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Short communication. Plant density effect on the individual plant to plant yield variability expressed as coefficient of variation in barley

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Abstract

The effect of plant density on the coefficient of variation (CV) for individual plant yield was studied in barley (*Hordeum vulgare* L.). An F_2 population originating from the cross Niki × Carina was planted in three densities: high (51.32 plants m^{-2}), intermediate (4.61 plants m^{-2}), and low (1.15 plants m^{-2}) using the honeycomb design. In each of the experiments, the most promising 15 plants were selected based on the individual plant yield. Progeny (F_3) of the 30 plants selected from the intermediate and the low plant density were grown the following year in two experiments under an intermediate and low density. It was observed that in the F_2 population the CV was reduced from 71 to 55% when the density reduced from 51.32 to 4.61 plants m^{-2}, whereas the CV value was increased when the density was further reduced to 1.15 plants m^{-2}. Similarly, the following year the CV was increased from 39 to 56% when the density was decreased from 4.61 to 1.15 plants m^{-2} in the F_3 generation, and from 22 to 58% in the control. It was concluded that for barley an optimum plant density might exist under which the CV for individual plant yield is minimized and therefore the effectiveness of selection might be optimized.

Additional key words: honeycomb design, *Hordeum vulgare* L., selection efficiency.

Resumen

Comunicación corta. Efecto de la densidad de la plantación en la variabilidad planta a planta del rendimiento expresado como coeficiente de variación en cebada

Se estudió en cebada **(***Hordeum vulgare* L.**)** el efecto de la densidad de plantación en el coeficiente de variación (CV) del rendimiento individual de la planta. Se plantó una población F_2 originada desde el cruce Niki × Carina en tres densidades: alta (51,32 plantas m^{-2}), intermedia (4,61 plantas m^{-2}), y baja (1,15 plantas m^{-2}) utilizando un diseño en colmena. En cada uno de los experimentos se seleccionaron las 15 plantas con mayor potencial según el criterio de rendimiento de planta individual. La descendencia (F_3) de las 30 plantas seleccionadas de zonas de densidades baja e intermedia se cultivó el año siguiente en dos experimentos en condiciones de densidad intermedia y baja. Se observó que en la población F_2 el CV se redujo desde 71 al 55% cuando la densidad bajó de 51,32 a 4,61 plantas m^{-2}, mientras que el valor del CV aumentó cuando se redujo aún más la densidad, a 1,15 plantas m^{-2}. De forma similar, el año siguiente el CV aumentó de 39 a 56% cuando la densidad bajó de 4,61 a 1,15 plantas m^{-2} en la generación F_3 y de 22 a 58% en el control. Se concluye que, para cebada, podría existir una densidad de plantación óptima bajo la cual el CV del rendimiento individual se minimiza y, por tanto, la efectividad de la selección se puede también optimizar.

Palabras clave adicionales: diseño en colmena, eficiencia de la selección*,* *Hordeum vulgare* L.

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Generally, the coefficient of variation (CV) is the most widely used parameter to quantify variability among individual plants of a crop stand (Edmeades and Daynard, 1979; Tokatlidis *et al.,* 2006). In addition, it is widely reported that the CV value for individual plant yield is higher under a high plant density than at a lower plant density. In particular, Glenn and Daynard (1974) in their study with two maize (*Zea mays* L.) hybrids, applied three plant densities (4.9, 7.9, and 10.8 plants m^{-2}) and reported that the CV values of the two hybrids were 19 and 23%, 26 and 30%, and 26 and 40% for the three plant densities, respectively. In addition, Hamblin *et al.* (1978) working with an F_3 barley population reported that at low plant density (6.25 plants m^{-2}) the CV value (32%) was lower than the one (51%) observed at high plant density (625 plants m^{-2}). Similar results have been reported in several crops such as maize (Daynard and Muldoon, 1983; Tokatlidis *et al.,* 2005), rye (*Secale cereale* L.) (Kyriakou and Fasoulas 1985; Pasini and Bos, 1990), sunflower (*Helianthus annuus* L.) (Xanthopoulos, 1990) and sugarcane (*Saccharum* spp.) (De Sousa-Vieira and Milligan, 1999). In contrast, Iliadis *et al.* (2003) working with chickpea (*Cicer arietinum* L.) and three plant densities (51.32, 12.83, and 1.15 plants m^{-2}), reported that while the CV value was reduced from 56 to 48% when plant density decreased from 51.32 to 12.83 plants m^{-2}, it increased to 71% at the density of 1.15 plants m^{-2}. This may indicate the existence of a critical interplant distance under which the CV value is minimized.

Fasoula and Fasoula (2002) reported that the increased CV at high plant density is most likely due to the interplant competition which contributes to the interplant yield variability more than the variability caused by the increased soil heterogeneity introduced by lower plant densities. If this is the case, CV of individual plants is expected to constantly decrease as interplant distance increases until a critical point. Further increase of the interplant distance, beyond that critical point, is expected to lead to CV stabilization, or even to an increase of the CV value, on account of increased soil heterogeneity and other unpredictable factors. In such a case, the critical interplant distance at which the CV reaches the smallest value should be the plant density under which selection efficiency is expected to be maximized.

Based on this brief review, plant density affects the plant to plant variability and therefore the optimum density at the early selection stage is worth studying. This work was undertaken to see whether the CV value for individual plant yield in early generations of barley (*Hordeum vulgare* L.) is constantly reduced when plant density is reduced from 51.32 to 1.15 plants m^{-2}, aiming to a possible determination of the optimum density for early generation selection.

Seeds of the F_2 generation which was a mixture of equal number of seeds originating from 40 F_1 plants of the barley cross Niki × Carina, were grown during 2001-02 growing season in three experiments under different plant densities, at the University Farm of Thessaloniki in northern Greece. The unreplicated-0 (UNR-0) honeycomb design (Fasoulas and Fasoula, 1995) with 1150 up to 1260 hills was used in all of the experiments (Table 1). Sowing interplant distances were 0.15, 0.50 and 1.00 m corresponding to plant densities 51.32 (high density), 4.61 (intermediate density) and 1.15 plants m^{-2} (low density), respectively. Three seeds were sown at each plant position and thinned later to one plant. At maturity, plants were threshed individually and grain yield was determined. The HONEY microcomputer program (Batzios and Roupakias, 1997) was used for individual plant selection in the honeycomb design. Finally, from each of the two experimental fields established at the intermediate and low plant density, the 15 highest yielding plants (1.4% selection pressure) were selected, based on the moving ring procedure (Fasoulas and Fasoula, 1995). Progeny of these plants constituted the 30 F_3 families which were evaluated in the next growing season (2002-03) in two nearby experimental fields at the intermediate and low density applying the same cultivation techniques with those of the first growing season. The replicated (R-31) honeycomb design with 60 replications was used in these experiments (Fasoulas and Fasoula, 1995). The experiment at the high plant density was not replicated, firstly, because it is generally accepted that the CV value at high plant density is higher than the CV at lower plant densities, and secondly, due to a seed limit. At maturity, plants were threshed individually and grain yield was recorded separately. In each experiment the CV value was calculated based on the overall plant variability. In these two experiments cv. Niki was used as control.

It was observed that in F_2 generation the CV value (71%) was highest at the high plant density (Table 1). The CV reached its lowest value (55%) at the intermediate plant density and slightly increased again (59%) at the low plant density (Table 1). Similarly, in the F_3 generation the CV value (39%) was lower under the intermediate plant density than that (56%) under low plant density (Table 2). A similar response has been recorded

Table 1. Number of plants tested, yield per plant and coefficient of variation (CV) values of an F_2 barley population established at three plant densities evaluated under the honeycomb UNR-0 design

Plant density (plants m^{-2})	No. of plants	Yield[1] (g plant^{-1})	CV (%)
High 51.32[2] (27.76)[3]	1150[4] (622)[5]	14.74 ± 0.42	71
Intermediate 4.61 (3.61)	1180 (922)	63.48 ± 1.14	55
Low 1.15 (0.78)	1260 (857)	92.64 ± 1.87	59

[1] Mean yield and standard error. [2] Sowing plant density. [3] Actual plant density (after plant growth). [4] Number of seeds sown. [5] Number of plants harvested.

for the control where the CV values were 22% and 58% respectively. This may indicate that these results contradict with the general conclusion that the CV value for individual plant yield is higher at high plant densities, reached by a number of researchers working with different crops (Glenn and Daynard, 1974; Hamblin *et al.,* 1978; Edmeades and Daynard, 1979; Daynard and Muldoon, 1983). This is not true however, because the lowest plant density used by most of them was 4.9 plants m^{-2} or similar to the intermediate plant density used in this experiment. Therefore, it is not known whether the CV value at lower plant densities, even in the above experiments, would continue to decrease and if so, up to what interplant distance. In addition, Kyriakou and Fasoulas (1985), Pasini and Bos (1990) and De Sousa-Vieira and Milligan (1999) who applied a low plant density similar to the one used in this experiment, included only two plant densities in their experiments. It is obvious that the CV value from only two plant densities is impossible to reveal whether an intermediate plant density would have a lower value than in the lowest plant density. It could be argued however that due to poor germination and the missing hills the actual high plant density was 27.76 plants m^{-2}, the intermediate 3.61 and the low 0.78 plants m^{-2} in the F_2 and 3.86 and 0.74 plants m^{-2} in the F_3 (Tables 1, 2). Yet, this does not seem to affect the general conclusion of this work. This is supported by the results reported by Tollenaar and Wu (1999). These researchers applied two plant densities (3.5 and 11 plants m^{-2}) in maize, under uniform and nonuniform stands and observed that the CV value at high plant density was higher than the one at low plant density regardless of stand uniformity. The results of the present study indicate that the CV value is decreased as plant density is decreased up to a critical interplant distance under which the CV value is minimized. Further increase of the interplant distance could stabilize the CV value or even increase its value (Tables 1, 2).

The higher CV values observed at the high interplant distance compared to the CV values observed in the intermediate interplant distance could be partly attributed to an increased soil heterogeneity due to the larger area covered by the experiment of the high interplant distance. However, additional unpredictable environmental factors could also have a negative effect on the CV value at the low plant density, at a higher rate, than that of the intermediate density. *Barley yellow dwarf virus* (BYDV) was a factor with such an effect, which was observed in the experiments of the present study in both growing seasons. Plants grown at low plant density were infected more compared to the plants grown at

Table 2. Number of plants tested, yield per plant and coefficient of variation (CV) values of an F_3 barley population and the check variety Niki evaluated at two plant densities under the honeycomb R-31 design

Genetic material	Plant density (plants m^{-2})	No. of plants	Yield[1] (g plant^{-1})	CV (%)
Population	Intermediate 4.61[2] (3.86)[3]	1860[4] (1558)[5]	20.80 ± 0.21	39
Control (Niki)	Intermediate 4.61 (3.86)	60 (50)	13.18 ± 0.40	22
Population	Low 1.15 (0.74)	1860 (1197)	34.86 ± 0.56	56
Control (Niki)	Low 1.15 (0.74)	60 (40)	17.00 ± 0.62	58

[1,2,3,4,5] See Table 1.

the intermediate plant density. A similar observation was reported by Slykhuis *et al*. (1959) in oat (*Avena sativa* L.) and it was pointed out by Irwin and Kampmeier (1989). In addition, Ntanos (personal communication) has observed that about 50% of the rice (*Oryza sativa* L.) plants grown at an interplant distance of 0.70 m were attacked by pink stem borer (*Sesamia inferens* Walker), whereas only 5% of plants were infected in a lower interplant distance (0.25 m). Furthermore, Milinco and Nagy (1987) reported a most severe attack by aphids when barley plants were grown at low plant densities.

It could be concluded therefore, that for barley and probably for each plant species, a critical interplant distance should exist under which the CV value for individual plant yield is minimized. Under such plant density the selection efficiency is probably expected to be maximized. However, data discussed are preliminary evidence based on a restricted data set on the phenotypic barley plant to plant variability and its association with two and three planting densities, which is worth further studying. Therefore, more work is needed for the critical interplant distance to be identified focusing on the critical sowing interplant distances of 0.50 to 1.00 m.

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