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Viscosity of triticale varieties differs in its response to temperature after flowering

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ABSTRACT

Triticale produced to feed monogastric livestock needs to have a low potential applied viscosity (PAV). Five varieties were cultivated at nine locations (430–700 m a.s.l.) in Switzerland over three years. Six of the locations were sampled for at least two consecutive years, and PAV was related to meteorological data. The data was subjected to correlation and regression analysis, as well as a multiplicative model, to evaluate interactions. Extent and stability of PAV differed between experimental locations across all genotypes, notably between varieties and years, but also between single locations in the same year. Interactions between genotype and environment were responsible for up to 12% of the PAV variance. With the exception of one variety, PAV was negatively correlated with the cumulated mean temperatures over a 20-day period, starting on day 24 after heading. In these cases, temperature data explained the differences in PAV much better than precipitation did. By linear regression, PAV could be predicted from mean temperature during grain development and grain hardness at harvest for the four thermosensitive varieties. Two varieties were of particular interest, as they had either a favorably low PAV (Tridel) or a PAV resistant to environmental influences (Prader). A combination of these two traits could be used to create a type of triticale particularly suitable for livestock feeding.

1. Introduction

For the feeding of poultry and pigs, certain grain quality criteria are very important, including the contents of water-soluble non-starch polysaccharides (Bakker et al., 1998; Pettersson and Aman, 1988), as high levels in cereals may negatively affect its nutritional value (Moss and Givens, 2001). There is a considerable variation in this trait. For instance, wheat grains contain 20–60 g/kg of pentosans; arabinoxylans (AX) are the main pentosans, whereas β-glucans make up only 5–10 g/kg (Cui and Wang, 2009). The AX in the endosperm cell walls includes structures with both few and many branches. These cereal constituents determine the viscosity of the aqueous extract. Viscosity is easy to assess compared to the chemical analysis of carbohydrates. Viscosity is positively and highly correlated to water-soluble arabinoxylan ($r = 0.961$, Carré et al., 2002) but relationships between viscosity, structure of AX and solubility are rather complex. Viscosity has been assumed to reflect mainly the highly branched AX as they could be better soluble in water and thus promote viscosity more intensively than AX with few branches which may aggregate into large, insoluble clusters (Ebringerova et al., 1994). However, this relationship could actually be more complicated. For instance, the water extractable AX from wheat endosperm have been found to be even slightly less branched than the not water extractable AX from the same tissue (Ordaz-Ortiz and Saulnier, 2005) even though its AX are quite highly substituted (A/X ratio around 0.6). Additionally, in outer tissue of grain (pericarp) very highly substituted AX is present that are not water soluble at all (Saulnier et al., 2007).

The primary factor found to affect viscosity in wheat is the genotype (Oury et al., 1998). Gebruers et al. (2010) estimated that the content of water-extractable AX in wheat is determined 50% by genotype. Still, a considerable part of the variation remains unexplained, and environment and genotype × environment interactions may be important as well. Environmental factors, such as level and variation in temperature, precipitation, altitude, and soil properties, are known to have a major impact on yield and yield-related variables, as well as on the seed quality of different crops (Baux et al., 2008; Li et al., 2010; Barraclough et al., 2010). Accordingly, fluctuations in temperature and water availability have been

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shown to affect crude protein content, sedimentation volume, Hagberg falling number, and specific weight of wheat grains (Gooding et al., 2003). However, studies have not provided much information about environmental impacts on viscosity. Toole et al. (2007) described that AX structures change from highly branched (HB) soluble to low-branched (LB) water-insoluble forms during grain filling of wheat. This transition occurred faster when the wheat was grown at high ambient temperature and restricted availability of water, but this process also differed among cultivars (Toole et al., 2007). Coles et al. (1997) reported a positive relationship between AX accumulation, resulting in high viscosity, and drought in a selected wheat variety. In the same study, nitrogen availability increased the AX content of the grain only when there was an abundant supply of water.

Triticale (×*Triticosecale Wittmack*), a hybrid of wheat (*Triticum* ssp.) and rye (*Secale* ssp.), has become an important feed cereal globally (Mergoum and Gómez-Macpherson, 2004); however, research on this cereal is limited. It seems that triticale has an unfavorably higher viscosity than wheat (Cyran and Lapinski, 2006). In addition, there seems to be variation in AX, and therefore, viscosity, among triticale genotypes. Accordingly, tetraploid triticale cultivars have been reported to have a much higher AX level (15.3 g/kg) than hexaploid cultivars (9.1 g/kg) (Cyran and Lapinski, 2006).

The objective of the present study was to test the following hypotheses: (i) environmental factors cause substantial variation in the viscosity of triticale; (ii) there are significant genotype × environment interactions in viscosity level; and (iii) there are linear relationships between viscosity and other traits in a given environment, which can be used for predicting viscosity.

2. Materials and methods

2.1. Experimental design

Five hexaploid varieties of winter triticale of similar maturity were tested in 2007, 2008, and 2009. Four were obtained from Delley Semences et Plantes SA, Delley, Switzerland: Tridel (released in 1994), Prader (1997), Bedretto (2003), and Dorena (2007). The fifth variety, Triamant, was released in 2003 by Lochow-Petkus GmbH, Bergen, Germany.

In the present study, daily mean temperature and precipitation were recorded between the anthesis and maturity periods by meteorological stations located within 5 km of the experimental locations. Each individual field trial consisted of one experimental location in a given year. Samples were collected at nine locations, for a total of 21 field trials conducted during the experimentation. Six locations were sampled in at least two consecutive years, resulting in 15 field trials. Depending on the statistical analysis, either the whole dataset (21 trials) or data replicated over the years at a given location (15 trials) was used. These locations were situated at different altitudes (Table 1). Soils differed in pH (5.8–8.0) and organic matter content (15–33 g/kg), whereas the proportions of clay, silt, and sand in the soil were mostly similar, with averages of 240, 395, and 365 g/kg, respectively. Each field trial was based on a completely randomized block design, with three replications per cultivar. 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 or growth regulator treatments and with an average input of 120 kg nitrogen/ha) was carried out at all locations. Nitrogen fertilizer application was adapted to available soil mineral N amount, split into two to three separate dressings (Table 1). Phosphorus and potassium were supplied when required, according to low soil availability values.

Table 1
Description of the six experimental locations and their management during the three experimental years.

Location (altitude, m a.s.l.)	Growing period	Soil composition					Fertilization				Previous crop			Day/year	
		pH	OM (g/kg)	P (mg/kg)	K (mg/kg)	Mg (mg/kg)	Dates of N application	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Culture	P_2O_5 (kg/ha)	K_2O (kg/ha)	Sowing (October)	Harvest (July)
Changins	2006–2007	8.0	23	44	118	327	23 F., 22 M. 2007	51 + 60	0	0	Pea	97	0	12/2006	15/2007
(430)	2007–2008	7.8	26	78	187	214	19 F., 7 A. 2008	50 + 70	0	0	Soya	0	0	16/2007	23/2008
	2008–2009	7.9	25	42	110	255	27 F., 7 A. 2009	50 + 60	0	0	Soya	0	0	15/2008	14/2009
Begnins	2006–2007	6.3	22				22 F., 16 M. 2007	55 + 55	33	65	Wheat			16/2006	18/2007
(541)	2007–2008	7.2	21				14 F., 20 M. 2008	60 + 60	33	125	Wheat			16/2007	29/2008
	2008–2009	6.2	21				7 M., 1 A. 2009	60 + 60	0	0	Wheat			13/2008	21/2009
Goumoens	2006–2007	7.8	25	56	190	207	2 A. 2007	110	0	42	Soya	24	89	16/2006	17/2007
(610)	2007–2008	6.0	27	56	157	98	16 May, 9 J. 2008	60 + 60	0	0	Soya	0	0	12/2007	29/2008
	2008–2009	6.4	33	87	188	148	18 M., 15 A. 2009	60 + 60	0	0	Soya	84	0	20/2008	27/2009
Delley	2006–2007	7.3	16	53	100	58	15 M., 3 A. 2007	69 + 70	58	116	Soya	49	98	16/2006	19/2007
(500)	2007–2008	6.7	15	65	107	48	26 F., 17 A. 2008	67 + 85	60	121	Soya	31	63	16/2007	23/2008
Posieux	2007–2008	6.1	15	54	112	64	19 M., 9 A., 5 May 2008	30 + 50 + 30	60	120	Potato	86	225	12/2007	25/2008
(700)	2008–2009	5.8	18	59	69	54	23 M., 8 A., 6 May 2009	40 + 40 + 30	35	75	Potato	75	390	14/2008	30/2009
Ellighausen	2007–2008	7.5	23	80	10	147	19 M., 2 A., 30 A. 2008	40 + 40 + 55	0	0	Maize			15/2007	26/2008
(520)	2008–2009	7.6	32	184	24	112	14 M., 22 A., 15 May 2009	50 + 60 + 30			Maize			14/2008	27/2009

Notes: Dates of N application: F., February; M., March; A., April; My, May; J., June. OM, organic matter.