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Quality of organically and conventionally grown potatoes: Four-year study of micronutrients, metals, secondary metabolites, enzymic browning and organoleptic properties

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Abstract
The quality of potatoes from organic and conventional farming was investigated in this study. Tubers of eight potato varieties, organically and conventionally produced at one or two geographical sites in controlled field trials, were collected in four consecutive harvests from 1996–1999. The parameters analysed included nitrate, trace elements (As, Cd, Co, Cu, Fe, Hg, Mn, Ni, Pb, Se, Zn), vitamin C, potato glycoalkaloids, as well as chlorogenic acid, polyphenol oxidase and rate of tuber enzymic browning. The results indicated lower nitrate content and higher vitamin C and chlorogenic acid content to be the parameters most consistently differentiating organically from conventionally produced potatoes. Elevated concentrations of glycoalkaloids were also observed throughout the experiments in some potato varieties grown in organic farming systems. Principal component analysis (PCA) of the analytical and other data using three PCs confirmed a good separation between the organically and conventionally produced potatoes when studied in single crop years. However, score-plots (objects) and loading-plots (variables) of pooled results from the consecutive harvests showed that between the years' changes and also variety as well as geographical variations are equally or more important factors determining the quality of potatoes than the farming system. Further studies of various marker compounds of potato quality related to the organic or conventional farming systems should be performed before unbiased information can be given to the consumers.

Keywords: *Potato, organic farming, conventional farming, quality profiles, PCA analysis*

Introduction

As a part of changing lifestyles in the developed countries, reflected by a pronounced public concern about environmental and personal health issues, organically produced foods are attracting a growing interest both among the scientific community and consumers. In Europe, discussion concerned with Action Plan for Organic Food and Farming has been opened in the recent years (Organic Farming EU website).

In order to be able to make a free and informed choice between organic and conventional foods the consumers need an objective assessment of product quality based on sound scientific knowledge. One of the main arguments, used in the promotion of organic foods, is their presumed beneficial influence on human health (Heaton 2001). Higher quality standards, better taste and greater satisfaction represent other frequent consumers' motives for the purchase of organic products (Bollinger 2001). However, despite internationally well established regulation and control systems exercised at the production level (EU Regulation 1991), there is still a general lack of data on the quality of organic food products related to their nutritional value and health-risk associated properties (Williams 2002; Worthington 1998). The earlier studies by both the proponents and opponents of ecological farming often suffered from serious drawbacks in design, conduct and quality control of the methods used (Heaton 2001; Slanina 1995; Woese et al. 1997). More recent, better controlled experiments comparing the organic and conventional production systems have often shown contradictory results (Malmauret et al. 2002; O'Doherty-Jensen et al. 2001). This may

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be due to a limited number of samples analysed, different varieties of particular crops being compared, short time-span of the experiments and/or geographical/environmental variability.

The parameters studied in this investigation included marker compounds related to the nutritional quality (selected micronutrients – minerals, vitamin C), occurrence of potentially toxic agents (heavy metals, nitrates, total glycoalkaloids), sensory properties of the potatoes and factors related to the rate of fresh tuber enzymic browning (chlorogenic acid, polyphenol oxidase activity). Selected agronomic parameters such as yields, tuber size distribution, germination of tubers as well as starch content and dry weight were also compared. In addition, the influence of storage on the levels of some nutrients and toxic substances in the potatoes from both production systems was investigated. Potato varieties commonly available at Czech markets were selected for the presented study.

The ultimate goal of the project was:

1. To collate data for the assessment of a potential influence of foods from organic production system on consumers' health by studying differences between potatoes grown in both systems (for this purpose the levels of potentially toxic compounds as well as nutritionally valuable components with regard to variety, geographical location and inter-annual variation were determined);
2. To identify other chemical and agronomic quality markers of organically produced potatoes;
3. To compare overall quality profiles of organically and conventionally produced potatoes using the principal component analysis.

Materials and methods

Farming sites

Two separate geographic localities L1 – Jindřichův Hradec – Rodvínov (South-east Bohemia, altitude 520 m) and L2 – Vodňany – Budyně (Southern Bohemia, altitude 540 m) were chosen for the field trials. Conditions in these localities are typical for growing potatoes in the Czech Republic. Climate parameters (mean air temperature, rainfall) during the growing seasons 1996–1999 are given in Table I.

Table I. Climatic conditions at the experimental localities during the growing seasons 1996–1999 (aggregated data, April–September): mean temperatures (°C) and mean precipitations (mm).

Year	1996		1997		1998		1999	
Locality	°C	mm	°C	mm	°C	mm	°C	mm
L1	12.8	77.9	13.0	70.6	13.9	69.9	14.3	61.0
L2	13.2	68.2	13.9	65.7	14.7	61.1	–	–

L1 – Locality Jindrichuv Hradec-Rodvinov; L2 – Locality Vodnany-Radyne.

At each locality two farms were available, one with an organic and the other one with a conventional production. Plots for planting of individual potato varieties were randomized within each farm. The farms with (certified) organic production were converted to this way of farming more than three years before the start of trial. All the production practices including crop rotation (potato crop was always followed by at least one year of cereals production), exclusive use of organic farmyard manure and avoidance of synthetic pesticides were in compliance with the basic standards of International Federation of Organic Agriculture Movements (IFOAM, http://www.ifoam.org) for organic production.

In both localities 40–45 t ha^{-1} of manure were used as fertilizer in the organic system. In the conventional systems, in addition to common manure, the following mineral fertilizers (total amount in the range from 35–40 t ha^{-1}) were used in both experimental localities and all crop years: mineral N (cca 100 kg ha^{-1}), P (15–50 kg ha^{-1}) and K (33–180 kg ha^{-1}). Pesticide preparations applied in conventional production in accordance with the principles of good agriculture practice (GAP) contained a wide range of active ingredients, for example, in Locality 1 herbicides such as metobromuron, clomazone, diquat, and fungicides mancozeb, cymoxanil, dimethomorph, fentin, maneb, metiram, metalaxyl were used for crop protection.

In Locality 2, fungicides such as cymoxanil, mancozeb, maneb, fentin, and insecticide lambda-cyhalotrin were used for the field treatments. The application rates were in compliance with label recommendations. The two types of farms (with trial plots for the organic or conventional cultivation) at each locality were situated close to each other (approx. 500 m) and had a similar type of sandy-clay brown soil. The soil pH values were 6.4–6.6 and 6.5–6.7 in L1 and L2, respectively. No major pollution sources such as waste dump or heavy traffic (highways) were in the vicinity of the experimental fields. Locality L1 is situated approx. 5 km from Jindrichuv Hradec (population 25 000) and approx. 1 km from the nearest main road. Locality L2 is situated approx. 5 km from Bavorov (population 7000) and approx. 0.5 km from the nearest road.

Test material

Eight common potato (*Solanum tuberosum* L.) varieties *Christa* (CHR), *Koruna* (KOR), *Krystala*

(KRY), *Rosara* (ROS) (very early maturing), *Krasa* (KSA) and *Monalisa* (MON) (both early maturing), and *Karin* (KAR) and *Rosella* (REL) (both semi-early maturing) were grown in each cultivation system. While the planting and harvesting (at the stage of physiological maturity) of potatoes were carried out manually, furrowing and hilling of the experimental fields were conducted mechanically. The amount of potato plantlets was the same for organic and conventional plots. Regarding the phytosanitary aspects, no serious fungal infections and/or insect attacks occurred during experimental growing seasons. Three varieties *Krystala, Monalisa* and *Rosara* were sampled for examination at four consecutive harvests in 1996–1999 from both localities with the exception of the crop year 1999 when potatoes were harvested only in L1. The other five varieties *Christa, Karin, Koruna, Krasa* and *Rosella* were harvested in all crop years from both cultivation systems at locality L1 only. The harvest of matured tubers occurred for each counterpart (organic-conventional variety) on the same day.

Sampling and sample preparation

Potatoes. Sampling of matured tubers was performed by personnel from the University of South Bohemia, Agricultural Faculty, České Budějovice, Czech Republic. Randomized primary samples (approx. 10 kg of each particular variety) were collected from each plot. Samples were carefully inspected and any damaged or green tuber was discarded. Remaining tubers defined the primary sample and were on the basis of individual weight divided into three groups according to the size (<4 cm: T4, 4–6 cm: T6 and >6 cm: U6). The primary samples were then further divided into smaller sub-samples (2 kg). The size distribution of individual tubers within each sub-sample was carefully adjusted to reflect the primary sample. The sub-samples were stored (max. 7 days) in refrigerator at 4°C. In the next step, the tubers from each sub-sample were washed in tap water and then quartered by stainless knife. The homogenate prepared from pooled quarters (one quarter from each tuber) was divided into 200 g aliquots and either immediately analysed or freeze-dried and stored until the analysis. Some parameters such as vitamin C, chlorogenic acid content and/or enzymic browning of tubers were always measured in fresh sample. For analysis of trace metals, the homogenate was prepared in the same way from peeled tubers (approximately 1 mm surface layer removed by plastic knife). Remaining tubers representing sub-samples prepared from the primary sample by procedure described above were stored in a dark room in which constant humidity and a temperature (6–8°C) were held. After 4–5 months of storage, determination of vitamin C, glycoalkaloids and chlorogenic acid was again carried out to characterize potential changes in the content of these constituents.

Soils. A composite sample of 2 kg was taken from several spots (soil layer in the depth range 1–20 cm sampled) at each experimental site. The lumps were crushed using a quartz roller and then sieved (2 mm meshes) to remove stones and plant debris. The samples were stored after air drying at laboratory temperature.

Agronomic parameters. The information on the potatoes yield (YI), content of starch (ST) and dry weight (DM) of tubers was provided by partner responsible for field experiments.

Chemical analyses

Trace elements (TE). Homogenate prepared from peeled potatoes (3 g) were digested using microwave high pressure digestion technique (3 ml of 65% HNO_3 and 1 ml of 30% H_2O_2 added to sample). Dried soil (5 g) was extracted by shaking with 50 ml of HNO_3 (2 mol/l). The extract was centrifuged and the supernatant (1 ml) was then decomposed in a microwave digestion unit (BM1-S, Pharmatronika, Poland). Digestion was effected by 10 min heating (max. power 280 W per vessel, max. pressure 2.5 MPa). After cooling, the mineralizate was transferred into a calibrated flask and made up to 50 ml with deionized water. The content of target metals was determined by ICP-MS technique (ICP – mass spectrometer Elan 6000, Perkin-Elmer, equipped with cross-flow nebulizer, USA). Sample digests were diluted and spiked with internal standards (In and Bi 100 μg/l). Intensities of ^{55}Mn, ^{57}Fe, ^{59}Co, ^{58}Ni, ^{60}Ni, ^{62}Ni, ^{65}Cu, ^{66}Zn, ^{75}As, ^{77}Se, ^{82}Se, ^{111}Cd, ^{114}Cd, ^{115}In, ^{206}Pb, ^{207}Pb, ^{208}Pb and ^{209}Bi were measured using "peak hopping" mode. The applied reference power was 1000 W, the value of nebulizer argon flow was daily optimized and ranged from 0.70–0.85 l/min. Mercury was determined without preliminary sample decomposition by amalgamation flameless atomic absorption spectrometry using mercury analyser AMA 254 (Altec, Prague, Czech Republic).

The relative standard deviation (RSD) of the above method ranged from 2% to 8% for individual analytes. The limits of detection (LODs) were 0.002 mg/kg for As, 0.001 mg/kg for Cd, 0.0005 mg/kg for Co, 0.015 mg/kg for Cu, 0.15 mg/kg for Fe, 0.07 mg/kg for Mn, 0.02 mg/kg for Ni, 0.02 mg/kg for Se, 0.07 mg/kg for Zn, 0.002 mg/kg for Pb and 0.002 mg/kg for Hg.

Nitrates (NO). 10 g of homogenized potato sample or 10 g of soil sample were extracted with 100 ml of distilled water, and after removing solid particles by filtration, nitrates (expressed as $NaNO_3$) were determined by capillary zone electrophoresis (CZE, EA 100, Villa-Labeco, Czech Republic) with conductivity detection. The mixture of 7 mM-succinic acid, 0.4 mM-BisTrisPropan, 5% polyvinylpyrrolidone and 0.1% hydroxypropylmethyl celulose was used as supporting electrolyte (pH 3.85); propulsive current was 25 µA. RSD of the method was 1.5%, the recovery 95% and the LOD (expressed as $NaNO_3$) 2.5 mg $NaNO_3$/kg.

Total glycoalkaloids (TGA) – α-solanine (SO) and α-chaconine (CA). Samples of 30 g potato were extracted with 200 ml of methanol. 5 ml aliquot (i. e., 0.75 g of original matrix) obtained by filtration of a crude extract through microfilter was diluted with 10 ml of deionized water and then 5 ml aliquot was purified by solid phase extraction (SPE) using reversed phase C18 cartridge (Supelclean™ LC-18, 500 mg column, Supelco). An automated SPE instrument (Aspec XL, Gilson, France) was employed for this purpose. Prior to the use the cartridge was conditioned with 10 ml of methanol and 10 ml of water. After sample loading some co-extracts were washed out with 5 ml 40% (v/v) methanol, solanine glycoalkaloids were then eluted with 15 ml of methanol. The residue, after evaporation of the solvent, was dissolved in 1 ml of mobile phase, analytes were determined in 20 µl aliquot by HPLC/UV (HP 1100, Hewlett-Packard HPLC, USA, instrument, equipped with DAD detector, set at 208 nm). The amino silica column (Merck, Germany) LiChroCART (250 × 4 mm), LiChrospher 100 NH_2 (5 µm) with precolumn (Merck, Germany) LiChroCART (4 × 4 mm), LiChrospher 100 NH_2 (5 µm) was used for HPLC separation. Acetonitrile – 0.02 M KH_2PO_4 mixture (75:25, v/v) was used as mobile phase with a flow rate of 1 ml/min. RSD of the method was 2%, the recovery 95% and the LOD 3 mg/kg for α-chaconine and 5 mg/kg for α-solanine, respectively.

Vitamin C – ascorbic acid (AA). A sample of 50 g fresh potato was homogenized in 200 ml 2.5% metaphosphoric acid. The ascorbic acid content in this extract was determined by HPLC (HP 1100, Hewlett-Packard, equipped with DAD detector, USA) at UV 254 nm. A reversed phase octadecylsilica column (Merck, Germany) LiChroCART (250 × 4 mm), LiChrospher 100 RP-18 (5 µm) with precolumn (Merck, Germany) LiChroCART (4 × 4 mm), LiChrospher 100 RP-18 (5 µm) was used for HPLC separation. The mobile phase was 2% $(NH_4)H_2PO_4$ (pH 2.5), the flow rate was 1 ml/min. RSD of the method was 5%, recovery 95% and LOD 0.5 mg/kg.

Chlorogenic acid (CH). 30 g of fresh potato sample were homogenized in 200 ml of methanol, and after filtration of the crude extract, chlorogenic acid was determined by HPLC (HP 1100, Hewlett-Packard, equipped with DAD detector, USA) using UV detection at 324 nm. The reversed phase column (Merck, Germany) LiChroCART (250 × 4 mm), LiChrospher 100 RP-18 (5 µm) with precolumn (Merck, Germany) LiChroCART (4 × 4 mm), LiChrospher 100 RP-18 (5 µm) was used for HPLC separation. The mobile phase was: A – 80% methanol, B – 2% acetic acid (linear gradient A: 5 – 50%, 20 min), the flow rate was 0.6 ml/min. RSD of method was 5%, recovery 96% and LOD 5 mg/kg.

Activity of enzymes responsible for enzymic browning – polyphenol oxidase (PPO). 30 g of fresh potato sample were homogenized in 100 ml of phosphate buffer (pH 6.8–6.9); 0.5 g of ascorbic acid was added and the volume of solution was made to 1000 ml with distilled water 1 g of N-polyvinyl pyrrolidone (BASF, Germany) was added to a 20 ml aliquot and after 5 minutes of shaking the sample was centrifuged (9000 × *g*). The activity of the polyphenol oxidase enzyme was determined in the supernatant by means of Clark-type oxygen sensor (Chemoprojekt, Czech Republic). The measured rate of electric current decrease (measured in nA), indicating the drop of oxygen in medium, was proportional to PPO content.

The rate of enzymic browning of fresh potatoes (RE). Peeled fresh potatoes were homogenized and the rate of enzymic browning was determined by comparing the colour of the homogenate with a colour scale after 30 and 120 min. Quantification of the browning rate was carried out by estimating the difference in colour intensity between the two points in time 0 and after 2 hours. Colour table for "determination of coloration of potato pulp" provided by Institute for Plant Production, Braunschweig-Vőlkenrode (Germany) was used for this purpose.

Sensory evaluation (SE)

Profile of cooked tubers. Ten representative tubers from each sub-sample were washed, boiled in steam for 20 min and after the skin had been removed immediately evaluated by a panel. Sensory analysis

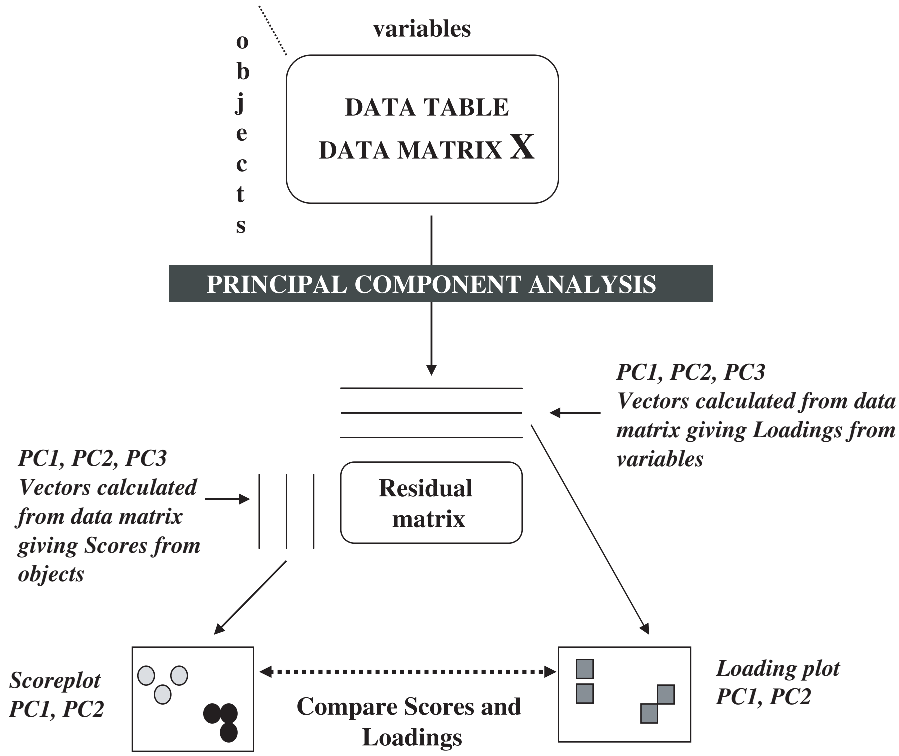

Figure 1. Scheme of Principal Component Analysis applied for data evaluation.

was carried out according to relevant standard (ISO 6658 1985) in a laboratory equipped with six booths (ISO 8589 1988). The members of the evaluation panel were specialists trained in sensory analysis. The following parameters were assessed: Appearance of cut tubers (AP), surface colour (CS), odour acceptability (OA), overall taste (OT), effort in swallowing (ES), consistence (CT), flouriness (FL), cookability (CK), moisture (MO) and overall texture (TX) of potatoes. The descriptors were evaluated according to the intensity, using the non-structured graphic scale (length 100 mm) described in respective standard (ISO 4121 1987).

Statistical methods

Univariate comparisons of mean differences between the two farming methods were conducted using Student's *t*-test. For further evaluations of the results multivariate data analysis and principal component analysis based on stepwise discriminant analysis were used.

Principal component analysis (PCA). Principal component analysis based on projection of a matrix X to a few latent variables, was performed using program SIRIUS 6.5 (PRS, Bergen Norway), the scheme is shown in Figure 1. The raw data were pre-treated by the commonly used techniques "Standardize" and "Block Normalize" before the calculation of the principle components. A total of 22 objects (eight potato varieties in L1 and three in L2, two types of farms) were used in the PCA evaluation. In all tests a probability of $p \leq 0.05$ was accepted as significant.

Standardize technique. PCA/PLS is a least-squares method and therefore variables with large variance tend to dominate the first components. Systematic variance in variables with small variables is often masked in such cases. Standardization multiplies each variable with the inverse of its standard deviation. Thus, every variable has variance equal to one after this weighting. This technique is also known as auto-scaling.

Block Normalize technique. This is a procedure for making the size of the objects comparable. The variables within a block are divided by their sum, so that the objects sum to 1.

Results

Agricultural

Compared to the conventional production, organic potatoes tended to give lower yields (approx. 50%) and smaller tubers (sub-samples obtained by procedure described above contained typically two times more tubers with diameter <4 cm). The majority of potato varieties showed (considering aggregated

Table II. Selected agricultural parameters (mean values ± standard deviation) of organically (org) and conventionally (conv) grown potatoes averaged over all test years and both localities (aggregated data).

Production system (no. of samples, *n*)	Starch (%)	Dry weight (%)	Yields t/ha	Size distribution (%)		
				<4 cm	4–6 cm	>6 cm
Org ($n=41$)	13.5 ± 1.3	20.1 ± 1.4	22.9 ± 12.3	28.9 ± 23.3	58.2 ± 16.8	12.9 ± 16.8
Conv ($n=41$)	12.5 ± 2.8	19.0 ± 2.0	45.0 ± 26.4	13.2 ± 11.9	61.2 ± 19.4	25.5 ± 22.1

data) a higher dry weight (20.1% vs 19.0%) and increased starch content (13.5% vs 12.5%) when produced by organic farming as compared to conventional one, respectively, see Table II. The difference between the two production systems (comparison of the means, all varieties considered) was statistically significant regardless of where (the location) and in which year the potatoes were grown (*t*-test, $\alpha = 0.05$). The germination rate of potatoes, on the other hand, was similar in both production systems (data not shown).

Analytical examination of tubers

Trace elements. Among trace elements only Cu and Ni elevations in the organic potatoes were found out but these differences were statistically significant (*t*-test, $\alpha = 0.05$) in both localities only in crop year 1996. Variations related to the variety were, with the exception of Zn, rather small (not shown). In addition to the seven trace elements shown in Table III, the samples were also analysed for arsenic (As), selenium (Se), lead (Pb) and mercury (Hg). The levels of As were generally below LOD (2 µg/kg) in potatoes from the L1 locality, whereas quantifiable levels of this toxic element were found in both organically and conventionally produced potatoes from L2 (17.6 µg/kg and 16.0 µg/kg, respectively). The levels of Se were below LOD (1 µg/kg) in the majority of samples from both localities. The content of Pb and Hg did not exceed the LOD (2 µg/kg) of the analytical method in any potato sample.

Nitrates. Tubers from the conventional farming system in most cases contained higher levels of nitrate as compared to potatoes from the organic production (Table IV). This trend was observed in potatoes grown at both localities in all experimental seasons with the exception of the year 1996 when slightly higher mean levels of nitrates were found in the organically produced crop at the L2 locality. Overall, the differences between the two production systems shown in Table IV were statistically significant in crop years 1996–1998 at locality L1 (*t*-test, $\alpha = 0.05$).

The nitrate levels in potatoes were partly dependent on variety. The cultivars *Rosella* and *Monalisa* typically contained the lowest levels of nitrate, whereas *Rosara*, *Krasa* and *Krystala* exhibited the highest contents. Although in most cases, and in accordance with the general trend mentioned above, nitrates were lower in organic potatoes, exceptions were observed in some crop years as illustrated by the variety *Rosella* in Figure 2.

Total glycoalkaloids. The variation in total glycoalkaloids content (sum of major components represented by α-solanine and α-chaconine) between tubers obtained from the farms using the two alternative production systems were more complex. The mean total glycoalkaloids content seemed to be slightly higher in the organic tubers (80.8 ± 44.5 mg/kg, all varieties pooled together) than in conventional ones (58.5 ± 44.1 mg/kg). However, the total glycoalkaloid levels varied considerably from variety to variety. The total glycoalkaloids content in the organically produced potatoes ranged between 16 and 157 mg/kg fresh weight at L1 and between 47 and 97 mg/kg at L2. The conventionally grown tubers contained between 15 and 245 mg/kg at locality L1 and between 34 and 108 mg/kg at locality L2, respectively (details not shown). In addition to the cultivar-dependent range of TGA content of tubers, there were pronounced inter-annual, locality related variations (compare L1 and L2 in Figure 3). As a consequence, no clear-cut differences in TGA content in tubers produced by the two farming systems could be identified. However, the variety *Rosara* showed throughout the experiments at both localities significantly (*t*-test, $\alpha = 0.05$) higher levels of total glycoalkaloids when grown organically. A similar trend was observed with *Rosella* and *Monalisa* but only at locality L1 and L2, respectively (see Figure 3).

No statistically significant changes in total glycoalkaloid levels between the freshly harvested and stored tubers could be detected. It should be also noted that the differences observed in the levels of total glycoalkaloids between the two production systems after storage varied between individual varieties.

Vitamin C (ascorbic acid). As shown in Table IV, the vitamin C content tended to be higher in potatoes

Table III. Trace elements (mean contents in fresh weight ± standard deviation, SD) in potatoes from conventional (conv) and organic (org) farming system (aggregated data).

		Mg (mg/kg ± SD)		Fe (mg/kg ± SD)		Co (μg/kg ± SD)		Ni (μg/kg ± SD)		Cu (mg/kg ± SD)		Zn (mg/kg ± SD)		Cd (μg/kg ± SD)	
Production system	Crop year	L1 ($n=8$)	L2 ($n=3$)	L1 ($n=8$)	L2 ($n=3$)	L1 ($n=8$)	L2 ($n=3$)	L1 ($n=8$)	L2 ($n=3$)	L1 ($n=8$)	L2 ($n=3$)	L1 ($n=8$)	L2 ($n=3$)	L1 ($n=8$)	L2 ($n=3$)
Org	1996	1.8 ± 0.2	1.6 ± 0.1	3.7 ± 0.5	4.5 ± 0.2	4.3 ± 0.9	13.1 ± 4.5	40.6 ± 19.8	132.7 ± 78.0	1.0 ± 0.1	1.3 ± 0.1	3.7 ± 0.9	3.7 ± 0.2	18.4 ± 8.7	8.3 ± 1.4
Org	1997	1.6 ± 0.8	1.6 ± 0.1	9.7 ± 1.5	11.8 ± 2.8	8.8 ± 2.8	53.7 ± 19.6	77.8 ± 17.0	185.7 ± 18.7	0.9 ± 0.3	0.8 ± 0.1	2.6 ± 0.7	2.9 ± 0.4	22.7 ± 6.3	20.4 ± 6.3
Org	1998	1.3 ± 0.2	1.5 ± 0.1	4.3 ± 3.6	3.8 ± 0.1	9.3 ± 3.1	17.3 ± 5.7	19.9 ± 13.1	126.3 ± 27.7	0.4 ± 0.1	0.6 ± 0.2	1.5 ± 0.2	2.4 ± 0.2	17.0 ± 5.0	24.3 ± 5.5
Org	1996–1998	1.6 ± 0.5	1.6 ± 0.1	5.9 ± 3.5	6.7 ± 4.1	7.4 ± 3.3	28.1 ± 22.0	46.1 ± 29.3	148.2 ± 50.9	0.8 ± 0.3	0.9 ± 0.3	2.6 ± 1.1	3.0 ± 0.6	19.4 ± 7.0	17.7 ± 8.4
Conv	1996	1.3 ± 0.2	1.1 ± 0.1	3.4 ± 0.4	3.8 ± 0.5	4.0 ± 2.0	4.4 ± 2.3	9.0 ± 8.5	34.7 ± 28.5	0.4 ± 0.1	0.4 ± 0.1	2.4 ± 0.6	2.8 ± 0.7	21.4 ± 11.2	19.3 ± 6.8
Conv	1997	1.8 ± 0.4	1.4 ± 0.2	13.0 ± 2.5	10.7 ± 1.3	20.5 ± 9.3	147.0 ± 41.8	87.8 ± 26.1	130.3 ± 14.8	0.8 ± 0.3	0.6 ± 0.6	3.2 ± 0.8	2.6 ± 0.4	20.4 ± 11.3	25.2 ± 3.7
Conv	1998	2.5 ± 1.3	1.3 ± 0.3	3.4 ± 0.8	4.6 ± 0.9	6.4 ± 2.3	12.3 ± 4.5	16.4 ± 12.1	122.7 ± 43.8	0.5 ± 0.2	0.5 ± 0.2	2.4 ± 0.7	2.6 ± 0.1	18.1 ± 1.7	28.6 ± 8.7
Conv	1996–1998	1.9 ± 0.9	1.3 ± 0.2	6.6 ± 4.8	6.4 ± 3.4	10.3 ± 9.2	54.6 ± 72.6	37.7 ± 39.9	95.9 ± 53.4	0.6 ± 0.3	0.5 ± 0.1	2.7 ± 0.8	2.7 ± 0.4	20.0 ± 8.9	24.4 ± 7.1

L1 – Locality Jindrichuv Hradec-Rodvinov; L2 – Locality Vodnany-Radyne; *n* – Number of examined varieties.

Table IV. Nitrate (NO), ascorbic acid (AA), chlorogenic acid (CH) and total glycoalkaloids (TGA) (mean values in fresh weight ± standard deviation, SD) in organically (org) and conventionally (conv) grown potatoes (aggregated data – all studied varieties in particular crop year involved).

Production system	Crop year	NO (mg/kg ± SD)		AA (mg/kg ± SD)		CH (mg/kg ± SD)		TGA (mg/kg ± SD)	
		L1 ($n = 8$)	L2 ($n = 3$)	L1 ($n = 8$)	L2 ($n = 3$)	L1 ($n = 8$)	L2 ($n = 3$)	L1 ($n = 8$)	L2 ($n = 3$)
Org	1996	81.2 ± 59.9	148.9 ± 55.7	69.5 ± 28.6	86.2 ± 14.6	114.1 ± 44.2	72.9 ± 13.9	98.0 ± 58.3	79.9 ± 13.9
Org	1997	102.4 ± 53.3	91.4 ± 33.6	100.8 ± 24.1	105.6 ± 14.5	234.1 ± 113.4	173.3 ± 75.0	118.3 ± 39.1	89.1 ± 12.7
Org	1998	72.2 ± 27.7	60.0 ± 21.3	70.1 ± 19.0	124.2 ± 67.9	249.8 ± 147.1	230.9 ± 92.6	65.5 ± 37.3	67.3 ± 17.6
Org	1999	374.2 ± 126.7	n.a.	118.1 ± 27.6	n.a.	232.5 ± 86.0	n.a.	37.5 ± 22.9	n.a.
Org	1996–1999*	157.5 ± 146.7	100.1 ± 51.9	89.6 ± 31.9	105.4 ± 39.1	207.6 ±113.8	159.0 ±91.6	81.4 ± 49.9	78.8 ± 16.0
Conv	1996	171.9 ± 53.6	123.3 ± 48.6	61.6 ± 22.6	70.8 ± 30.1	68.6 ± 37.8	92.8 ± 23.5	82.5 ± 69.3	67.4 ± 36.8
Conv	1997	188.1 ± 105.0	250.4 ± 128.4	105.3 ± 20.2	89.0 ± 9.3	183.4 ± 78.0	157.9 ± 92.1	89.8 ± 42.9	50.1 ± 17.4
Conv	1998	175.4 ± 73.2	107.0 ± 33.0	85.3 ± 28.9	82.9 ± 21.8	182.9 ± 75.8	116.5 ± 70.0	37.5 ± 22.9	37.2 ± 2.7
Conv	1999	465.7 ± 250.3	n.a.	132.5 ± 29.3	n.a.	139.8 ± 70.3	n.a.	32.0 ± 11.7	n.a.
Conv	1996–1999*	250.3 ± 185.7	160.3 ± 98.0	96.2 ± 35.9	80.9 ±20.8	143.7 ±79.8	122.4 ± 65.6	60.5 ± 48.4	51.5 ± 24.3

L1 – Locality Jindrichuv Hradec-Rodvinov; L2 – Locality Vodnany-Radyne; *n* – Number of examined varieties; n.a. – Not analysed; *L2 1996–1998 only.

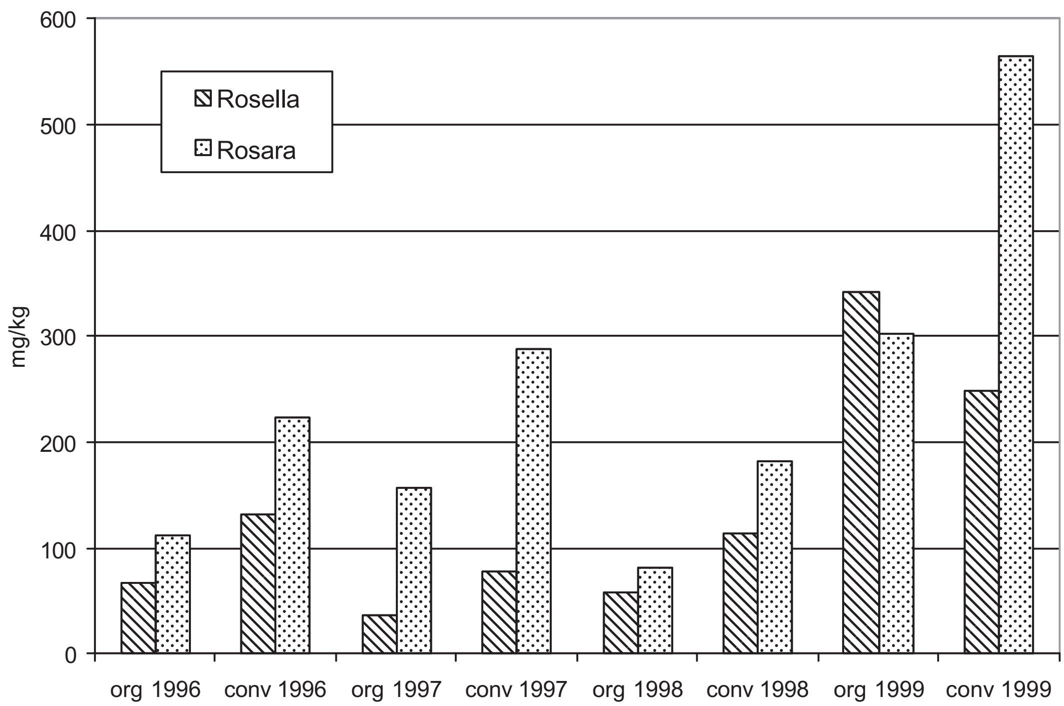

Figure 2. Nitrate concentrations (in fresh weight) in organic (org) and conventional (conv) potatoes – varieties Rosella and Rosara grown at locality L1 during four consecutive crop years.

from the organic farming at locality L2 but with the exception of the year 1998, the differences observed in our study were not statistically significant. There was a substantial variation in vitamin C content between individual varieties with *Krasa* showing a typically low content of vitamin C (64.8 ± 32.6 mg/kg – aggregated data) and *Karin* and *Krista* displaying in most cases high contents of this nutritionally important component (114.5 ± 28.8 mg/kg and 104.2 ± 37.5 mg/kg, respectively – detailed data not shown). Although there was an appreciable decrease in vitamin C content in tubers after five months of storage (ranging from 39–48% for years 1996–1998), no significant difference in the dynamics of ascorbic acid levels related to the cultivation system could be identified.

Enzymic browning, chlorogenic acid, polyphenol oxidase activity. Organically produced tubers contained higher levels of chlorogenic acid (208 ± 114 mg/kg and 159 ± 92 mg/kg fresh weight in L1 and L2

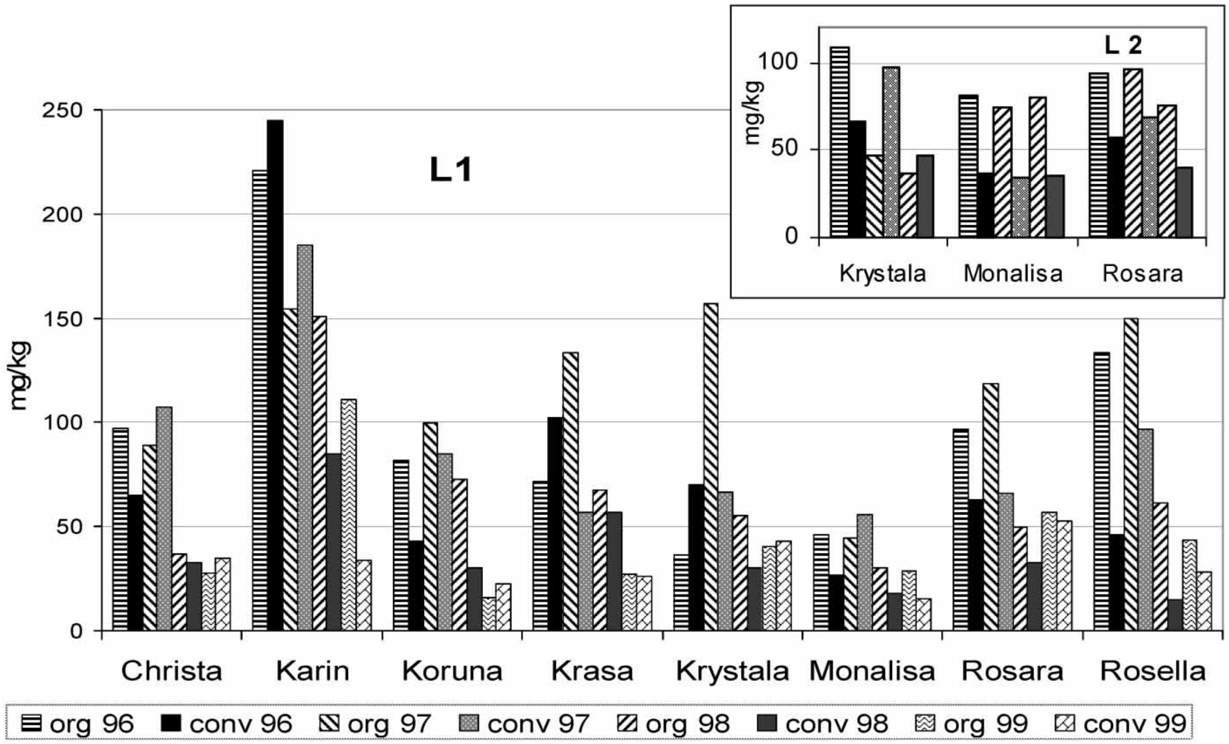

Figure 3. Total glycoalkaloid concentrations (in fresh weight) in tested potato varieties produced in organic (org) or conventional (conv) farming systems at localities L1 and L2 (only those varieties grown at the latter locality displaying apparent dependence on the production system are shown here).

respectively) as compared to tubers from conventional farms (144 ± 80 mg/kg and 122 ± 66 mg/kg in L1 and L2 respectively) (see Table IV). The differences were statistically significant (*t*-test, $\alpha = 0.05$) for all the varieties and in all the crop years with exception of *Monalisa* and *Krista*. Chlorogenic acid content largely varied between the varieties studied. Low levels were e.g., seen in *Krystala* while in *Karin* the chlorogenic acid concentrations were relatively high (results not shown). In all the crop years, there was approximately 30% decrease in chlorogenic acid content during storage of tubers for five months but no significant difference related to the cultivation system was detected. No statistically significant differences in polyphenol oxidase activity were found between the potatoes from organic and conventional farming (results not shown). The rate of enzymic browning was either not statistically significant.

Organoleptic properties. The differences in organoleptic properties of potatoes from the two farming systems were not statistically significant. There were recognized variety-related differences in the set of evaluated parameters of the potatoes involved in this study. The organically produced varieties *Krasa* and *Rosara* scored better in the majority of the tested features, while *Koruna* and *Krystala* from the organic farming scored poorly in the most of tests performed.

Trace elements and nitrates in soils. Trace elements in soil showed a relatively uniform distribution at both localities when soils from conventional and organic farms were compared in single crop years (Table V). One exception was As which was measured at very high levels in soil from locality L2 in 1996.

Some variations in nitrate soil content were observed between the two farming systems (e.g., at locality L2 in 1997), higher content of nitrates was found (see Table V) in soils sampled in conventional fields (with the exception of L1, year 1997). At locality L1 no distinct differences were observed, but there was a conspicuous elevation of the soil nitrates detected in 1999 as compared to the other crop years.

Principal component analysis

Chemical components and agricultural parameters – single crops (years). Principal component analysis (PCA) was based on a sample set comprising agricultural parameters and analytical results from all the 22 samples-objects of eight potato varieties. All parameters studied except year, locality, cultivation

Table V. Nitrates and trace elements in soils collected in experimental localities in which organic (org) and conventional (conv) potatoes were grown.

Production system	Crop year	Locality	NO (mg/kg)	As (mg/kg)	Cd (μg/kg)	Co (μg/kg)	Cu (mg/kg)	Fe (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Ni (μg/kg)	Se (mg/kg)	Zn (mg/kg)	Pb (μg/kg)
Org	1996	1	26.6	1.6	0.2	4.3	8.1	4106	0.163	519	0.5	0.1	34.5	19.4
Conv	1996	1	27.9	0.7	0.1	1.5	3.9	2833	0.050	252	0.5	0.1	16.7	8.0
Org	1997	1	89.0	0.7	0.1	1.1	3.4	2262	0.005	150	1.4	0.3	9.1	n.a.
Conv	1997	1	65.7	0.8	0.3	2.7	3.3	2972	0.005	597	1.1	0.3	14.3	n.a.
Org	1999	1	253.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Conv	1999	1	310.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Org	1996	2	39.9	41.3	0.1	8.0	4.4	6510	0.075	414	11.1	0.1	26.1	17.2
Conv	1996	2	59.1	88.0	0.2	4.3	4.7	3240	0.084	432	4.6	0.1	30.5	19.6
Org	1997	2	75.8	13.1	0.2	4.4	3.6	5437	0.005	408	6.8	0.8	13.7	n.a.
Conv	1997	2	307.4	1.1	0.1	4.2	3.4	1679	0.005	211	2.7	0.3	15.6	n.a.

L1 – Locality Jindrichuv Hradec-Rodvinov; L2 – Locality Vodnany-Radyne; n.a. – not analysed.

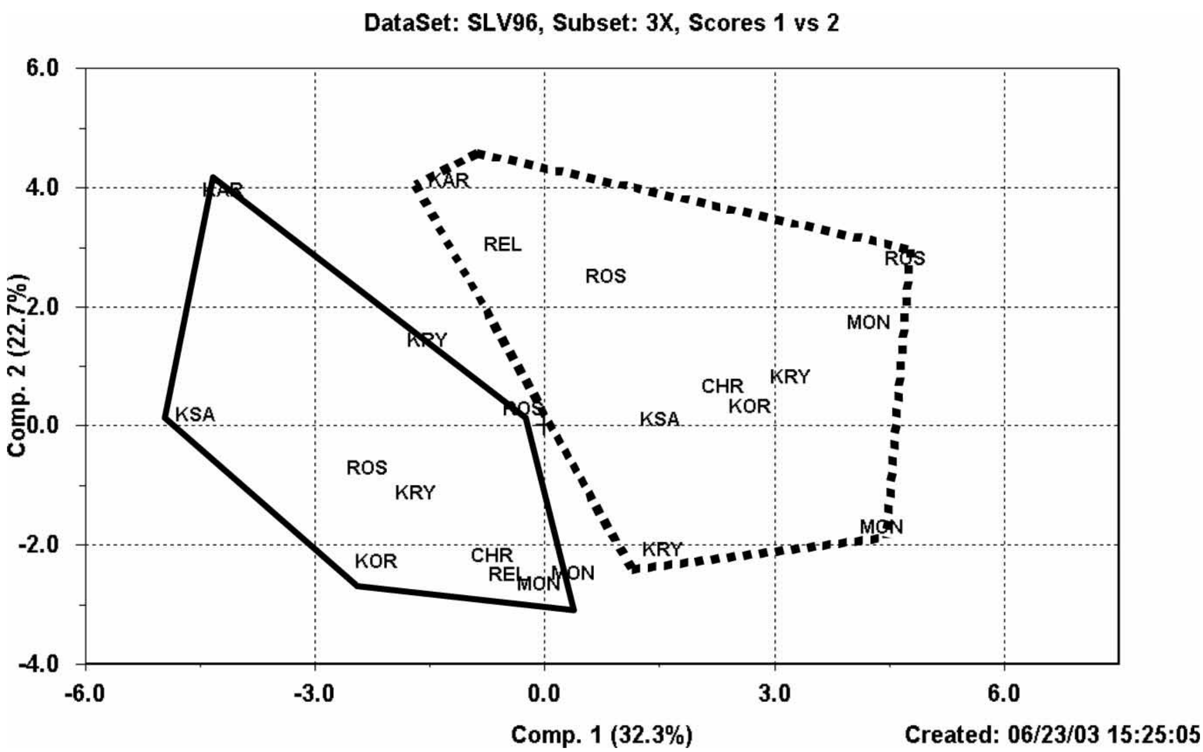

Figure 4a. Scoreplot of data obtained by examination of potatoes grown in the year 1996; PC1 (32%) is plotted against PC2 (22%). All the 22 objects from 1996 and following variables: ST, DM, T4, T6, U6, YI, NO, CA, SO, TGA, AA, CH, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd are included. Organically produced potatoes are coded with dotted lines and conventionally produced potatoes with filled lines.

system and sensory analysis were used as variables in calculation of principal components (PCs). Three principal components were determined with explanation grade of the variations in the data set, e.g., for 1996, PC1–32%, PC2–22% and PC3–15% were obtained. Scores plots of PC1 against PC2 or PC2 against PC3 with corresponding loading plots for single crops (years) 1996–1998 are shown in Figures 4a,b–6a,b. As can be seen from the Figures 4a–6a, there is a clear separation between organically and conventionally grown potato varieties in each year indicating statistically significant differences ($p \leq 0.05$) between potatoes from the two farming systems. A corresponding separation was also shown for the crop year 1999 (not shown).

The scatter plots of loadings for PC1, PC2 and PC3 (Figures 4b–6b) illustrate which variables are important characteristics of the potatoes from organic and conventional farming system, respectively. A comparison (superimposition) of object plots (Figures 4a–6a) with corresponding loading plots shows (Figures 4b–6b) that in addition to the agricultural parameters such as yields and tuber size (>6 cm), only nitrate content (NO) was consistently increased each year during the period 1996–1998

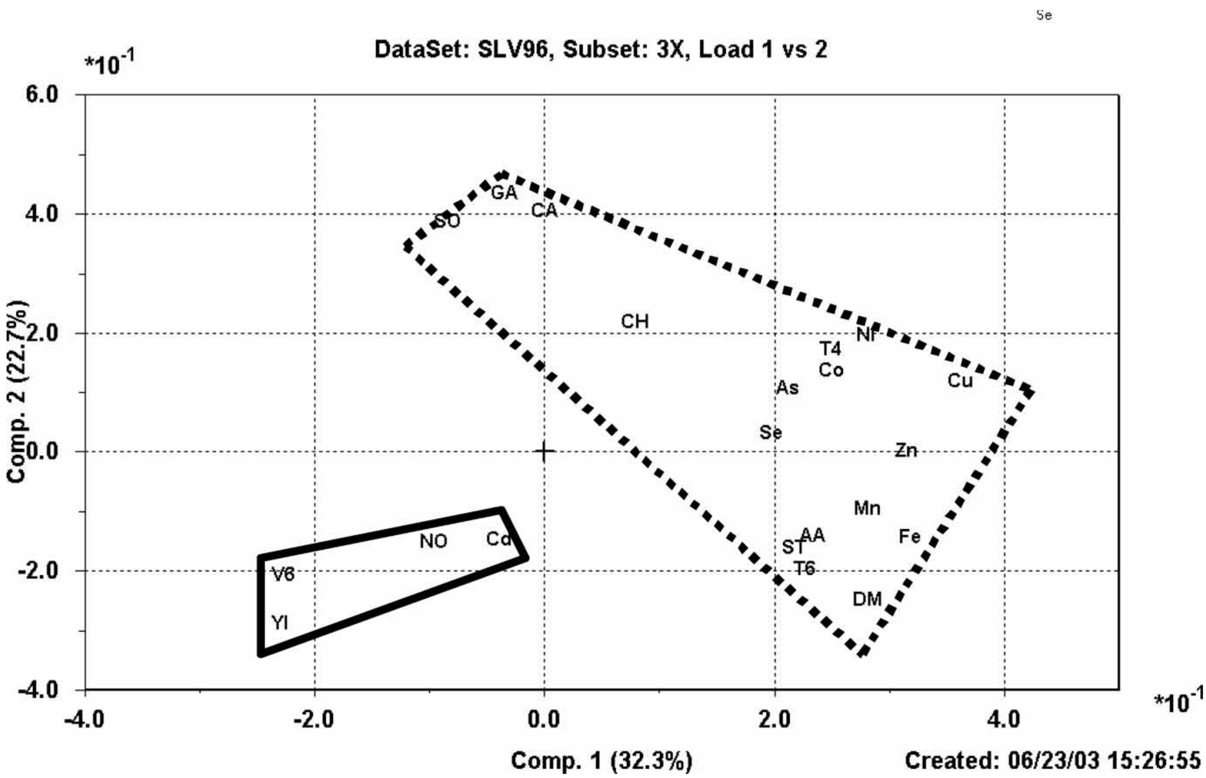

Figure 4b. Loading plot corresponding to the scoreplot in Figure 4a, showing the influence of the different variables (measured parameters) on the scores of the objects (remark: The principal components of the score and the loading plot can be superimposed to show the positive and negative influence of the different variables on the objects. Each variable present (superimposed) within the filled line group (conventional potatoes) or dotted line group (organic potatoes) reflects a statistically significant increased level in the respective farming system).

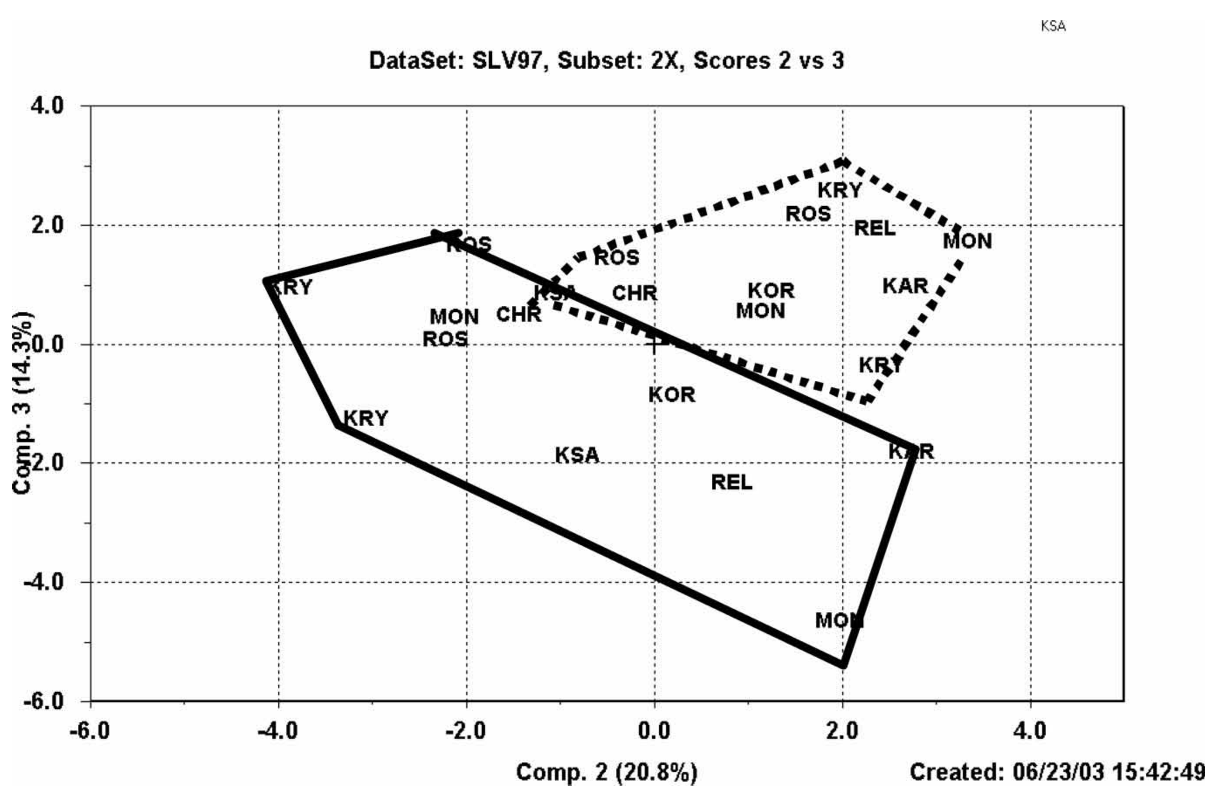

Figure 5a. Scoreplot of data obtained by examination of potatoes grown in the year 1997; PC2 (21%) is plotted against PC3 (14%). All the 22 objects from 1997 and the same variables as listed in legend Figure 4a, are included. Organically produced potatoes are coded with dotted lines and conventionally produced potatoes with filled lines.

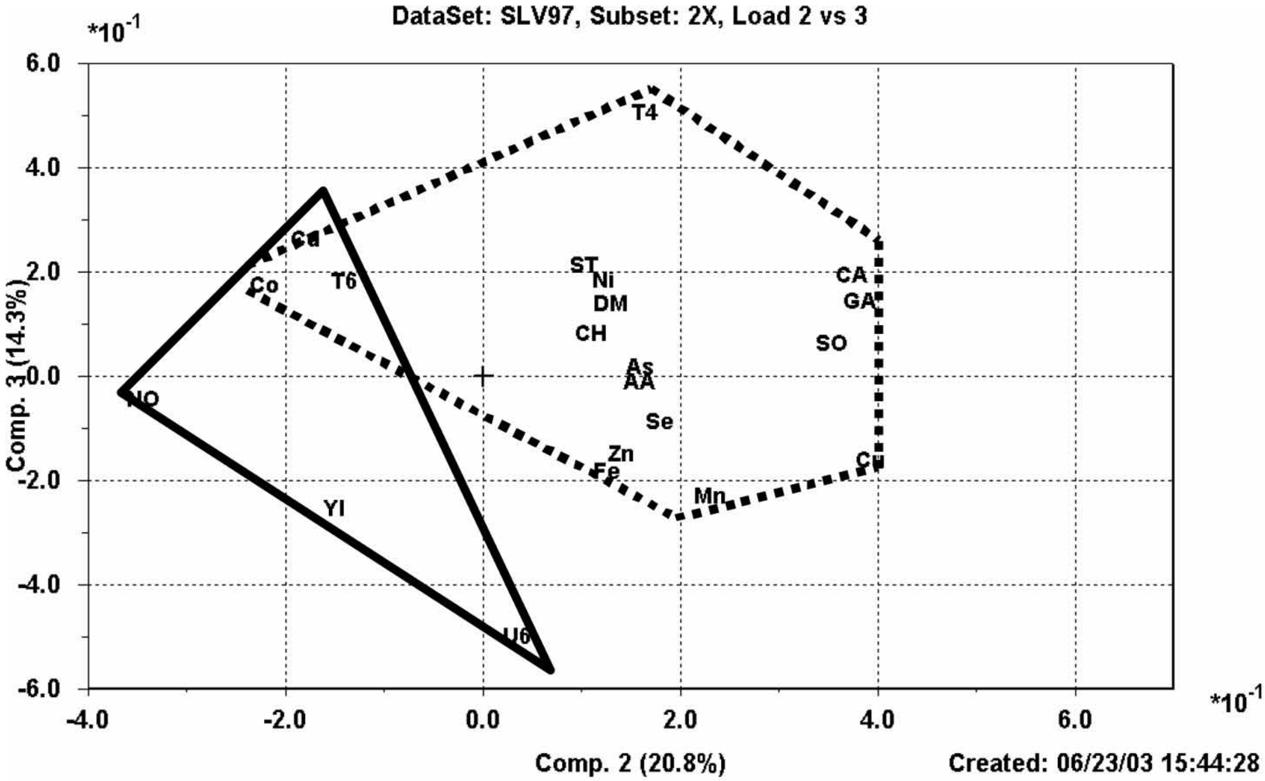

Figure 5b. Loading plot corresponding to the scoreplot Figure 5a, showing the influence of the different variables on the scores of the objects (for more explanation see remark in legend Figure 4).

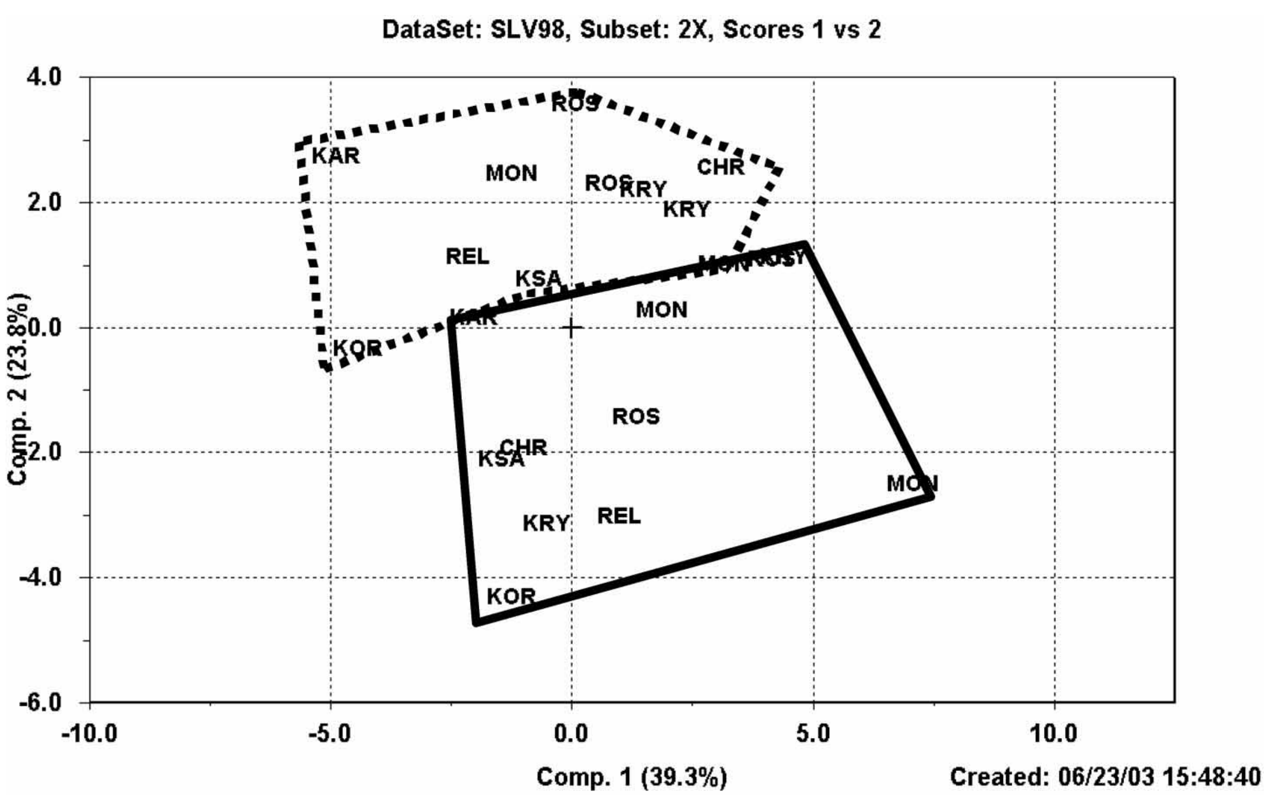

Figure 6a. Scoreplot of data obtained by examination of potatoes grown in the year 1998; PC1 (39%) is plotted against PC2 (23%). All the 22 objects from 1998 and the same variables as listed in legend in Figure 4a are included. Organically produced potatoes are coded with dotted lines and conventionally produced potatoes with filled lines.

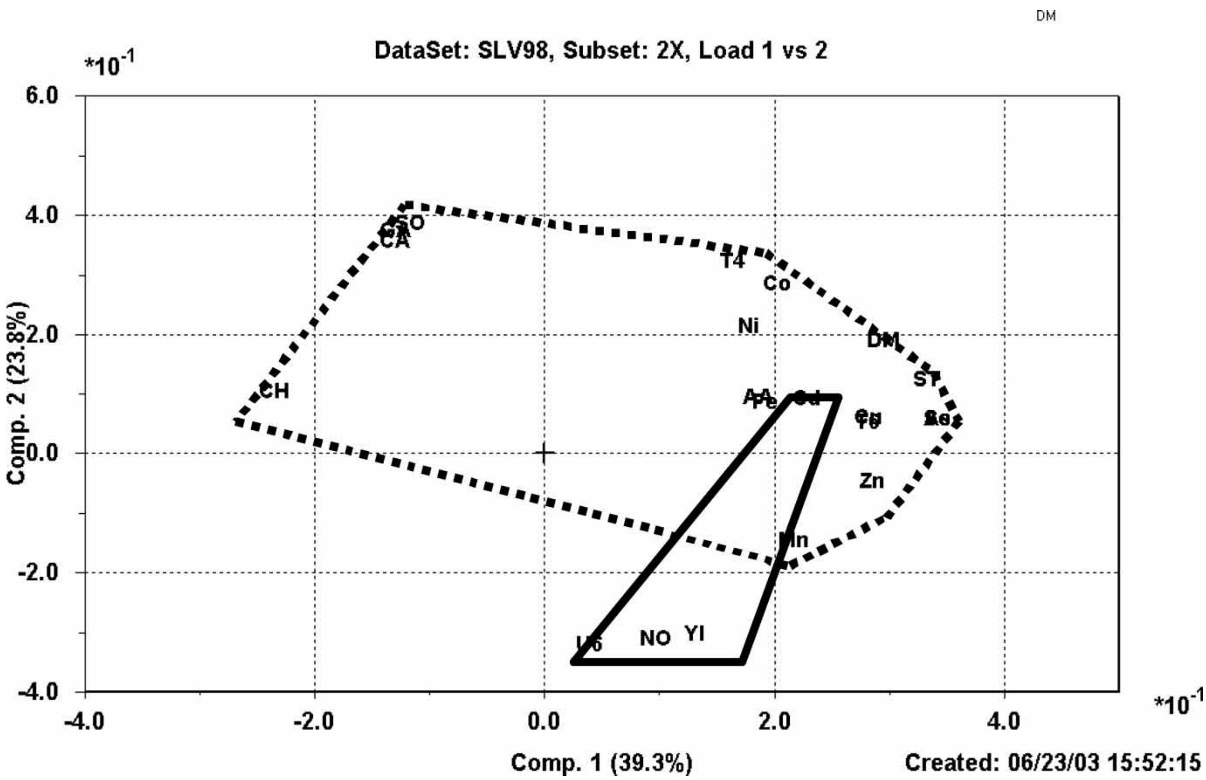

Figure 6b. Loading plot corresponding to the scoreplot Figure 6a, showing the influence of the different variables on the scores of the objects (for more explanation, see remark in legend Figure 4).

in the conventional tubers as compared to the organic potatoes.

On the other hand, the organically produced potatoes displayed higher levels of ascorbic acid (AA) and chlorogenic acid (CH) as well as a higher content of dry matter and starch content than the conventional ones in all the crops. It is interesting to note that a significant difference in AA observed using the PCA was not always detected by univariate analysis of mean differences between the two systems (see *Analytical examination of tubers – paragraph Vitamin C)*. The loading scatter plot from 1999 showed a similar tendency but was not fully comparable to other years because of an incomplete data basis for variables.

A comparison of micronutrients and other trace elements in organically and conventionally grown tubers showed significant variations from year to year and/or between farming localities with no clear separation between the two production systems (Figures 4b–6b).

Since the organic potatoes had a significantly higher dry matter, the score plots (PC1/PC2 and PC2/PC3) were also standardized for dry matter using the same variables with the exception of element analysis. The latter were omitted because they showed a lower loading in the PCA model used (see above). The correction for dry matter resulted in a poorer separation between the production systems. A clear separation between organically and conventionally farmed varieties were seen in 1996 and 1998 crops but not in crops from 1997 and 1999 (not shown).

Pooled results from 1996–1998 crops. In contrast to the separation of the potato varieties by the production system observed in single years (see above) the analysis of the data set pooled from 1996–1998 (PC1/PC2) only showed a tendency but not any distinct grouping into organic and conventional products (Figure 7a,b). This was probably due to the inter-annual variation since in scoring plots with PC1/PC2 and PC1/PC3 clearly separated classes of potato varieties could be seen when coded for the production year (Figure 8). It appears that the inter-annual variation dominate over the variation according to production system and/or genotype (variety). In addition to that, a certain influence of the location (farming site) on the results could also be seen in the PCA analysis of compounded 1996–1998 data since the separation between the two sites was not complete (Figure 9).

Health-related compounds. An attempt was also made to evaluate possible differences between organic and conventionally farming concerning the levels of potentially harmful and health beneficial compounds

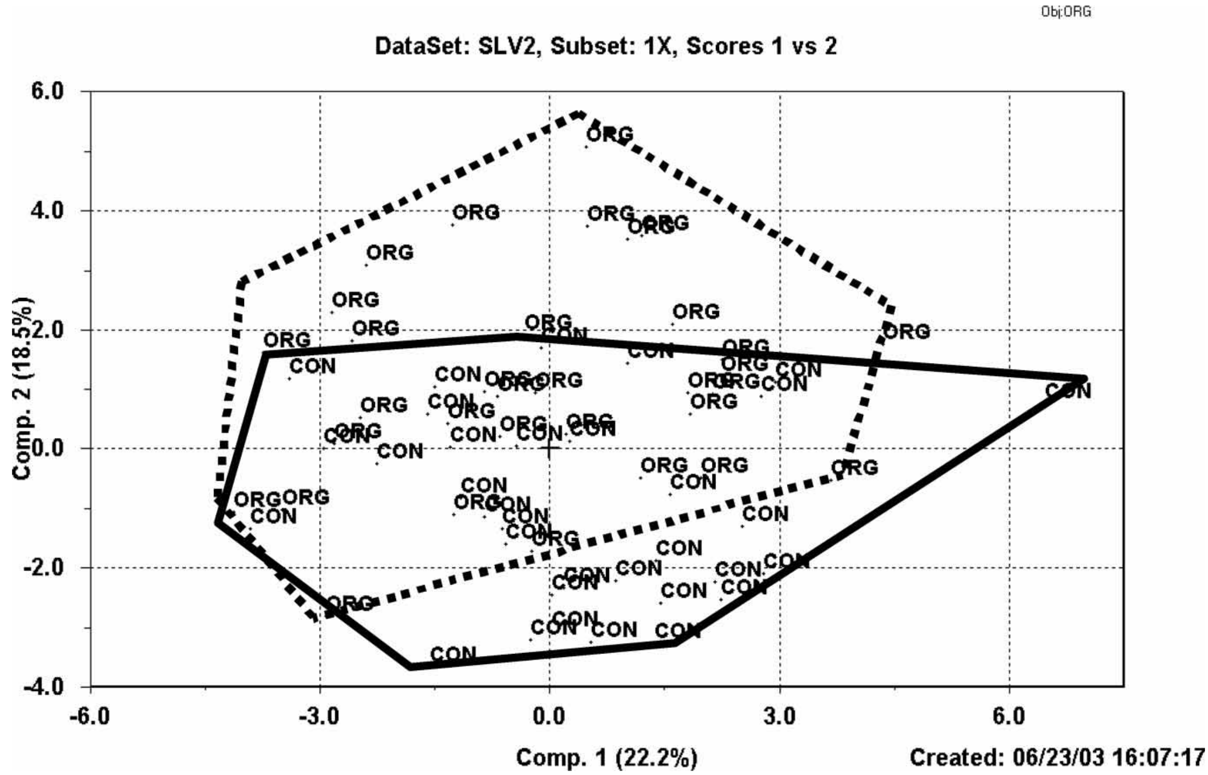

Figure 7a. Scoreplot of compounded data from potatoes grown in the years 1996–1998; PC1 (22%) is plotted against PC2 (18%). All the 66 objects from 1996–1998 and the following variables: ST, DM, T4, T6, U6, YI, NO, CA, SO, TGA, AA, CH, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd are included. Organically produced potatoes are coded with dotted lines and conventionally produced potatoes with filled lines.

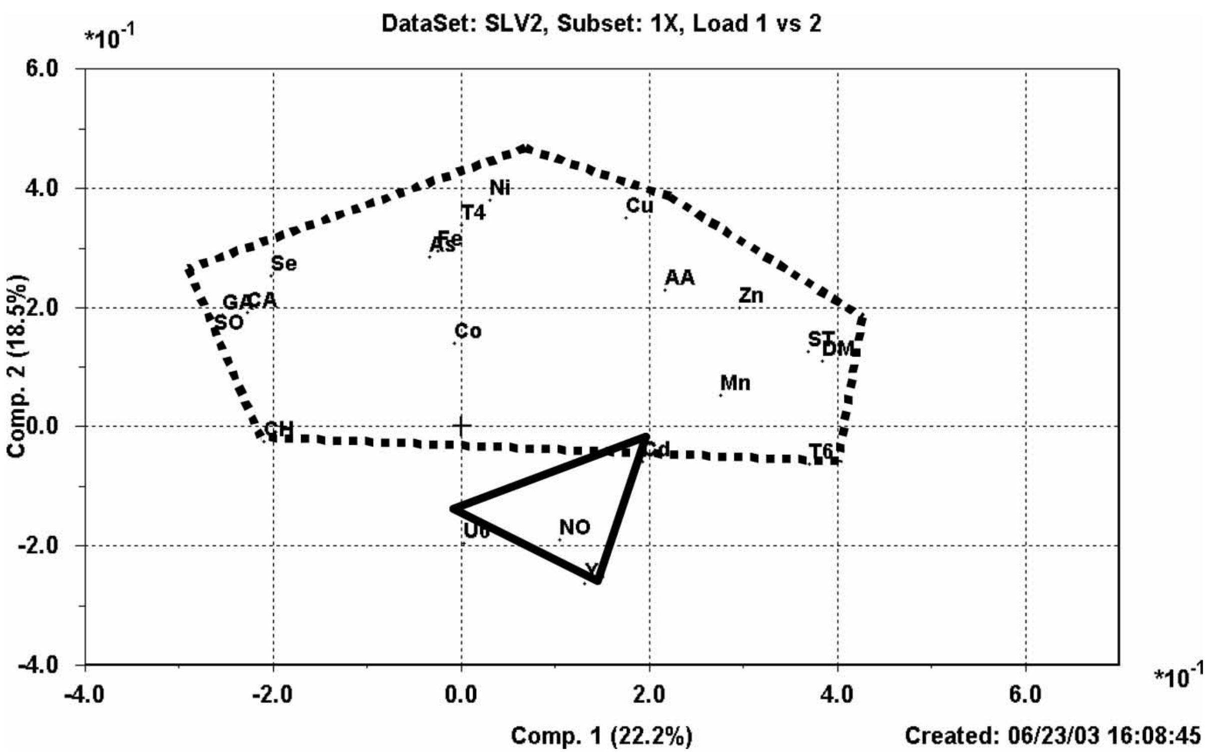

Figure 7b. The loading plot corresponding to Figure 7a, showing the influence of the different variables on the scores of the objects (for more explanation, see remark in legend Figure 4).

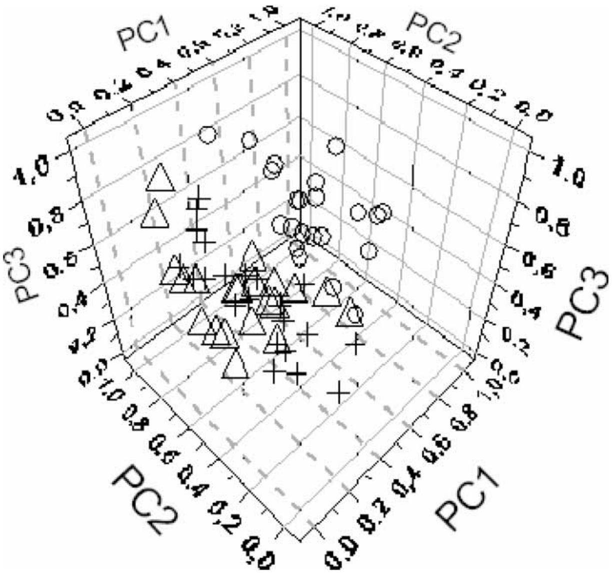

Figure 8. Scoreplot of compounded data from potatoes grown in the years 1996–1998; PC1 (22%) is plotted against PC2 (18%) and PC3 (14%). All the 66 objects from the years 1996–1998 and the following variables: ST, DM, T4, T6, U6, YI, NO, CA, SO, TGA, AA, CH, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd are included. The data are coded according to the year: Open triangle = 1996, Open circle = 1997, Cross = 1998.

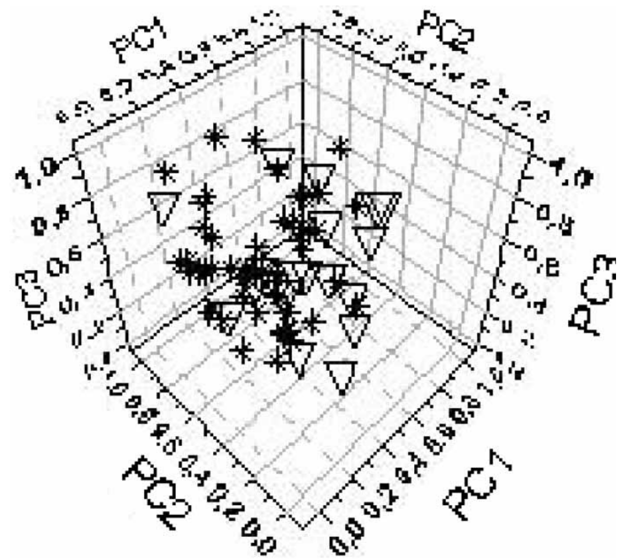

Figure 9. Scoreplot of compounded data from potatoes grown the years 1996–1998; PC1 (21%) is plotted against PC2 (17%) and PC3 (15%). All 66 objects from 1996–1998 and the following variables: ST, DM, T4, T6, U6, YI, NO, CA, SO, TGA, AA, CH, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd are included. The data is coded according to farming site: Star = location 1, Open inverted triangle = location 2.

in potatoes. The crops were analysed using a PCA model (scores PC1/PC2) with ascorbic acid, Mn, Fe, Co, Zn and Se as health beneficial variables or nitrates, α-chaconine, α-solanine, TGA and chlorogenic acid (although this compound could be looked upon also as a beneficial for health) as harmful variables, respectively. In none of the cases there was a clear separation between the two production systems (as an example see Figures 10–11). Similarly, no differentiation between organically and conventionally grown varieties could be seen when the trace elements studied or sensory parameters analysed were used as variables (results not shown).

Sensory parameters. A comparison of the organic and conventional tubers from the L1 locality with regard to their properties evaluated in the sensory testing did not show any clear separation on the scores plots (PC1/PC2) from the pooled data set 1996–1998 between the two groups (results not shown).

Discussion

The present investigation comprising agronomic parameters, health-related (nutritional and toxicological), technological, as well as sensory properties of eight potato varieties during four consecutive crop years from two farm localities, represents, to our knowledge, the most extensive comparative study of organically and conventionally produced potatoes. The evaluation of results by univariate comparison test (*t*-test) on mean differences between the two farming systems provided an indication of separation between organically and conventionally produced potatoes. To be able to determine more clearly potential differences between the two farming systems in terms of potato quality characterized by parameters measured within this study, PCA was used to identify the subsets of variables (principle components) providing the highest degree of explanation of the data set.

The PCA of the data obtained in single crop years indicates that potatoes from the two production systems can be separated with regard to the agricultural and technological parameters. Lower yields and smaller tuber size, which were observed in the organic crops, may be expected due to lower fertilizer input (Varis et al. 1996). Other significant differences observed in this investigation were a higher dry matter and starch content in the organic potatoes. Similar trend was also reported in earlier studies concerned with organic potatoes and other vegetables (Lampkin 1990; Woese et al. 1995). In general, an increased dry matter represents a higher energy density of this commodity but the significance for consumers in terms of its nutritional value is not clear (O'Doherty-Jensen et al. 2001). In any case, this characteristic is important with regard to the texture of cooked potatoes (van Marle et al. 1997).

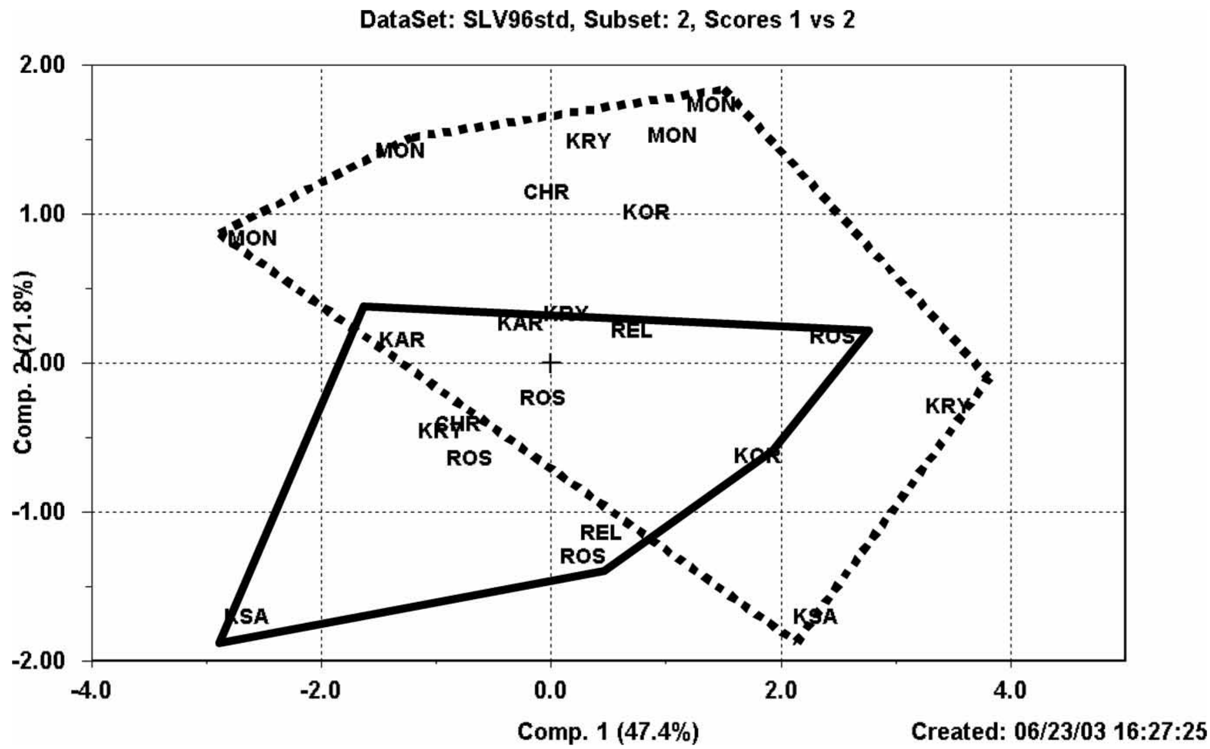

Figure 10. Scoreplot of data from potatoes grown in 1996, PC1 (47%) is plotted against PC2 (22%). All 22 objects from 1996 and the following variables: AA, Mn, Fe, Co, Zn, Se are included. Organically produced potatoes are coded with dotted lines and conventionally produced potatoes with filled lines.

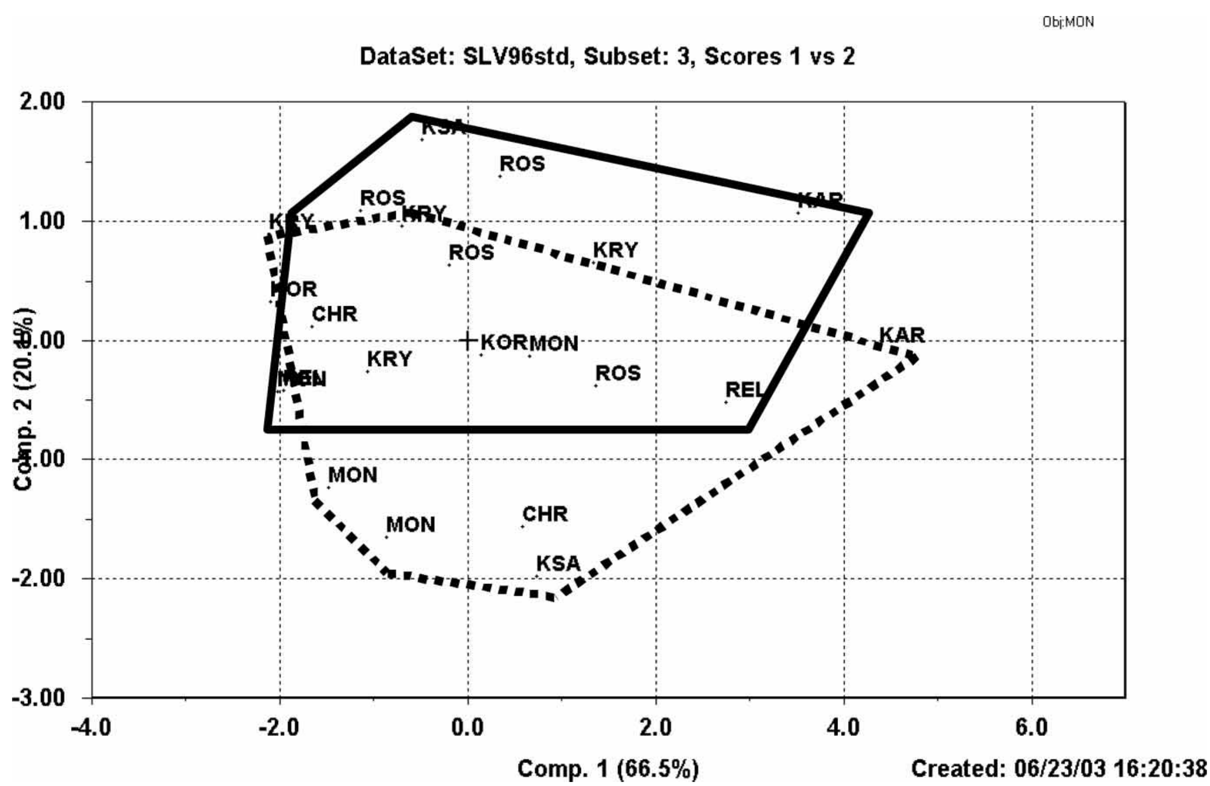

Figure 11. Scoreplot of data from potatoes grown in 1996, PC1 (66%) is plotted against PC2 (22%). All 22 objects from 1996 and the following variables: NO, CA, SO, TGA, CH are included. Organically produced potatoes are coded with dotted lines and conventionally produced potatoes with filled lines.

As regards health-related components measured in tubers, the only ones which separated conventionally and organically grown potatoes when analysed separately for each year, were lower concentration of nitrates and higher content of vitamin C in the organic crops. An inverse relationship between the fertilizer (nitrogen) input and vitamin C levels in plants has been reported in several studies (Mozafar 1993; O'Doherty-Jensen et al. 2001; Soerensen 1984). A tendency to higher vitamin C levels in organically grown potatoes as compared to conventionally ones has also been shown in some other investigations (Rembialkowska 1999; Schuphan 1974; Štorková-Turnerová and Prugar 1988). Considering the main dietary sources of the antioxidative vitamin C, the increased content of this essential compound in organic potatoes might be of importance in diets with a high proportion of potatoes and a lower amount of other vegetables and fruits.

The observation that organic potatoes contain significantly lower levels of nitrate than conventionally produced tubers are in agreement with findings from several other controlled field experiments and farm surveys (Guziur et al. 2000; Rembialkowska 1999; Schuphan 1974; Stopes et al. 1988; Štorková-Turnerová and Prugar 1988), and are conceivably related to the lower nitrogen input in organic farming (Rembialkowska 1999). A similar trend, i.e., lower nitrates in organically grown tubers, was documented in a three-year study concerned with evaluation of several factors including the way of cultivation on the composition of seven potato varieties grown in Czech Republic. However, considering the aggregated data, the differences were not statistically significant (Hamouz et al. 1999a). Also in older, less well controlled investigations, significantly lower levels of nitrates were observed in organically produced leafy vegetables and other plants, whereas the result with potatoes were not conclusive (Woese et al. 1997; Worthington 1988). In spite of that, this tendency is undoubtedly an important issue since nitrates are considered a potential indirect precursor for the formation of carcinogenic nitrosoamines in the human digestive system. As some vegetables naturally contain high nitrate levels, international maximum residue limits have been established for lettuce and spinach (Fernlöf and Darnerud 1996; Malmauret et al. 2002). Because of a relatively high consumption of potatoes in some diets, such as the Scandinavian and Central European diets, this food commodity may represent a major dietary source of nitrates regardless of the relatively low levels occurring in this food staple (Pentila et al. 1990). However, the exact toxicological significance of the reduced nitrate content in organic potatoes is at present unclear.

It has been suggested (Worthington 1998) that the differences recorded between organic and conventional food crops are essentially due to a relatively higher moisture content in conventional products, resulting in some ''dilution'' of contained chemical constituents. In the present study, a separation according to the production system was observed for crops harvested in 1996 and 1998 when generated data were corrected for dry matter, whereas a less clear separation according to the cultivation method was noted for the years 1997 and 1999. However, an overall differentiation between potatoes from the organic and conventional farming system based on selected quality parameters as established by PCA still remained apparent in the latter case (years 1997 and 1999). Thus, it appears that the higher content of dry matter in organic products only partly (at the most) contributes to the observed difference in the quality parameters of potatoes grown on farms using organic as compared to conventional cultivation methods.

The distinct separation of potato varieties according to the production system illustrated with the help of PCA in separate crop years, with nitrate, vitamin C, chlorogenic acid and agricultural parameters as the significant variables, became partially obscured when the analytical data for all the crop years (1996–1999) were pooled together. This fact indicates that inter-annual differences may be of equal or even greater importance with regard to the nutritional and technological quality parameters of potatoes than the production system. This interpretation is supported by the relative statistical weight of data for nitrates, total glycoalkaloids and chlorogenic acid in potatoes as estimated by multivariant discriminant stepwise analysis to approximately 86% for inter-annual variation but only 76% for the production system. In all cases there was also a significant influence of genotype (53%) and, in case of total glycoalkaloids, also geographical locality (45%).

Due to the substantial variation in content of principal potato glycoalkaloids (α-chaconine and α-solanine) and/or their total amount in tubers from year to year, but also between the potato varieties/genotypes (though less pronounced), as well as between geographical areas of cultivation, no statistically significant differences could be established in the content of these natural toxins in tubers produced by the two different production systems. The impossibility to draw unequivocal conclusion on the influence of cultivation way on total glycoalkaloids content was stated by authors (Hamouz et al. 1999a) of another Czech study concerned with similar research subject (most potato varieties as well as growing localities involved in their study were different). Earlier pilot studies conducted by the Swedish National Food Administration indicated lower levels of total glycoalkaloids in organically produced tubers, based on a pairwise comparison of crop obtained from ecological and conventional farms or controlled research plots (Hellenäs and Branzell 1995).

However, this particular experiment was limited to two years, and in the case of the field study, different potato varieties were used in organic and conventional farming, hence no generalization of results was possible. An important finding in the present investigation is that certain potato varieties such as *Rosara* displayed significantly higher levels of total glycoalkaloids in organically produced tubers regardless of the year or locality. A similar trend was seen with *Rosella* and *Monalisa* but each only at one of the experimental sites; locality L1 and L2, respectively. The total glycoalkaloid contents found in the Czech varieties involved in our investigation were relatively low compared to the levels reported for most potato varieties in the Swedish study (Hellenäs and Branzell 1995), and always well below 200 mg/kg what is the maximum level adopted by some countries for regulation of 'solanine' in potatoes. Nevertheless, the results indicate that specific potato varieties may be prone to produce elevated amounts of glycoalkaloids when grown organically (Hellenäs 1994).

One recently published study (Gundersen et al. 2000) analysed major and trace elements in onion and pea samples, respectively, produced in organic and conventional farms. With the help of PCA it was shown that the elemental concentration profiles were different in organically and conventionally grown vegetables. Contrary to these results, no difference in the levels of the studied elements between organic and conventional potatoes could be observed in the present investigation. The discrepancy between these findings could be due to many reasons such as different character of food crops involved in particular study, a lower number of elements analysed in our 'potato' study, and/or only single harvest/year data were presented in quoted Danish study which does not allow for any statistics-based generalization on the long-term trends.

Similarly to the conclusions derived from our study, several recent reviews focusing on the levels of minerals and trace elements in potatoes and other plant foods show that no conclusive scientific evidence is available regarding significant differences in nutrient and mineral quality in relation to the production system (Woese et al. 1997; Worthington 1998; Brandt and Mølgaard 2001; Williams 2002). The confident proponents of organic farming, on the other hand, claim that a critical scientific review of the published studies postulates a clear trend toward a superior nutritional quality of organic food products (Woese et al. 1995) in this respect. In any case, it is of interest that the pattern of uptake of trace elements from the soil into potatoes was shown to depend on the fertilization practices (nitrogen input) (Bibak et al. 1999). Clearly, more studies are needed to further elucidate this question.

Among the toxic elements studied, Cd is of a particular interest since potato tubers are estimated to contribute between 10 and 20% to the daily dietary intake of this metal in several European countries (Hovgaard and Andersen 1983; MAFF 1983; Müller et al. 1988; Varo et al. 1980). The absence of any consistent differences in Cd levels between organic and conventional tubers in the present investigation is in agreement with earlier studies concerned with potatoes and grains (Jorhem and Slanina 2000). It was documented that atmospheric emissions, soil composition and its pH, as well as genetic and other factors known to affect Cd uptake in plants (Eriksson et al. 1990, 1996; Jones and Johnston 1989; MAFF 1983; Malmauret et al. 2002; Müller et al. 1988; Sing et al. 1995; Varo et al. 1980) must be considered in the final assessment of the influence of the production system on the level of this toxic metal in potatoes. Several investigators (Andrey et al. 1988; Brüggemann and Kumpulainen 1995; Golaszewska and Zalewski 2001; McLaughlin et al. 1997) also showed that the Cd levels in potato tubers depended also on varieties, however, in our experiments, no variety-related differences between the two production systems were observed.

The presence of residues of potentially harmful synthetic pesticides in the conventional crops is one of the main concerns among consumers (Baker et al. 2002). Although only a limited number of "traditional" agricultural chemicals are authorized for use in the case of immediate threat to organic crop, products from this way of farming can never be defined as absolutely pesticide-free. Trace levels of some pesticides may occasionally be found even in certified organic foods due to the previous land uses or because of input from emissions (atmospheric transport leading to plant and soil contamination). However, the maximum residue limits (MRLs) in these cases are highly unlikely to be exceeded.

To explore the contamination situation, a separate pilot study was carried out (Parkányiová 1999) focusing on pesticide residues in potatoes from harvests in 1996 and 1997. No detectable residues of synthetic pesticides (LODs ≤ 0.05 mg/kg) applied in field experiments were found in conventional crop, similarly, no residues could be detected in organic tubers. These results indicate that synthetic pesticide residues in potatoes even from conventional system, when treated properly, are of limited significance for consumers' health (regardless of the production system, it should be noted that the post-harvest treatment of potatoes by sprout inhibitors may occasionally leave detectable residues).

To our knowledge, this is the first comprehensive study comparing the influence of organic and conventional production methods on the content of chlorogenic acid, polyphenol oxidase activity and the rate of enzymatic browning of fresh potatoes. Statistically significantly increased levels of chlorogenic acid (this compound contributes typically up to 90% of the total phenolics content) in organically grown potatoes under the experimental conditions used in the present study. A similar trend – distinctly higher content of total polyphenols in organic tubers (variety *Agria* and *Karin*) – was recognized in another three-year Czech study (Hamouz et al. 1999b). The impact of growing conditions on the amount of chlorogenic acid and other phenolic compounds in potato tubers was also shown in other studies (Thybo et al. 2001).

In any case, these finding are in line with theoretical assumptions: polyphenols together with glycoalkaloids and other secondary metabolites are considered to constitute a plant protection system against adverse effects of light and mechanical injuries, as well as against damage caused by pests and/or pathogens. In addition to this role, elevated levels of chlorogenic acid might according to some studies (Friedman 1997) have several other implications including both positive and negative effects on potato flavour, colour and nutritional quality. As regards the first two attributes (organoleptic properties), no distinct correlation with higher chlorogenic acid levels were observed in our study. However, considering the higher content of chlorogenic acid in organic tubers we should take into account a growing body of evidence indicating that plant-based phenolics including chlorogenic acid may play critical roles in human health due to their potent antioxidant activity and wide range of other pharmacologic properties including anti-cancer effects (Beecher 1999; Shahid and Ho 2005). In future comparative studies of organically and conventionally produced potatoes, other potentially beneficiary phytochemicals occurring such as flavonoids (Daniel et al. 1999) might be the subject of investigation.

Better taste is another claim motivating some consumers to purchase organic foods. The controversy shown by sensory trials comparing organic and non-organic products has been discussed for example by the Institute of Food Science & Technology in UK (IFST 1999). It was concluded, among other matters, that the results obtained with consumer panels and panels with trained personnel might give opposite results although the evaluation is conducted under identical, carefully controlled experimental conditions. Like in the case for other food crops, a comparison of conventional potatoes with their organic counterparts is complicated by flavour variation related to variety, different degree of ripeness or freshness, and length of storage. Although the influence of all these variables was minimized in our experiments, no clear influence of the production system could be established. Similar conclusions with no significant preference for products from one or the other cultivation system were presented in a review of the studies comparing sensory properties of potatoes (Woese et al. 1997). Only minor differences in sensory quality and rheological properties were demonstrated in a recent study (Thybo et al. 2001) assessing six different organic treatments of potatoes.

Conclusions

In conclusion, the results of this investigation indicate that the most consistent differences between organically and conventionally farmed potatoes are agricultural parameters such as yield, tuber size, dry matter and starch content. As regards factors directly related to human health (due to dietary intake), lower nitrate levels and higher vitamin C levels appear to be the most prominent characteristics of the organic tubers when studied in separate years. In comparison, the concentration of total glycoalkaloids (with the exception of certain varieties) and the profile of essential or toxic minerals do not seem to be consistently different between the organic and conventional tubers. In contrast to that, the concentration of chlorogenic acid, which may be seen as a compound having both positive and negative effects on the quality, was consistently higher in the organic products. No clear difference can be recognized with respect to the sensory qualities of organic or conventional potatoes. Regardless of the parameter studied, PCA of all the analytical results as well a sensory testing shows that year to year variation, as well as genotype and locality variation, appear to be equally or more important factors influencing the quality of this staple commodity than the production system. It is therefore important to bear in mind the complexity in the concept called quality of potatoes in relation to organic and conventional farming systems when general recommendations are given to the consumers. Further extensive, long-term investigations are necessary to obtain reliable information on the influence of farming systems on the quality of potatoes.

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