ПРОДУКТИВНОСТ И АЗОТНА ЕФЕКТИВНОСТ ПРИ ОБИКНОВЕНАТА ПШЕНИЦА – СРАВНИТЕЛЕН АНАЛИЗ НА СТАРОДАВНИ И СЪВРЕМЕННИ БЪЛГАРСКИ СОРТОВЕ

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Резюме

Значителното нарастване на световните добиви при пшеницата след Зелената революция се дължи до голяма степен на глобалното интродуциране на ниски сортове и на 7-кратното увеличение на употребата на азотни торове. В България всички съвременни сортове обикновена пшеница, създадени след 1960-те години, носят гени за ниско стъбло. Стародавните високостъблени сортове са създадени в условия на слабо обезпечаване с хранителни елементи и следователно, представляват източник на генетично вариране за селекция на генотипи, подходящи за отглеждане в условия на по-слабо торене и за нуждите на биологичното земеделие. В настоящето проучване се прави сравнение между 79 съвременни и 21 стародавни български сортове пшеница по отношение на тяхната продуктивност и азотна ефективност при отглеждане на два варианта на азотно торене в две местонахождения (София и Генерал Тошево). Установени са значими ефекти на факторите „Тип сорт“ (стародавни или съвременни), „Торене“ и „Място“, както и на взаимоотношенията „Тип сорт х Място“ и „Торене х Място“. При екстензивните условия на експерименталното поле в София, характеризиращо се с по-слаба почва и предшественик царевица, по-голяма част от стародавните сортове (18) бяха определени като ефективни и отзивчиви на азотно торене, а повечето съвременни сортове (45) – като неефективни и неотзивчиви на азот. Обратна тенденция беше наблюдавана в Генерал Тошево в условия на излужен чернозем и бобов предшественик.

Abstract

Landjeva S., V. Koutev, N. Tsenov, P. Chamurlijski, T. Trifonova, V. Nenova, T. Kartseva, K. Kocheva, P. Petrov, G. Georgiev, 2014. Productivity and nitrogen use efficiency in bread wheat – comparative analysis of old and modern Bulgarian cultivars

The worldwide yield outbreak in wheat following the Green Revolution has been associated with the introduction of semi-dwarf nitrogen (N)-responsive high-yielding cultivars, as well as with substantial increase in N fertilizers consumption. In Bulgaria, all modern cultivars released after 1960s are semi – dwarf. The old tall-stature cultivars have been developed mostly in environments with low nutrient availability and, therefore, represent a source of genetic variation for selection of genotypes suitable for growing in low-input or organic farming systems. The present study compares the productivity and N efficiency of 79 modern and 21 old Bulgarian bread wheat cultivars, grown at two N levels in two environments (Sofia and General Toshevo). Significant effects of the cultivar type (old vs modern), N-fertilization and environment on grain yield were established. There were significant interactions between cultivar type and environment and between N-fertilization and environment. Under the more extensive conditions in Sofia experimental field with poorer soil characteristics and maize predecessor, the majority of old genotypes were efficient and N-responsive, while most of the modern cultivars were inefficient and N non-responsive. On the contrary, under the conditions of General Toshevo on haplic chernozem and pea predecessor, the vast part of old gemplasm was inefficient and N non-responsive, while modern releases were efficient and responsive to N supply.

Key words: nitrogen use efficiency, old cultivars, productivity, wheat.

INTRODUCTION

The doubling of wheat productivity worldwide over the past 50 years has been associated with progressively higher nitrogen (N) inputs and with introduction of semi-dwarfing (*Rht)* genes. The intensive N applications and the generally low plant N efficiency create risk of environmental pollution. Much research has been conducted to improve N efficiency by developing fertilizer management strategies (Ladha et al., 2005). Restrictions on the use of N fertilizers have been imposed in many countries (Doberman, 2005). Development and growing of cultivars that could utilize the soil N more efficiently is considered the optimal approach from an economic and environmental perspective (Ladha et al., 2005).

Wheat breeding in Bulgaria has been directed at achieving yield increments, improved grain quality and increased abiotic stress tolerance (Tsenov et al., 2009[a,b,] 2010). Since 1960s, more than 130 semi-dwarf cultivars have been released in the two main breeding centres in General Toshevo and Sadovo. The effects of N nutrition on plant growth, yield and grain quality and the genotypic effects on nutrient efficiency have been investigated in several cultivars and advanced breeding lines (Ivanova et al., 2006, 2007; Rachovski et al., 2005). As a result, the nutrient efficient cultivar Fermer has been developed (Rachovska et al., 2010).

The historic „old” cultivars are relatively homogeneous selections from local forms, or early breeding releases, that were once on a variety registration list but are no longer in use. This germplasm evolved from a broader gene pool and therefore is a valuable and yet underutilized resource for breeding purposes. Bulgarian old varieties were noted for their stable yield, drought tolerance, high protein content, or good bread-making quality (Majdrakov, 1945). Most of this germplasm is not cultivated anymore and preserved as seeds in *ex situ* genebanks.

This study was conducted with the aim to compare the productivity and N use efficiency, defined as grain yield per unit applied N, in a large number of old and modern Bulgarian bread wheat cultivars, grown on N-fertilized and non-fertilized plots at two environmental locations.

Table 1. List of 100 Bulgarian bread wheat cultivars, breeding lines and *Rht* near-isogenic lines (NILs) used in the study

Group	Cultivar names / line designation	Contributor
Old cultivars (21)	No14, No16, No84, No7, No127, No165, No19, No182, No2315, Beliya, Burgas-1, Ferrugineum-113, Ivancha, Karnobat-92, Knezha, Maritsa, Nedan, Okerman-804, Sadovska ranozrejka-2, Slomer, Sofia-312	Federal *ex situ* Genebank of Germany, IPK, Gatersleben
Modern semi-dwarf cultivars and lines (79)	Aglika, Albena, Anna, Bolyarka, Bozhana, Charodejka, Demetra, Dobrotitsa, Dobrudzha-1, Dragana, Elitsa, Enola, Galateya, Goritsa, Iveta, Kaloyan, Karat, Karina, Kiten, Kremena, Kristal, Lazarka, Liliya, Medeya, Merilin, Milena, Neda, Ogosta, Perla-2, Prostor, Rada, Rubin, Russalka, Skitiya, Slaveya, Slavyanka, Stoyana, Svilena, Todora, Trakiya, Vega, Yantar, Yasen, Yubilej, Zlatitsa, Zlatoklas	Dobrudzha Agricultural Institute, General Toshevo
	Bononiya, Boryana, Diamant, Fermer,Geya-1, Guinnes, Katya, Khrabrets, KM 135, Lada, Lyusil, Momchil, Mustang, Niki, Nova Zvezda, Petya, Pobeda, Prelom, Sadovo-1, Sadovo-552, Sadovo-772, Slaven, Tsarevets, Yunak, Zdravko	Institute of Plant Genetic Resources, Sadovo
	Altimir-67, Lozen-6, C63-2012, P3-2012, Sadovo-1 NIL *Rht-B1b*, Sadovo-1 NIL *Rht-B1d*, Sadovo-1 NIL *Rht-D1b*	Institute of Plant Physiology and Genetics, Bulgarian Academy of Sciences

MATERIAL AND METHODS

A total of 100 bread wheat genotypes were used (Table 1). Seed of old genetic resources (21 accessions) was kindly provided by the Federal *ex situ* Genebank of Germany, IPK, Gatersleben. Seed samples of modern semi-dwarf germplasm (79) were provided by the Dobrudzha Agricultural Institute, General Toshevo, Institute of Plant Genetic Resources, Sadovo and Institute of Plant Physiology and Genetics, Sofia. This material included advanced cultivars, two breeding lines and three *Rht* – near isogenic lines of cv. Sadovo-1, the latter developed and kindly provided by Dr. G. Ganeva.

The experimental material was sown in October 2012 at two locations: Sofia (42°41'N 23°19'E) and General Toshevo (43°42'N 28°2'E). Brief characteristics of the experimental sites are presented in Table 2.

Table 2. Characteristics of the experimental fields

	Sofia	General Toshevo
Coordinates	42°41'N 23°19'E	43°42'N 28°2'E
Soil type	Leached vertisol	Haplic chernozem
Humus (%)	3.1	3.5
pH	6.1	6.5
Total N (mg/kg soil)	1420	1560
Innorganic N (mg/kg soil)	18	20
P_2O_5 (mg/100g soil)	12	5.3
K_2O (mg/100g soil)	32	22
Predecesor	maize	pea
Total precipitation (Oct 2012-July 2013) (mm)	353.5	387.0

At each location, the experimental field was divided into two blocks: high N and low N, separated by a 4 m-plot to avoid movement of N between treatments. In each N block, the genotypes were sown in a randomized complete block design with three replications. Individual plots contained 4 rows of 2 m length spaced 25 cm apart with 5 cm space between plants within a row and 50 cm between plots. The high N block received 12 kg N/da as ammonium nitrate in two split doses as follows: 4 kg/da two weeks after sowing and 8 kg/da in March 2013. The low N block received no fertilizer N. Hand weeding and herbicide applications were carried out for weed control. At harvest, for each genotype (replication) N block two samples of 0.5 m were taken from the inner two rows for yield determination. The grain yield was determined and presented on a 1-linear-meter basis.

Statistical analysis of the data (factorial ANOVA) was performed using the software package STATISTICA v. 7.

RESULTS

A factorial ANOVA revealed that there was significant main effect of factor "Cultivar type" on grain yield ($F_{(1,392)} = 16.4$, $p < 0.01$) with modern cultivars displaying higher grain yield than the old ones (Table 3). As expected, the application of fertilizer N had significant effect on the trait ($F_{(1,392)} = 138.2$, $p < 0.001$), the grain yield obtained under N_{12} being greater (193.4 ± 71.8) than

Table 3. Grain yield (mean and standard deviation) components in 100 Bulgarian bread wheat cultivars grown at two N levels (low N – no fertilizer N added; high N – N_{12} added as ammonium nitrate) in two environments – comparison of old and modern cultivars

Cultivar type	Low N			High N			Total Average
	Sofia	G. Toshevo	Average	Sofia	G. Toshevo	Average	
Old (21)	105.6±25.0***	167.0±37.9***	136.3±44.4ns	153.2±22.7**	202.3±48.1***	177.8±44.7ns	157.0±48.9**
Modern (79)	58.8±17.1	237.0±31.2	147.9±92.8	129.3±31.0	265.9±39.2	197.6±77.1	172.7±88.7
Average	68.6±26.9	222.3±43.3		134.3±30.9	252.6±48.5		

, * – significantly different from modern cultivars at $p<0.01$ and 0.001, respectively; ns – non-significant that from the non-fertilized plots (145.5 ± 85.0) regardless of the cultivar type. There was no significant “Cultivar type x N – fertilization” interaction ($F_{(1,392)} = 1.1$, $p = 0.29$) suggesting that on average over the two experimental locations, the productivity of old cultivars although generally lower did not differ significantly from that of modern cultivars both under low and high N. There was highly significant effect of the “Environment” ($F_{(1,392)} = 752.2$, $p < 0.001$), the grain yield obtained in General Toshevo (237.4 ± 48.3) being more than twice greater compared to that obtained in Sofia (101.5 ± 43.9). The “Cultivar type x Environment” ($F_{(1,392)} = 173.4$) interaction was also significant. The nature of this interaction suggested that for General Toshevo old cultivars yielded less than modern ones, while in Sofia the old cultivars were significantly more productive (Table 3). There was also a significant “Environment x N-fertilization” interaction ($F_{(1,392)} = 12.1$, $p < 0.001$) suggesting that the yields obtained at General Toshevo under both low (222.3 ± 43.3) and high (252.6 ± 48.5) N levels were significantly higher compared to those harvested at Sofia (low N: 68.6 ± 26.9; high N: 134.3 ± 30.9). The interaction “Cultivar type x Environment x N-fertilization” was not significant ($F_{(1,392)} = 3.5$, $p = 0.06$).

The response pattern of the material was visualized by plotting the grain yields under high N against grain yields under low N (Figure 1). In Sofia, the majority of old cultivars (18) were efficient and responsive to N application, two were efficient non-responsive and one was inefficient non-responsive. Forty-five out of 79 modern cultivars were inefficient and non-responsive, 15 were inefficient and responsive, 15 were efficient and responsive, and 4 were efficient and non-responsive. The distribution of genotypes observed in General Toshevo was drastically different. The majority of old cultivars (17) were inefficient non-responsive, the rest were efficient responsive (2), inefficient responsive (1), and efficient non-responsive (1). The modern cultivars followed the distribution: 46 efficient and responsive to N fertilization, 12 efficient non-responsive, 9 inefficient responsive and 12 inefficient non-responsive.

DISCUSSION

According to the comparative analysis described above, the productivity of old wheat germplasm was lower compared to the modern releases on average over two environments and two N levels. However, the established significant “Cultivar type” (old vs modern) x “Environment” and non-significant “Cultivar type” x “N-fertilization” interactions suggest that the observed diverse behaviour of old resources could represent a potential source of variation for breeding genotypes suitable for growing in specific agro-climatic and soil conditions. The old germplasm might also be of interest for direct cultivation, or as a parent in breeding material tailored for growing in low-input or organic farming systems.

The contemporary wheat cultivars are, on general, of intensive type and highly responsive to N application, whereas the old tall-stature material has been developed mostly in environments with low nutrient availability, and is expected to exhibit greater adaptability to adverse environments, including nutrient deficiency (Newton et al., 2010). In addition, the old wheat germplasm is characterized by high genetic heterogeneity as revealed by molecular markers (Klestkina et al., 2004; Landjeva et al., 2014; Roussel et al., 2004). The inherent wide genetic

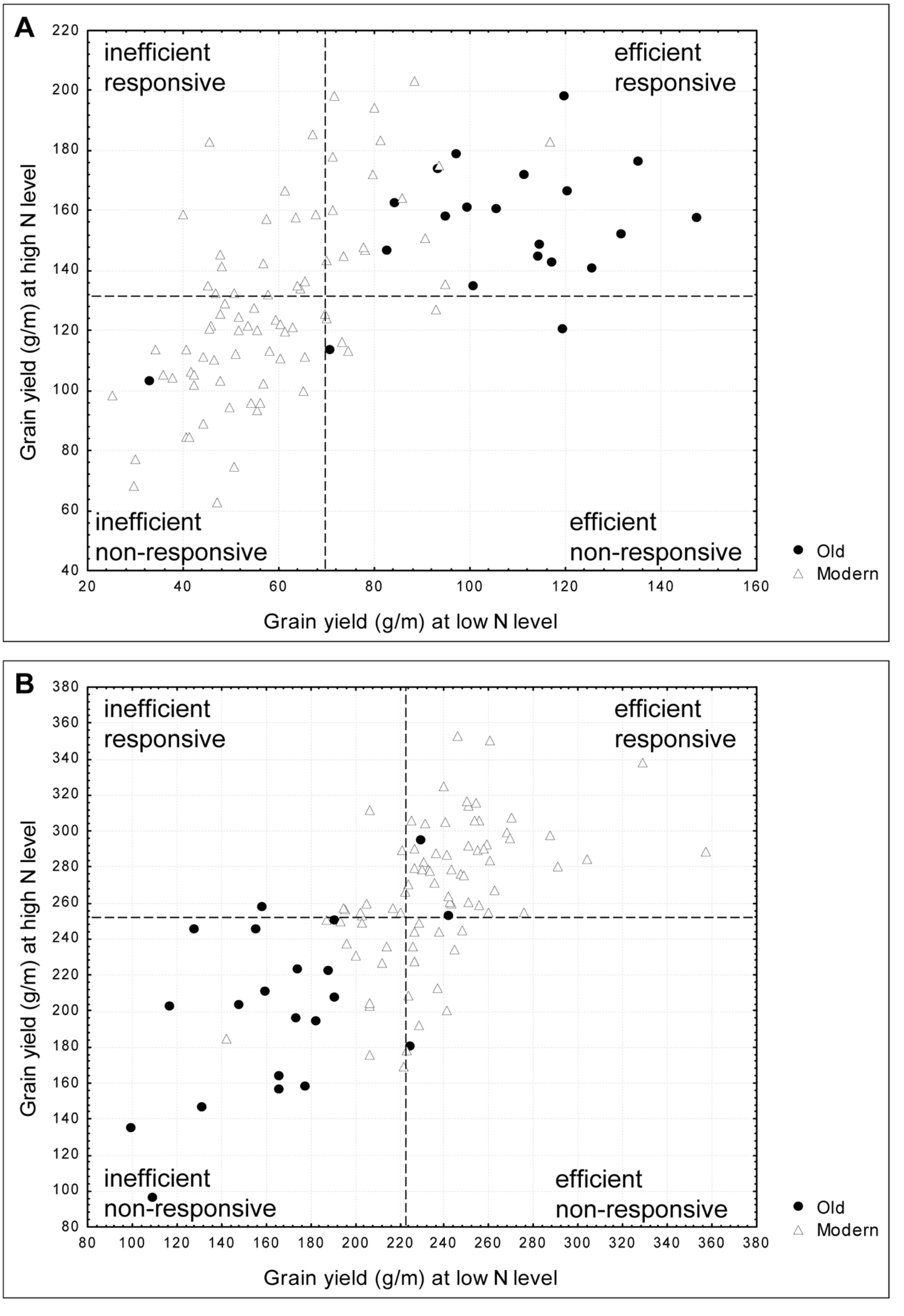

Figure 1. Bi-plot of grain yield in 100 old and modern Bulgarian wheat cultivars at high (N_{12}) and low (no fertilizer N added) N levels in two environments: **A.** Sofia; **B.** General Toshevo. Broken lines represent means for each N level.

variability of this germplasm is supposed to secure better plant adaptation and survival under diverse conditions.

The soil at Sofia experimental location is relatively poor compared to the rich haplic chernozem in General Toshevo. The predecessor crop was also different creating further difference between the two locations with regard to the N background. Therefore, under the rich soil and higher N background in General Toshevo most of the modern intensive cultivars responded notably to the N application by higher grain yields. Under these agronomic conditions, the old cultivars did not respond to additional N supply. Moreover, the old genotypes produced greater amount of biomass and most of them suffered lodging which resulted in yield loss and determined their low N efficiency.

On the contrary, in Sofia under the conditions of poorer soil characteristics and maize predecessor, almost all old cultivars were lodging resistant at both N levels, N efficient and responded well to the N application, while the majority of modern intensive cultivars failed to display their high productive potential and were classified mostly as inefficient and non-responsive to N fertilization.

Differences of N efficiency could be attributed to differences in pre-anthesis uptake and in translocation from vegetative parts to the developing grain. In conditions of more extensive low input environments with limiting N availability during grain filling, the greater pre-anthesis uptake and buffering capacity in old genotypes with high vegetative biomass are supposed to contribute more to N efficiency than translocation efficiency (Baresel et al., 2008; Newton et al., 2010). This could explain the observed trend in the Sofia experimental site. Moreover, in cases when there are differences in the amount of soil N combined with differences in the cultivar ability to accumulate and utilize N to obtain optimum crop growth, the site-specific and genotype – specific application of fertilizer N is of importance (Ladha et al., 2005). The results of the present study are in support of this opinion. Based on the obtained results, old and modern genotypes with contrasting productivity and responsiveness to N supply were selected and included in physiological studies on the N efficiency.

CONCLUSIONS

Significant effects of the factors cultivar type (old vs modern), N-fertilization and environment on grain yield were established. There were significant “Cultivar type x Environment” and “N-fertilization x Environment” interactions. Under the more extensive conditions in Sofia experimental field with poorer soil characteristics and maize predecessor, the majority of old genotypes were efficient and N-responsive, while most of the modern cultivars were inefficient and N non-responsive. On the contrary, under the conditions of General Toshevo on rich haplic chernozem and pea predecessor, the vast part of old gemplasm was inefficient and N non-responsive, while modern releases were efficient and responsive to N supply.

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