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Nutritional quality of organic and conventional wheat*

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Summary

The popularity of organic food and the farming area managed according to organic agriculture practices have been increasing during the last years. It is not clear, whether foods from organic and conventional agriculture are equal with respect to nutritional quality. We chose wheat (*Triticum aestivum* L., cv. Titlis) as one of the most important crop plants to determine a range of substances relevant for human nutrition in crops from organic and conventional agriculture systems. Wheat grains of 2003 originating from a long term field experiment, the Swiss *DOK* trial, consisting of bio-dynamic, bio-organic and conventional farming systems were used. Thousand seed weight, protein content, phosphate levels, antioxidative capacity, levels of phenols, fibre, fructan, oxalate and phytic acid were determined in whole wheat meal from the various organic and conventional growing systems of the *DOK* trial. Levels of these substances fell into a range that is known to occur in other wheat crops, indicating that wheat from the *DOK* trial was not special. Clear-cut differences were observed for none-fertilised wheat, which was significantly lowest in thousand seed weight, protein and significantly highest in total oxalate. For the majority of the nutritionally important substances analysed, there were no significant differences between bio-dynamic, bio-organic, and conventional growing systems. Only protein content and levels of fibres were statistically different. Taken together, the magnitude of observed variations was very small. The results of our investigations do not provide evidence that wheat of one or the other agriculture system would be better or worse.

Introduction

Organic food is perceived by many consumers as safer and healthier than conventionally produced food (e. g. Bourn and Prescott, 2002; Kuhnert et al., 2003). The question arises, whether this perception can be confirmed on scientific grounds. In order to establish a basis to draw sound conclusions with respect to nutritional quality, it is necessary to analytically determine a range of substances and physiological parameters with relevance for human nutrition in both, organic and conventional food. This approach of comparing key nutrients of food, including wheat, from both farming systems has been used in a number of studies. However, it is difficult to draw firm conclusions from most of these studies for several reasons: *i*) the analysed food was purchased from retailers, *ii*) samples from different farm locations, with varying soil types and micro climate were used, *iii*) statistical analyses of the data were insufficient, *iv*) the analytical methods employed are now subject to criticism (Worthington, 1998; Bourn and Prescott, 2002; Williams, 2002).

The *DOK* field trial has been conducted continuously since 1978 (Mäder et al., 2002). The experiment uses a field plot design where different organic and conventional farming systems with identical crop varieties are run side by side, thus eliminating variation in climatic conditions and soil types. Exclusively, the mode of fertilisation and crop protection practises are different in the various systems. The levels of applied plant nutrients are distinctly lower in the organic systems (see Materials and methods for details). Wheat grains from the *DOK* experiment provide an excellent basis for any comparative study addressing different farming systems. Using these materials, we have set out to clarify by biochemical analyses, whether there are any differences in relative concentrations of nutritionally relevant substances and parameters in wheat from bio-dynamic, bio-organic and conventional farming systems.

Materials and methods

Wheat production

Wheat grains (*Triticum aestivum* L., cv. Titlis) were harvested in 2003 from the *DOK* field trial conducted near Basel, Switzerland. The *DOK* field trial was started in 1978 by the Research Institute of Organic Agriculture (FiBL, Frick, CH) and the Agroscope Reckenholz-Tänikon Research Station ART (Zürich, CH). Refer to Mäder et al. (2002) for a detailed description of the field trial. In our study, wheat material was used from two organic farming systems defined as bio-dynamic (dyn) and bio-organic (org) and two conventional systems, one with mineral fertiliser plus farmyard manure (conv) and the other with mineral fertiliser only (mineral). In the organic systems fertiliser levels corresponded to 1.4 livestock units per hectare and in the conventional systems fertiliser was supplied at the level of the plant-specific Swiss standard recommendation [fertiliser high]. For each of the four systems there was a second fertilisation level applying half of the above described standard levels [fertiliser low]. Nutrient supply with respect to N, P and K was between 34 and 51% lower in the organic systems (Mäder et al., 2002). Additionally, wheat grains from plots without fertilization (none) were included. These plots received nutrients from two cultivations of green manure in a seven year crop rotation and N-entries by air (ca. 40 kg/ha). Crop rotation, varieties, and tillage were identical in all systems.

Analyses

Thousand seed weight was determined by recording the mass of three times 100 grains.

Whole wheat meal was obtained by grinding wheat grains (100 g from each field plot) in a Teflon laminated mill using a sieve with 0.5 mm pore size (Retsch, Germany). Air dried whole wheat meal was used in all analyses.

Nitrogen levels were determined using the procedure of Kjeldahl (EN ISO 3188, 1994). Factor 5.7 was applied to calculate protein content.

Phosphate content was determined according to Gericke and Kurmies (1952).

Antioxidant capacity of whole wheat meal was determined using DPPH (2,2-diphenyl-1-picrylhydrazyl) as described (Miller et al.,

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2000). Standard curves were obtained for the reaction of DPPH with Trolox (6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid), a water soluble analogue of vitamin E. Data were expressed as µmol Trolox equivalents (TE) per g whole wheat meal.

Phenols were measured with the Folin-Ciocalteu reagent (Merck) as described (PETERSON et al., 2002). For soluble phenols 2 g of whole wheat meal were stirred in 20 mL methanol for 30 min at 25°C. Extracts were brought to a volume of 25 mL with methanol and were filtered (FRETZDORFF, 2005). Total phenols were extracted using alkaline conditions as described by PIBER and KÖHLER (2004) with minor modifications: whole wheat meal was 100 mg and the volumes were adapted. After drying of the organic phase in a rotating evaporator, the residues were resuspended in 5 mL methanol. The Folin-Ciocalteu reaction was performed with 0.25 mL suspension. Ferulic acid was used as a standard for calibration.

Soluble and **total oxalic acid** were determined enzymatically as described by FRETZDORFF (2005).

Phytic acid levels were determined according to WHEELER and FERREL (1971).

Fructan was determined using the AOAC method 999.03 (Megazyme, Ireland) as described by FRETZDORFF and WELGE (2003).

Soluble and **insoluble dietary fibre** was determined with an enzymatic-gravimetric method (ANON., 1997), based on the method of LEE et al. (1992).

Statistical evaluation was carried out using the Tukey-test algorithm of the students range using SAS software (Institute Inc., Cary, NC USA). Significance was tested at the 5% level. For each of the various wheat farming systems, samples of at least three individual field plots were analysed.

Results and discussion

Thousand seed weights were not significantly different between wheat samples from the various farming systems, regardless of the fertilisation level. Only wheat that was grown without any fertilisation had a significantly lower thousand seed weight (Fig. 1A). These results with wheat from the 2003 harvest confirm results obtained with wheat grown in three crop rotations between 1978 and 1998 in the *DOK* experiment (MÄDER et al., unpublished). The independence of the thousand seed weight from the farming system indicates that development of endosperm, germ and bran was similar in all systems, if there was fertilisation. Thus, possible differences that might be found in levels of nutritional parameters in wheat from organic and conventional systems cannot be attributed to variations in proportions of endosperm, germ and bran. However, since total wheat yields in the *DOK* trial were decreased in the organic systems between 10 and 14% (MÄDER et al., 2002, MÄDER et al., unpublished), it is most probable that the number of tillers was reduced in the organic systems. By doing so, the plant is capable of achieving fully developed seeds also at the lower level of available nutrients.

Variation in crude protein content was observed (Fig. 1B). As expected, protein content increased with the amount of fertiliser applied. Protein content was significantly highest in wheat that received exclusively mineral fertiliser. The trend of increased protein content in mineral fertilised wheat was observed in other studies comparing organic and conventional systems (STEINECK and LIEBHARD, 1984; BOLLING et al., 1986; ELTUN, 1996). Wheat protein levels were relatively high, i. e. between 13 and 15%, in all systems of the *DOK* trial that used fertiliser (Fig 1B). As for phosphate, there were no significant differences between the farming systems, none-fertilisation included (Fig. 1C). This finding is in full agreement with the results of other experiments showing that phosphorus was sufficiently available for plants in the various *DOK* field plots (OEHL et al., 2002).

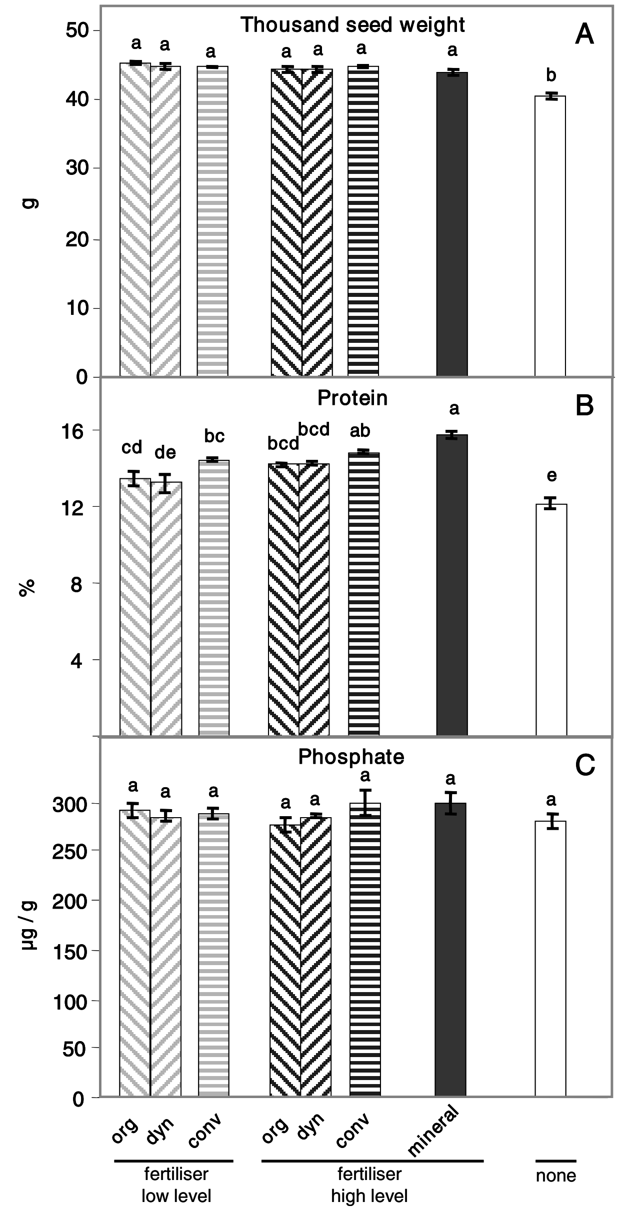

Fig. 1: Basic properties of wheat grains grown at different farming conditions in 2003. Thousand seed weight (**A**), Protein content (**B**) (nitrogen content x 5.7), Phosphate levels (**C**). Values are means of replicates from at least three independent field trials. Standard errors of the mean are shown. Statistical significance was tested using the Tukey-test algorithm of the students range ($\alpha = 0.05$). Differing small print letters above histograms indicate significant differences. (org = bio-organic, dyn = bio-dynamic, conv = conventional).

Antioxidants such as vitamins C and E, carotenoids and polyphenols are of particular interest in animal and human nutrition. It has been reported that these antioxidants can lower the risk of developing cardiovascular disease, certain types of cancer and age-related degenerative processes due to their radical scavenging capacity (STANNER et al., 2004). In order to assess the antioxidative capacity of the various wheat samples, the free radical scavenging capacity was determined and samples were analysed for soluble and total phenolic compounds. For none of these parameters any significant difference was found between wheat samples from the farming systems using fertiliser (Fig. 2A-C). None-fertilised wheat, however, had increased levels of soluble phenolic compounds (Fig. 2C).

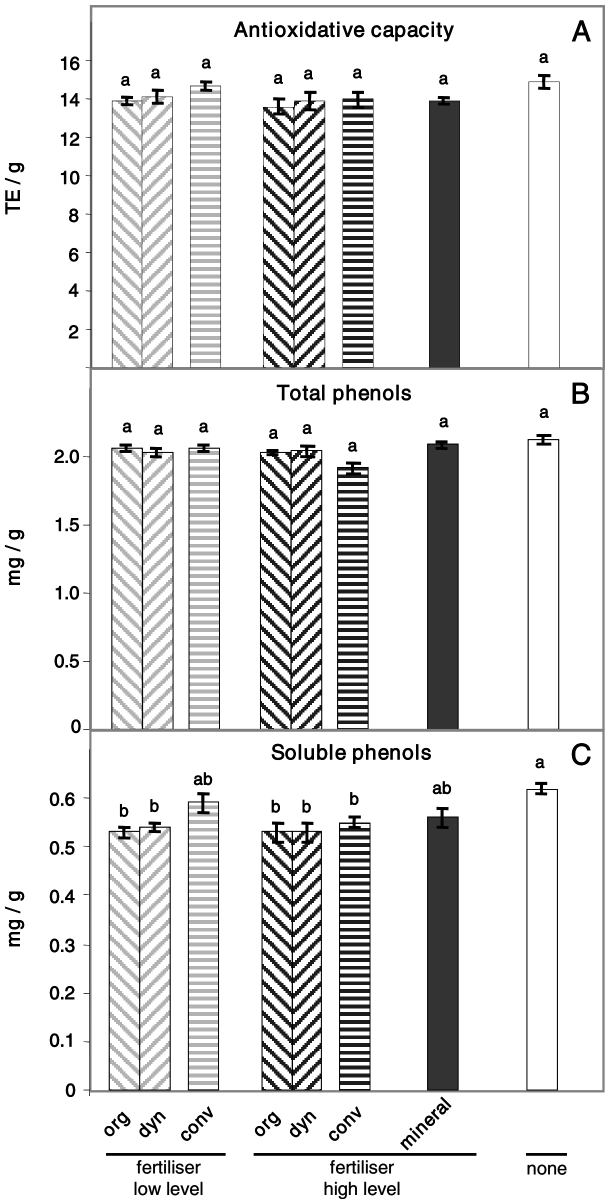

Fig. 2: Antioxidative capacity (**A**), expressed as μmol Trolox equivalents (TE) per g whole wheat meal, levels of total phenols (**B**) and soluble phenols (**C**) in wheat grains grown at different farming conditions in 2003. For details see legend to Fig 1.

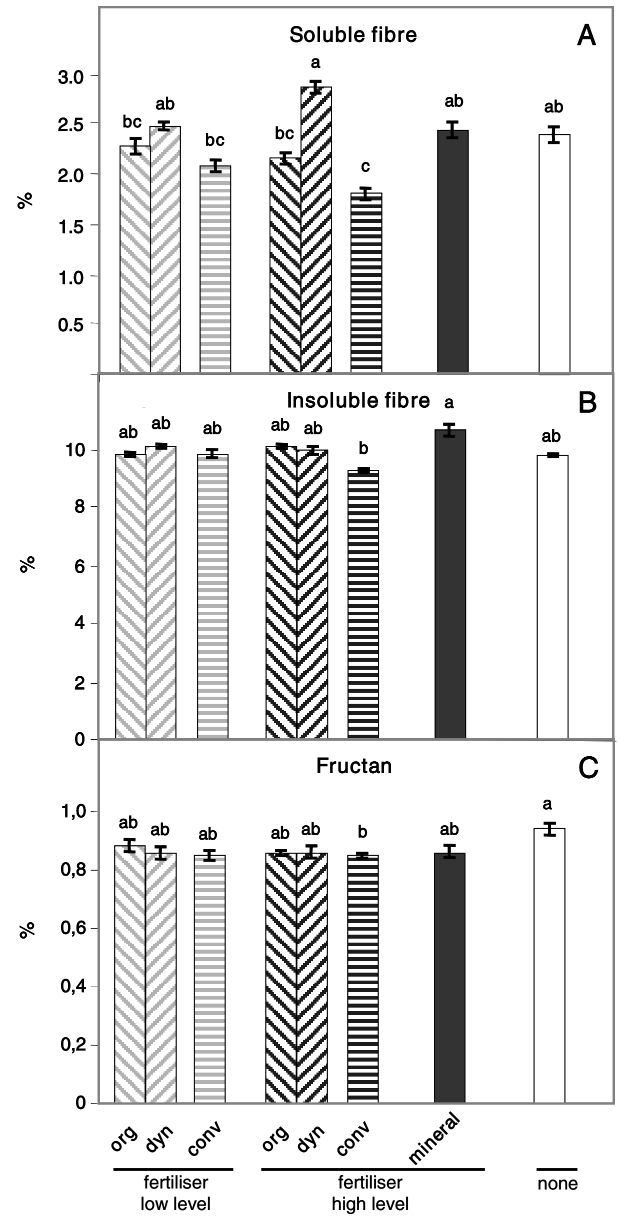

Fig. 3: Levels of soluble fibre (**A**), insoluble fibre (**B**) and fructan (**C**) in wheat grains grown at different farming conditions in 2003. For details see legend to Fig 1.

Antioxidative capacity and phenol levels are considered as indicators for „stress conditions“. The lack of differences in these parameters is considered as evidence that organic agriculture would not induce „stress conditions“ for plants because of possible mal-nutrition.

Dietary fibres comprise mainly carbohydrates that are resistant to human digestion (Asp, 2004). There is increasing evidence from epidemiological studies that dietary fibre intake is health-promotive, in particular with regard to obesity, diabetes, coronary heart disease and certain types of cancer (Miller Jones, 2004). Because of these favourable features, the levels of different components of dietary fibre were determined. It was observed that levels of soluble fibre were elevated in the bio-dynamic system [fertiliser high] and were significantly decreased in the conventional system [fertiliser high] (Fig. 3A). The levels of soluble fibre in the other systems were intermediate (Fig. 3A). Levels of insoluble fibre did not vary to a large extent, but were significantly increased in mineral fertilised wheat versus conventional wheat [fertiliser high] (Fig. 3B). Taken together, no relationship was found between dietary fibre level and farming system, organic versus conventional. Fructan-levels were equal in wheat from organic and conventional farming systems (Fig. 3C). However, fructan was moderately increased in none-fertilised wheat (Fig. 3C), probably indicating a stress condition due to lack of nutrients.

In human and animal nutrition oxalic acid is considered an „undesired compound“, occurring frequently in plant tissues, including cereal grains (Fretzdorff and Betsche, 1998). Health related problems associated with oxalic acid are reaching from irritation of intestinal mucosa caused by oxalate crystals, reduction of the bioavailability of Mg, Ca and Fe, to increasing the risk in development of renal stones for humans who are genetically predisposed (Franceschi

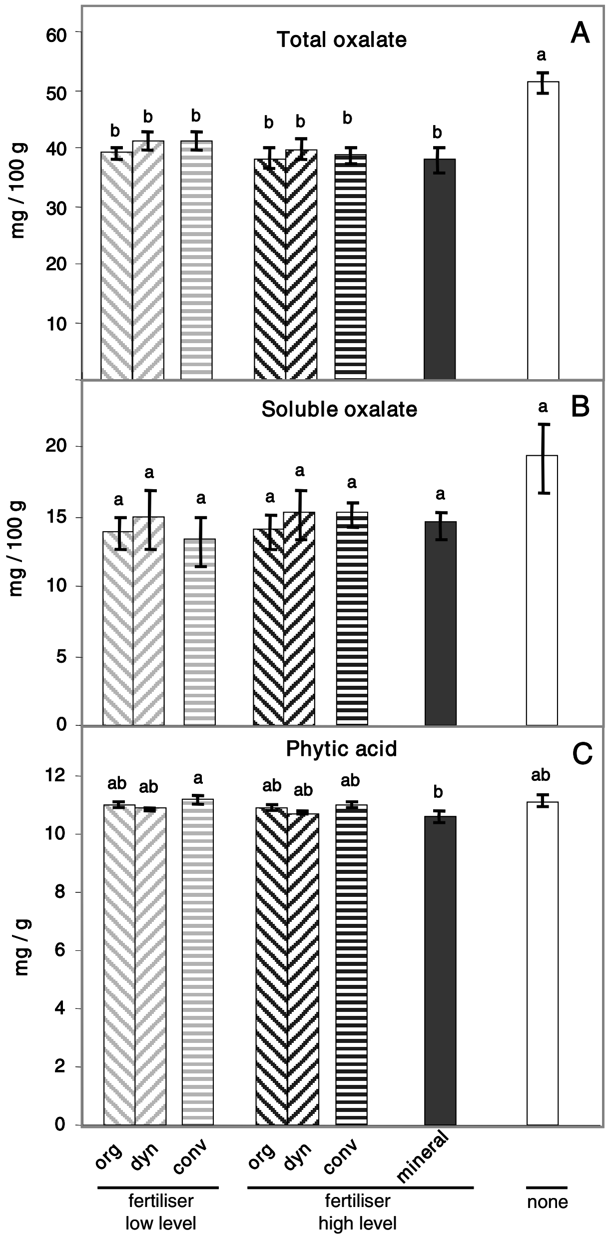

Fig. 4: Levels of total oxalate (**A**), soluble oxalate (**B**) and phytic acid (**C**) in wheat grains grown at different farming conditions in 2003. For details see legend to Fig 1.

and LIBERT, 1987; DUNWELL et al., 2000). Total and soluble oxalate were not significantly different between any of the wheat samples originating from the farming systems using fertiliser (Fig. 4AB). It has been observed that levels of oxalate can vary, in vegetable plants (e. g. FRANCESCHI and LIBERT, 1987) and also in wheat grain (BETSCHE and FRETZDORFF, 1997), with the amount and type of fertiliser applied. Our results show that oxalate is equal in wheat grain from organic and conventional farming systems. This finding further supports the proposal that organic agriculture is not a „stress condition" for wheat in the *DOK* trial. The result that a significantly increased level of total oxalate was detected in none-fertilised wheat (Fig. 4A), is corroborative. Oxalate oxidase activity was determined, but no significant differences in activity were detected between any of the wheat samples (data not shown). Oxalate oxidase activity is correlated with germination and sprouting (e. g. BETSCHE and FRETZDORFF, 2005).

Phytic acid has long been regarded as an anti-nutrient, because it can form complexes with mineral ions rendering them unavailable for intestinal uptake (LOPEZ et al., 2002). However, more recently, also positive effects of phytic acid have been proposed, e. g. a role as an antioxidant through its iron chelating properties (MINIHANE and RIMBACH, 2002) and a function as an anti-cancer substance (SHAMSUDDIN, 2002). In the *DOK* wheat samples, levels of phytic acid did not vary to a large extent between the different farming systems (Fig. 4C).

Conclusion

Thousand seed weight, protein content, phosphate levels, antioxidative capacity, levels of phenols, fibre, fructan, oxalate and phytic acid were determined in whole wheat meal from the various organic and conventional growing systems of the *DOK* trial (2003 harvest). Levels of these substances fell into a range that is known to occur in other wheat crops, indicating that wheat from the *DOK* trial was not special. None-fertilised wheat was different from wheat stemming from either organic or conventional farming systems. There were no significant differences between bio-dynamic, bio-organic, and conventional growing systems for the majority of the nutritionally important substances analysed. All in all, if differences were observed, the magnitude of variations was very small. Taken together, the results do not provide evidence that wheat of one agriculture system or the other would be better or worse.

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