Yield and vitamin C content of tomatoes grown in vermicomposted wastes

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Abstract: Increasing quantities of earthworm digested materials (vermicompost) are being marketed as a peat-free growth medium for amateur and professional food producers. Several studies indicate that growing tomatoes in peat mixed with low concentrations of vermicompost (10–20% by volume) produced by the earthworm *Eisenea fetida* increases yield of plants and marketability of fruits. Here we examined the effect of substituting commercial peat-based compost with four different vermicomposts produced by the earthworm *Dendrobaena veneta*. Vermicompost was added to peat-based compost at rates of 0%, 10%, 20%, 40% and 100% (v/v) and the following characteristics of tomato (*Lycopersicon esculentum* var. Money maker) assessed: germination, yield, marketability, fruit weight and ascorbic acid concentration. Vermicompost significantly increased germination rates (176%) and improved the marketability of fruits at 40% and 100% substitution rates due to the lower incidence of physiological disorders ('blossom end rot' and fruit cracking). Total fruit yield, marketable fruit yield, fruit number, individual fruit weight and vitamin C concentration were unaffected by the presence of vermicompost. Although vermicompost may provide a viable alternative to peat-based growth media, overall, we found little added benefit from using vermicompost. We conclude that some of the previously reported benefits of vermicompost on horticultural production may be overstated and that marketing strategies should reflect this in order to preserve consumer confidence in vermicompost products.

Keywords: ascorbic acid; marketability; tomato; vermicompost; horticulture

INTRODUCTION

Large quantities of earthworm digested materials (vermicompost) are produced annually worldwide, most of which is marketed as a natural fertilizer/inorganic fertilizer substitute for amateur gardeners and professional food growers. Vermicomposts are typically produced from a combination of wastes including animal manures (e.g., cow, horse and pig), green waste, paper pulp or vegetable/fruit processing wastes. In addition, vermicompost is also produced as a by-product of the earthworm breeding process.

Vermicomposting is a low-cost method of treating organic wastes exploiting the ability of some earthworms to fragment the waste residuals in their grinding gizzards.[1,2] The digestion process fragments the waste substrate, accelerates rates of decomposition and increases its plant available nutrient content.[3–5]

Vermicomposts can contain biologically active substances such as plant growth regulators and have frequently been shown to increase plant growth rates in glasshouse and field trials, whether used as a soil additive or as a substitution to soilless growth media.[3–13] Most studies have reported beneficial effects of vermicompost on germination, plant growth and yield with substitutions of 20–40% of vermicompost into a commercial growth medium. The potential for yield enhancement is not unique to vermicompost and increases in tomato yield when grown in municipal solid waste-derived compost have been demonstrated.[14,15] However, not all plant growth experiments have produced such positive results and it may be that plant responses to vermicompost are more species specific than previously reported.[16,17] It is interesting to note that vermicompost production methods in the USA differ in two fundamental ways to those of the UK. The American process is largely undertaken indoors using the earthworm *Eisenia fetida*, whereas in the UK, it is generally an outdoor process using the earthworm *Dendrobaena veneta*, differences in production (i.e. management and earthworm species) may significantly affect compost quality.

Since the discovery that a diet rich in tomato-derived antioxidants can reduce the incidence of some degenerative diseases,[18] there has been much interest in identifying tomato genotypes, growing conditions and post-harvest processes that enhance antioxidant concentrations in fruit.[19–23] Although much of this work has concentrated on the antioxidant lycopene, there is also interest in determining the factors regulating the levels of other antioxidants such as ascorbic acid. The objective of our study was to investigate the effect of *Dendrobaena veneta* derived vermicompost on the germination, growth, yield, marketability and vitamin C content of tomatoes.

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EXPERIMENTAL

Tomatoes (*Lycopersicon esculentum* Mill. var. Money maker) were grown from seed at the University of Wales Bangor, Henfaes Research Centre, Abergwyngregyn, Gwynedd, north Wales (53° 14′ N, 4° 01′ W). A commercial peat-based plant growth medium was purchased from Humax (L & P Peat Ltd, Carlisle, UK). Four separate vermicomposts from commercial *D. veneta* worm breeders were supplied by the Wormcast Company, Canterbury, UK. The basic chemical properties of all composts are summarized in Table 1.

Growing media

Growing media were the main treatment in the experiment, and five different mixtures of commercial peat-based plant growth medium and vermicompost were developed. The vermicompost and peat-based growing media were mixed on a volume basis in the following ratios: 10:90%, 20:80%, 40:60%. These mixtures were prepared on-site, and were used for all germination and growth trials. Results were compared with 100% peat-based growth medium and 100% vermicompost.

Germination experiment

Ten tomato seeds were sown into plug trays containing each experimental treatment in February 2005 (three peat–vermicompost mixtures, one vermicompost only and one peat only control; four separate vermicomposts, total $n = 170$) and allowed to germinate in a heated growth room (20 °C, 16 h photoperiod, 70% relative humidity). After 14 days the germination rate of each treatment was determined.

Plant growth experiment

Twenty-eight days after sowing, five tomato seedlings were selected randomly from each treatment plug tray ($n = 85$) and transplanted into 10 cm diameter plant pots containing the five prepared growth mixtures and transferred into a temperature-controlled glasshouse (min. 12 °C, max. 21 °C) for the remainder of the study, with a minimum of 12 h day length, and watered as required. After a further 35 days, the tomatoes were transplanted into larger pots (25 cm diameter, 14 L volume) for the remainder of the experiment. Thereafter, the plants were watered daily as required and fertilized with a commercial tomato nutrient solution (Levington Tomorite®) containing N:P:K 4:4.5:8 plus 200 mg kg^{-1} Mg (Scotts Company UK, Godalming, UK) following the manufacturer's recommendations. Vegetative suckers were removed and plants were supported with stakes throughout the experiment to reflect commercial growing practices. Fruits were harvested twice weekly over a total of 60 days[7] from the day the first fruits were considered ripe (fruits were considered ripe 9 days after ''breaker'' stage[24]).

Compost analysis

Compost nutrient analysis follow conventional soil nutrient analytical methods. Nutrients from the composted media were extracted using 1 mol L^{-1} KCl at a 1:5 w/v ratio of compost to 1 mol L^{-1} KCl. The samples were extracted by shaking for 1 h at 250 rpm, centrifuged for 10 min at 14 000 × g and the supernatant recovered for analysis after filtering through a Whatman No. 40 filter paper.[25] Total P, K, Ca and Na were measured by perchloric acid digestion. Briefly, 0.2 g of dry compost was digested with 2 mL perchloric acid at 200 °C for 4 h, allowed to cool, diluted to 15 mL with distilled water, filtered (Whatman No. 541) and stored for analysis.

Total C and N were measured using a LECO2000 CHN analyser (LECO Corp., St Joseph, MI, USA). NO_3^- and NH_4^+ were determined colorimetrically[26,27] with a Skalar SAN segmented flow analyser (Skalar Analytical, Breda, The Netherlands). Phosphate was measured colorimetrically.[28] K, Na and Ca were measured using a Sherwood Scientific 410 flame photometer (Sherwood Scientific, Cambridge, UK). pH and electrical conductivity (EC) were determined in a 1/1 v/v extraction.[29] Moisture content was determined by drying at 105 °C for 24 h.

Vitamin analysis

Analar forms of ascorbic acid, sodium acetate and metaphosphoric acid (HPO_3) (Sigma-Aldrich Co., Gillingham, UK) were obtained and used as received. Ultrapure deionized water (17 MΩ resistance) was used to prepare solutions throughout the study.

Table 1. Chemical properties of the commercial peat-based growth medium and four vermicomposts prior to planting

	Commercial growing medium	Vermicompost A	Vermicompost B	Vermicompost C	Vermicompost D
Electrical conductivity (mS cm^{-1})	1.7 ± 0.1	0.3 ± 0.1	0.4 ± 0.0	0.4 ± 0.1	0.4 ± 0.1
pH	5.9 ± 0.1	6.8 ± 0.0	7.0 ± 0.0	7.0 ± 0.0	6.4 ± 0.0
Total C (g kg^{-1})	446 ± 6	147 ± 5	250 ± 68	239 ± 54	333 ± 6
Total N (g kg^{-1})	8.1 ± 0.2	11.6 ± 0.5	13.0 ± 2.4	9.8 ± 1.6	18.0 ± 0.5
Extractable NO_3^- (mg N kg^{-1})	2 ± 1	112 ± 2	121 ± 4	130 ± 1	117 ± 4
Extractable NH_4^+ (mg N kg^{-1})	3 ± 1	123 ± 31	42 ± 22	35 ± 22	596 ± 202
P (mg kg^{-1})	776 ± 39	62 ± 9	74 ± 32	69 ± 24	85 ± 30
K (g kg^{-1})	5.5 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	0.4 ± 0.1	0.2 ± 0.1
Ca (g kg^{-1})	18 ± 2	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1

Values represent means ± SEM ($n = 3$).

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Five fruits, at the same development stage, from each growth medium were harvested on 23 August 2005 (total $n = 85$). On the day of harvest, each tomato was cut into quarters, and immediately frozen in liquid N_2 and stored at $-20\,^{\circ}C$ until extraction. Ascorbic acid was extracted by homogenizing 2 g tissue in 10 mL of 0.75 mol L^{-1} metaphosphoric acid. The homogenate was then centrifuged at $6283 \times g$ for 10 min and filtered through a Whatman No. 40 filter paper. The samples were then made up to 25 mL with 0.75 mol L^{-1} HPO_3 solution[30] and analysed immediately. All samples were filtered through a 0.2 μm filter immediately prior to chromatographic analysis.

High-performance liquid chromatography (HPLC) was performed on a Varian Prostar high-performance liquid chromatograph (Varian Inc., Palo Alto, CA, USA) equipped with a Varian Prostar 310 variable-wavelength ultraviolet detector. Chromatographic peaks were quantified using a Star chromatographic integrator (Varian). Separation of ascorbic acid was accomplished by reverse-phase HPLC with an octadecylsilyl stationary phase (4 mm i.d. × 150 mm; 5 μm particle size; Phenomenex Corp., Torrance, CA, USA) at room temperature.[30] The mobile phase was 0.1 mol L^{-1} sodium acetate buffer (pH 4.25), the flow rate was 0.8 mL min^{-1}, sample volume 50 μL and the detection wavelength 250 nm. The retention time of ascorbic acid on the HPLC column was 1.3 min.

Statistical analysis

For the main growth trial, individual tomato plants were laid out in a randomized block design with five replicates of each treatment and five blocks each containing one replicate. All data were analysed using a two-way ANOVA using SPSS (SPSS Inc., Chicago, IL, USA), with the growing medium treatment and block being the main factors. Least significant difference (LSD) was used as post hoc analysis, with significance defined at the $P \leq 0.05$ level unless stated otherwise. Data were analysed for equal variance using Levene's test; where variances were not equal, Dunnett T3 was used as a post hoc test. Where percentage values were not normally distributed, values were transformed using the Arcsine command prior to statistical testing. Results of ANOVA tests are presented in Table 3.

RESULTS

Germination and plant growth

Vermicompost significantly increased the germination and emergence rate of tomato in all but one case ($P \leq 0.05$; Fig. 1). It was only in seeds planted in 100% vermicompost A that germination was not significantly enhanced. In comparison to the peat-based growth medium, increased germination rates were observed in all vermicomposts, regardless of source. Overall, the highest germination rates were observed in the 20% vermicompost treatment (208% increase over peat-based control), while the 10% vermicompost treatment gave the lowest enhancement of germination rates (145% increase over the control). In comparison to the peat-based compost, the amount and type of vermicompost had no significant effect on plant height at the time of first flower emergence (23 ± 1 cm), time to flower (67 ± 4 days) or the time

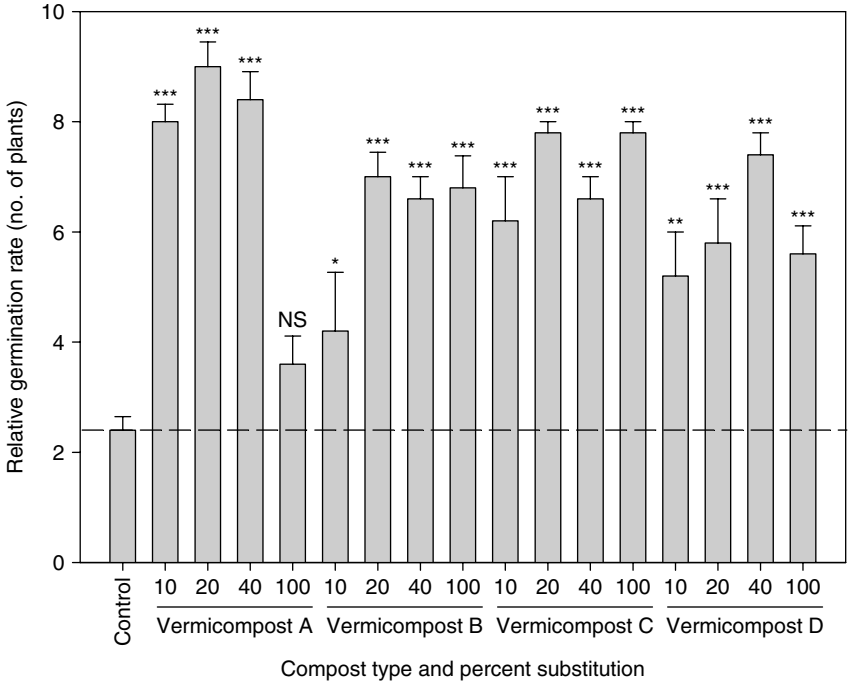

Figure 1. Germination of tomato seeds grown in a commercial growth medium substituted with four different vermicomposts at rates of 0%, 10%, 20%, 40% and 100%. Values represent mean ± SEM ($n = 10$). Level of statistical difference compared to peat-based growing medium (control) is indicated as follows: $^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$; NS, no significant differences (LSD). Dashed line denotes the control value.

to achieve fully ripe fruit (151 ± 1 days) ($P > 0.05$; data not presented).

Fruit yield and quality

Although vermicompost substitution rates of 10% and 20% increased fruit yield in comparison to the peat-only treatment, substitution rates of 40% and 100% resulted in a slightly decreased yield, although none of these effects were statistically significant (Table 2, 3).

Growing tomatoes in vermicompost significantly increased the amount of marketable fruit, particularly in the 40% substitution treatment (Table 2, 3). This increased percentage marketability resulted from a decrease in tomatoes found to have blossom end rot and other skin blemishes (Table 2, 3); however, reduced yield at 40% substitution rates meant that statistical analysis of marketable tomato yields revealed fewer treatment differences in comparison to the total yield results (Table 2, 3).

Vitamin content

The mean ascorbic acid content of the tomatoes was $126 \pm 9\,mg\,kg^{-1}$. No significant differences were apparent in tomato vitamin C content irrespective of vermicompost type or substitution level ($P > 0.05$; Table 2, 3).

DISCUSSION

Small increases in fruit yield were seen when tomatoes were grown at low vermicompost substitution levels; however, these were lower than reported previously.[7,9] Moreover, no significant differences in number of fruits produced per plant were observed in this case.

Our study shows that four commercially produced vermicomposts did not increase plant growth, total tomato yield or fruit vitamin C content (Table 2). Our work failed therefore to reproduce the previously reported tomato yield-enhancing effect ascribed to some vermicomposts.[3,7,9] This implies that significant variation may exist in the growth-promoting properties of different vermicomposts or that plant response is cultivar specific. In a glasshouse study similar to the one performed here, also normalized for nutrient content, increases in tomato fruit yield of 58% have been reported at a 20% vermicompost substitution rate,[7] compared to only a 16% non-significant increase observed here. Moreover, in our study, within-treatment group variability was greater than between treatment groups and a yield enhancement at similar substitution level cannot be claimed. Atiyeh *et al*.[7] reported a growth enhancement for the 'Rutgers' tomato cultivar, while our study used 'Money maker'. We used 'Money maker' as it represents the industry standard for assessing compost quality in the UK. Further studies are therefore required to investigate the influence of cultivar variety on plant response to vermicompost. If significant differences do exist, then genomics and proteomics technology could be used to elucidate the mechanistic basis of the vermicompost response.

Our study used vermicompost produced by the earthworm *D. veneta* rather than *Eisenea fetida*; however, as the behaviour, lifestyle and digestive processes of both species are very similar it is unlikely that they had a negative effects on the properties of the vermicompost (e.g., phytotoxin production, stimulation of fungal pathogens). However, this factor cannot be discounted and is worthy of further research.

The four vermicomposts studied here originate from different producers distributed throughout the UK, each composting different combinations of manures, paper pulp and fruit wastes. Although the vermicomposts had been matured for different times from 1 year (vermicompost A) to 5 years old (vermicompost C), with the exception of NH_4^+, there was little overall difference in plant nutrient content at the beginning of the growing period. We assume that differences in initial NH_4^+ content or other nutrients (e.g., Cu, Zn, Mn, B) did not affect final yield since no significant differences were observed between compost type (data not presented). N speciation has little influence on tomato yield, although it does significantly influence the taste characteristics of the fruit.[31] Some vermicompost manufacturers claim

Table 3. Details of ANOVA statistical analysis for selected parameters

Parameter		
Yield (kg fruit per plant)	$F(4, 83) = 2.562$	$P = 0.530$
Damaged fruit (number per plant)	$F(4, 83) = 10.772$	$P = 0.000$
Percent marketable fruit	$F(4, 83) = 4.632$	$P = 0.004$
Vitamin content ($mg\,kg^{-1}$)	$F(4, 18) = 0.762$	$P = 0.564$

Table 2. Yield responses of tomato (*Lycopersicon esculentum* var. Money maker) to substitution of commercial peat-based growth medium with vermicompost

Percentage growth medium substituted with vermicompost	0% (Control)	10%	20%	40%	100%
Total yield (kg per plant)	2 ± 0.1	2 ± 0.1 NS	2 ± 0.3 NS	2 ± 0.2 NS	2 ± 0.3 NS
Marketable yield(kg per plant)	1 ± 0.1	2 ± 0.1 NS	2 ± 0.1 NS	12 ± 0.1 NS	1 ± 0.1 NS
Percentage marketable fruit	62 ± 3.0	70 ± 3 NS	69 ± 6 NS	$82 \pm 3^{**}$	$75 \pm 10^{*}$
Blemished fruits (number per plant)	10 ± 3	12 ± 1 NS	9 ± 1 NS	$5 \pm 1^{***}$	$3 \pm 1^{***}$
Fruit vitamin C content ($mg\,kg^{-1}$)	124 ± 10	133 ± 19 NS	126 ± 29 NS	141 ± 11 NS	90 ± 14 NS

Level of statistical difference compared to peat-based growing medium (control) is indicated as follows: $^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$; NS, no significant differences (LSD).

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enhanced taste for fruits and vegetables grown in vermicompost in their publicity material. No scientific evidence exists to support this claim and we did not rigorously test the taste properties of tomatoes produced from the different treatments. Further work is required to clarify the effect of vermicompost on fruit taste.

Our previous work has shown that vermicomposts produced by *D. veneta* can enhance and depress plant growth depending upon the rate of vermicompost substitution and horticultural crop type. In those trials the vermicomposts were less than 6 months old and had been produced in indoor experimental beds. In many situations in the UK, vermicomposts are stored outdoors where precipitation and leaching of soluble nutrients and other compounds may occur. Long-term storage either indoors or outdoors can also be expected to cause changes in both the chemical and microbiological properties of the vermicompost. As this can be expected to significantly affect its effectiveness as a growth medium, further work is required to ascertain the optimal storage time and conditions to preserve vermicompost quality.

It has been hypothesized that changes in physio-chemical properties and the presence of plant growth regulators within vermicompost are major factors which enhance tomato fruit yield.[3,7,32] Plant growth regulators and plant growth-promoting rhizobacteria are ubiquitous in soils and other organic soil amendments,[32] yet rarely have they been shown to actually cause a yield enhancement under commercial conditions. While high numbers of IAA-producing plant growth-promoting rhizobacteria have been isolated from conventional growing media, these have been shown to actively suppress tomato, lettuce and beet seedling growth.[33–35] As plant growth regulatorss can be expected to undergo a number of fates in compost (e.g., leaching, biotic and abiotic transformation, sorption[32]), further work is needed to characterize their dynamics in vermicomposts. This work reinforces the need for further work to elucidate the yield enhancement factors of vermicompost. Without this information it will remain difficult to formulate effective quality standards that may be used by the vermicompost industry to ensure product quality and maintain consumer confidence.

Although overall fruit yield was not affected by the addition of vermicompost, germination rates were significantly enhanced, as was the proportion of marketable fruit, particularly at a 40% substitution rate. While we showed substantial increases in germination within most vermicompost treatments, previous studies have only reported germination enhancement at low vermicompost substitution levels.[7] Again this highlights the differences between individual vermicomposting studies using the same plant species. This lack of clarity is preventing the formulation of effective horticultural guidelines and reinforces the need to move away from using substitution volume as a key criterion for ranking effectiveness.

At the beginning of the cropping period, fruit marketability was directly affected by the incidence of blossom end rot. Vermicompost, particularly at 40%, reduced the incidence of this and other skin blemishes (Table 2). Blossom end rot is a common physiological disorder induced when the demand for Ca exceeds supply. This may result either from (1) low intrinsic Ca levels within the compost, (2) excessive concentrations of N, S, Mg, K, Cl leading to rapid vegetative growth, or (3) reduced movement of Ca into the plant resulting from excessive soil moisture fluctuations.[36] Since plants were watered regularly, we can rule this out; however, changes in water availability induced by structural changes in the growing medium may have resulted from vermicompost addition. Toward the end of the cropping period the incidence of green fruit cracking increased; this is a result of environmental conditions, particularly swings in moisture content of the growth medium, but as with blossom end rot it was ameliorated by the substitutions of vermicompost, particularly at higher levels (Table 2). Few fruits showed low-temperature-related disorders such as misshapen fruits (cat facing), although a slightly higher incidence of high-temperature-induced uneven ripening (greenback) was observed, particularly in the corners of the glasshouse; vermicompost addition had no effect on the incidence of this. No studies have reported on the suppressive effect of vermicompost on physiological disorders and this merits further research.

The levels of vitamin C measured here were very similar to previous studies on tomatoes grown under conventional conditions.[17] Plants grown in 100% vermicompost showed lower concentrations of ascorbic acid than plants growing in other media, although the highest concentrations of ascorbic acid were recorded in plants growing in 40% vermicompost (+12% relative to the peat-based control). Fruit antioxidant concentrations in fruit are dependent upon external factors (e.g., light intensity, temperature) and internal factors (e.g., cultivar variety, fruit load and position).[19–21,37,38] While plant growth media and fertilizer regime may influence antioxidant concentrations,[17,39,40] our study showed that vermicompost exerted little influence on vitamin C levels in tomato. Further studies are required to ascertain the effects of vermicomposts on other nutritional aspects of tomato fruits.

CONCLUSIONS

We conclude that the vermicomposts used in this study showed little of the yield and growth-enhancing effects previously reported for vermicomposts. It is likely that this disparity arose due to either differences in vermicompost production method, earthworm species, process management or storage conditions. In our study, vermicompost source had little effect on the overall growth response and quality of a tomato crop. Several workers have reported on the growth

enhancement properties of vermicomposts. Further, there are many largely unsubstantiated claims made by some vermicomposting companies in an effort to enhance product sales. Further work is therefore clearly needed to explicitly confirm and understand the mechanistic basis of the growth enhancement effect. If this is understood then vermicompost quality standards can be formulated allowing the industry to develop and maintain consumer confidence.

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