RESEARCH

Preliminary comparisons of early generation individual selection efficiency of a local wheat landrace under different experimental field designs

Vasileios Greveniotis[1*], Evangelia Sioki[2], and Constantinos G. Ipsilandis[3]

[1]Technological Educational Institute of Thessaly, Department of Agricultural Technology, School of Agricultural Technology, Food Technology and Nutrition, Larissa 41110, Greece.
[*]Corresponding author (vgreveni@mail.com, vgreveni@teilar.gr).
[2]Aristotle University of Thessaloniki, Department of Agricultural Economics, Thessaloniki 54124, Greece.
[3]Regional Administration of Central Macedonia, Department of Agriculture, Thessaloniki 54622, Greece.

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ABSTRACT

Wheat (*Triticum aestivum* L.) landraces are traditional adapted varieties developed and used by farmers but not usually improved by breeders. The objective of our study was to compare the efficiency of three different methods (arrangements) of homogeneity blocks to produce high-yield progenies during the breeding procedure of a local bread wheat landrace. This original genetic material underwent a mass selection scheme in F_2 individual plants in three different experimental designs to reduce soil heterogeneity (honeycomb, gridding, double rows); selection was based on individual plant grain weight. In F_3 lines, bulk density was the selection criterion in a specific arrangement that divided the experimental field into three plots for 12 subplots to reduce soil heterogeneity. The F_4 lines were evaluated in randomized complete block trials for 2 yr based on grain yield, 1000-kernel weight, and bulk density. Progenies from the three different experimental designs were compared. The gridding method seemed more efficient for evaluating sister lines because it maximized yields, provided a greater number of promising lines, and F_3/F_4 correlations were high and significant. Wheat plants did not perform well under the double row system (mean bulk density 756 g L^{-1}). Heritability was high for all studied traits (0.93) and bulk density was a reliable criterion for selecting promising genetic materials (90.1% genotype contribution in variability) and revealed differences between methods. The local landrace was unstable and exhibited specific adaptability to the cultivated environment. Selected lines (from the most efficient method) improved yield performance by 11% on the average compared with the original population.

Key words: Evaluation, gridding, heterogeneity, honeycomb, *Triticum aestivum*.

INTRODUCTION

A successful breeding program must always develop cultivars with high and stable performance. Shebeski (1967) first described selection for high yield performance based on early generation evaluation of individual plants. This concept was later proven as not promising because of its low effectiveness (McGinnis and Shebeski, 1968; DePauw and Shebeski, 1973). Fasoulas (1988) recognized the single plant as the selection unit to improve yield potential. In plant genome, a contrasting balance exists between genes that improve yield and performance stability and deleterious genes that lead to deterioration (Fasoulas, 1993). This author also stated that soil heterogeneity and plant-to-plant competition might reduce selection effectiveness. Fasoulas (1988) explained that, despite the type of heritability effects, the soil heterogeneity parameter negatively affects selection efficiency by inducing non-uniform comparison conditions and reducing the heritability of superior phenotypes. He also separated the Genotype × Environment interactions as a different negative efficiency factor. The author therefore proposed the honeycomb methodology and field designs suitable for evaluating individual plants and reducing the masking effects of competition and soil heterogeneity. Vafias et al. (2007) also found that inputs and intra-field soil heterogeneity are the major negative efficiency factors.

Early stage evaluation and pedigree selection of segregating genetic materials is a common practice in bread wheat (*Triticum aestivum* L.) in organizations such as the International Maize and Wheat Improvement Center (CIMMYT) and other institutions (Stratilakis and Goulas, 2003). These researchers have also depicted the problems of soil heterogeneity and competition and concluded that proper plant allocation is needed to safely select the best individuals without the masking effects of competition and soil heterogeneity. The honeycomb designs described by Fasoulas (1988) certainly provide a plant allocation scheme in a hexagonal field arrangement with equal and adequate plant spacing and a type of blocking with similar soil characteristics to reduce soil heterogeneity and improve individual plant comparisons. Gardner (1961) was the first to suggest homogeneity blocks (grids) to compare plants safely within blocks. His grid mass selection arrangement is a method to reduce soil heterogeneity within grids and increase selection efficiency. Shebeski (1967) used a specific row arrangement and compared it to the adjacent check (control) rows to obtain more comparable results that were free of soil heterogeneity within a block of rows. McGinnis and Shebeski (1968) later used double rows and early generation evaluation but reported no progress.

Landraces are mixtures of sibling plants that are usually sown by local traditional farmers; they have great variability, are not easily described, and have good potential to cope with abiotic stresses (Dwivedi et al. 2016). Camacho Villa et al. (2005) described local populations as traditionally and historically sown materials with certain relative characteristics that are collections with no official breeding. Jaradat (2011; 2013) reported that landraces were the main type of genetic materials used by farmers. These local populations exhibit specific adaptability to the environments where they are cultivated for many years (Almekinders et al., 1994). The improvement of local populations, old varieties, or landraces is important because it can provide breeders with valuable genetic materials to develop cultivars by specifically adapting to certain environmental conditions and novel genetic diversity (Dotlacil et al., 2010; Lopes et al., 2015). Landraces can also increase biomass and 1000-kernel weight, which are important traits for adapting to drought and high heat (Lopes et al., 2015). The evaluation of wheat landraces with beneficial diversity and certain stress adaptation stored in gene banks can be used for wheat improvement (Hoisington et al., 1999; Lopes et al., 2015). Dotlacil et al. (2010) reported important regressions for environmental responses of these genetic materials and trait correlations to be exploited by breeders.

The objective of our study was to compare three different methods of homogeneity blocks for their efficiency in producing high-yield (with performance stability) progenies during the breeding procedure of a local bread wheat landrace. Although early stage evaluation is considered ineffective due to environmental effects (Allard, 1960), we compared the three methods (honeycomb, gridding, and adjacent control) based on certain criteria involving plant yield index (PYI; Fasoula, 2006; 2013), grid yield (Gardner, 1961), and relative yield (McGinnis and Shebeski, 1968). Bulk density calculations were preferred (as the basic selection trait) and estimations of variation and heritability were performed simultaneously.

MATERIALS AND METHODS

The original genetic material was a well-adapted local bread wheat (*Triticum aestivum* L.) landrace (used locally as a variety) from an isolated area in western Macedonia, Greece. Seeds of this genetic material were sown in 2007 on the farm of the Technological Educational Institute (TEI) of Western Macedonia in Florina (40°46’ N, 21°22’ E; 705 m a.s.l.); the soil was sandy loam: 61.2% sand, 27.6% silt, 11.2% clay, and pH 6.25. Climatic data (6-yr period) are shown in Figure 1.

Seeds from the 2008 harvest were used (in early November) to establish four experiments with different evaluation designs to reduce intra-field soil heterogeneity. The first design (H) was an NR-0 (non-replicated) honeycomb design (Fasoulas, 1988) with 500 wheat plants and 0.87 m plant spacing (Figure 2). The second design (G) was a grid arrangement (Gardner, 1961) with 32 grids and 16 plants per grid (Figure 3). Overall, 512 plants were sown with 0.5 m plant spacing. The third design (S) was based on the design described by McGinnis and Shebeski (1968) with seven double wheat rows (0.45 m plant spacing) and 0.9 m row spacing (Figure 4). Each row consisted of 40 wheat plants (0.45 m plant spacing) with 560 plants. The fourth experiment was a honeycomb R-3 with three genetic materials (Figure 5) of the local landrace, cv. Irnerio, and the old cv. Nestos to explore the variability between an older cultivar, a local landrace, and a well-adapted

Figure 1. Climatological data, monthly rainfall, and monthly maximum temperature (Max. temp) and minimum temperature (Min. temp) means for 6-year period.

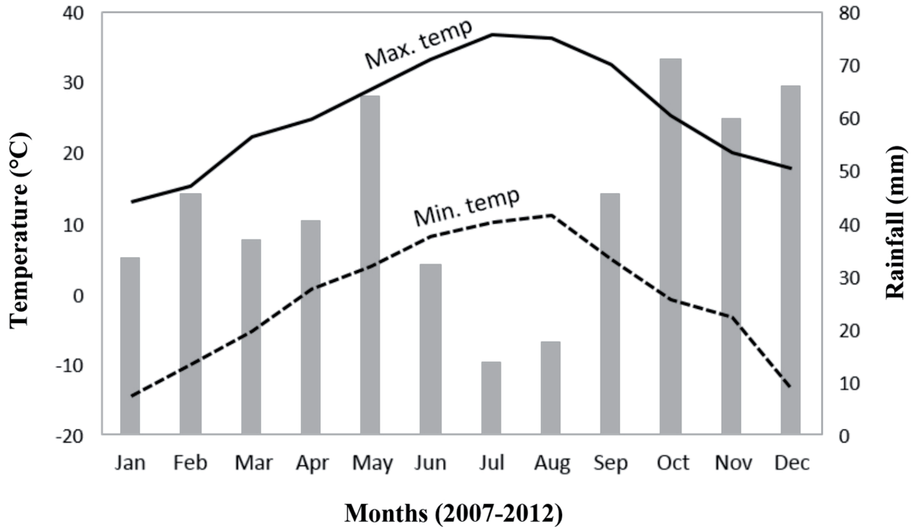
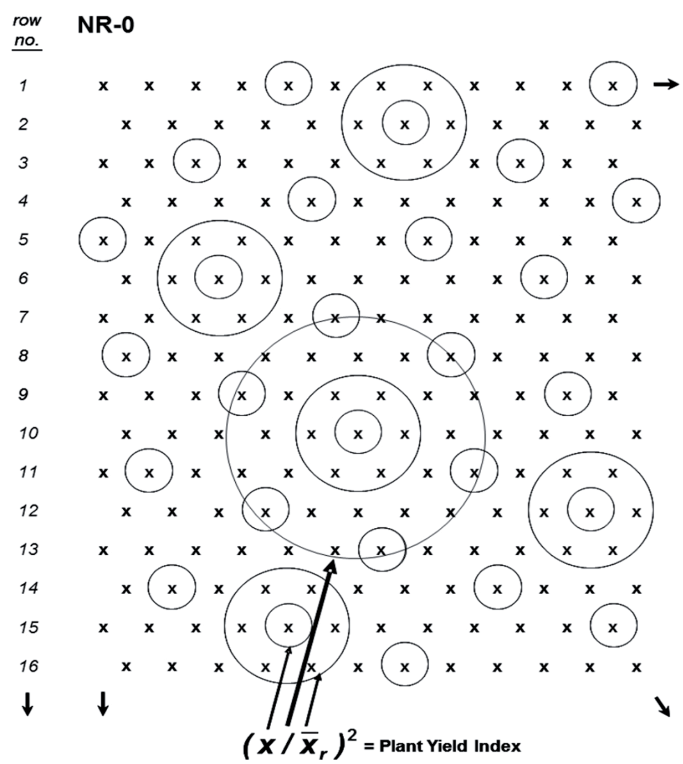


Figure 2. The honeycomb NR-0 arrangement with selection rings and plant yield index as selection formula for the original population (landrace) on the farm of the Technological Educational Institute of Western Macedonia, Florina, Greece.



cultivar in a certain region. Evaluation included 100 plants of each material. Three F_2 seeds were sown in each hill and thinning to one plant followed in the early development stages (February). l) Individual plants were manually harvested in July 2009. Grain yield (GY) of individual plants was weighed on an electronic balance (g). Selection for the evaluation of the next generation was based on GY.

Figure 3. The gridding method with blocks (grids) that reduce soil heterogeneity for the original population (landrace) on in the farm of the Technological Educational Institute of Western Macedonia, Florina, Greece.

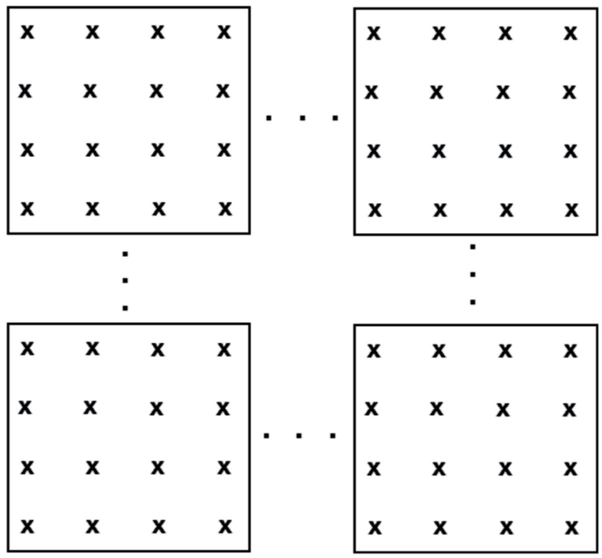
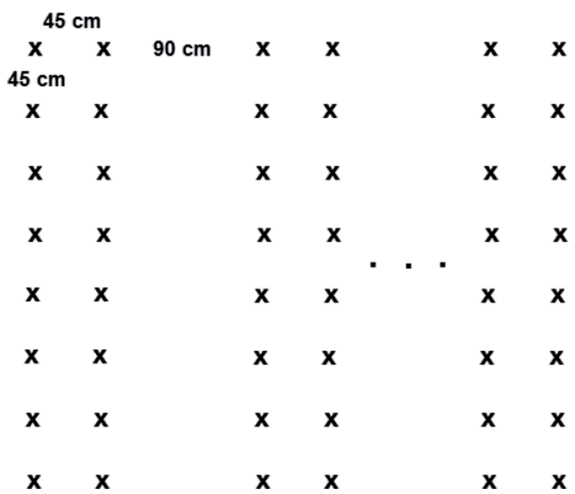


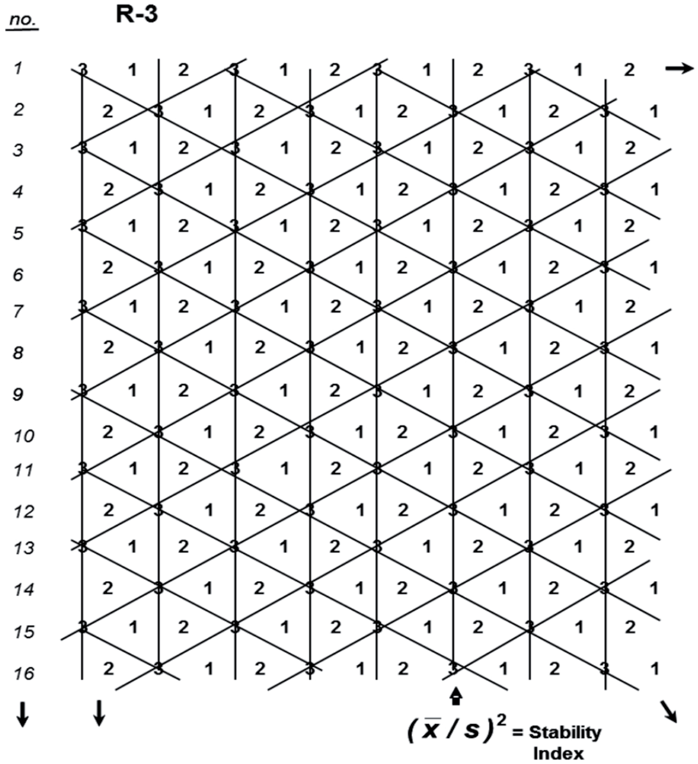
Figure 4. The double row arrangement for the original population (landrace) on the farm of the Technological Educational Institute of Western Macedonia, Florina, Greece.



For honeycomb NR-0 (H), the 32 best plants were selected based on plant yield index calculations (Figure 2), $PYI = (x/\bar{x}_r)^2$, where x is yield per plant (g) and $\bar{x}_r$ is the mean plant yield of the surrounding plants within the moving ring (Fasoulas, 2006; 2013). For the gridding method (G), the best plant in each grid was selected according to yield performance (32 plants). For the third arrangement with double rows (S), the 32 plants of all rows with the best yield were determined and selected without any further comparisons. In the fourth experiment, plants were weighed and means were calculated.

The three materials (local landrace, 'Irnerio', and 'Nestos') were ranked and compared based on the coefficient of homeostasis calculations (Figure 5) $CH= (\bar{x}/s)$, where $\bar{x}$ and s are the entry mean yield and standard deviation, respectively (Fasoulas, 2006; 2013). Stability was estimated based on the reverse coefficient of variation (CV) of the honeycomb design (Fasoulas, 1981). The 32 F_3 pedigree lines of each selected plant formed three plots of rows that were sown separately and randomly (in separate blocks according to the experimental arrangement from which they were selected) in November 2009. In every eighth row, the local landrace was sown as a control; it was also used for the four borders of

Figure 5. The honeycomb R-3 arrangement with three entries (original local landrace, old 'Nestos', and 'Irnerio') and stability index or coefficient of homeostasis (CH) on the farm of the Technological Educational Institute of Western Macedonia, Florina, Greece.

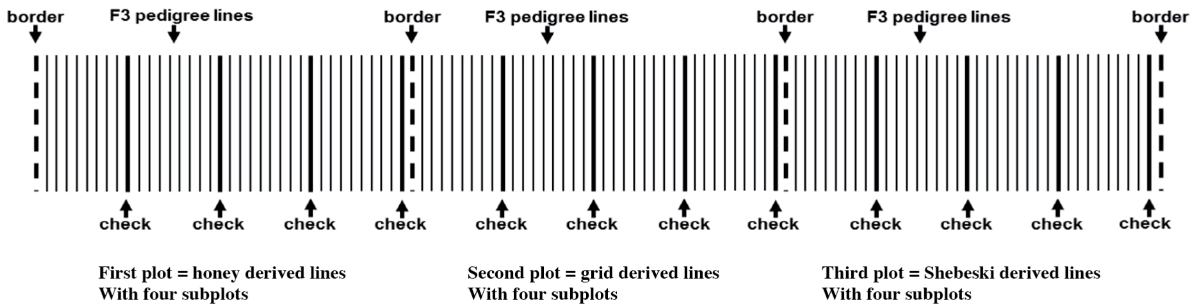


the whole experiment and the three different plots of rows derived from the three experimental arrangements (Figure 6). Each plot of rows was divided into 4 subplots. Altogether, 112 rows were sown (96 = 3 × 32 F_3 lines and 16 rows of the local landrace = 12 controls and 4 borders), creating a 3 × 4 = 12 grid arrangement (Figure 6). Row spacing was 0.25 m and each row was 10 m long. Each row was harvested in July 2010.

The bulk density (as yield estimate) of each line was calculated with an electronic balance that also measures volume (g L^{-1}). It was also calculated for the 12 controls. Relative bulk density was compared with the following control in each subplot was calculated for all 96 F_3 lines. Borders were not harvested. The best five lines from each of the three plots were selected (15 lines). The first four lines in each plot were selected as having the best performance (relative bulk density) compared with the following control in each grid (subplot). The fifth line was selected as having the best yield in each plot (for bulk density). Karimizadeh et al. (2012) refer to bulk density as a suitable selection criterion for yield improvement, positively correlated (among other traits), and up to 0.90 grain yield (Hanchinal et al., 1993; Mason et al., 2007); it is used in a recent study in terms of test weight (Yabwalo et al., 2018).

In November 2010 and 2011, two randomized complete block (RCB) designs were conducted (by selected seed division) with the 15 F_4 lines (five lines for each selection design) and the original local landrace as a control. Each plot consisted of 7 rows, 4 m long and with 25 cm row spacing (350 plants m^{-2}) and four replicates. Harvest was in July 2011 and 2012, respectively. Grain yield (GY, Mg ha^{1}), 1000-kernel weight (TKW, g), and specific weight (bulk density, g L^{-1}) of each plot were measured. An ANOVA was performed separately for each year and as a total (year as additional factor). Genetic materials were considered as a separate fixed factor. Analyses were based on Steel and Torrie (1980) and means were separated according to Duncan's method and Tukey's honest test. The total sum of squares was used to estimate the contribution of the two factors (genetic materials and year) based on the model's expected mean squares (McIntosh, 1983; Baxevanos et al., 2013). Cultivar phenotypic variance (σ^2_p) and genetic variance (σ^2_g) were computed (McIntosh, 1983). The broad-sense heritability estimation (H^2) was calculated as the σ^2_g/σ^2_p ratio (Guillen-Portal et al., 2004). Finally, the genotypic coefficient of variability (GCV), phenotypic coefficient of variability (PCV), and genetic advance (GA) were

Figure 6. The F_3 line arrangement scheme with three plots of lines derived from the three compared methods and 12 subplots with adjacent controls (checks) to reduce soil heterogeneity on the farm of the Technological Educational Institute of Western Macedonia, Florina, Greece.



calculated according to Johnson et al. (1955), Akcura (2009), and Joseph et al. (2015). Correlations of GY values between F_3 and F_4 lines (F_4 was repeated in 2011 and 2012) for each method were performed according to Pearson's coefficient (Steel and Torrie, 1980). Correlations between GY, bulk density, and TKW were also calculated.

RESULTS

Table 1 provides data from the F_2 evaluation for the three different methods, showing that measurements of the best plants selected for the GY trait ranged from 36.8 to 56.0 g for all methods; this wide range was achieved due to the honeycomb design. Table 1 includes only the 32 best-performing plants selected by the evaluation criteria of each method. Yield and stability estimations (Table 2) showed that the local landrace (34.4 g mean plant yield) was better than Greek 'Nestos' (32.8 g) but inferior to 'Irnerio' (37.8 g). Stability and coefficient of homeostasis (CH) were estimated. The local landrace was rather unstable with stability of 4.5 and CH of 20.6 compared with the commercial cultivars.

The F_3 line evaluation data were based on bulk density and selected F_3 are in boldface in Table 3. The G-method gave the best plants (mean of selected lines 771 g L^{-1}) and the best control yield performance (mean 734 g L^{-1}) was followed by the H-method with a mean of 769 g L^{-1}, while the S-method obtained the worst (mean 756 g L^{-1}).

Table 4 displays the ANOVA components; it is clear that genotypes showed significant differences for all measurements and only TKW showed significant differences for years. No interaction was found. This was better according to Baxevanos et al. (2013) because of the sum of squares for years (SS(Y)%), sum of squares for genotypes (SS(G)%), and sum of squares for interaction (SS(G×Y)%); SS(G)% was the greatest proportion of total estimated variability (over 90% for GY and bulk density). As for TKW, it was somewhat greater than SS(Y)% and SS(G×Y)%. Genetic variability (σ^2_g) and phenotypic variability (σ^2_p) were similar, that is, 3.44 and 3.7 for GY, 125.2 and 134.6 for bulk density, 0.39 and 0.42 for TKW, respectively. Therefore, broad-sense heritability (H^2) was high for all measurements (0.93). Bulk density showed stability across years and the highest GA(21.43). Genotypic CV% (GCV) was approximately equal to phenotypic CV% (PCV), and GY exhibited the highest (over 7%) compared with the other two traits (under 1%). The experimental coefficient of variation CV (%) across years for GY was also the highest (8.83%). Separate ANOVA (based on means of the lines) for the three methods and the control revealed that there were significant differences only for bulk density and TKW.

Table 5 indicates the total comparisons of means across the 2 yr for each trait measurement (GY, TKW, and bulk density) of the five selections of F_4 progeny lines for the S, H, and G methods as well as the number of lines that outyielded the control for each method. Means were separated according to Duncan's and Tukey's tests: differences between methods were negligible for GY, a little for TKW, and more for bulk density. Duncan's test showed greater differences, especially for bulk density, and means were separated more easily. Gridding showed the best results, followed by the H-method and S-method. The control was outyielded for all the trait measurements with 15/15 lines from all studied traits (5+5+5against 13/15 (4+5+4) for the H-method and 11/15 (3+4+4) for the S-method. They also showed the highest mean values across years (GY = 3.56 Mg ha^{-1} increased 5.9% for the worst method and 10.6% for the control, bulk density = 740.6 g L^{-1} increased 1.4% for the worst method and 2.7% for the control, and TKW = 36.56 g increased 1.6% for the worst method and 2.8% for the control).

Table 1. The 32 individual plants selected in the first year of experimentation for the three methods: Honeycomb (H-method), Gridding (G-method), and McGinnis and Shebeski (S-method) and their yield performance in g (means for all methods of all plants).

H-method	Yield per plant	G-method	Yield per plant	S-method	Yield per plant
	g		g		g
H1	54.8	G1	51.3	S1	50.5
H2	49.4	G2	48.6	S2	48.9
H3	44.3	G3	50.7	S3	46.7
H4	43.9	G4	47.9	S4	46.0
H5	46.1	G5	45.3	S5	45.9
H6	39.6	G6	43.1	S6	45.8
H7	39.9	G7	46.1	S7	45.7
H8	40.9	G8	45.1	S8	45.5
H9	42.2	G9	47.3	S9	45.3
H10	49.4	G10	50.3	S10	45.3
H11	40.9	G11	48.7	S11	45.2
H12	44.6	G12	48.7	S12	45.0
H13	43.5	G13	48.2	S13	44.6
H14	50.0	G14	47.8	S14	44.4
H15	41.8	G15	46.3	S15	44.0
H16	56.0	G16	46.2	S16	43.8
H17	45.3	G17	45.5	S17	43.7
H18	41.5	G18	47.2	S18	43.6
H19	37.4	G19	44.0	S19	43.3
H20	52.0	G20	48.1	S20	43.3
H21	48.2	G21	49.5	S21	43.2
H22	39.8	G22	49.1	S22	43.2
H23	43.1	G23	47.3	S23	42.9
H24	36.8	G24	48.8	S24	42.8
H25	43.7	G25	50.1	S25	42.8
H26	43.0	G26	52.5	S26	42.7
H27	46.7	G27	47.2	S27	42.6
H28	45.7	G28	49.3	S28	42.5
H29	47.5	G29	47.4	S29	42.5
H30	44.7	G30	49.9	S30	42.4
H31	48.9	G31	44.3	S31	42.4
H32	44.2	G32	46.6	S32	42.4
Mean	**33.3**	**Mean**	**36.4**	**Mean**	**34.8**

Bulk density maximized statistical differences between methods and the control, showing significant differences for the mean of the best method compared with the control and near limit differences for the mean of the best method compared with the mean of the worst method. The most efficient method (G-method) also produced the best-performing line for bulk density (754.0 g L^{-1}), whose yield was 5% higher than the control (720.8 g L^{-1}), followed by a line derived from the H-method (747.5 g L^{-1}). Both superior lines also showed the best GY performance (3.77 and 3.78 Mg ha^{-1}, respectively). Separate comparisons of means for the 2 yr (2011 and 2012) for each trait measurement (GY, TKW, and bulk density) were performed and were of no statistical interest because of the low genotype × year interaction. Bulk density exhibited the most significant results for comparisons between selected lines and the control.

The F_3/F_4 correlations for the three methods showed that F_3 to 2011-F_4 for the G-method were statistically significant. The correlation coefficient was 0.95 (year 2011-F_4) and 0.81 (year 2012-F_4) at the limit of significance ($p = 0.05$) only for the G-method. The GY to bulk density correlations were significant at $P = 0.05$ (0.63 for 2011 and 0.83 for 2012).

Table 2. Mean yield per plant and stability and coefficient of homeostasis (CH) estimations for the three genetic materials used in replicated honeycomb design R-3 (‘Irnerio’, local landrace, and ‘Nestos’).

Entry	Mean yield	Mean	Stability	Stability	CH	CH
	g	%		%		%
Irnerio	37.85	100.00	5.88	100.00	34.54	100.00
Local landrace	34.39	90.85	4.54	77.17	20.57	59.55
Nestos	32.80	86.67	5.54	94.30	30.72	88.92

Table 3. The F_3 line evaluation data based on bulk density for three methods with selected lines in boldface, mean of controls, and mean of selected lines.

H-method		G-method		S-method	
Line Nr	Bulk density	Line Nr	Bulk density	Line Nr	Bulk density
	g L^{-1}		g L^{-1}		g L^{-1}
H7	689	G6	711	S8	703
H1	715	G7	713	S3	709
H6	722	G1	720	S5	712
H8	730	G8	724	S7	716
H3	735	G5	731	S1	717
H5	744	G2	732	S6	740
H2	755	G4	736	S4	752
H4	**773**	G3	**778**	S2	**753**
Control	705		753		725
H10	654	G14	723	S14	714
H11	720	G16	724	S15	719
H14	724	G11	726	S9	727
H9	740	G9	733	S11	727
H12	740	G12	734	S12	731
H15	742	G15	746	S13	731
H16	742	G10	753	S10	738
H13	**757**	G13	**771**	S16	**740**
Control	721		708		696
H24	664	G17	714	S20	719
H17	723	G22	724	S18	736
H21	730	G20	738	S24	736
H18	735	G18	749	S17	743
H19	742	G24	752	S22	748
H23	742	G21	754	S23	748
H20	***759***	G23	***765***	S19	752
H22	**785**	G19	**769**	S21	**758**
Control	744		754		714
H28	703	G28	711	S22	693
H31	707	G25	718	S29	703
H29	716	G29	718	S26	712
H26	720	G31	721	S30	718
H32	721	G30	741	S25	719
H27	738	G32	748	S31	727
H25	746	G26	753	S32	***757***
H30	**772**	G27	**773**	S27	**772**
Control	727		721		693
Mean of control	724		734		707
Mean of selected lines	769		771		756

Selected lines are in boldface (additional selected lines in italics).
H-method: Honeycomb; G-method: gridding; S-method: McGinnis and Shebeski.

DISCUSSION

Plant breeders seek the most effective selection procedure to achieve progress. Early stage evaluation and pedigree selection of segregating genetic materials combined with soil heterogeneity has triggered the demand for plant field arrangements to overcome individual plant selection problems. Our data analyzed the efficiency of three field arrangements to reduce the negative effects of soil heterogeneity using criteria such as the basic selection trait that ensures stability across years, yield maximization, heritability, GA maximization, promotion efficiency of promising materials, and the relationship between advanced generations. Furthermore, starting materials must be appropriately selected by a prognostic methodology that ensures the yield potential of individual plants, which develop promising progeny lines with heritable results, thus maximizing efficiency.

Table 4. Factor analyses (ANOVA) for each trait: grain yield (GY), 1000-kernel weight (TKW), and specific weight (bulk density). Estimations of sum of squares for years (SS(Y)%), sum of squares for genotypes (SS(G)%), sum of squares for interaction (SS(G×Y)%), genetic variability (σ^2_g), phenotypic variability (σ^2_p), genetic advance (GA), heritability (H^2), phenotypic CV% (PCV), genotypic CV% (GCV), and experimental coefficient of variation (CV) across years.

Effects	GY	Bulk density	TKW
	Mg ha^{-1}	g L^{-1}	g
Years (Y)	ns	ns	**
Genotypes (G)	***	***	***
G × Y	ns	ns	ns
Methods (M)	ns	**	*
SS(Y)%	2.4	3.6	38.9
SS(G)%	90.9	90.1	56.4
SS(G×Y)%	6.7	6.3	4.7
σ^2g	3.44	125.2	0.39
σ^2p	3.7	134.6	0.42
H^2	0.93	0.93	0.93
GA	3.55	21.43	1.20
PCV	7.43	0.016	0.018
GCV	7.17	0.015	0.017
CV, %	8.83	1.96	2.12

*, **, ***Significant at the 0.05, 0.01, 0.001 probability levels, respectively.
ns: Nonsignificant.

In our dataset, the local landrace showed expected unstable field performance according to the criteria being used, a mixture of homozygous genotypes that led to a considerable variation (Fasoulas, 1988; Moghaddam et al., 1997). Our local landrace exhibited satisfactory performance because it was better than the old Greek 'Nestos', exploiting buffering and stable performance of promising individuals (Fasoulas, 1993; Karagöz, 2013) and exhibiting specific adaptability to the environment where it has been cultivated for many years (Almekinders et al., 1994).

Gridding (Gardner, 1961) was the first systematic attempt to reduce soil heterogeneity within relatively homogeneous blocks. In our study, the G-method had the best plants and the best control yield performance, followed by the H-method; the S-method exhibited the worst results, indicating that double rows are not a suitable arrangement for wheat plants. The H-method had the widest range in F_2 generation, contributing to better individual differentiation (Fasoulas, 1988). The G-method obtained the best results for selecting lines because this method selected 15/15 lines for all traits against 13/15 for the H-method and 11/15 for the S-method that outyielded the control and showed the highest values of means across years.

Lines developed by the three methods showed significant differences in RCB, reflecting the genetic differentiation incorporated in the selected genetic materials. Heritability was high for all measurements (traits) and GA was higher for bulk density. Bulk density was a stable trait across years, with low CV and satisfactory genotype differentiation. Yabwalo et al. (2018) mentioned stability in test weight as a criterion for selecting genotypes: test weight is another calculation of bulk weight. In addition, this trait (bulk weight) showed the largest number of lines that outyielded the original population (landrace). Bulk density maximized differences between all methods and the control. The most efficient method (G) also obtained the best performing line for this trait, followed by a line derived from the H-method. These two superior lines also exhibited the best GY performance. Charmet et al. (2014) reported high heritability for test weight (trait similar to bulk density) and Yaqoob (2016) for GY with a low GCV/PCV ratio under normal conditions, but not under abiotic stresses.

Grain yield showed the highest experimental CV, indicating that it is better to rely on a similar trait such as bulk density (or test weight) that had a more reliable (statistically) performance under various conditions (Kumar et al., 2001); simultaneously, it is highly correlated to GY and suitable for breeding programs (Kaddem et al., 2014). In our dataset, correlations of bulk density with GY and TKW were significant, indicating that this trait can substitute direct yield estimations, which concurs with findings by Kaddem et al. (2014). Although heritability can be high in various experiments, Fasoulas (1988) stated that CV values, especially for yield, can also be high (as a stability criterion), and the negative effects of soil heterogeneity can reduce the phenotypic superiority expression. Bulk density was the basic selection criterion of our study because it provided the most significant results for comparisons between selected lines and the control. Aydin et al. (2010) suggested that plant height and bulk weight (hectolitre test weight) could be used as

Table 5. Total comparisons of means across 2 years for each trait measurement: Grain yield (GY), 1000-kernel weight (TKW), and specific weight (bulk density) of the five selections (1 to 5) of F_4 progeny lines for the McGinnis and Shebeski (S), honeycomb (H), and gridding (G) methods as well as the means of all methods and the number of lines that were better than the control (local landrace) for each method.

Genotypes	GY	Bulk density	TKW
	Mg ha^{-1}	g L^{-1}	g
1-(S2)	3.50abc	734.5bcdef	36.68ab
2-(S16)	3.48abc	738.8abcde	36.83a
3-(S21)	3.05cd	705.3g	34.94e
4-(S32)	3.67ab	746.3abc	36.51ab
5-(S27)	3.08abc	727.0def	35.91bc
S-mean	3.36abc	730.4cdef	36.17abc
S better than control	3	4	4
1-(H4)	3.78a	747.5ab	36.89a
2-(H13)	3.49abc	743.3abcd	36.57ab
3-(H20)	3.28abc	732.0bcdef	35.81bcd
4-(H22)	3.50abc	730.0cdef	35.63cde
5-(H30)	2.81d	723.0ef	35.06de
H-mean	3.37abc	735.2bcdef	36.0bc
H better than control	4	5	4
1-(G3)	3.77a	754.0a	36.95a
2-(G13)	3.67ab	747.1ab	36.61ab
3-(G23)	3.46abc	743.0abcd	36.33abc
4-(G19)	3.40abc	721.5f	36.08abc
5-(G27)	3.51abc	737.3bcdef	36.85a
G-mean	3.56abc	740.6abcd	36.56ab
G better than control	5	5	5
Control	3.22bcd	720.8f	35.56cde
F test	***	***	***
CV, %	8.8	1.95	2.12

primary selection criteria to improve GY in wheat. Furthermore, it is a criterion for productivity and seed quality (ADAS, 2015). This trait is important because landraces or local populations also contribute in improving wheat quality (Dotlacil et al., 2010; Lopes et al., 2015).

The F_3/F_4 correlation coefficients for the three methods showed that only the G-method for 2011-F_4 showed relatively high and significant results. For 2012-F_4, all methods showed similar, relatively high, but nonsignificant results except for the G-method (at the limit of significance). McGinnis and Shebeski (1968) estimated the correlation between F_2 plant yield and F_3 line yield as 0.13 for wheat. McKenzie and Lambert (1961) reported low but significant correlation coefficients (0.31 to 0.54) between F_3 and F_6 generations in barley (*Hordeum vulgare* L.); they concluded that early selection from the F_3 generation is practically ineffective. Briggs and Shebeski (1967) reported zero correlation in progressive wheat generations, but the same authors later reported significant correlations between F_3 and F_5 generations (Briggs and Shebeski, 1971). Shebeski (1967) reported significant correlations between F_3 and F_5 generations (r = 0.85). Skorda (1973) also reported zero correlations between F_2 plant yield and F_3 line yield in wheat.

Method comparisons have never performed as analyzed in the present study. However, Nagi et al. (1987) and Singh et al. (1987) reported a higher efficiency of the H-method compared with other pedigree methods to isolate superior cotton genotypes. As for wheat, Stratilakis and Goulas (2003) did not find a higher efficiency of the H-method compared with other pedigree methods. Fasoulas (2006; 2013) described prognostic equations for selection efficiency. We used PYI (Fasoula, 2006; 2013) and the honeycomb design to safely select the best plants in F_2, although we tried three different methods to cope with soil heterogeneity.

CONCLUSIONS

The gridding method was more efficient for evaluating wheat genetic materials because it maximized yields, provided a greater number of promising lines, and had high and significant F_3/F_4 correlations. Given that local populations are a mixture of inbred wheat individuals, they were not suitable in double row spacing; this indicates that wheat cannot be cultivated under a double row system, which could not boost the performance of wheat genotypes. Heritability was high for breeding purposes and bulk density was a reliable criterion for selecting promising genetic materials. The local population (landrace), although unstable, can exhibit specific adaptability in the cultivated environment where it showed good performance. Lines selected (from the original population) by the most effective method (gridding) improved yield performance (grain yield) by 11% on the average (6.5% for lines from all methods).

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