRI, SUNBROOK, SUNCO, SUNECA, SUNELG, SUNLAND, SUNMIST 和 SUNSTATE。

1.2 试验方法

于播种后 75, 90, 105, 120, 140 和 160 d 取样, 分别对应小麦拔节期、挑旗期、抽穗期、开花期、乳熟期和成熟期。用 0.5 m² 取样框在每小区中间 4 行随机用剪刀从地表剪下植株。根据植株器官发育情况, 立即将样品分离为叶片、茎秆(含叶鞘)、穗壳(穗去掉籽粒)和籽粒, 在微波炉杀青 4 min 左右, 然后在 60 ℃烘至恒重, 称重后用 Christy & Norris 实验磨磨粉。氮和果聚糖含量(%)用近红外仪(Technicon Infranlyzer 300)测定, 并校正。氮积累和果聚糖积累(kg/hm²)为各组织器官氮含量和果聚糖含量乘以其干物质积累, 籽粒氮积累(kg/hm²)为籽粒氮含量乘以籽粒产量。表型相关以基因型均值进行分析, 方差分析和相关分析用 Minitab Release 10.2 for Windows 统计软件完成。

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2 结果与分析

2.1 干物质的积累与分配

由图1可以看出,在播种后75,90,105,120和140 d,小麦植株干物质积累分别占成熟期植株干物质积累的16.8%,31.6%,49.9%,72.6%和98.6%。叶片干物质积累在120 d达到最大值,茎秆和穗壳干物质积累于140 d达到高峰,植株在160 d积累到最大值。播种后140 d,叶片、茎秆干物质积累减少,而籽粒干物质积累迅速增加。播种后90 d,叶片、茎秆干物质积累大约各占植株总干物质积累的50%;至105 d,这种平衡变为茎秆干物质积累占58.9%,叶片占38.6%,其余部分为穗的形成。在开花期(120 d),植株干物质积累分配于茎秆、叶片和穗的比率分别为54.8%,29.1%和16.1%。在播种后140 d,籽粒干物质积累占植株干物质积累的25%,茎秆占42%,叶片和穗壳各占17%;而在成熟期(160 d),籽粒占37.7%,茎秆占34.4%,叶片和穗壳各占14%。

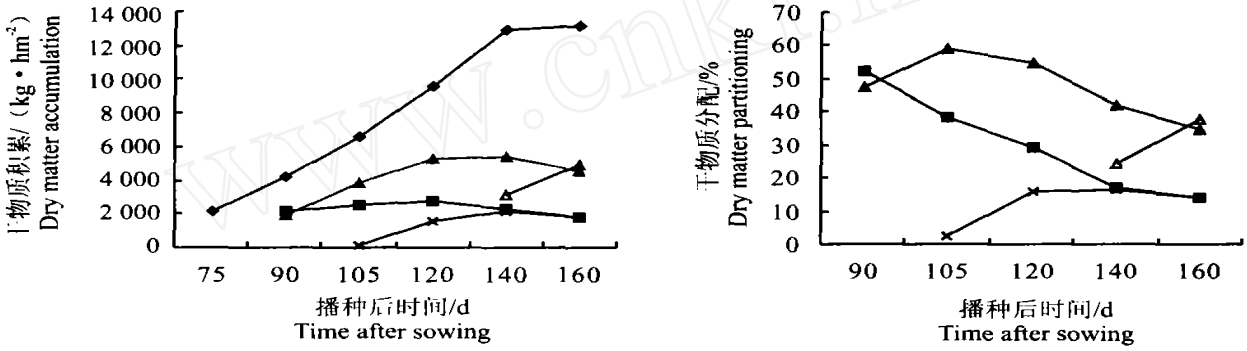

图1 不同取样期小麦植株及其器官干物质的积累与分配

-◆-.植株;-■-.叶片;-▲-.茎秆;-×-.穗壳;-△-.籽粒

Fig.1 Dry matter accumulation and partitioning of total plant and plant parts at various sampling dates in wheat

-◆-.Plant;-■-.Leaves;-▲-.Stems;-×-.Chaffs;-△-.Grains

2.2 果聚糖的积累与分配

由图2可见,植株果聚糖积累从播种后75 d的161.4 kg/hm²,持续增加至成熟期达到最高,为3 285.5 kg/hm²,特别是在籽粒灌浆期,植株果聚糖积累随着籽粒果聚糖积累的快速增加而迅速增加。茎秆果聚糖积累从播种后90 d的107.3 kg/hm²增加到120 d的962.9 kg/hm²,达到峰值,然后降低到成熟期的540.4 kg/hm²;而在同一时期,叶片果聚糖积累相对稳定在107.3~165.9 kg/hm²,变化较小;穗壳果聚糖积累高峰出现在乳熟期(140 d)。

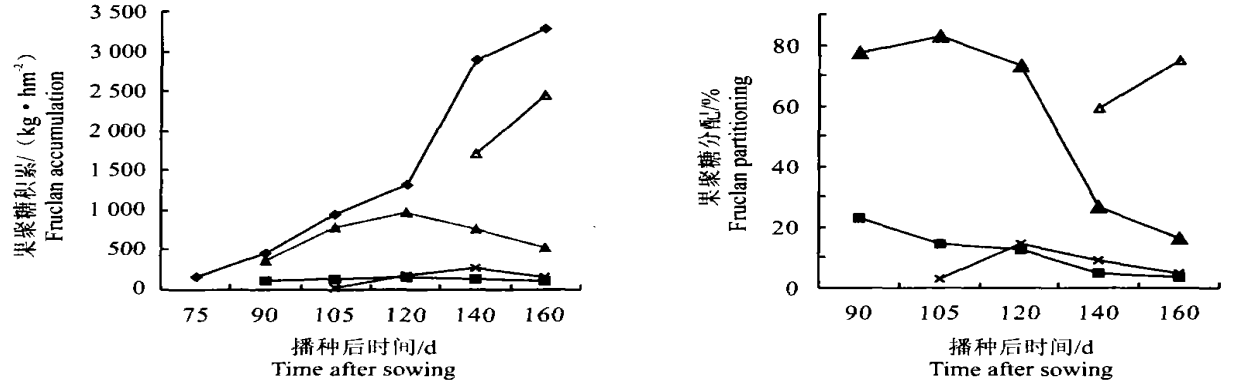

图2 不同取样期小麦植株及其器官果聚糖的积累与分配

-◆-.植株;-■-.叶片;-▲-.茎秆;-×-.穗壳;-△-.籽粒

Fig.2 Fructan accumulation and partitioning of total plant and plant parts at various sampling dates in wheat

-◆-.Plant;-■-.Leaves;-▲-.Stems;-×-.Chaffs;-△-.Grains

叶片在播种后90 d约占植株果聚糖积累的20%,在成熟期降低为4%。在营养生长期(120 d前)

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茎秆占植株果聚糖积累的 73%～ 83%, 到成熟期降低为 16. 5%。而穗(穗壳和籽粒) 由 120 d 的 14% 快速增加到成熟期的 80% 左右(图 2)。这一结果说明, 开花期前茎秆是果聚糖积累的最主要器官, 而开花期后籽粒成为贮存果聚糖的最主要器官, 其次为茎秆。

2. 3　氮的积累与分配

由图 3 可知, 植株氮积累从拔节期(75 d) 的 70 kg/hm^2 增加到成熟期的最大值 240 kg/hm^2, 增加了 3 倍多。叶片氮积累从播种后 90 d 的 70 kg/hm^2 降低到成熟期的 28 kg/hm^2, 降低了约 60%; 而同期茎秆氮积累增加了 50% (从 31 kg/hm^2 增加到 63 kg/hm^2)。一般地, 叶片在开花期、茎秆和穗壳在乳熟期氮积累达到高峰。植株氮积累在播种后 90, 105, 120, 140 和 160 d 分配到叶片的分别约为 70%, 60%, 45%, 20% 和 10%, 而茎秆的对应分配值为 30%, 40%, 40%, 33. 5% 和 26. 5%。在乳熟期(140 d), 穗壳和籽粒分别分配有植株氮积累的 15% 和 30%, 而在成熟期分别为 10% 和 50%。这些结果表明, 花期前叶片是氮积累的最主要器官, 而花期后籽粒成为贮存氮的主要器官, 其次为茎秆。

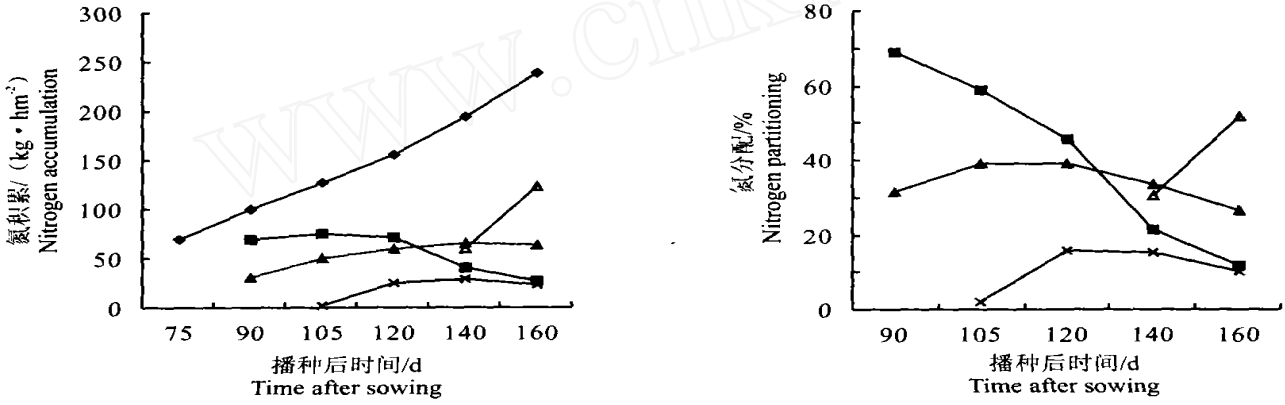

图 3　不同取样期小麦植株及其器官氮的积累与分配

- ◆- . 植株; - ■- . 叶片; - ▲- . 茎秆; - ×- . 穗壳; - △- . 籽粒

Fig. 3　Nitrogen accumulation and partitioning of total plant and plant parts at various sampling dates in wheat

- ◆- . Plant; - ■- . Leaves; - ▲- . Stems; - ×- . Chaffs; - △- . Grains

2. 4　小麦干物质、果聚糖和氮积累与籽粒产量、籽粒氮产量和籽粒氮含量的相关性

在多数取样期, 植株和茎秆干物质积累与 GY 和 GNY 显著正相关, 但与 GNC 无显著相关关系(除 140 d, R = - 0. 534*)。花期后叶片干物质积累与 GY 和 GNY 多达显著负相关, 而与 GNC 显著正相关。该结果表明, 籽粒产量与植株干物质积累关系密切, 越是到生育后期, 这种相关性越显著(表 1)。

GY, GNY 和 GNC 和果聚糖积累的相关关系与其和干物质积累的关系相似, 只是其与果聚糖积累的相关系数比与其干物质积累的相关系数大。

多数取样期植株和穗壳氮积累与 GY, GNY 和 GNC 无显著相关关系, 仅是成熟期植株氮积累与 GY (R = - 0. 551, P < 0. 05) 显著负相关, 而与 GNC (R = 0. 553, P < 0. 05) 显著正相关; 叶片和茎秆氮积累在花期后与 GY 和 GNY 显著负相关, 但在花期前多无显著相关关系, 其与 GNC 也无显著相关关系(表 1)。

表 1　小麦干物质、果聚糖和氮积累与籽粒产量(GY)、籽粒氮产量(GNY)和籽粒氮含量(GNC)的表型相关系数

Table 1　Phenotypic correlation coefficients between dry matter, fructan and nitrogen accumulation with grain yield (GY), grain nitrogen yield (GNY) and grain nitrogen concentration (GNC) in wheat

组织器官 Tissue organs	干物质积累 Dry matter accumulation vs			果聚糖积累 Fructan accumulation vs			氮积累 Nitrogen accumulation vs		
	GY	GNY	GNC	GY	GNY	GNC	GY	GNY	GNC
P75	0. 354	0. 425	- 0. 148	0. 450	0. 034	- 0. 615**	0. 215	0. 427	0. 057
P90	0. 556*	0. 501*	- 0. 360	0. 515*	0. 246	- 0. 545*	0. 303	0. 378	- 0. 079
P105	0. 387	0. 480*	- 0. 136	0. 336	0. 302	- 0. 263	0. 101	0. 364	0. 184
P120	0. 487*	0. 476	- 0. 291	0. 574*	0. 470	- 0. 441	0. 308	0. 180	0. 131

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续表 1 Continued Table 1

P140	0.444	0.133	-0.534*	0.821**	0.521*	-0.738**	0.155	0.035	-0.205
P160	0.541*	0.606**	-0.258	0.861**	0.566*	-0.731**	-0.551*	-0.258	0.553*
L90	-0.051	0.112	0.037	-0.244	-0.261	0.107	0.096	0.174	0.044
L105	-0.356	-0.071	0.457	-0.363	-0.081	0.426	-0.291	0.044	0.471
L120	-0.530*	-0.365	0.490*	-0.229	-0.092	0.268	-0.491*	-0.344	0.457
L140	-0.663**	-0.615**	0.445	-0.567*	-0.545*	0.357	-0.640**	-0.595*	0.428
L160	-0.616**	-0.249	0.689**	-0.520*	-0.175	0.610**	-0.581*	-0.580*	0.359
S90	0.618**	0.524*	-0.434	0.536*	0.292	-0.530*	0.496*	0.548*	-0.221
S105	0.458	0.469	-0.270	0.288	0.225	-0.257	0.270	0.378	-0.053
S120	0.583*	0.517*	-0.405	0.552*	0.398	-0.467	0.182	0.289	-0.006
S140	-0.111	-0.265	-0.074	-0.148	-0.142	0.114	-0.548*	-0.550*	0.310
S160	0.215	0.348	-0.033	0.018	0.165	0.135	-0.595*	-0.606**	0.317
C140	0.143	-0.064	-0.271	-0.345	-0.462	0.107	-0.025	-0.110	-0.051
C160	0.320	0.411	-0.115	-0.224	-0.092	0.242	-0.011	0.232	0.204

注: P, L, S 和 C 分别表示植株、叶片、茎秆和穗壳, 数字 75, 90, 105, 120, 140 和 160 分别为播种后天数。*, ** 分别表示在 0.05 和 0.01 水平差异显著。

Note: P, L, S and C stand for Plant, Leaf, Stem and Chaff respectively, numbers 75, 90, 105, 120, 140, and 160 are the sampling dates at the days after owing. * and ** mean the significant differences at 0.05 and 0.01 levels, respectively.

3 结论与讨论

小麦生育期干物质、果聚糖和氮积累规律相似, 叶片、茎秆和植株分别在开花期、乳熟期和成熟期积累到高峰; 从灌浆中期到成熟期, 籽粒产量、籽粒氮产量和籽粒果聚糖积累随着这些性状在营养器官中的减少而迅速增加; 茎秆是贮存果聚糖的最主要器官, 在花期前其分配有植株果聚糖积累的 75%～83%, 在花期前, 氮的最主要贮存器官为叶片, 而在花期后是籽粒, 其次为茎秆。

由于作物干物质、果聚糖和氮的积累受自然、栽培条件影响较大[1～10, 14, 18, 20], 因此有关这些性状与 GY, GNY 和 GNC 相关性的研究结论不尽一致[1～4, 8, 10, 12, 21]。前人研究[1, 8, 12, 22]多数认为, 成熟期植株干物质积累与 GY、GNY 和 GNC 呈显著正相关; Mckendry 等[1]发现, 植株氮积累与 GY, GNY 和 GNC 之间存在显著的正相关。本研究同样发现, 成熟期植株干物质积累与 GY (R = 0.541*) 和 GNY (R = 0.606**) 显著正相关, 但与 GNC 无显著相关关系; 植株果聚糖积累比其干物质积累与 GY 和 GNC 的相关性更为密切; 多数取样期植株氮积累与 GY, GNY 和 GNC 相关不显著。由于成熟期植株果聚糖积累与 GY 呈极显著正相关 (R = 0.861**), 植株氮积累与 GNC 呈显著正相关 (R = 0.553*), 因此, 选择成熟期植株果聚糖积累和植株氮积累均较高的植株, 很有可能在提高 GY 的同时提高 GNC。

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Dry matter, fructan and nitrogen accumulation and partitioning and their correlation with grain yield and quality in wheat

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Abstract: Dry matter, fructan and nitrogen accumulation and partitioning and their relationships with grain yield (GY), grain nitrogen yield (GNY) and grain nitrogen concentration (GNC) were studied in seventeen Australia wheat genotypes (*Triticum*, *aestivum* L.) under 200 kg/hm^2 application in one growing season. The accumulation pattern of dry matter, fructan and nitrogen were similar, the contents of which in leaf, stem and total plant peaked at flowering, milk-ripe stage and maturity respectively. Stems were the major fructan storage organs, and leaves were the main nitrogen storage tissues prior to anthesis, while grains store fructan and nitrogen most after anthesis, next were stems. GY, GNY and grain fructan accumulation increased sharply while dry matter, fructan and nitrogen accumulation of vegetative parts decreased from milk-ripe stage to maturity. Plant dry matter accumulation and plant fructan accumulation were significantly positive with GY and GNY, while negatively correlated with GNC at most sampling dates; plant nitrogen accumulation at mturity were significantly negative with GY, positive with GNC; nitrogen accumulation of leaves and stems were significantly negative with GY and GNY after anthesis.

Key words: wheat; dry matter; fructan; nitrogen accumulation and partitioning; GNY; GNC

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