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Stability of yield and baking quality parameters of heterogeneous wheat populations

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Abstract

In this study, heterogeneous winter wheat populations are compared to commercial pure line varieties in terms of performance and stability of yield and baking quality parameters. Comparative field trials were conducted in Germany and Switzerland under organic conditions over two years at four sites (trial 1) and over three years at 5-6 sites (trial 2). The test entries include heterogeneous winter wheat populations representing contrasting genetic backgrounds, among them officially registered populations within the temporary experiment 2014/150/EU. As reference varieties commercial cultivars of the highest German baking quality category 'E' suitable for organic production were used. Grain yield, wet gluten content and sedimentation value were measured in both trials and protein content in trial 2. The results of the trials indicate that two of the officially registered populations have a yield potential and baking quality characteristics comparable to the mean of the reference varieties. Other populations reached either lower yield and higher baking quality than the reference varieties or vice-versa. The stability analysis shows that the populations exhibited a distinctly higher dynamic as well as static stability for all baking quality parameters compared to the varieties. Averaged over all three quality parameters, the mean values of the stability measures for populations were 55% (dynamic) and 27% (static) lower than the means of the varieties. Notably, the two officially registered populations ranked first and second among the test entries for static stability for all quality parameters. The yield stability analysis indicated a tendency towards a higher dynamic stability in the populations.

Keywords
Organic farming · protein content · sedimentation value · *Triticum aestivum* · yield trial

Introduction

Increasingly extreme environmental stresses caused by climate change will severely impact future agricultural production (Mbow *et al*. 2019). Breeding strategies with the aim to stabilize yield as well as quality traits of crops across variable environments are therefore urgently required. An additional approach to multi-environment testing (MET) or resistance breeding may be to utilize genetic diversity directly in the field in the form of heterogeneous cereal populations (Soliman & Allard 1991). Heterogeneous populations are resulting from genetically diverse parental germplasm, being managed as bulk populations with or without conscious selection by breeders. A legal framework for the marketing of heterogeneous populations will be provided by the new organic regulation, which will come into force on January 1, 2022.

There are „static" as well as „dynamic" concepts of stability (Becker & Léon 1988). A statically stable genotype tends to maintain the same performance across environments (*i.e*. location by year combinations). A dynamically stable genotype performs parallel to the mean of each environment thus corresponding to low genotype×environment interactions. Dynamic stability measures have the advantage that they reward genotypes that show a positive response to favorable environmental conditions. On the other hand, the static stability concept has a more straightforward agronomic interpretation since it measures the security of agricultural production (Annicchiarico 2002). Although the two concepts account for different aspects of stability, certain wheat genotypes can be superior to others for both stability measures (see *e.g.* Knapp *et al*. 2017).

The static and dynamic stability of heterogeneous cereal populations was investigated in prior studies: Döring *et al*. (2015) found that wheat composite cross populations tended to exhibit a grea-

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ter static stability of grain and protein yield compared to the mean of their parental varieties. Studying the same populations over several generations in Germany, Weedon & Finckh (2019) demonstrated that the populations had a tendency towards a higher dynamic grain yield stability than commercial pure line varieties under organic management. However, no difference was found for static stability measures. In Italian trials conducted by Raggi *et al*. (2017), heterogeneous spring barley populations achieved a higher level of dynamic yield stability than the pure line reference varieties, but a similar stability compared to pure lines derived from the populations.

It should be noted that all of these studies also investigated other aspects of heterogeneous populations and were not exclusively designed as yield stability assessments. The aim of our analysis is to extend the experimental setup in two respects: First, the number of test environments should be increased. The above mentioned studies were carried out in 8 to 12 environments. The minimal number of test environments required for stability assessments is considered eight according to Kang (1998) and Piepho (1998). Second, the heterogeneous populations should include populations with contrasting genetic background and in particular, a similar number of populations and pure line reference varieties should be tested in the analysis.

Material and methods

Plant material and field trials

The datasets evaluated in this study originate from two multi-environment winter wheat field trials under organic management. The first trial included twelve heterogeneous populations (among them the officially registered 'Evolito A - E', 'Brandex' and 'Liocharls' populations within the temporary experiment 2014/150/EU of the European Commission) and five pure line reference varieties of the baking quality E ('Aristaro', 'Wiwa', 'Butaro', 'Trebelir', 'Genius'). The trial was conducted as randomised complete block design with four replications at four locations (Dottenfelderhof, DE, plot size: 9 m²; Gladbacherhof, DE, 9 m²; Forchheim am Kaiserstuhl, DE; 12.8 m²; Feldbach, CH, 4 m², 3 replications) in two years (2019 and 2020). The second trial (Ökolandessortenversuche Baden-Württemberg - the official organic variety trials of the Federal State of Baden-Württemberg) included six populations (in addition to Brandex and Liocharls the populations OQI and OYQII studied in Weedon & Finckh (2019), as well as the population CC2K from Agroscope/DSP, CH, and CCPWS from TU München) and eight E wheat varieties ('Alessio', 'Aristaro', 'Baretta', 'Butaro', 'Ponticus', 'Royal', 'Titlis', 'Trebelir'). This trial was also conducted as randomised complete block design with four replications at 5 to 6 locations in Baden-Württemberg representing 4 to 5 soil-climate areas (Hohenheim, Crailsheim, Karlsruhe-Grötzingen, Forchheim am Kaiserstuhl, Ochsenhausen, Maßhalderbuch) for three years (2018, 2019 and 2020). The plot size varied between 10.5 and 14.4 m² depending on year and location. The field trials were evaluated according to the guidelines of the German Federal Plant Variety Office (Bundessortenamt 2000). Baking quality analysis were conducted for the parameters protein content (%) (only available for trial 2), wet gluten content (%) and sedimentation value (mL) (trial 1: SDS sedimentation test, trial 2: Zeleny sedimentation test).

Stability measures

The results of the stability analysis are only presented for trial 2 with the 16 year×location combinations considered as environments. For the calculation of the dynamic stability of the test entries Wricke's ecovalence W_i^2 (Wricke 1962) was applied and as a static measure the environmental variance EV_i (see Becker & Léon (1988) and Annicchiarico (2002) for definitions). The greatest stability is achieved at $W_i^2 = 0$ and $EV_i = 0$, respectively.

Results and discussion

Mean yield and baking quality performance

In trial 1 all but one of the twelve populations had higher grain yields than the mean of the varieties. Four populations exhibited higher protein content and three populations exhibited higher sedimentation value than the mean of the check varieties (Figure 1). In trial 2 there was no difference in grain yield between the mean of the populations and the mean of the varieties. The means

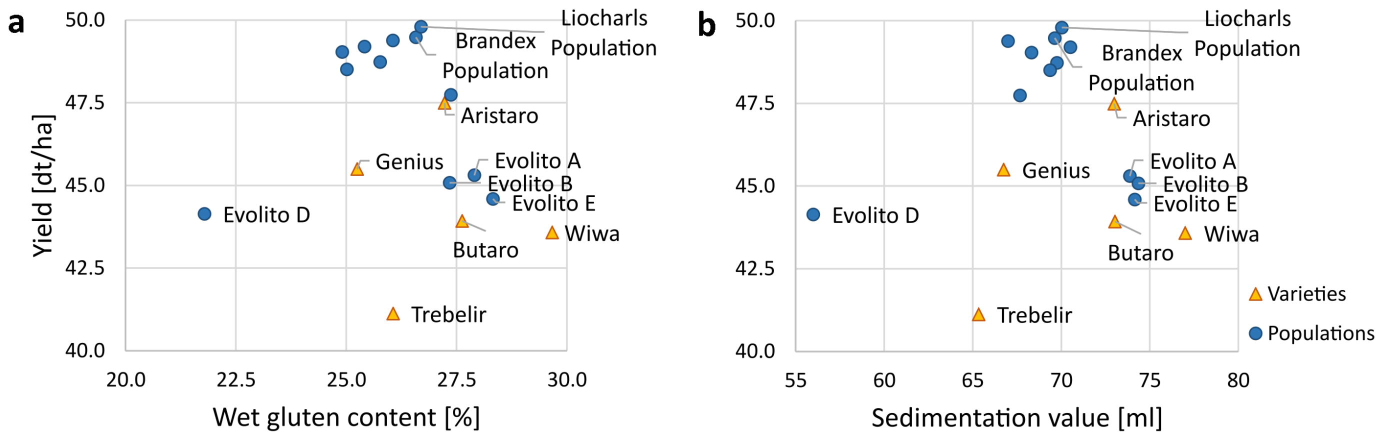

Figure 1 Relationship between grain yield and quality parameters of check varieties and populations of winter wheat in trial 1: **a** wet gluten content; **b** SDS sedimentation value. Values represent adjusted means across environments; triangles indicate pure-line varieties, circles indicate population varieties.

Table 1 Mean value, environmental variance EV_i and Wricke's ecovalence W_i^2 for grain yield (at 14% H_2O), protein content, wet gluten content and Zeleny sedimentation value for check varieties and populations of trial 2 (*n*=16).

Entry	Grain yield (dt/ha)			Protein content (%)			Wet gluten content (%)			Zeleny sedimentation value (mL)		
	Mean	EV_i	W_i^2	Mean	EV_i	W_i^2	Mean	EV_i	W_i^2	Mean	EV_i	W_i^2
Check variety												
Alessio	50.8	132.0	60.4	12.2	0.8	1.7	26.9	3.8	14.5	44.5	41.3	162.7
Aristaro	49.9	96.3	68.9	11.8	0.7	4.0	26.2	5.4	48.1	39.0	61.6	486.0
Baretta	52.8	149.3	148.8	11.1	0.8	1.5	24.2	4.0	8.6	34.7	56.5	311.2
Butaro	45.8	88.0	159.6	12.1	1.0	1.3	26.3	4.4	13.5	42.3	46.2	111.7
Ponticus	52.4	140.5	139.0	10.9	0.9	1.2	23.5	4.4	8.3	32.6	51.9	145.9
Royal	52.3	141.1	108.2	11.3	1.1	3.1	24.1	5.8	30.1	38.9	67.3	437.9
Titlis	50.3	102.7	105.3	11.8	1.4	5.0	26.1	5.7	16.6	38.8	84.8	351.2
Trebelir	47.4	113.8	69.4	11.9	0.8	2.3	25.9	4.3	15.0	37.6	58.8	350.3
Mean	50.2	120.5	107.4	11.6	0.9	2.5	25.4	4.7	19.3	38.5	58.5	294.6
Population												
Brandex	50.2	126.5	117.0	11.6	0.5	0.7	25.4	2.5	5.6	38.4	30.1	44.4
Liocharls	50.3	125.9	51.1	11.8	0.6	0.5	25.7	3.5	12.5	39.0	35.5	50.8
CCPWS	50.3	128.8	57.3	11.5	0.7	1.2	24.7	4.2	15.8	35.5	46.0	111.0
CC2K	50.6	91.8	66.6	11.4	0.8	0.9	24.7	4.0	7.7	34.6	50.0	125.9
OQI	49.7	105.1	27.8	11.5	0.7	1.4	25.0	3.9	14.0	35.8	46.0	133.9
OYQII	51.4	112.7	107.5	11.0	0.6	0.6	23.5	3.9	7.2	30.8	53.8	215.5
Mean	50.4	115.1	71.2	11.5	0.7	0.9	24.8	3.7	10.5	35.7	43.6	113.6

of the protein and wet gluten content of the populations were slightly lower than the means of the varieties (11.5% vs. 11.6% and 24.8% vs. 25.4%). The mean sedimentation value of the populations was 7% lower compared to the mean of the varieties (35.7 mL vs. 38.5 mL). In trial 2 'Brandex' and 'Liocharls' reached mean grain yields and mean baking quality values almost exactly equal to the mean of the varieties for all parameters (Table 1).

Yield stability

Most likely due to the limited number of test environments, conclusive results could not be obtained from the stability analysis of trial 1. The populations of trial 2, however, showed a tendency towards higher grain yield stability compared to the pure line reference varieties which is in line with the findings of Weedon & Finckh (2019) for wheat and Raggi *et al*. (2017) for barley. The mean W_i^2 value was 34% lower for the populations compared to the check varieties, indicating a higher dynamic yield stability of the populations. Still, four of the varieties had lower W_i^2 values than two of the populations (Table 1). The static stability analysis did not reveal clear differences between populations and varieties since the mean EV_i value between the two groups differed only slightly (4% lower for the populations).

Stability of baking quality parameters

For the baking quality parameters, all populations achieved greater dynamic as well as static stability than the mean of the varieties. The mean W_i^2 value of the populations was 64% (protein content), 46% (wet gluten content) and 61% (sedimentation value) lower compared to the mean of the varieties. The mean EV_i value of the populations was 28% (protein content), 22% (wet gluten content) and 26% (sedimentation value) lower than the mean of the varieties. Ordering the test entries according to the values of the stability measures (with lower values first), the populations always occupied the first two ranks and four out of the first six ranks (Table 1).

Notably, the populations 'Brandex' and 'Liocharls' ranked first and second for EV_i for all three quality parameters. In the case of W_i^2 at least one of the populations always occupied the first rank. In particular, these results confirm that genotypes can have both a higher dynamic as well as static stability relative to other test entries, in line with the findings of Knapp *et al*. (2017).

Taking into account the absolute values of the quality parameters by considering *e.g.* for the static stability the coefficient of variation (CV%) instead of EV_i does not change the general assertions outlined above. 'Brandex' und 'Liocharls' still rank first and second for the stability of all quality parameters, except for sedimentation value where they rank first and third. Moreover, in all but one case, the CV% of all populations are still below the mean of the varieties.

In conclusion, the results of this study demonstrate that the tested populations exhibited both a higher dynamic and static stability than the pure line reference varieties for the baking quality parameters protein content, wet gluten content and sedimentation value. These findings are well substantiated by the high number of test environments and the representative set of eight reference varieties with excellent baking quality under organic growing conditions. We shall defer the investigation of the statistical significance of the results in this study as well as investigations of reliability indices, which combine the mean performance and stability measure in one parameter, to future work.

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