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Experimental Determination of Genetic and Environmental Influences on the Viscosity of Triticale

L. LEVY HÄNER[1]*, P. STAMP[2], M. KREUZER[2], A. BOUGUENNEC[3,4] and D. PELLET[1]

[1]Agroscope Changins-Wädenswil ACW, Route de Duillier 50, 1260 Nyon, Switzerland
[2]ETH Zurich, Institute of Agricultural Sciences, Universitaetstrasse 2, 8092 Zurich, Switzerland
[3]INRA, UMR 1095 GDEC, F-63039 Clermont-Ferrand, France
[4]UBP, UMR1095 GDEC, F-63000 Clermont-Ferrand, France

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Low viscosity in cereals is important for monogastric livestock feeding. With respect to triticale, knowledge on the variability of its viscosity and its environmental dependence is deplorably low. Six winter varieties with similar earliness at maturity were chosen that covered a large range of potential applied viscosity (PAV) (individual values ranging from 1.8 to 4.9 ml/g). These were cultivated in four locations in Switzerland, at altitudes ranging between 430 and 700 m a.s.l., in 2008 and 2009. The effect of genotype on the PAV was significant and clearly influenced by the location factor. Although variety × location and variety × year interactions were rather low, they were still very important for the PAV compared with other variables such as grain yield and specific grain weight. The PAV expression of one variety seemed not to be susceptible to environmental conditions. The varietal range in viscosity demonstrates a high potential for breeding to raise quality, especially as the viscosity and the grain yield were not correlated. The favourable relationship between the PAV and protein content found in the present study may provide a further incentive to improve this trait to yield high-quality triticale. Existing variability might be used to guide the choice of favourable varieties.

Keywords: viscosity, genotype by environment interaction, protein, variety, triticale

Introduction

Triticale (× *Triticosecale* Wittmack), a wheat (*Triticum* ssp.) × rye (*Secale* ssp.) hybrid, gained globally in importance from the mid-1980s onwards (Mergoum and Gómez-Macpherson 2004). Sixty to 90% of triticale production in France is used on farms for feed purposes (Masson et al. 2004). This country ranks third worldwide in triticale production. The wide acceptance of this man-made cereal is due not only to increases in productivity, but also to increases in its protein content and its specific grain weight (Schori et al. 2007).

Currently, quality assessments of feed cereals are mainly based on specific grain weight, a criterion that can easily be determined. However, there is no robust relationship

* Corresponding author; E-mail: agroscope@admin.ch

for several cereals between the specific weight and indicators of the feed composition and feeding value, for instance the metabolisable energy content when fed to pigs, poultry or ruminants (Stewart et al. 1997; Moss et al. 1999; McCracken and McNab 2000). For monogastrics, especially poultry, the viscosity of the aqueous cereal extract is an important quality criterion in feed cereals (Grosjean and Barrier-Guillot 1996). It is determined by the prevalence of water-soluble nonstarch polysaccharides or pentosans, mainly arabinoxylans (AXs). Through their branched molecules, pentosans tend to absorb water and are responsible for antinutritive effects associated with increased dietary viscosity and for deceleration of the passage of the feed through the intestinal tract, resulting in inefficient nutrient absorption (Grosjean and Barrier-Guillot 1996; McGoverin et al. 2011). Thus, grain (feed) viscosity correlates negatively with the metabolisable energy content (Bedford et al. 1998; Grosjean et al. 1998), making high viscosity unfavourable for animal performance. In addition, high grain viscosity results in osseous malformations, as well as softer faeces (Choct and Annison 1990), which may lead to unfavourable animal housing sanitary conditions and soiling of eggs. In the context of viscosity, various terms are used. The relative viscosity refers to the measured viscosity of a sample in relation to the viscosity of a buffer solution. The real applied viscosity (RAV) refers to the viscosity measured when endogenous enzymes are active. These break up the AX chains, thereby decreasing the viscosity. The potential applied viscosity (PAV) used in the present study refers to viscosity after inactivation of xylanase activity.

According to Cyran and Lapinski (2006), triticale takes an intermediate position between wheat and rye in terms of soluble AX. However, the level of soluble AX in hexaploid triticale is significantly lower than that of tetraploid triticale and far nearer that of wheat than rye (8.5, 9.1, 15.1 and 27.8 g/kg, respectively, for wheat, hexaploid triticale, tetraploid triticale and rye). Therefore, breeding for high feeding value has to concentrate on reducing the viscosity towards that of wheat.

There is evidence of differences between cereal varieties in metabolisable energy contents, as well as in viscosity (Bedford et al. 1998). In common with metabolisable energy (Bedford et al. 1998), viscosity might be influenced by addition of enzymes in feed mixtures. Information about impacts of crop management practices on viscosity is scarce. Vilariño (2008) was able to exclude factors such as sowing date, type of wheat (for bread making or feeding) and grain conservation. N-fertilisation and fungicide protection did not affect AX contents (Dornez et al. 2008b; Vilariño 2008). In addition to clear differences between triticale varieties, the location of the production site playing a role was also obvious from a study by Bouguennec et al. (2001), with some locations apparently promoting higher viscosity than others.

The objective of the present study was to determine the presence and the extent of the influences of variety, year and location on the viscosity of triticale grains. Interactions between these factors were also determined. Our results can be used to develop recommendations for future breeding efforts.

Materials and Methods

Varieties

In a preliminary screening study, the flowering, maturity dates and PAV (data not shown) of 20 hexaploid winter triticale varieties were analysed. Six varieties were chosen for the experiments from 2008 and 2009. These varieties had similar earliness at heading (varying within ±1 day), which was determined according to the international BBCH scale (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) as the heading day, when half of the ears were visible (BBCH stage 55). These varieties covered nearly the full PAV range of scores (individual values ranging from 1.8 to 4.9 ml/g). The similar maturity ensures that the observed differences in PAV were not based on the response to environmental factors but on genetic characteristics. The varieties consisted of Triamant (released in 2003, Lochow-Petkus GmbH, Bergen, Germany), SW Talentro (2002, Svalöf Weibull AB, Svalöf, Sweden), Prader (1997), Bedretto (2003), Dorena (2007) and Tridel (1994), all of which were obtained from Agroscope Changins-Wädenswil and Delley Semences et Plantes, SA.

Experimental design

The four experimental locations contrasted in altitude (Table 1). The pH values (5.8 to 7.9) and organic matter content (15 to 33 g/kg) of the soils differed, whereas the clay, silt and sand components of the soil were mostly similar, at about 230, 380 and 350 g/kg, respectively. Both the daily average temperature and the precipitation were recorded between the anthesis and the maturity period. On average, 2009 was somewhat warmer (1242 as compared to 1207 degree days) and drier (185 ml as compared to 195 ml) during the study period than 2008. The sum of precipitation varied between 103 and 319 mm in the measurement period. The experiments were based on a completely randomised block design with three replications. The individual experimental plots consisted of eight rows (with inter-row spaces of 16 cm), each 1.5 m wide and 4.75 m long, covering a total area of 7.1 m^2.

Low-input crop management (without fungicide and growth regulator treatments and with moderate nitrogen input) was carried out at all the locations. A maximum of 120 kg N/ha of nitrogen fertiliser was applied in two to three separate dressings as recommended by Ryser et al. (2001), reduced according to available soil mineral N (Table 1). Phosphorus and potassium were supplied when required, according to low soil availability values. Triticale was sown around mid-October and harvested in July of the following year. The seeding rate was 350 grains/m^2.

Plant sampling and analysis

Grains of the whole plots (7.1 m^2) were machine harvested at the BBCH stage 92, impurities were removed, and they were dried to a constant weight at 32°C. The yield was then calculated at 15% humidity. The specific weight and the PAV were determined for each plot. The specific grain weight was measured with a HM-400 Grain Gage (Harvest Data

System, Wintersteiger GmbH, Ried, Austria). The grain protein content (N × 6.25) was assessed in samples pooled from the three field replications, by near infrared spectrometry (in 2008, a Foss 6500, Foss NIRSystems Inc. Maryland, USA; in 2009, a Büchi Nirflex N-500, Büchi Labortechnik AG, Flawil, Switzerland). Calibration tests were performed by analysing the same set of flours with both NIR analysers (the correlation coefficient for protein content prior to the adaptation of the calibrations accounted for $r = 0.98$, bias = 0.30, $n = 49$). The amount of protein per grain was calculated based on the protein content, grain yield and thousand-kernel weight.

For the PAV analysis, triticale grain samples were ground to pass through a 0.8-mm mesh. Thereafter, pretreatment was performed with 80% ethanol at 80°C for 60 min to inactivate endogenous enzymes. Extraction was done with an acetate buffer (pH 4.5) according to the method developed by Carré et al. (1994) and adapted by Oury et al. (1998). The PAV of the extract was measured at 30°C with an automated viscometer (AVS370, Schott-Instruments, Germany) equipped with a 2-ml Micro-Ostwald capillary tube. Bouguennec et al. (2001) reported a high correlation between the original (Carré et al. 1994) and the adapted method (Oury et al. 1998) for wheat ($r = 0.90$). The PAV results were expressed as: log (η_r)/(content in g/ml of the original material in the final extract), where η is the relative viscosity, i.e. the extract viscosity divided by the viscosity of the acetate buffer solution. To ensure accuracy of measurements, the buffer viscosity was determined daily with a 0.2 M acetate solution and individually for each Micro-Ostwald capillary tube. Data are expressed in ml/g dry matter.

Statistical analysis

The data were subjected to an analysis of variance considering the year, location and variety as fixed effects. F-tests were performed with WIDAS (Web-enabled Information Delivery and Analysis System, Waelti AG, Buchs, Switzerland). Multiple comparisons among the year, the location or the variety means were carried out with the Student Newman–Keuls test using the same software. Pearson's correlation coefficients were calculated with XLSTAT 2011.2.04.

Results

About 77% of the variability in the PAV could be attributed to the varietal influence (Table 2), whereas the grain yield was mostly influenced by location (59%) and year (15%). Variation in the heading day and the specific weight was mainly explained by annual environmental conditions (74% to 79%). The year × location interaction was the most important, especially for the grain yield (19%), but much less so for the other parameters (2.8% to 3.1%). The variety × year interaction was highly significant for all the parameters, whereas the variety × location interaction was only significant for the PAV and the specific grain weight.

Across all locations, the PAV, yield and specific grain weight were significantly higher in 2009 than in 2008 and plants headed earlier (Table 3). The PAV ranged from 2.90 to 3.45 ml/g dry matter at the location × year level. At two locations (Changins and

Table 1. Description of crop management practices and nitrogen fertilisation in the different experimental locations and growing periods

Location	Altitude	Growing	Nitrogen		Dates	
	(m a.s.l.)	period	Application dates	(kg/ha)	Sowing	Harvest
Changins	430	2007–2008	19 Feb. & 07 April 2008	50 + 70	16 Oct. 2007	23 July 2008
		2008–2009	27 Feb. & 07 April 2009	50 + 60	15 Oct. 2008	14 July 2009
Begnins	541	2007–2008	14 Feb. & 20 April 2008	60 + 60	16 Oct. 2007	29 July 2008
		2008–2009	07 March & 01 April 2009	60 + 60	13 Oct. 2008	21 July 2009
Goumoens	610	2007–2008	16 May & 09 June 2008	60 + 60	12 Oct. 2007	29 July 2008
		2008–2009	18 March & 15 April 2009	60 + 60	20 Oct. 2008	21 July 2009
Posieux	700	2007–2008	19 March, 09 April & 05 May 2008	30+50+30	12 Oct. 2007	25 July 2008
		2008–2009	23 March, 08 April & 06 May 2009	40+40+30	14 Oct. 2008	30 July 2009

Table 2. Analysis of variance for viscosity, grain yield, specific grain weight and heading day: the mean squares are expressed as % of the total. The degrees of freedom (DF), as well as the levels of significance, are specified for each factor analysed

Source of variation	DF	Viscosity (%)	Grain yield (%)	Specific grain weight (%)	Heading day (%)
Year (Y)	1	8.8***	14.9***	73.6***	79.2***
Location (L)	3	6.3***	59.5***	13.0***	16.5***
Variety (V)	5	77.1***	3.1***	8.1***	1.2***
Replication	2	0.3	0.2	0.2	0.0
L×Y	3	3.1***	19.3***	2.8***	2.9***
V×Y	5	1.9***	1.5*	1.5***	0.1**
V×L	15	1.5***	0.7	0.4***	0.0
V×L×Y	15	0.8***	0.3	0.3***	0.0
Error	94	0.2	0.5	0.1	0.0

*, **, *** significant at $P < 0.05$, 0.01 and 0.001, respectively.

Table 3. Year, location and year × location effects on various traits of the plant and the grain across all six varieties

Environments	Viscosity (ml/g)	Grain yield (t/ha)	Specific grain weight (kg/hl)	Heading day (calendar day)
Year				
2008	3.16b	6.93b	70.1b	144.5a
2009	3.33a	7.69a	74.0a	137.4b
Location				
Changins	3.28f	7.10f	73.7e	136.1g
Begnins	3.40e	6.27g	69.8d	142.8e
Goumoens	3.06g	9.51e	72.8f	142.0f
Posieux	3.25f	6.35g	71.9g	142.9e
Location × year				
Changins 2008	3.10u	6.95u	70.8u	139.3x
Changins 2009	3.45y	7.25u	76.6z	132.9t
Begnins 2008	3.40xy	5.09t	67.7t	148.3z
Begnins 2009	3.39xy	7.44u	72.0u	137.2u
Goumoens 2008	2.90t	8.58x	71.0u	144.8y
Goumoens 2009	3.22ux	10.44y	74.5y	139.2x
Posieux 2008	3.25ux	7.08u	70.9u	145.5y
Posieux 2009	3.25ux	5.61t	73.0x	140.2x
Mean	3.24	7.31	72.1	140.9
Standard error	0.05	0.15	0.27	0.41

Means with unequal letters significantly differ at $P < 0.05$; a–b, year means, e–g, location means, t–z, location × year means.

Goumoens), the values significantly differed from one year to the other. Higher PAV values were obtained in 2009 (a drier year, with 185 mm precipitation cumulated from BBCH 55 to BBCH 92) as compared to 2008 (197 mm precipitation). The grain yields varied largely between both years at all the locations, except for the location Changins where medium-level yields were consistently delivered. Heading occurred about one week earlier in 2009. At Changins, it occurred, on average, five to seven days earlier than at higher altitude locations. The highest PAV was in triticale grown in Begnins. Changins had the highest specific grain weight and the earliest heading day. The yields were the highest in Goumoens and the lowest in Begnins and Posieux. In Begnins, the specific grain weight was the lowest at a concomitantly late heading day. The correlation coefficient between the PAV measured in 2008 and 2009 was $r = 0.88$ ($P < 0.001$), and relationships ranged from $r = 0.75$ (n.s.) to $r = 0.99$ ($P < 0.001$) for the PAV at the location × year level (results not shown).

An irrigation trial conducted in 2009 with similar triticale varieties led to small but statistically significant ($P < 0.01$) differences among irrigation treatments (150 mm water irrigated over the May to June growing season, in addition to 135 mm rainfall), with higher viscosity observed in the nonirrigated treatment (only 135 mm rainfall) (3.84 ml/g) as compared to the irrigated one (3.75 ml/g)/g (data not shown).

The PAV significantly varied between the varieties, from 2.32 in Tridel to 4.20 ml/g dry matter in Bedretto (Table 4). The grain yields varied proportionately much less than the PAV, ranging from 6.81 to 7.85 t/ha. No significant correlation existed between the PAV and the grain yield. However, on average, the two varieties with the lowest PAV values and the variety with the highest PAV value, respectively, had the significantly lowest and highest yields. Recently released varieties, such as SW Talentro (2002), Dorena (2007) and Triamant (2003), showed a significantly higher specific grain weight in comparison to the other varieties.

Table 4. Effects of the six triticale varieties a on various traits of plant and grain heading day across the two experimental years and the four locations

	Viscosity (ml/g)	Grain yield (t/ha)	Specific grain weight (kg/hl)	Heading day (calendar day)
Variety				
Tridel	2.32a	6.91b	69.9d	142.1a
Prader	3.00b	6.81b	71.3c	139.8d
Triamant	3.22c	7.71a	72.3b	140.0cd
Dorena	3.26c	7.39ab	73.6a	140.9b
SW Talentro	3.50d	7.18ab	74.1a	142.3a
Bedretto	4.20e	7.85a	71.1c	140.6bc
Overall mean	3.24	7.31	72.1	140.9
Standard error	0.05	0.15	0.27	0.41

a–e Variety means with unequal letters significantly differ at $P < 0.05$.

For the three most contrasting varieties, the PAV is displayed in relation to the average PAV achieved at each single site to demonstrate the different interaction types of variety × environment (Fig. 1). Tridel, the variety with the lowest PAV, was the most conformant variety, as it showed an average reaction compared with the other varieties, with a slope close to 1.

Bedretto (highest PAV) reacted strongly to environmental conditions (slope of 1.78), whereas Prader (second lowest PAV) was nearly not susceptible (slope of 0.45).

There were clear year effects in the protein content (12.3% in 2008 and 8.6% in 2009) of the grain and in the amount of protein per grain (5.1 and 4.4 mg). The varieties also differed with respect to the grain protein content (9.8 to 10.9%) and the protein amount per grain (4.4 to 5.3 mg). There was a weak but statistically significant ($P < 0.05$) correlation coefficient between the PAV and the protein amount per grain ($r = –0.31$). When the relationship between the PAV and the other variables was analysed within each single variety in the eight environments (two years and four locations; data not shown), the PAV was negatively (though not always significantly) correlated to the protein content and the protein amount per grain for each variety. This relationship was significant for the two varieties with the lowest (Tridel) and the highest PAV (Bedretto). The respective correlation coefficients between the PAV and the protein content, as well as the protein amount per grain, were $r = –0.78$ ($P < 0.05$) and $r = –0.83$ ($P < 0.05$) in Tridel, and $r = –0.93$ ($P < 0.001$) and $r = –0.92$ ($P < 0.01$) in Bedretto.

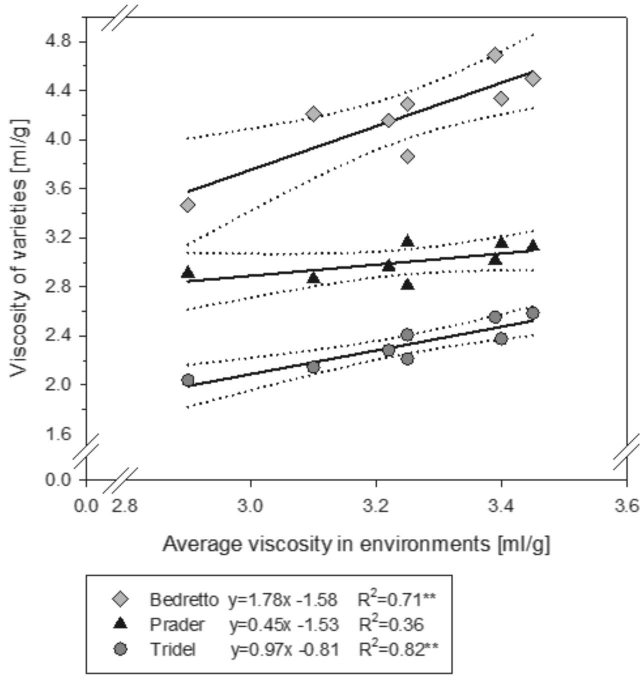

Figure 1. The interaction between the variety and the environment is presented for three contrasting varieties. The average viscosity in the environments was the average viscosity of all varieties grown in a given environment. The environments were ranked by the increasing average potential applied viscosity of triticale: Goumoens 2008, Changins 2008, Goumoens 2009, Posieux 2008, Posieux 2009, Begnins 2009, Begnins 2008, Changins 2009. Regression lines were drawn with the respective confidence interval (dotted lines; $P = 0.05$)

Discussion

Varietal effects on PAV

Researchers have neglected triticale, particularly this minor crop's quality parameters. The PAV has been mostly investigated in wheat, where researchers found a strong impact of variety (Oury et al. 1998; Martinant et al. 1998). The variation among triticale varieties seems to be similarly large (Masson et al. 2004). Carré et al. (1994) described the range of the PAV for triticale as between 2.8 to 7.3 ml/g dry matter, as opposed to only 2.3 to 4.2 ml/g dry matter in the present study (Table 4; single values reaching from 1.8 to 4.9 ml/g). As the method used in this paper is an adaptation of Carré's method as suggested by Bouguennec et al. (2001), some variation might be due to the different methods and varieties. Within our group of preselected cultivars, Bedretto was the only one with a critically high PAV. Some breeding lines in the pre-selection tests had a PAV as low as 1.5 ml/g; unfortunately, these had to be excluded from the main experiments due to divergent maturity dates, but they corroborated the presence of a relatively low PAV in hexaploid triticale (Boros 1999; Bouguennec et al. 2001).

Bedford et al. (1998) recommended taking into consideration the variation in the PAV between cereal samples when formulating broiler feed, especially when the formulation includes specific amino acids. In this respect, the contrasting PAV properties of the varieties deserve special attention. However, there is little information about the upper level of viscosity above which problems in poultry feeding may occur. Masson et al. (2004) classified viscosities of less than 2.0 ml/g as very good, 2.0 to 2.8 ml/g as good and 2.8 to 4.0 ml/g as requiring supervision. They stated that those above 4 ml/g should be avoided. However, these authors applied another method for analysis and measured the RAV when endogenous plant enzymes were still active. Idi (1997) declared that an RAV above 2.5 ml/g in wheat might lead to tangible negative effects in poultry. Considering that the PAV usually is higher than the RAV, Bouguennec et al. (2001) suggested that a PAV above 3 ml/g may be risky for safe poultry feeding. Using this classification basis, only two of our six already approved varieties would be suitable for poultry nutrition. Counter-measures include adding enzymes or limiting dietary proportions of triticale, or both.

Environmental effects on PAV

As expected, the PAV values were closely and significantly correlated ($r = 0.88$) between both experimental years. There was a significant year effect in the present study (Table 2) that Bouguennec et al. (2001) did not find. Oury et al. (1998) noted close correlations (from $r = 0.88$ to $r = 0.98$) between six environments within one year for the PAV of wheat varieties. These were corroborated to some extent by Bouguennec et al. (2001) in triticale. Lower correlations in the latter study might be due to the rainy climate of one location at higher altitude, which could have reduced the highest PAV (Bouguennec et al. 2001). However, the present study found no such relationship between the altitude of the different locations and the PAV, despite a wide altitudinal range from 430 m a.s.l., optimal, to 700 m a.s.l., marginal, for triticale cultivation (Table 1). The pairwise correlation coefficients between the eight environments ranged from $r = 0.75$ to $r = 0.99$, i.e. at a similar level as has been reported for rye (Gan et al. 1996a). These underline the absence of the influence of the factor ‘altitude’, *per se,* on the PAV in this study.

Effects due to environmental factors described in the literature are sometimes controversial, with conclusions difficult to reconcile. No studies could be found that dealt with the viscosity of triticale in relation to environmental factors. In wheat, dry conditions have been reported by some authors to cause higher viscosity (Hong et al. 1989; Oury et al. 1998), especially when drought follows flowering (Grosjean et al. 1997). Indeed, the PAV values of the present study were somewhat higher, on average, in 2009 (drier year; Table 3). According to the results of the irrigation trial, limited water availability could only weakly explain the observed difference in the PAV among the years, suggesting that other environmental factors affect the PAV. This is in line with the work of Shewry et al. (2010) who found that the viscosity of wheat is more closely related to temperature than to water availability. Moreover, they found a negative correlation between drought and WE-AX accumulation (in both flour and bran). Dornez et al. (2008a) documented that conditions favouring preharvest sprouting in wheat augmented WE-AX levels because increases in endogenous xylanase activity degraded AX. As we studied several varieties in four contrasting locations over two years, the present study contributes important data for a better understanding of the PAV and suggests that triticale may show a similar physiological response to environment as wheat. Many authors have reported various relationships between environmental factors and viscosity, but they were reluctant to give a physiological explanation (Hong et al. 1989; Grosjean et al. 1997; Bouguennec et al 2001). Therefore, more detailed studies are needed.

Variety × environmental interactions in the PAV

The environment also affected the expression of differences between the varieties, with observed interactions due to varieties with similar average PAV values showing different responses to environmental factors. Thus, when comparing the results of single environments (location – year, data not shown), an inversion of ranking order may occur. This is less likely for highly contrasting varieties, as the genotypic effect is then dominating (Grosjean et al. 1997; Bouguennec et al. 2001). However, PAV-associated interactions have often been neglected. In the present study, interactions of variety × year and variety × location were more important for the PAV than the grain yield, specific weight and the other variables (Table 2). Some varieties may overreact to environmental factors (Fig. 1, Bedretto), whereas others seem not to be susceptible to them (Prader). Divergences found in the literature concerning the environmental impact on viscosity may be due to two factors. First, the reactiveness of single varieties was probably not taken into account in these studies (interactions of variety × environment). Second, the period during which temperature or precipitation is recorded and analysed in relation to the PAV is critical for the explanatory power of these environmental factors.

Implications for triticale breeding

Two strikingly different examples for future breeding attempts could focus on: (i) a variety with an almost environmentally stable PAV (here: Prader), which would allow reliable predictions to be used for feed formulation, and (ii) a variety with (accidentally) low PAV values that more than proportionally increase in environments conductive to an occasionally low PAV (here: Tridel). The latter would be suitable for the production of poultry feed only after previous assessment of the PAV because predictions of this factor are notoriously inaccurate. Other varieties, such as Bedretto, which already has a high intrinsic PAV and shows large susceptibility to the environment, would not be suitable for further promotion in breeding for poultry feed. In contrast to a study on rye, where low viscosity was associated with a lower yield (Goncharenko et al. 2011), the present study found no significant correlation between the PAV and the grain yield. Nevertheless, the highest yielding varieties, i.e. the most attractive ones for cultivation, also had the highest PAV. These findings indicate that beyond the current complex variety × environment testing schemes, multivariety tests should be carried out to overcome the possible limitation of a concomitantly high yield and high PAV levels. In the future, it would be promising to identify markers for environmental stability of PAV to avoid high test costs in the laboratory.

Efforts have been undertaken to identify an auxiliary selection trait for PAV. Interestingly, a QTL on chromosome 1B in a haplo-diploid population of bread wheat explained up to 37% of relative viscosity (Martinant et al. 1998). It is particularly important to identify lines with low viscosity, as some trials to select indirectly for low viscosity (in rye) using falling number or grain weight failed (Gan et al. 1996b). According to Goncharenko et al. (2011), the selection of winter rye for low viscosity scores was less effective than for high ones (realised heritability – h^2 – varied within 0.33–0.44 and 0.70–0.74, respectively). These are sufficient reasons to increase research efforts for selection criteria for PAV in triticale.

In the present study the PAV declined when the protein content or the protein per grain increased, something that would be very attractive for animal nutrition. However, this relationship was only close for the two varieties with an extreme PAV. It has not been consistently found in other studies (r of –0.52 for wheat, but statistically not significant in Dornez et al. 2008b). In wheat, enhanced grain protein content (+1.5%) was associated with a lower RAV, but the PAV did not change (Carré and Oury 2001). Therefore, the protein content may not fulfil the high demands for an auxiliary selection trait for PAV.

In conclusion, the varietal range in the PAV demonstrates a certain potential for quality breeding, especially as the PAV and the grain yield were not correlated. Based on the existing variability, poultry farmers have the possibility to choose favourable varieties with low viscosity. However, a corresponding classification should be implemented. By showing to what extent the variability in the PAV may be related to genotypes, the environment and the interactions of those factors, this paper provides information to improving knowledge of this minor crop.

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