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Sensory quality and mineral and glycoalkaloid concentrations in organically and conventionally grown redskin potatoes (*Solanum tuberosum*)

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Abstract: Triangle tests were used to determine if panellists could distinguish (by tasting) cooked wedges of potatoes grown organically, either with (+) or without (−) compost, and conventionally. Mineral and glycoalkaloid analyses of tuber skin and flesh were also completed. When the skin remained on the potatoes, panellists detected differences between conventional potatoes and organic potatoes, regardless of soil treatment. However, they did not distinguish between organic treatments (± compost) when samples contained skin, or between any treatments if wedges were peeled prior to preparation and presentation. Glycoalkaloid levels tended to be higher in organic potatoes. In tuber skin and flesh, potassium, magnesium, phosphorus, sulfur and copper concentrations were also significantly higher in the organic treatments, while iron and manganese concentrations were higher in the skin of conventionally grown potatoes.

Keywords: organic production; conventional production; potato; mineral concentrations; glycoalkaloids; sensory evaluation; *Solanum tuberosum*; compost; crop quality

INTRODUCTION

Organic markets are thriving, as a growing number of consumers worldwide prefer organic products.[1–5] Growth in the industry is fuelled in part by consumers' attitudes towards food production systems and product quality. With respect to product quality, surveys indicate that consumers consider organic foods to be more positive for the environment and human health and more flavourful than their conventionally grown counterparts.[1,3,6]

Pre- and postharvest management affect plant biochemistry and physiology and therefore product quality. These relationships are discussed at length within the scientific literature and many texts and proceedings.[7–12] Specific soil management is central to organic production, making potato a potentially ideal system for exploring management effects on crop quality. In previous studies with potato, P, Mg, Na and Mn levels, but not vitamin C content, were influenced by production system (organic, conventional).[13] Also, tuber N content (expressed as crude protein nutritive value) was positively related to the N available to crops, regardless of N form as initially supplied by various fertilisers, including manure.[14] Among 10 crop fertility treatments, organic N-treated potatoes contained higher levels of nitrate,[15] although lower nitrate levels in potatoes fertilised with composts versus mineral fertilisers have also been reported.[16]

However, recent reports and reviews concerning management system effects on product quality emphasised the need for additional research using well-controlled, well-defined experimental systems.[1,17,18] With this in mind, we employed conventional and certified organic field plots differing primarily in parameters related to management system (ie soil type, variety and other factors were consistent across plots) to assess cumulative system effects on potato quality with few confounding factors, as encouraged

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by previous works.[19–22] Our objectives were (1) to determine if sensory panellists could distinguish (by tasting) cooked wedges of potatoes grown organically, either with (+) or without (−) compost, and conventionally and (2) to measure the mineral and glycoalkaloid levels in the skin and flesh of tubers taken from the same plots.

EXPERIMENTAL

Fields and crop production

In 2002, neighbouring plots of conventionally and organically managed 'Dark Red Norland' potatoes, separated by approximately 650 m, were established as a part of two distinct studies at the OARDC in Wooster, OH (Wayne County; latitude 40°47′ N, longitude 81°55′ W, elevation 310 m). The organic variety × soil management study included plots receiving no amendments and plots receiving compost, whereas the conventional variety trial was managed uniformly throughout. Therefore samples later used in postharvest analysis were collected from plots of three field treatments: organically grown with (+) compost, organically grown without (−) compost and conventionally grown. Plots in the organic system were arranged in a randomised complete block design with four replications, while plots in the conventional system were arranged in a completely randomised design with three replications.

Historically, the organically managed potato field was in an organic corn/soybean/clover/spelt rotation for 4 years prior to the initiation of the potato study in 2000, at which time potato was substituted for corn. These plots were certified as organic in the summer of 2002. In 2001 the conventionally managed potato field was planted with Sudan grass as the main crop and wheat as the autumn cover crop.

In both fields the soil type was a Wooster Silt Loam (Fine-loamy, Mixed, Mesic, Typic Fragiudalf), with a pH of 5.6 and 6.8 for the conventional and organic plots respectively. Relative soil pH values are not unexpected given reports suggesting that applications of organic amendments (eg compost, manure) tend to increase soil pH in organic systems.[23–25]

Granular fertiliser (10-20-20 N-P-K, 672 kg ha^{-1}) was applied to the conventional field before and at planting, per standard local practice. In the organic field, composted dairy manure (2.5–2.9, 1.4 and 2.9% N, P and K by dry weight respectively, total C/N ratio 11.8:1, 6.5 Mg ha^{-1}) was applied and incorporated into 120 m^2 subplots 16 days before planting, delivering approximately 62 kg N ha^{-1}. Residual N from clover rotation crops was estimated at 62 kg ha^{-1}, based on percentage stand, height and mineralisation rates.

Potato seed was cut (approximately 35 g pieces) on 15 and 31 May 2002 and cured until planting on 23 May and 10 June in the conventional and organic plots respectively. Seed was planted with a mechanical one-row planter leaving 30.5 cm between hills and 90 cm between rows in all plots. Plots were not irrigated throughout the experiment. Conventional plots were treated with labelled herbicides, insecticides and fungicides from planting until vine kill. Pre-emergence herbicides were applied on 27 May. Insecticides were applied at planting and later as needed, based on insect scouting in the field. Fungicides were applied every 5–16 days after emergence, based on weather conditions and threat of disease. No chemicals were applied to organic plots. For weed control, rows were machine cultivated three times before canopy closure and hills were reshaped 28 days after planting.

Vines were killed in all plots when the majority of tubers had reached 3.2–7 cm in diameter. In conventional plots, vines were killed with Rely® desiccant (Bayer CropScience, Research Triangle Park, NC, USA) on 13 September; organically managed vines were mowed on 28 August, per typical commercial practice in the area. Potatoes were field cured until mechanical harvest on 8 October and 20 September for conventional and organic plots respectively. After harvest, potatoes were placed in darkened storage at 7 °C for approximately 15 days, graded for size and external quality and returned to storage until postharvest evaluation. Potatoes vary in size at horticultural maturity and harvest. In commercial packing sheds, populations of fresh market potatoes are sorted into size classes based on market criteria and packaged for display at points of purchase. Smaller tubers, particularly those less than 5 cm in diameter (eg 'B' size), tend to have a higher market value in the USA.[26] Likewise, concentrations of important crop constituents vary with product size. Therefore, to balance scientific and practical factors, all tubers forwarded to subsequent sensory and chemical analyses were 3.2–5 cm in diameter, as measured perpendicular to the apical-stolon end axis, regardless of orientation.

Sensory evaluation

An excess of round, 3.2–5 cm diameter tubers (mean weight 110 g) were selected for analysis in order to ensure that wedges used for sensory evaluations were of a consistent size and weight. Tubers were prepared the day before each evaluation by either lightly brushing the skin with a brush or peeling with a standard hand-held vegetable peeler. Tubers were then cut into quarter wedges using a four-section Wedge Master Wedger (Lincoln Foodservice Products, Inc, Fort Wayne, IN, USA). Wedges were then placed in boiling water, cooked for 15 min and immediately drained. Running cold water over the samples for 5 min halted cooking. Wedges were then double-bagged in quart-size Ziploc freezer bags labelled with randomly selected three-digit codes. Bags containing samples were placed overnight in a refrigerator at 11 °C.

All methods for testing human subjects were approved by the Office of Responsible Research Practices (ORRP) at The Ohio State University

(Federal Assurance Number 01E0341) before testing began. Evaluations were conducted at the OARDC on 30 and 31 January 2003 from 10:00 to 13:00. Fifteen panellists (nine males and six females, ages 23–65) participated on the first day; one male did not return on the second day. Potatoes from the three field treatments (conventionally grown, organically grown with compost, organically grown without compost) were evaluated in replicated triangle tests. Every panellist assessed all three possible sample pairings (conventionally grown vs organically grown with compost, conventionally grown vs organically grown without compost, organically grown with compost vs organically grown without compost) twice. On the first day, samples were evaluated with skins; on the second day, samples were evaluated without skins. Samples were evaluated under red light to minimise visual differences between samples, and panellists made their assessments in isolation. Chilled bottled Dannon® water and Italian white bread were available to panellists to cleanse their palates.

Thirty minutes before an evaluation, bags were placed in an Isotemp 220 hot water bath (Fisher Scientific, Pittsburgh, PA, USA) set at 80 °C. For each triangle test, panellists received three 118.4 ml Styrofoam cups (J-cup, 4J6, Dart Container Corp, Mason, MI, USA), each with a single wedge and three-digit code, in a randomised order. Two wedges were from the same field treatment and the third from a different treatment, and panellists were asked to first select the different sample and then describe how it differed from the other two samples. Sample order was counterbalanced within and across panellists.

Mineral analysis

Flesh and skin samples for four replications per treatment, with a composite of five potatoes per replication, were oven dried at 65 °C for 72 h. Samples (5 g) were then ground to a fine powder in a coffee grinder (Mr Coffee coffee grinder IDS55, Cleveland, OH, USA) and submitted to the Service Testing and Analytical Research Laboratory at the OARDC in Wooster, OH for analysis of 11 essential plant macro- and micronutrients by inductively coupled plasma (ICP) emission spectrophotometry.

Glycoalkaloid analysis

Freeze-dried flesh and skin samples (5 g) were ground to a fine powder in a coffee grinder (Mr Coffee coffee grinder IDS55). There were four replications per treatment, with a composite of five potatoes per replication. Solanidine concentrations were determined according to the procedure of Lawson *et al.*[27]

Data analysis

Frequencies of correct responses for each panellist were tabulated and input into IF Programs™ version 7.6 software (The Institute for Perception, Richmond, VA, USA). The resulting analysis gave a P value indicating if samples were significantly different and if panellist variability was significant. When panellist variability was significant, the beta-binomial model was used to interpret the data; when panellist variability was not significant, the binomial model was used.[28] The amount of overdispersion (γ), or panellist variability, was estimated as

$$\frac{n_\mathrm{R}S}{\bar{p}(1-\bar{p})N_\mathrm{J}(n_\mathrm{R}-1)} - \frac{1}{n_\mathrm{R}-1}$$

where n_R is the number of replications per panellist, $\bar{p}$ is the mean probability of a choice response, N_J is the number of judges and

$$S = \sum_{i=1}^{N_\mathrm{J}} \left(\frac{x_i}{n_\mathrm{R}} - \bar{p} \right)^2$$

with x_i the number of choice responses in the ith trial. Because this analysis approach accounts for panellist variability, equivalent panel size can then be calculated using[29]

$$\frac{N_\mathrm{J} n_\mathrm{R}}{1 + (n_\mathrm{R}-1)(\gamma)}$$

The advantage of this approach is that equivalent panel sizes are typically larger than the panel size, which increases the statistical power and sensitivity of discrimination tasks. The open-ended comments of triangle tests answered correctly were compiled and examined for trends.

Mineral and glycoalkaloid concentrations were subjected to analysis of variance (ANOVA) using the general linear model procedure of Statistical Analysis System version 7 for Windows™ (SAS Institute, Cary, NC, USA).

RESULTS

Sensory evaluation — discrimination test

With samples containing skin, panellists detected differences between organic, grown either with or without compost, and conventional potatoes ($P \leq 0.0002$ and 0.001 respectively) (Table 1). They did not detect a difference between the two organically managed treatments nor did they distinguish between any pairs of potato wedges if samples were peeled ($P > 0.05$). In all tests, panellist variability was not significant ($P > 0.05$), indicating that the simpler binomial model fitted the data and that calculated equivalent panel sizes were larger than the actual panel size (Table 1). Compiled open-ended comments revealed few trends. For example, when the skin was left on, potatoes grown organically without compost were described as less intense (parameter unspecified) than those grown conventionally, while potatoes grown organically with compost were described as more bitter than those grown conventionally. With peeled samples the two organically managed treatments were described as more intense and bitter than the

Table 1. Results for triangle tests used to assess ability of sensory panellists to distinguish samples of 'Dark Red Norland' potatoes grown using three management regimens at OARDC, Wooster, OH in 2002. Regimens consisted of conventionally grown potatoes and potatoes grown organically, either with or without the addition of compost. On day 1, tuber samples contained skin; on day 2, samples lacked skin[a]

	Conventional vs organic with compost	Conventional vs organic without compost	Organic with compost vs organic without compost
With skin (day 1)			
Panellist variability	<0.0001	<0.0001	0.4000
Panellist *P* value	0.8708	0.6665	0.0607
Proportion of correct responses	0.6333	0.6000	0.3333
Sample *P* value	0.0002	0.0010	0.4998
Equivalent panel size	30	30	21
Without skin (day 2)			
Panellist variability	<0.0001	0.0476	<0.0001
Panellist *P* value	0.9033	0.4293	0.5077
Proportion of correct responses	0.3929	0.2500	0.4643
Sample *P* value	0.2519	0.1749	0.0707
Equivalent panel size	28	27	28

[a] Number of panellists equalled 15 on day 1 and 14 on day 2. Number of replications equalled two in all tests. Binomial model used in all tests. Null probability = 0.3333 in all cases.

conventionally managed treatment, and the organic treatment with compost was described as more earthy than the organic treatment without compost.

Glycoalkaloid analysis

The solanidine concentration in the flesh of conventionally grown potatoes was less than half of that found in either organically grown group (Table 2). Conventionally grown potatoes also had the lowest solanidine concentration in the skin, while organic potatoes grown with and without compost had intermediate and highest levels of solanidine respectively, nearly double that of potatoes from conventional plots.

Mineral nutrient analysis

In tuber skin and flesh, K, Mg, P, S and Cu concentrations were significantly higher in both organic treatments compared with the conventional potatoes (Table 3). Skin concentrations of Mn and Fe were higher in conventional than in organic potatoes. Fe and Mo concentrations in the flesh of organically grown tubers were nearly double those of conventionally grown potatoes. Ca levels were not significantly different between treatments.

Table 2. Concentration of solanidine in flesh and skin of 'Dark Red Norland' potatoes grown organically, with or without compost, or conventionally at OARDC, Wooster, OH in 2002

Sample type	Solanidine concentration ($\mu g\,g^{-1}$ dry weight)[a]
Flesh	
Conventional	11.6 ± 2.2
Organic without compost	28.2 ± 4.9
Organic with compost	28.4 ± 11.9
Skin	
Conventional	1406.2 ± 164.2
Organic without compost	2679.1 ± 674.7
Organic with compost	2058.7 ± 163.4

[a] Results from analysis of variance (ANOVA) indicate that treatment effects on flesh and skin levels were not significant at $p \leq 0.10$. Values shown are the mean of four replicates ± standard error. Replicate means based on the analysis of four five-tuber composite samples.

DISCUSSION AND CONCLUSIONS

Quality in the vegetable industry has typically been described by farmers and produce handlers using easily measurable parameters that affect harvestability, handling, shelf-life and appearance.[30] Yet, marketing systems offering organically grown vegetables may also require consumer-oriented (ie sensory and nutritional) factors. Additional information regarding management–quality relationships, particularly in organic systems, will assist organic farmers and marketers in achieving and maintaining crop quality targets from production to points of purchase. The major goal of this study was to assess cumulative production system effects on potato quality while controlling for soil type, variety and other major factors.

Panellists discriminated between boiled wedges of potatoes taken from conventional and organic systems, provided that samples contained tuber skin. Tuber physiological age, climatic conditions during tuber formation, and levels of glycoalkaloids and other metabolites (eg phenols) could explain the sensory differences perceived between samples.

Physiological age is most often described in terms of its effects, but its mechanism is unknown. However, temperature is thought to drive physiological age, with high temperatures during growth advancing tuber physiological age and altering tuber chemical composition.[31] In the current study, organic potatoes were planted 3 weeks after the conventional potatoes and harvested 2 weeks earlier. Altering planting and harvesting dates has minimised weed pressure in organic potato systems,[32] and this approach had the desired effect in our study. Nevertheless, organic potatoes accumulated fewer heat units than

Table 3. Macro- and micronutrient levels in flesh and skin of 'Dark Red Norland' potatoes grown organically, with or without compost, or conventionally at OARDC, Wooster, OH in 2002

	Nutrient concentration (μg g^{-1} dry weight)[a]										
Sample type	Ca	K	Mg	P	S	B	Cu	Fe	Mn	Mo	Zn
Flesh											
Conventional	343.3	24024.8b**	1183.6b**	3613.4b**	1586.8b**	6.3	10.4c**	51.9b^{+}	16.9	0.5b^{+}	29.4b^{+}
Organic without compost	425.5	34819.0a	1572.3a	5014.5a	2495.7a	5.9	12.1b	102.9a	11.1	1.0a	30.7ab
Organic with compost	259.3	33780.0a	1646.7a	5030.1a	2612.7a	4.6	13.9a	96.7ab	12.4	0.9ab	32.6a
LSD$_{0.05}$	31.0	2001.4	172.9	236.3	206.9	5.6	1.7	49.6	6.6	0.5	2.7
Skin											
Conventional	1445.7	52700.0b**	1706.4b**	3632.7b**	1946.5b**	13.1	16.7b*	779.7a**	99.6a*	0.6	37.8
Organic without compost	1481.7	64206.0a	2304.4a	4532.3a	2575.1a	13.9	19.9a	445.0b	25.9b	0.6	40.7
Organic with compost	1127.9	61343.0a	2215.8a	4972.4a	2563.5a	12.3	20.0a	420.7b	28.0b	0.7	42.2
LSD$_{0.05}$	535.4	5975.0	215.9	476.4	262.8	4.0	2.0	182.9	50.8	0.4	5.5

[a] Means within the same sample type and column followed by different letters are significantly different at $^{+}P \leq 0.1(+)$, $^{*}P \leq 0.05$ or $^{**}P \leq 0.001$. LSD, least significant difference.

the conventional potatoes (data not shown) and, although few visual differences between organic and conventional potato plants were noted, differences in heat unit accumulation may have impacted tuber sensory quality.

Differences in glycoalkaloid content may also have contributed to perceived sensory differences, as previously reported.[33,34] Glycoalkaloids occur at low levels in all potatoes, can impart a bitter flavour and may have antimicrobial and pesticidal properties. The major glycoalkaloids found in potato are α-solanine and α-chaconine, both of which have solanidine as their alkaloidal aglycone base.[27] Glycoalkaloid content can fluctuate with genetics, soil type, fertilisation practices, tuber size, maturity and processing, and abiotic or biotic crop stress (eg disease, insect, rough handling, moisture, temperature).[34–37]

Few consistent responses of glycoalkaloid levels to crop fertilisation treatments have been reported. Cronk *et al*[38] (as cited in Ref 37) found that excessive N application increased glycoalkaloid content relative to controls receiving normal N applications, while Nowacki *et al*[39] (as cited in Ref 37) found a negative relationship between N and glycoalkaloid levels. In the current study, glycoalkaloid levels appeared to increase with decreasing N application rate, as rates were greatest, moderate and lowest in conventional, organic with compost and organic without compost plots respectively.

Tuber size is also thought to influence glycoalkaloid content, with tubers weighing less than 40 g reported to contain more than double the total glycoalkaloids of larger tubers.[36] Regardless of field treatment, all potatoes used in this study were 3.2–5 cm in diameter and none weighed less than 57 g. Nevertheless, variation in tuber size may have contributed to variation in solanidine levels, as organic tubers tended to be smaller (*ca* 3.5 cm) than conventional tubers (*ca* 4.5 cm).

Processing may also affect glycoalkaloid content. In potato tubers, glycoalkaloids are often concentrated in a 1.5 mm thick layer containing the first *ca* 100 cell layers of cortical and storage tissue beneath the skin. Peeling most tubers removes approximately 60–96% of the glycoalkaloids present.[37] Likewise, during boiling, glycoalkaloids migrate into tuber flesh or otherwise leach from tubers.[40] And, once peeled, judges could not differentiate, using a triangle test, between samples of cooked tubers that had been exposed to various durations of fluorescent light to stimulate solanine concentration.[35] Taken together, these observations could explain why panellists discriminated between conventional and (+) compost wedges with skin but not between any wedges lacking skin. However, it is also important to note that panellists did not distinguish between the two organic treatments, regardless of sample type (± skin). On a dry weight basis, glycoalkaloid levels in the skin were up to 100 times higher than in the flesh. Differences in glycoalkaloid levels as measured in raw potato skins mirroring those in the flesh of cooked samples would be additional evidence that glycolalkaloid levels contributed to the sensory differences among treatments. Levels of phenolic compounds, reported to affect sensory responses in potato[40] but not measured in this study, may have also underlain treatment differences.

Sinden *et al*[34] reported that a threshold concentration in potatoes of 140 μg g^{-1} solanine was routinely perceived as bitter, whereas concentrations above 200 μg g^{-1} caused burning sensations in the throat and on the tongue. However, glycoalkaloid values typically found in commercial potatoes do not influence their acceptance by consumers.[33,34] In our study, panellists evaluating organic samples with skin used descriptors such as 'bitter' and 'metallic', which were also evoked from panellists given potato samples amended with higher than normal levels of glycoalkaloids.[34]

Differences among field treatments in mineral content were also found. Potato is an important source of vitamins and minerals. In this and a related study,[13] P and Mg levels were higher in organic than in conventional tubers. K, S and Cu concentrations were also higher in organic tubers of our study. Mineral levels in the skin and the flesh were measured separately here and higher concentrations of Fe and Mo were found in the flesh of only organically grown potatoes. However, Fe and Mn concentrations were higher in the skin of conventional potatoes. Warman and Havard[13] also found higher levels of Mn in conventional whole tubers, although Fe content varied with year. Based on previous reports suggesting that the strength of potato flavour is tied to mineral levels,[41] differences in mineral concentration found here may have contributed to perceived differences in taste.

This study employed well-controlled but representative conventional and organic field systems to assess their cumulative effects on potato tuber taste, glycoalkaloid levels and mineral nutrient content. Panellists detected differences between organically and conventionally grown potatoes if the skin remained on the samples. Glycoalkaloid levels tended to be higher in organic potatoes. Additional studies employing descriptive analysis are required to understand the nature of this perceived difference. In addition, potatoes from organic plots had significantly higher concentrations of four macronutrients. Future studies will benefit from greater regulation of planting and harvest dates and other production factors.

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