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Production of Certified Tomatoes, Peppers and Eggplants with Reference to Existing Legislation

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ABSTRACT

There are two basic forms of certified produce of the Solanaceae (tomato, pepper and eggplant): (1) certified produce from sustainable management, and (2) produce grown by organic cultivation methods. In the first part of this review, the certification agencies, the rules and certification procedures are presented. In the second part, recent research relating to the maintenance of soil fertility for the production of certified produce is presented. Composts derived from various organic and waste materials are described and evaluated with particular reference to organically grown tomatoes, peppers and eggplants. Finally, the quality and safety of organic produce is briefly discussed.

Keywords: *Capsicum annuum*, certified produce, *Lycopersicon esculentum*, organic crops, *Solanum melongena*, sustainable agriculture

Abbreviations: BRC, British Retail Consortium; **CAP**, Common Agricultural Policy; **CB**, Certification Bodies; **EANUCC**, European Article Numbering International Uniform Code Council; **EU**, European Union; **FAO**, Food and Agriculture Organization of the United Nations; **GAP**, Good Agricultural Practices; **ICPR**, Importing Countries' Phytosanitary Requirements; **IFOAM**, International Federation of Organic Agricultural Movements; **IOAS**, International Organic Accreditation Services; **ISTA**, International Seed Testing Association; **IVA**, Independent Verification Agency; **MSSC**, municipal sewage sludge compost; **OM**, organic matter; **RH**, relative humidity; **USDA**, United States Department of Agriculture

CONTENTS

INTRODUCTION

During recent years in Europe, there has been an ever increasing demand for agricultural products that are free of chemical residues from agricultural practices, such as soil fumigation, plant protection, weed control or the use of plant growth regulators, and which (particularly in leafy vegetables) do not contain high concentrations of nitrate

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Invited Review

(La Via and Nucifora 2002; Magkos *et al*. 2006). Such produce is widely deemed to be healthier than that produced by conventional practices, the residue or nitrate content of which may be high, and is frequently perceived to be more nutritious (Magkos *et al*. 2003). The cultivation methods employed to produce it fall into two categories: (1) the certified production of produce using methods of sustainable agriculture, incorporating for example integrated pest management, and (2) organic vegetable cultivation.

The production of certified vegetable produce is not, as some sellers of such products wish to express, 'a return to the past', but rather the systematic adoption of all the research findings to date for the purpose of confronting the problems of plant nutrition, pest and disease control during cultivation (Poincelot 2004). Moreover, a basic aim is to improve the use of soil, water and energy so as to minimize the adverse consequences of agricultural practices on the environment. The requirements for the production of such produce include strict legislation to regulate the production process, the provision of reliable inspection services and, most importantly, the conscientious choice of the growers to adopt such a model of vegetable cultivation (ICCA 2007).

Each country has its own certification system and organizations, either public or private, which undertake the task of inspecting and certifying the produce. Although the inspection agencies are different for each country, the rules and standards that are followed are common for all. The International Federation of Organic Agricultural Movements (IFOAM) is an international organization (IFOAM 2008) that has the responsibility for coordinating and processing the rules that govern organic agriculture, with the basic regulation 2092 (EC 1991) and its subsequent amendments, and informing its members on the correct implementation of rules. The products of organic and sustainable agriculture must be labeled. The label must carry the following essential information: species, date of production, producer's data (such as altitude, climatic conditions, production techniques), the name of the certification agency and an indication of the status of the product within the certification process. For example, within organic agriculture, there are two fundamental stages: (1) A transitional stage of one year for annual crops and two years for perennials, and (2) The final stage of certified organic production.

Tomato (*Lycopersicon esculentum* Mill.), pepper (*Capsicum annuum* L.) and to a lesser extent eggplant (*Solanum melongena* L.) are three vegetable species that are commonly grown within Europe and make an important contribution to the daily human diet. A significant proportion of the total production of these crops is grown under controlled conditions within greenhouses, where the cultivation methods in general do not differ significantly from those of conventional greenhouse production. However, techniques that create better lighting, aeration and the avoidance of excessive RH within the crop environment contribute to the prevention of disease occurrence and are therefore commonly practiced for organic crops. Such techniques include suitable pruning and training of plants, as well as carefully controlled irrigation and ventilation.

Organic greenhouse crops differ significantly from conventionally grown crops in that synthetic chemical inputs of fertilizer or pesticide for pest and disease control are not permitted (Day 1990). By contrast, in sustainable agricultural systems, low inputs of chemicals are permitted, but the final product must be free of residues. In consequence, one could consider sustainable systems as the forerunners in the transition to organic agriculture. Despite an increase in the price of produce grown by organic methods, the consumer gains from the availability of produce which, because it does not contain chemical residues, may be considered healthier than that of conventional agriculture (Canavari *et al*. 2002), while the environment benefits from the conservation of natural resources (soil, water, energy) (Poincelot 2004).

In the present review, current European legislation with respect to the production and marketing of certified produce (tomato, pepper and eggplant) is presented, following which recent research into relevant cultivation techniques is described and discussed.

LEGISLATION RELATING TO THE PRODUCTION OF CERTIFIED FRUIT OF TOMATO, PEPPER AND EGGPLANT

Certification refers to the confirmation of certain characteristics of an object, product, person, or organization. This confirmation is often, but not always, provided by some form of external review, education, or assessment. One of the most common types of certification in modern agriculture is crop certification, where a farm is certified as being able to competently fulfill a norm or standard.

There are six main points of certification in the Solanaceae:

1. EU Certification for market: 1148 (EC 2001) and 408 (EC 2003).
2. Certification of sustainable management (EurepGap-GlobalGap)
3. Organic agriculture: 2092 (EC 1991).
4. Certification of plant hygiene (phytosanitary certification).
5. The International Seed Testing Association (ISTA) certification of seed.
6. The Codex Alimentarius for the Solanaceae.

European certification and checks on conformity to the marketing standards applicable to fresh Solanaceae

Quality and certification requirements

The marketing standards for quality and labelling of fruit and vegetables are laid down in the basic regulation EC 2200/96 (EC 1996) within the framework of the Common Agricultural Policy (CAP) of the EU. The products that do not comply with these standards are barred from the market. Sweet peppers are subject to the EC Marketing Standards as laid down in regulation 1455/1999 (EC 1999) amended by regulation 2147/2002 (EC 2002). Tomatoes are subject to regulation 790/2000 (EC 2000), whereas eggplants are subject to regulation 1292/81 (EC 1981).

Certificate of Conformity

In June 2001, the EU Commission adopted Commission Regulation EC 1148/2001 (EC 2001), under which all imported fresh fruit and vegetable consignments from countries outside the EU and subject to the EC Marketing Standards are required to have a recognised Certificate of Conformity before they are allowed to enter the EU market.

Phytosanitary certificates (EC 2001) are required to:

- bear the official text in conformity with the FAO model,
- be drawn up in one of the official languages of the European Community,
- be filled in completely and either entirely in capital letters or entirely in typescript; if an annex is used, the phytosanitary certificate shall bear the words: "see annex" and the annex shall bear the words: "annex to phytosanitary certificate number … ". The annex must be authorised by a stamp of the organisation and signature,
- be *e*-stamped and signed by an authorised officer of the Plant Protection Service,
- be issued not more than 14 days before leaving the country,
- indicate the origin and the destination of the plants or plant products,
- indicate, besides the name of the produce, the botanical names of the plants,
- indicate the number and a description of the packages,
- indicate net weight.

Certification and EurepGAP-GlobalGAP

EurepGAP is a private sector body that sets voluntary standards for the certification of agricultural products around the globe. EurepGAP is an equal partnership of agricultural producers and retailers who want to establish certification standards and procedures for Good Agricultural Practices (GAP) (EurepGAP 2008).

EurepGAP is a pre-farm-gate-standard, which means that the certificate covers the process of the certified product from before the seed is planted until the product leaves the farm. EurepGAP is a business-to-business label in the form of a set of normative documents, and is therefore not directly visible to the consumers. The EurepGAP standard is primarily designed to maintain consumer confidence in food quality and food safety. Other important goals are to minimize the detrimental environmental impacts of farming operations, optimize the use of inputs and to ensure a responsible approach to worker health and safety. EurepGAP is one of the very few standardization organizations that operates globally and enjoys a high level of political and financial independence from the public sector, as well as from the influence of individual members and shareholder agendas. To keep its independence, EurepGAP does not conduct the certification process itself. Farmers or farmer groups can only be certified against the EurepGAP criteria by authorized Certification Bodies (CB). A EurepGAP Certification Body is a company fulfilling the requirements for approved EurepGAP CBs to grant EurepGAP certification in the relevant product scope. Currently EurepGAP is working with over 100 CBs in more than 70 countries.

In international trade and major markets, there are several private sector quality standards. For example, the 'Tokyo Standard' is believed to be the highest in any international market. In the UK, there is the 'British Retail Consortium (BRC) Standard', which was established by the five largest supermarket chains to ensure uniformity of imported product. Included in the Grade (Condition) Standards for the Solanaceae (Hargreaves 2004) are the following:

- Size
- Colour
- Firmness
- Shape
- Interior (hidden) damage
- Overall appearance
- Stems cut at the appropriate place
- Dryness (discoloration) of stem
- Freshness
- Presence of dirt

Overlaying the BRC Standard is the EurepGAP Standard, which can easily lead to confusion at packing-houses. EurepGAP was established by a group of European agricultural interests (the Euro-Retailer Produce Working Group, Good Agricultural Practices) following public outcry over the lack of adequate food safety controls and no traceability back to origin, especially of imported goods.

EurepGAP standards provide a product quality verification framework, which ensures that certain environmental and social conditions must be met by the suppliers of fresh produce and cut flowers. EurepGAP standards extend to seed, seedlings, soil and water management, fertilizer, pesticides, harvest methods, post-harvest treatments, waste management, worker health and safety, as well as environmental management. The EurepGAP organization serves as its own accreditation body and auditing is carried out by EurepGAP-sanctioned bodies. There is no labeling requirement *per se*. A product identification system, such as the one proposed by the EANUCC Traceability Implementation (Annex C), calls for the documentation of product movement from the farm to the point of sale. Traceability has become part of the business agreement between exporters and importers covering shipments into some of the larger international markets.

Certification and organic agriculture

Organically-grown fruit and vegetables (including fruit of the Solanaceae) have become increasingly popular, especially in European markets and North America (Delate 2002; ITC 2004; Winter and Davis 2006). Consumers are willing to pay more if they feel assured that the products have been grown without the use of synthetic fertilizers or pesticides (Makatouni 2002; Magkos *et al*. 2006). Familiarity with the organizations that set the standards for the production and processing of organic produce is essential. The IFOAM has articulated standards that are largely incorporated at a national level for agricultural commodities and for processed food. Their accreditation body is known as the International Organic Accreditation Services Inc. (IOAS), and audits are performed by third-party, IOAS-accredited certifying bodies. The EU has a Statutory Law on Organic Food Labeling for organic agricultural commodities and for organic processed food. In the USA, there is a national organic programme established by the USDA with accreditation authority (Winter and Davis 2006). In Canada, organics are not yet regulated by the government.

According to EU Regulation 2092/91 (EC 1991), seeds of the Solanaceae and vegetative propagation material (potato) used in organic agriculture must also be produced by organic methods. However, conventional seeds and propagation material may still be used for organic production during a limited transitional period, and subject to the approval of the competent authority of the Member State.

Certification of plant hygiene (phytosanitary certification)

Phytosanitary seed inspection methods

For the Solanaceae, the phytosanitary inspection of seeds usually aims principally at the elimination of the pathogen *Xanthomonas campestris* pv. *vesicatoria*. Each state designnates a public or private service to carry out the phytosanitary inspection and the issue of phytosanitary certification (USDA-NSHS 2002). The inspection service must conform to the following criteria:

Criterion 1 - Empirical Test Data

New techniques should have the following parameters included in the development process.

Sensitivity - Determine how sensitive the assay is in terms of either percent-infected seed or target pathogen quantification, such as CFU, number of conidia, etc. The members may need to make an arbitrary determination as to whether the methods in question are sensitive enough, or they may make a recommendation that the test requires further work. The panel members should also make recommendations on the sample size if this is not clearly spelled out in the existing procedures for that test.

Specificity - Determine whether the assay is capable of detecting a range of isolates of the pathogen, for example from different geographical regions or races. Determine whether other closely related organisms are separated with the technique.

Repeatability and Reliability - Replicate experiments of 1 and 2 will help determine these parameters. Additional experimentation, including samples of different types of seed (varieties, production areas, etc.), will further refine these parameters.

Criterion 2 - Comparative Test Data

Comparisons with already established techniques will yield useful information regarding new techniques. If a new technique performs as well or better than an established technique then it should be accepted. This information is generated internally through the developmental process or through comparative testing. (These criteria may be of limited applicability to panel members evaluating existing test methodologies.)

Criterion 3 - Historical Data

If a technique has been used in industry or academia, there may be some indication or record of the number of uses of that technique. There may also be a record of the number of complaints associated with a particular assay. These records may be a good indicator of the effectiveness of the assay.

Other Criteria

The members should also consider other criteria that might have a significant impact on their recommendation, such as cost, time, and any special facilities required to perform the test.

Phytosanitary field inspection methods

The presence or absence of diseases relevant to the inspection requirements for the Solanaceae is first determined by visual examination of the plants in the field. Descriptions of the signs and symptoms are provided in a manual (CAMIB 2006) for the individual diseases of the seed crops, and other established aids to identification may also be used. Inspections have to be made at a crop growth stage when the signs or symptoms of a disease are likely to be evident, and an appropriate number of plant samples representative of diseases in the field should be taken for laboratory confirmation of the visual diagnosis. More extensive sampling should be carried out when visual symptoms are insufficient to ensure accurate diagnosis. Samples of suspected disease tissue should be kept flat in paper envelopes or towels in a plastic bag in an ice chest. All samples should be correctly labeled to indicate the date, time, location, crop, and plant part. Samples should be processed systematically in a laboratory facility with demonstrated proficiency in diagnosing plant diseases, and inspection reports and certificate should be made on a standard form (USDA-NSHS 2002).

Options for export phytosanitary certification

Official assurances may be provided for exports of plant products where an exporter elects to operate one of the following options:

End Point Consignment Inspection - Within this option every export consignment is subjected to phytosanitary inspection prior to export by an Independent Verification Agency (IVA) to confirm the plant product's compliance with the ICPR (Importing Countries' Phytosanitary Requirements) for the country of destination as nominated by the exporter.

Approved Organization Programme - This option formally recognizes the Approved Organizations System and the competent staff within it as the primary means of ensuring compliance with the ICPRs under an IVA regime of system and surveillance audits to verify the Organization's system output(s). Within this option, Organizations shall document their system using the HACCP / ISO2200 framework, as a means of identifying and managing the risks associated with their method of operating. The HACCP/ISO 22000 framework is used to identify, control, manage and eliminate or minimise hazards and other risk factors to plant products in compliance with ICPRs.

The International Seed Testing Association (ISTA) certification of seed

Issue of seed certificates

The ISTA certification covers the laboratory inspection of seeds of the family Solanaceae and is aimed at bringing uniformity to seed testing methods. For this reason, the Food and Agriculture Organisation of the United Nations (FAO) and the International Seed Testing Association (ISTA) signed a Memorandum of Understanding in 2006 (ISTA 2007) whereby the ISTA achieved its vision of producing internationally agreed rules for seed sampling and testing, accrediting laboratories, promoting research, and providing international seed analysis certificates, training and dissemination of knowledge in seed science and technology to facilitate seed trading nationally and internationally (ISTA 2007).

The number of ISTA certificates increased by 45% in 2006, compared to the previous year (ISTA 2008), with a total of 116,046 certificates being issued. The number of certificates issued in 2006 did not quite reach the level of 2000 (134,480) and 2004 (130,540), but increased considerably compared to the years 2003 (90,400) and 2005 (79,662).

ISTA Laboratory Accreditation Standard

This Standard specifies the criteria which must be fulfilled by laboratories in order to obtain and maintain their status as an ISTA-accredited laboratory and their authorisation to issue ISTA certificates. This Standard covers all steps from sampling to the issuance of ISTA certificates (ISTA 2007).

Application forms are obtainable from the ISTA Secretariat. In order to obtain accreditation, completed forms must be lodged with the ISTA Secretariat. The applicant must meet the required organizational and other requirements outlined in this Standard, show competence by successfully completing the pre-accreditation proficiency test, and demonstrate competence during the on-site assessment of the laboratory's facilities by auditors appointed by the ISTA Executive Committee. Applicants pay for the services rendered during the accreditation assessment (proficiency assessment, on-site assessment, and document evaluation), and pay an annual fee for being an accredited member of the ISTA (ISTA 2004).

The Codex Alimentarius for the Solanaceae

The Codex Classification of Foods and Feeds is intended primarily to ensure the use of uniform nomenclature and secondarily to classify foods into groups and/or sub-groups for the purpose of establishing group maximum residue limits for commodities with similar characteristics and residue potential (Codex Alimentarius 2006).

The major differences in exposure to pesticides and metabolites of pesticides in Solanaceous plants and animals call for a primary classification into foods and feeds of plant origin and those of animal origin. Processed foods prepared from these primary food commodities are again separated into those of plant origin and those of animal origin.

The Codex Classification of Foods and Animal Feeds was published in Part 4 of the "Guide to Codex Recommendations Concerning Pesticides Residues" in 1989 (Codex Alimentarius 1989). The Codex Classification uses five classes and each class is divided into types. Tomatoes, peppers and eggplants belong to Group 012, classed as 'Fruiting vegetables, other than Cucurbits, derived from the immature and mature fruits of various plants, usually annual vines or bushes'. The Codex Classification must be maintained throughout the entire certification process. In addition, since changes in the quality characteristics of produce frequently arise, the descriptors used for quality definition also change. For example, the definition of produce defined for tomato in 2007 (FAO/WHO 2007) is as follows:

'This Standard applies to commercial varieties of tomatoes grown from *Lycopersicon esculentum* Mill, of the *Solanaceae* family, to be supplied fresh to the consumer, after preparation and packaging. Tomatoes for industrial processing are excluded. Tomatoes may be classified into four commercial types: Round, Ribbed, Oblong or Elongated, "Cherry" tomatoes and "Cocktail" tomatoes'.

According to the Codex, the countries that certify exports of food and those importing countries which rely on export certificates should take measures to assure the validity of certification. Validation measures by exporting countries may include achieving confidence that official or officially-recognized inspections systems have verified that the product or process referred to in the certificate conforms with the Codex requirements. Measures by importing countries may include point of entry inspection systems, the audit of exporting inspection systems, and ensuring that certificates themselves are authentic and accurate (Codex Alimentarius 1995). Countries should recognise that different inspection/certification systems may be capable of meeting the same objective, and are therefore equivalent. The obligation to demonstrate equivalence rests with the exporting country.

THE MAINTENANCE OF SOIL FERTILITY FOR THE PRODUCTION OF CERTIFIED TOMATOES, PEPPERS AND EGGPLANTS

Manure

The oldest known method for maintaining soil fertility is the incorporation of manure, several forms of which may be used, e.g. bovine, poultry, horse, swine and rabbit manure. In addition to their value as an organic amendment, manure also contains nutrients such as N, P, K and others. The amount of manure applied should be regulated according to the nature of the soil and the crop, taking care to avoid overuse and possible leaching (Poincelot 2004). Although nitrate leaching is commonly attributed to the excessive application of mineral N fertilizers, Flores *et al.* (2005) showed that the organic matter derived from manure (e.g. horse manure) also contributed to nitrate leaching and affected the yield of greenhouse grown peppers.

The balanced use of farmyard manure in combination with inorganic nutrient applications has been shown to increase farm profitability for tomato and other vegetable crops (Parmar *et al.* 2007). The relative growth rate of eggplants in the greenhouse was increased more by the application of bovine manure than by bovine urine (Cardoso *et al.* 2008). The application of bovine manure to the soil gave a higher yield of peppers when supplemented with foliar or soil applications of bio-fertilizer, although total yield did not differ from that produced with mineral fertilizers (De Araújo *et al.* 2007). By contrast, the application of goat manure to field-grown peppers had less effect on growth and yield than the addition of mineral N, P and K (Awodun *et al.* 2007). Poultry manure was recommended for pepper production under a tropical climate since it had a greater effect on plant growth than P and is also cheap to obtain (Alabi 2006). Ojeniyi *et al.* (2007) recommend the use of manure in combination with plant waste. These authors found that the application of ground cocoa husk and spent grain in combination with poultry manure gave a higher yield of tomatoes than the application of mineral N, P and K. Ghorbani *et al.* (2008) recommended the use of sheep or poultry manure for high yields of tomato, but aqueous extracts of manure were not effective. Recently, Pearson *et al.* (2008) reported the use of human urine as a N source for tomato and other vegetable crops. Dry matter yield of tomato increased with increasing N, either in the form of urine or urea, up to 200 kg N ha^{-1}. However, human urine, unlike urea, increased the soil EC, thus indicating that the optimum rate of urine application may depend on the saline sensitivity of the crop.

Peat

Especially within the last half of the previous century, sphagnum peat moss was used extensively as a horticultural substrate for soil amendment, garden landscaping, soilless vegetable cultivation, plant propagation and the production of ornamentals and pot plants. As a result of this extensive use of peat, serious diminishment of peat bogs and concomitant damage to the bog or marsh ecosystems has occurred. Peat bogs comprise a valuable historical archive both of human activity and cultural heritage, as well as constituting a unique scientific assembly of plant and animal communities for the safeguard of which proper management and conservation are urgently required (Barkham 1993). Thus although peat is a natural product and as such its use is permitted within organic systems, nevertheless in view of environmental concern its use should be discouraged and alternative forms of soil amendment or composting promoted.

In the following section various alternative forms of compost are presented and evaluated.

Composts from plant debris and agricultural waste

Vegetable garden composts have long been used for soil amendment, plant propagation and pot substrates in conventional as well as organic horticultural situations. Garden waste may also be supplemented with other organic waste, such as cattle slurry (Leroy *et al.* 2008).

The use of traditional thermophilic composts has been shown to increase crop productivity and yields (Maynard 1993; Johnston *et al.* 1995), and their use is usually associated with improved soil structure and enhanced soil fertility (Follet *et al.* 1981), increased soil microbial populations (Barakan *et al.* 1995) and activity (Pascual *et al.* 1997), and an improved moisture-holding capacity of the soil.

The combination of raw materials and the chosen composting method yields a wide range of characteristics, such as organic matter (OM) content, nutrient content, the potential for disease suppression and other physical, chemical, and biological properties. Soil-applied composts improve soil fertility mainly by increasing soil OM and activating soil biota. The nutrient content of the compost should be high, especially N (>1.8%). Composts with these characteristics are produced from raw materials rich in both OM and N, the loss of which is minimized during composting. Typical raw materials for this purpose include animal manures and grass clippings, as well as industrial waste such as abattoir residues and sewage sludge. Various composting methods can yield the required results, including turned windrows, aerated static piles, and in-vessel composting. The composts must be stable, non-phytotoxic, and the hydraulic conductivity, air porosity, and available water should be high. Materials, such as softwood bark, wood shavings, various types of shells or hulls, and coconut coir are characterized by good physical properties after composting. However, because they are relatively resistant to decomposition, these materials should be subjected to long and well-controlled composting, which may be shortened by the incorporation of N-rich organic matter, such as animal manures. High temperatures (>65 °C) may cause ashing, which leads to reduced porosity. In addition to ligneous materials, composts serving as growing media may be produced from numerous organic wastes, such as manures, food industry wastes, etc. These materials are better composted in aerated static piles, which tend to minimize physical breakdown (Raviv 2005).

Because composts are a particularly valuable source of N in organic farming, it is important to minimize the loss of N during composting. Raviv *et al.* (2004) used high C/N additives (wheat straw, grape marc or orange peels) in order to reduce N loss during composting of cow manure. N availability was highest in the composts based on manure + orange peels or wheat straw, as indicated by the vegetative response of cherry tomato plants. Zhu *et al.* (2002) reported a higher yield of tomatoes and peppers in an organic substrate based on sawdust, vermiculite, chicken manure and coal cinder than in the soil. The increase in yield was attributed to the high N, P, K and organic matter content of the substrate, as well as its high microorganism and enzyme activity which favoured the transformation of organic components. Zhang *et al.* (2005) used different organic substrates, derived from corn stalks or wheat straw, mushroom residue and lawn grass with manure as substrates in comparison with the soil to select the best growth medium. The results showed that earlier and higher yields were obtained in organic substrates than in soil culture.

Heeb *et al.* (2006) compared the effect of organic (fresh cut grass-clover mulch) and mineral fertilizers on the yield, flavour and nutritional quality of tomatoes grown in sand in the greenhouse. It was observed that the organic fertilizers released nutrients more slowly than the mineral fertilizers, resulting in decreased S and P concentrations in the leaves, limited growth and reduced yield. Fruit from the organic treatment had a lower sugar and higher acid content, and flavour was rated lower than that of the fruit from the mineral fertilizer treatment. Thus, a need for supplementary nutrients in the case of the organic treatment was indicated. Politycka and Golcz (2006) reported that the repeated use of peat negatively affected the growth and yield of eggplant, due to a decrease of water in the substrate and an accumulation of phenolic compounds. By contrast, the repeated use of a bark + peat mixture as substrate positively affected plant growth and yield, due to increased water retention and a low concentration of phenolic compounds.

The intensive cultivation of olives within the Mediterranean basin generates large quantities of plant debris within the fields as well as solid and liquid waste at the processing sites. Olive tree leaves and branches may be composted for use as soil amendments despite the presence of organic acids that may prove phytotoxic during the early stages of composting (Manios *et al*. 1989). Ehaliotis *et al*. (1999, 2005) reported that composts derived from olive leaves and olive pomace could be used either to increase the temperature in the root zone of greenhouse-grown cucumbers or to provide nutrients without causing phytotoxicity.

Composts from agricultural and agro-industrial wastes

The disposal of agricultural and agro-industrial wastes and by-products is an enormous problem, with a negative impact on the environment and a high cost for both growers and the agro-industries. For instance, in Canada, most of the solid waste from greenhouses is trucked to landfills even though this practice wastes both the nutrient-rich plant residues and the land it occupies, as well as costing the greenhouse industry millions of dollars and polluting both the surface water and groundwater by leachates from the landfills (Cheuk *et al*. 2003).

Composting of agricultural and agro-industrial wastes is a promising alternative to the disposal of these valuable organic materials. Composts derived from agricultural and agro-industrial wastes and by-products are generally free of xenobiotics and excessive heavy metal concentrations. Their use in soils and potting media is particularly important in the agricultural regions of the Mediterranean basin, as they may replace livestock manures and imported, non-renewable peat media (Garcia-Gomez *et al*. 2002; Brunetti *et al*. 2005). The principal requirement for their safe application in soils and potting media is a high degree of stability and maturity and the absence of plant and animal pathogens.

Composts made from greenhouse wastes were found to possess a high nutrient value and good physical properties, and could be used as high quality growing media. Composts were tested in a greenhouse against conventional growth media (sawdust) and resulted in a 10% yield increase. Moreover, it was calculated that for vegetable greenhouses that do not have access to low-cost crop waste disposal, this type of on-site composting could be an economically viable waste management option (Cheuk *et al*. 2003).

Abbasi *et al*. (2002) reported that soil amendment by composted cannery wastes (including tomato processing by-products, duck manure, municipal yard waste, and reed canary grass straw) increased the marketable yield of organically grown tomatoes by 33% and reduced the incidence of anthracnose fruit rot. However, the beneficial effects of compost addition were cultivar-dependent. On the other hand, in conventional tomato production, composted yard wastes did not affect the incidence of anthracnose or increase marketable yield.

According to Manios (2004), agro-industry wastes such as olive press cake and pressed grape skin can be composted successfully, especially when mixed with other organic material. Pressed grape skins were considered to be an especially good basis for composting because the EC value was relatively low (1.57 mS cm^{-1}) and the organic matter concentration high (84.5%). The dry residue from olive mills contains phenolics and other substances that are implicated in phytotoxicity, and therefore this material must be composted or otherwise processed prior to horticultural use. One method of decreasing the phytotoxicty of olive mill waste is incubation with saprobe fungi (Sampedro *et al*. 2008). Moreover, ash derived from the combustion of wet olive cake, a by-product of processing, has been used successfully as a soil amendment for peppers (Nogales *et al*. 2006). According to Alburquerque *et al*. (2006), the composting of olive-processing waste with cotton waste resulted in a product that compared favourably with cattle manure and sewage sludge for the amendment of calcareous soils cultivated with peppers. Because of the risk of toxicity in insufficiently composted olive waste products, Cayuela *et al*. (2007) propose a bioassay based on *Lemna gibba* to determine compost maturity. Information on the composting processes employed for olive waste and a discussion of the properties of the composts produced is given by Arvanitoyannis and Kassaveti (2007) and Manios (2004).

Maniadakis *et al*. (2005) studied the use of vegetable residues from tomato, cucumber, eggplant, and pepper crops as a source of composts either used alone or in combinations with olive press cake, olive tree leaves and branches, and vine branches, as bulking agents. The vegetable crop residues were successfully composted only when the bulking agents were used, because in the absence of bulking the EC values were high (3 - 15 mS cm^{-1}) probably due to the presence of large amounts of soil, rich in fertilisers, attached to the roots of the plants. Similarly, Sánchez-Monedero *et al*. (2004) evaluated composts prepared from sweet sorghum bagasse, pine bark, plus either urea or brewery sludge as N source, for vegetable transplant production. Although the EC was too high (3.20 - 13.21 dS m^{-1}) to permit satisfactory use of such compost alone for tomato seedling production, when mixed with either a commercial substrate or peat it did not cause any detrimental effects on the growth or nutritional status of the plants.

Meunchang *et al*. (2006) showed that sugar mill by-products are a good source of N, P and Ca for soil amendment composts. In particular, soil amendment by a compost prepared from filter cake and bagasse resulted in a 112% increase in shoot growth of tomato plants 55 days after transplanting. In addition, inoculation of the compost with the plant growth promoting rhizobacteria, *Beijerinckia derxii*, *Azotobacter vinelandii*, and *Azospirillum* sp. enhanced shoot growth and the N content of plants more than uninoculated compost. Similarly, compost prepared from sugarcane filter cake (a waste by-product of sugarcane processing) was used effectively as a partial substitute for inorganic fertilizer in a tomato crop. Plants grown in media amended with compost had heavier shoots, thicker stems, higher total and early marketable fruit number and weight and larger fruit size than plants shown in media not amended with compost, regardless of fertilization rates (Stoffella and Graetz 2000). Özenc (2006) recommended composted hazelnut husk as a soil amendment for tomato production.

Composts from municipal sold wastes and sewage sludge

In urban areas, the daily production of large quantities of organic solid wastes creates serious disposal problems, environmental pollution, and may pose health risks. For example, over 500kg of municipal solid waste (MSW) per inhabitant and year are generated in the European Union. The direct application of organic waste to soil may have negative effects on soil fertility and cause toxicity to plants (Atiyeh *et al*. 2000d). Hence, considerable attention has been paid to the composting of these materials so as to produce a safer, soil amendment or growth substrate.

Shiralipour *et al*. (1992) reviewed the experimental data on the effect of soil incorporation of composted municipal solid waste (MSW). These authors stated that the use of

MSW usually has a positive effect on the growth and yield of a wide variety of crops and helps restore the ecologic and economic functions of land. Agricultural uses of MSW have shown promise for both field crops (e.g. maize, sorghum, forage grasses) and vegetables for human consumption (e.g. lettuce, cabbage, beans, potatoes, cucumbers). Responses by plant systems have ranged from none to over a twofold increase in yield; however the specific responses are crop and site dependent. In most cases, yields were highest when composts were applied together with fertilizer management programs. Furthermore, the composting of MSW and sewage sludge (biosolids) is regarded as a good way to reduce the amount of waste generated in densely populated areas, while the agronomic use of mature compost is one method of increasing soil organic matter (Madrid *et al*. 2007).

In an attempt to minimize the use of peat for nursery production of tomato seedlings, Castillo *et al*. (2004) and Herrera *et al*. (2008) found that a mixture of white peat (65%), MSW compost (30%) and perlite (5%) gave similar yield quality indices to those obtained with a conventional old peat + white peat sphagnum mixture. The presence physical characteristics of the substrate (particularly the porosity and aeration) were enhanced by the presence of white peat, whereas the MSW provided an adequate source of nutrients. However, the use of MSW compost alone or together with cocofibre depressed the growth of tomato seedlings (Castillo *et al*. 2004). This may have been due to changes in compost properties, such as porosity or salt level, both of which are known to contribute to compost suitability (Vavrina 1995). Therefore, methods of selective waste collection and compost processing are required in order to minimize the adverse effects of MSW amendments to potting media or soil (Herrera *et al*. 2008).

Bletsos and Gantidis (2004) investigated the possibility of using municipal sewage sludge compost (MSSC) mixed with river sand for tomato and eggplant transplants. Plant growth was significantly increased by the 50% MSSC medium (eggplant) or the 75% MSSC medium (tomato) while the concentration of heavy metals in the plants and fruits of both species was low. Hence it was concluded that the material tested was not an environment polluting factor and could be used as a low-cost, alternative component of growth media for healthy vegetable production.

Hu and Barker (2004a, 2004b) studied the effect of soil amendment with three kinds of composts, namely agricultural compost (poultry manure and cranberry press-cake), sewage compost (biosolids and woodchips), and yard waste (mostly leaves) either added alone or in combination with peat moss and soil, on the vegetative growth of tomato plants until the stage of fruit initiation. Plant growth and nutrient content was highest in plants grown in agricultural compost, followed by sewage compost and finally yard waste compost. Additions of peat moss and soil appeared to dilute the concentrations of nutrients in the media and increased the need for fertilizer addition to sustain growth.

Montemurro *et al*. (2005) considered that the application of MSW compost to tomato plants could serve as a N source in Mediterranean conditions, especially in conventional agricultural situations where MSW compost was combined with mineral N fertilizer and deeper soil tillage. Moreover, Clark *et al*. (2000) reported that the amendment of a sandy soil with MSW composts significantly improved plant growth and yield in the drip-irrigated cultivation of peppers and tomatoes, grown in autumn and spring respectively, in the field. The application of MSW composts at rates of 134 t ha^{-1} increased tomato yields by 18-27% and peppers yield by 17%. However, it was found that MSW composts should be incorporated into fields only when sufficient maturation time has been allowed prior to planting.

Heavy metals in relation to the use of MSW and sewage sludge composts

It is not uncommon for composts prepared from municipal waste materials to contain significant levels of pollutants such as trace and heavy metals. This limits the rate of application of the compost to the soil, because excessive loads of contaminants could negatively affect soil fertility and may constitute a long-term environmental hazard and threat to human or animal health (Muchuweti *et al*. 2006).

Many countries now have legislation and guidelines that limit the maximum amount of pollutants in compost, and source separated MSW are now preferred to obtain safe, high quality compost (Déportes *et al*. 1995). However, even source separated MSW may increase the metal content of amended soils (Zheljazkov and Warman 2004a, 2004b) depending on the particular metal present in the compost, the soil, and the characteristics of the organic matter added, particularly the degree of humification (Walker *et al*. 2004). Organic amendments can contribute to metal immobilisation through the formation of stable -OH or -COOH bonds on the solid surfaces of the organic polymers. However, organic amendments may also promote metal mobility if the complexes formed with soluble components of the amendments are more soluble than the initial form of the metal. Thus, fresh manure and immature compost, with a relatively high soluble organic matter content, could increase metal mobility (Madrid *et al*. 2007).

According to Madrid *et al*. (2007) the addition of MSW compost to the soil, resulted in an increase in metal content even when compost was added at moderate rates and the metal content of the compost was below the legal limits. When the compost was pplied a second time, the Zn and Pb content of the soil increased, as did the Cu and Ni content after a third application. It is noteworthy that the metals added via the compost were more readily available than the native metals in the soil. In order to minimize the risk of polluting the soil when using MSW composts, the limits for the metal content of composts should be more strict, and a greater effort should be made to separate wastes when they are collected so as to reduce metal content in the final compost. On the contrary, Montemurro *et al*. (2005) report that the incorporation of MSW compost (70 kg ha^{-1} as organic N) in the soil did not result in any significant increase of the heavy metals at the end of the two-year period of application.

Similarly, precaution must be taken in with the use of sewage sludge composts due to the excessive levels of some heavy metals. Hashemimajd *et al*. (2004) found that although compost prepared from sewage sludge mixed with rice hull proved to be a satisfactory ingredient for potting media, the use of sewage sludge compost + leaves at rates higher than 30% resulted in a decrease in tomato dry matter content, possibly due to high levels of Zn or other heavy metals in the compost.

Although "total" concentrations of Cd, Zn, Cu, Ni and Pb were found to be below pollutant limits in a greenhouse soil after a two year application of sewage sludge and MSW compost, the increase in available fractions was more marked than those of total concentrations (Topcuoğlu 2005). So, the application of these composts resulted in an accumulation of both total and DTPA-extractable Zn, Cu, Ni and Pb in the greenhouse soil, whereas the respective increase of total Cd was minimal. By contrast, manure application did not result in such an accumulation of total and bioavailable metals in the soil (Topcuoğlu 2005).

Logan *et al*. (1999) evaluating literature data on trace element and the organic composition of MSW composts, concluded that trace elements in MSW composts were low in most cases, and only Pb exceeded the concentration limit. Degradation, leaching and plant uptake studies with selected organics added to MSW prior to composting showed that these materials degrade during composting and in the soil, do not leach, and are taken up by crops at low but measurable levels. Trace element bioavailability in MSW composts was similar to, or lower than, that in sewage sludge compost. However, the concentration of B was often much higher in MSW compost than in sewage sludge. In consequence, recommended levels may be required with respect to B in the former.

Heavy metal uptake by plants is affected by a number of factors, including climate, soil, fertilizer and water quality (Lake *et al*. 1984; Devkota and Schmidt 2000; McBride 2002; Akoumianakis *et al*. 2008), and can seriously affect food safety (Ferguson 1990). Heavy metal uptake also varies between plant species and tissue, and with the stage of plant maturity at harvest (Voutsa *et al*. 1996; Moustakas *et al*. 2001; Muchuweti *et al*. 2006). Although the uptake of Cd, Cr, Ni and Pb by potatoes, peppers and broccoli grown in sewage sludge-amended soil did not differ from that of the control (unamended soil), Zn, Cu and Mo uptake by potato and pepper was higher in the former (Antonious and Snyder 2007). In a similar experiment with eggplant, Cr, Ni, Zn and Cu were found to be taken up by eggplant fruit, although the final concentrations did not surpass the Codex Commission's permissible levels (Antonious *et al*. 2008). Cadmium uptake by leafy vegetables was higher in the spring than in the winter (Akoumianakis *et al*. 2008), while the presence of heavy metals in composted sludge induced Ca deficiency and blossom-end rot to a greater extent in greenhouse-grown peppers than in the field crop (Casado-Vela *et al*. 2007).

Other forms of industrial waste have also been tested for their suitability as soil amendments. For example, Karagiannidis *et al*. (2002) reported that soil amendment with 'Thermanox' (a Mn-rich by-product of an industry producing raw materials for dry batteries) increased the yield of tomato, eggplant and pepper, although the concentrations of heavy metals (Mn, Fe, Pb, Ni, Co, Cr and Cd) in the plant tissues were higher than those in plants grown on unamended soil. Gebologlu *et al*. (2005) reported that organic waste from tobacco could be used as an organic fertilizer for tomato, eggplant, pepper and cucumber seedling production since it contained a high level of nutrients (N, P, K, Ca and Mg) and low concentrations of heavy metals. Aram and Rangarajan (2005) produced compost from manure plus food or brewery waste to increase soil C and N content, but pepper biomass was not consistently affected by soil amendment with this product.

Decomposition of pesticides during thermophilic composting of plant residues

Although the use of plant residues as a source of compost material may elicit the accumulation of pesticides, research data indicate that to the contrary the thermophilic decomposition of plant material during composting reduces the remains of pesticides carried over in the source material.

Maniadakis *et al*. (2005) reported that by the end of the composting and maturation phase (60 days after the end of the thermophylic phase) of all composts derived from vegetable residues of tomato, cucumber, eggplant, and pepper crops used either alone or in combination bulking agents, the residues of 13 pesticides studied fell below the levels of detection. Similarly, a progressive degradation of pirimiphos-methyl was observed during the thermophilic composting of a mixture of tomato plant residues, wood shavings, and MSW (Ghaly *et al*. 2007). During the composting of greenhouse wastes, the degradation of pirimiphos-methyl is accelerated by high temperatures, organic matter content, moisture, and biological activity.

Seaweed composts

Seaweed (fresh, dry) or its products (extracts, composts, soil conditioners) have long been used in agriculture to enhance plant growth and productivity (Blunden 1991). Eyras *et al*. (2008) evaluated the effects that seaweed composts at differentrates (5 and 10 kg m^{-2}) and degree of maturation (compost ageing for 9 and 20 months) had on the yield of tomatoes in Argentina. Production was earlier and total fruit yield and plant biomass were significantly higher for the compost treatments than those of unamended soil. Ageing of the compost was beneficial for the reduction of its EC (15 dS m^{-1}, and 1.5 dS m^{-1} after 9 and 20 months, respectively).

Castaldi and Melis (2004) in Sardinia studied the effects of different growth media based on composted seaweed (*Posidonia oceanica* [L.] Delile) on the growth, yield, and heavy metal concentrations of tomatoes. The decision to use *P. oceanica* as a growth medium or compost component was based on the large accumulation of deposits of this seaweed on the beaches of Sardinia. This seaweed is disposed of in waste dumps because it may accumulate heavy metals. According to Castaldi and Melis (2004), the growth and yields of plants was not affected by the growth medium because, although the heavy metal (Pb, Cd, Zn, Cr, Cu) content of the compost was higher than that of non-composted *P. oceanica*, most of the heavy metals strongly interacted with the organic matter in the compost, thus limiting accumulation in the fruit.

Composting and/or vermicomposting could turn large volumes of organic solid wastes such as MSW into material to be used as fertilizer, organic soil additive and crop substrate (Herrera *et al*. 2008).

Waste from fish farms

The possibility of using liquid or solid organic waste from the tanks used for intensive fish farming for the field production of bell peppers was tested in comparison with cow manure and commercial N fertilizers (Palada *et al*. 1999). The liquid effluent was obtained from tanks with a low (8 fish m^{-3}) and high (16 fish m^{-3}) fish density and applied to bell peppers two to three times a week. In the first year, marketable pepper yield was higher in the liquid N fertilizer treatment than in the fish effluent treatments. However in the second year, the differences in yield between the treatments were not significant. In other experiments, the use of fish effluent was successfully used both for irrigation and as a source of nutrients to complement the use of other organic materials (bovine, manure, poultry manure, vermicompost, commercial compost) during the cultivation of cherry tomato (Castro *et al*. 2006). Ashcroft *et al*. (2006) suggest the use of a new phosphorus fertiliser for organic production systems, derived from activated rock phosphate composted with fish waste. The application of this organic fertilizer in comparison to a traditional P fertiliser (Superphosphate) on processing tomatoes ('Heinz 9035') in the field, showed that the organic fertilizer is equally efficient to promote plant growth, fruit production and fruit quality characteristics (soluble solids, colour and pH) as the inorganic one.

Composts and pathogen suppression

According to the review of Noble and Coventry (2005), compost amendment of container media for greenhouse crops results in a lower incidence of soil-borne diseases, such as damping-off, root rots (*Pythium ultimum*, *Rhizoctonia solani*, *Phytophthora* spp.), and wilts (*Fusarium oxysporum* and *Verticillium dahliae*). However, compost amendment of soil in the field has a smaller and more variable effect than in container experiments. In general, the degree of disease suppression increased with the rate of compost incorporation.

Several studies have shown that disease suppression by composts decreases following sterilisation or pasteurisation (Hoitink *et al*. 1997; Cotxarrera *et al*. 2002) or after heat treatment of the soil-compost mixture (Serra-Wittling *et al*. 1996). This indicates that the mechanism of disease suppression is predominantly biological. According to Hoitink and Boehm (1999), the biological mechanisms involved in disease suppression by compost amendment include parasitism, antibiotic production and/or the successful competition for nutrients by beneficial micro-organisms, as well as the activation of disease-resistance genes in plants by micro-organisms (induced systemic resistance), improved plant nutrition and vigour.

According to Hoitink *et al*. (1997), the biological control agents within composts include antagonistic bacteria and fungi, such as *Bacillus* spp., *Enterobacter* spp., *Flavobacterium balustinum* Harrison, *Pseudomonas* spp., *Streptomyces* spp., *Penicillium* spp., several *Trichoderma* spp. and isolates of *Gliocladium* (=*Trichoderma*) *virens* Miller, Giddens & Foster. Similarly, De Brito-Alvarez *et al*. (1995) reported that the amendment of soil by some thermophilic composts increased the incidence of bacteria in the tomato rhizosphere that were antagonistic towards *Fusarium oxysporum* f. sp. *radicis-lycopersici*, *Pyrenochaeta lycopersici*, *Pythium ultimum*, and *Rhizoctonia solani*s.

Cheuk *et al*. (2003) successfully used composts derived from tomato crop waste to control tomato crown rot caused by *Fusarium oxysporum* f. sp. *radicis-lycopersici*. Cotxarrera *et al*. (2002) reported a 45% reduction in the incidence of this disease by the use of a compost based on sewage sludge and green waste., while composts prepared from cork and grape marc (Trillas *et al*. 2002) or paper mill sludge (Pharand *et al*. 2002) were even more successful. Similarly, Schönfeld *et al*. (2003) reported a 45% reduction in the occurrence of tomato wilt caused by *Ralstonia solananacearum* using MSW composts, while Moustafa *et al*. (1977) effectively controlled the damping-off of tomato (*Pythium ultimum*) by hardwood bark composts, and Abbasi *et al*. (2002) controlled tomato anthracnose fruit rot caused by *Colletotrichum coccodes* using cannery waste compost. However, not all compost additions were successful in controlling soil-borne diseases. For example, in pepper sewage sludge compost had no effect on the incidence of root rot caused by *Phytophthora capsici* (Kim et al. 1997), whereas in other experiments the use of this compost against the same disease was successful (Lumsden *et al*. 1983). The incidence of corky root disease of tomato (*Pyrenochaeta lycopersici*) was reduced by composts made from garden waste but stimulated by compost based on horse manure (Hasna *et al*. 2007).

The capacity of a compost to control soil-borne diseases may depend on its maturity at the time of application. Ntougias *et al*. (2008) reported that composts derived from waste and by-products of the olive oil, wine, and *Agaricus* mushroom agro-industries, suppressed *Phytophthora nicotianae* Breda de Haan in tomato when they were applied directly after curing, whereas 9 months after curing they were less effective.

Various forms of organic matter applied to soils may suppress arthropod pests and therefore reduce crop damage (Patriquin *et al*. 1995). Field applications of thermophilic composts are reported to reduce the incidence of attacks by aphids, scales and nematodes (Culliney and Pimentel 1986, Yardim and Edwards 1998). Vermicomposts are stated to suppress arthropod pests, aphids cabbage white caterpillars and nematodes in tomatoes, peppers and cabbage (Arancon and Edwards 2004, Arancon *et al*. 2005).

Arancon *et al*. (2007) added vermicomposts derived from food waste to potting media and studied their effect on the populations of mealy bugs (*Pseudococcus* sp.) on tomatoes, spider mites (*Tetranychus urticae*) on eggplants and aphids (*Myzus persicae*) on cabbages in the greenhouse. Pest populations and plant damage were decreased by the presence of vermicompost, the effect being greater on aphids than mealy bugs, and least on spider mites. According to Arancon *et al*. (2007) possible mechanisms for this suppression include the form of N available in the leaf tissues, micronutrient availability and the possible production of phenols by the plants after applications of vermicomposts, making the tissues unpalatable.

According to Jin *et al*. (2005), the addition of chitin compost or chitin broth to the soil increased the activity of chitinolytic bacteria, which are considered to be potential biological agents for the control of the root-knot nematode, *Meloidogyne incognita* on tomato. Although tomato biomass after inoculation with nematode eggs did not appear to be affected during 8 weeks after treatment, nematode parasitism diminished as a result of the action of chitinase-producing bacteria.

Vermicomposts

Vermicomposts are composts that are produced by the fragmentation of organic wastes during their passage through the digestive tracts of certain species of earthworm (e.g. *Eisenia fetida*, *Eisenia andrei*), along with the joint action of bacteria, but they do not undergo a thermophilic stage (Dominguez *et al*. 1997). Several enzymes, intestinal mucus and antibiotics of the earthworm's intestinal tract play an important role in the breakdown of organic macromolecules (Doube and Brown 1998). Vermicomposts normally have a free particulate structure, contain nutrients in forms that are readily available for plant uptake, have a good water retention capacity and include microbial metabolites with a plant growth regulatory activity. They can therefore make a valuable contribution to potting and growth media, as well as being excellent soil amendments or conditioners (Edwards and Burrows 1988; Atiyeh *et al*. 1999, 2000a; Paul and Metzger 2005).

Inn recent years, the use of earthworms to breakdown organic residues, including sewage sludge, animal manures, crop residues, and industrial refuse, to produce vermicomposts has significantly increased (Edwards 1998). The properties of the vermicompost depend on the organic materials used and the production method. Vermicompost production in American is largely undertaken indoors using the earthworm *Eisenia fetida*, whereas in the UK, it is generally an outdoor process using the earthworm *Dendrobaena veneta* (Roberts *et al*. 2007).

Effect of vermicomposts on the growth of seedlings

Atiyeh *et al*. (2000a) studied the effects of the earthworm *Eisenia andrei* (Bouche) on fresh, bovine manure within the laboratory. Earthworms were introduced into plastic containers containing fresh cow manure, while containers containing manure but without earthworms served as controls. The principal effect of earthworms was to accelerate the maturation of the organic wastes, resulting in the enhanced growth of lettuce and tomato seedlings. Paul and Metzger (2005) reported that the transplant quality and field performance of peppers and eggplants were improved by the substitution of up to 20% vermicompost produced from cattle manure for a commercial soilless compost whereas tomato was slightly reduced. Bachman and Metzger (2008) report that the incorporation of vermicompost based on pig manure origin into germination media increased seedling growth of tomato and French marigold, but not pepper or cornflower. However, after transplantation, all species showed better growth in media amended with vermicompost.

Zaller (2007a, 2007b) showed that the substitution of peat in potting media by vermicomposts produced from food and cotton waste significantly affected tomato emergence and seedling biomass allocation (root: shoot ratio), but not the subsequent yield. Significant differences in response between cultivars were noted. Hashemimajd *et al*. (2006) studied the physicochemical properties of vermicomposts derived from several organic wastes in relation to their use as an alternative for peat in potting media for the production of tomato seedlings. The organic wastes evaluated were yard leaf, sewage sludge + woodchips, municipal waste, saw dust, wheat straw + urea, sugar cane filter cake and dairy cattle manure. Tomato growth in pots containing vermicompost from sewage sludge + woodchips, municipal waste and wheat straw + urea was higher than that from the other sources.

Effect of vermicomposts on yield and fruit quality

Arancon *et al*. (2003a) studied the application of vermicomposts, produced commercially from cattle manure, market food waste and recycled paper waste to field plots planted with tomatoes and bell peppers supplemented with inorganic fertilizers. The increase in mean pepper fruit weight and number of fruits by vermicompost did not, however, relate to the vegetative growth of the plants and was not ascribed to better nutrient availability (Arancon *et al*. 2004). The addition of vermicomposts to the field increased marketable yields of tomato and pepper. The incorporation of vermicomposts, produced from cattle manure, pig manure, food wastes, into a commercial soilless bedding plant growth medium increased the rates of germination, growth and yields of ornamentals, tomatoes and peppers (Atiyeh *et al*. 2000a, 2000b, 2001, 2002). The inclusion of 10 or 20% vermicompost in either peat–perlite or coir–perlite mixtures also improved plant growth significantly compared to that in an unamended medium (Atiyeh *et al*. 1999).

Gutiérrez-Miceli *et al*. (2007) studied the effect of soil amendment by vermicompost from sheep-manure on the growth, productivity and chemical characteristics of tomatoes (cv. 'Rio Grande'). Although vermicompost addition increased plant height significantly, it had no significant effect on leaf number or early yields. Fruit from plants grown in the amended soil were judged to be better for juice production because the soluble solids content was high (>4.5%), titratable acidity was low (<2%) and pH < 4.4. Roberts *et al*. (2007) found that the substitution of commercial peat-based compost with four different vermicomposts produced by the earthworm *Dendrobaena veneta* did not affect total fruit yield, marketable fruit yield, fruit number, mean fruit weight or vitamin C content (cv. 'Moneymaker'), but germination rates increased and at the higher levels of vermicompost substitution there was a lower incidence of blossom end rot and fruit cracking.

As with other organic materials, aerobic sewage sludge can be ingested by the earthworm *Eisenia fetida* and egested as casts, in a vermicomposting system. During vermincomposting, sludge is decomposed and stabilized about three times faster than non-ingested sludge, while the populations of pathogenic micro-organisms (*Salmonella enteriditis*, *Escherichia coli* and other Enterobacteriaceae) are reduced (Dominguez *et al*. 2000). Earthworms can accelerate the decomposition of composts based on sewage sludge mixed with other organic materials (e.g. garden waste and food waste, paper pulp sludge), as well as improving the C:N ratio and reducing N losses due to ammonia volatilization (Domínguez *et al*. 1997).

Irrespective of whether they are used as an amendment to soilless container media or to soil in the field, most studies indicate that vermicomposts improve seed germination, seedling growth, plant flowering, fruiting and productivity more than could be expected simply from the conversion of mineral nutrients into more available forms (Atiyeh *et al*. 1999, 2000a, 2000b, 2000c, 2001, 2002). In general, the best responses are observed when vermicomposts constitute a relatively small proportion (10–40%) of the total plant growth medium (Arancon *et al*. 2003b), but high rates of vermicompost addition may adversely affect plant growth and yield of tomato (Atiyeh *et al*. 2000c) or pepper (Arancon *et al*. 2004). As in other composts, negative effects on plant growth may result from high soluble salt concentrations, poor aeration, heavy metal toxicity, and/or plant phytotoxicity in the undiluted vermicompost (Arancon *et al*. 2004). According to Zaller (2006), foliar application of vermicompost sprays may be beneficial for tomato fruit set and disease prevention.

A comparison of vermicomposts with other composts

Composting and vermicomposting are quite distinct processes, particularly with respect to the optimum temperatures for each process and the nature of the microbial communities that predominate during active processing (i.e. thermophilic bacteria in composting, mesophilic bacteria and fungi in vermicomposting). The wastes processed by the two systems are also differ (Atiyeh *et al*. 2000d). Compared to compost, vermicomposts have a finer structure and more diverse microbial activity (Edwards and Burrows 1988; Atiyeh *et al*. 2000b). In addition, vermicomposts release most N as nitrate, whereas composts release N in the ammonium (Edwards and Burrows 1988).

Atiyeh *et al*. (2000d) reported that vermicomposts based on pig solids or food waste and added at 10-20% in a commercial horticultural potting medium were superior to leaf compost for the growth of marigold (*Tagetes erecta* L.) and tomato seedlings. In addition, these vermicomposts were more appropriate as soil amendments for raspberry cultivation, than other organic media, such as yard, leaf or bark composts, whereas amending the soil with 4% chicken manure compost killed most of the raspberry plants. However, plant mortality was reduced and growth restored when the chicken manure compost was mixed with vermicomposted pig solids, but not with bark or yard composts. Plant growth in soils containing a mixture of chicken manure compost with 20% vermicomposted pig wastes was similar to that of plants grown in the unfertilized control (Atiyeh *et al*. 2000d).

Hashemimajd *et al*. (2004) showed the superiority of vermicomposts produced from raw dairy manure and composts from various organic wastes (tobacco residue, yard leaf, sewage sludge + rice hull, sewage sludge + yard leaf) comparing to raw dairy manure, as amendments in pot mixtures for the growth of tomato seedlings. Shoot and root dry matters were greatest in vermicompost and sewage sludge + rice hull compost additions, whereas addition of sewage sludge + yard leaf compost at a rate of 45% reduced seedlings' dry matters, indicating toxicity.

Pathogenic microorganisms in vermicomposts

According to Dominguez *et al*. (2000), vermicomposting with *Eisenia* earthworms is an effective way to reduce the population of pathogenic micro-organisms in composts based on mixtures of sewage sludge and bulking agents. Similarly, Gutiérrez-Miceli *et al*. (2007) reported that although sheep manure had large amounts of *Escherichia coli* (9.5×10^7 CFU kg^{-1} dry manure), *Salmonella* plus *Shigella* (2.3×10^7 CFU kg^{-1} dry manure), and *Enterobacter* (7.6×10^7 CFU kg^{-1} dry manure), after 60 days of vermicomposting *Shigella*, *Salmonella* or *Enterobacter* were not detectable. Similar results were reported for vermicomposting of biosolids supplemented with cow manure and oat straw (Contreras-Ramos *et al*. 2004). The reduction in the populations of pathogens that are potentially dangerous for human health may relate to the activity of the haemolytic system of earthworms, which has antibacterial properties (Pierre *et al*. 1982). However, like manures, the beneficial effects of vermicompost addition to plant growth and physiology, only occur if composts have been stabilized adequately before their utilization. Inadequately stabilized composts can be phytotoxic and therefore delay plant growth and reduce yield (Abbasi *et al*. 2002).

QUALITY AND SAFETY OF ORGANIC PLANT PRODUCTS

The primary reason for the rise in demand for organically-grown vegetables, such as tomato, pepper and eggplant, is public concern over food safety with respect to human health (Makatouni 2002; Magkos *et al*. 2006). Other factors (e.g. animal welfare and environmental protection) also contribute (Magnusson *et al*. 2001; Makatouni 2002; Magnusson *et al*. 2003; Saba and Messina 2003). The quality of the Solanaceous fruits is based on physical and sensory attributes, such as appearance, texture, taste, aroma and nutritive value (Passam and Karapanos 2008). Therefore, in order to compare organic and conventional produce, quality should be assessed on the basis of all the above factors.

Magkos *et al*. (2006) reviewed the scientific literature concerned with the quality and safety of organic food in comparison with conventional products. These authors concluded that "there is currently no evidence to support or refute claims that organic food is safer and thus healthier than conventional food, or *vice versa*". Many claims in the popular press, newspapers and magazines, are based on information gleaned from inadequately controlled scientific experiments or anecdotal reports and are therefore of dubious value. For an in-depth discussion of this subject the reader is referred to the reviews of Bourn and Prescott (2002), Magkos *et al*. (2003, 2006), Winter and Davis (2006) and Zhao *et al*. (2006).

Specifically with respect to the Solanaceae, some comparisons of organically grown and conventionally grown produce have been made. Organic tomatoes, peppers and eggplants should be free of chemical residues provided there is no transfer of agrochemicals from neighbouring areas (Gonzalez *et al*. 2003). They may also be expected to have a lower nitrate content than conventionally grown produce, although the reduction in nitrate levels due to organic growing methods is more pronounced in leafy vegetables than in fruit. For example, the nitrate content of conventionally cultivated tomatoes was higher than that of organically grown ones (Malmauret *et al*. 2002). Caris-Veyrat *et al*. (2004) reported that organic tomatoes contained higher concentrations of flavonoids than conventional tomatoes on a fresh weight basis, but the differences were less when based on dry weight. However, the experimental design of this study was criticized by Zhao *et al*. (2006). The flavour quality of organically grown tomatoes is reported to be either inferior (Poretta 1994) or superior (Vogtmann *et al*. 1993) to conventionally grown fruit. In a taste panel study, Johansson *et al.* (1999) found no differences in acidity, sweetness, and bitterness, but organic tomatoes were less firm, less juicy and redder.

Ren *et al*. (2001) reported that organically grown green peppers had a higher antioxidant and antimutagenic activity than the conventionally grown crop from a nearby farm, although little information was presented about the horticultural practices, thereby limiting the value of this study. Del Amor (2007) also reported increased antioxidant levels in organically grown peppers, whereas the chlorophyll and carotene contents were lower and fruit firmness, pericarp thickness, pH and total soluble solids were unaffected by the cultivation method. Del Amor *et al*. (2008) investigated the levels of peroxidase, total phenolics, and capsidiol activity in the fruit of organically and conventionally grown sweet peppers cultivated in the greenhouse under the same climatic conditions. It was found that both organic and conventional peppers had the same isoenzymatic form of peroxidase. Peroxidase activity and the concentration of total phenolics was higher in organic than in conventional peppers, and capsidiol activity was also higher in organically grown red mature fruit. These characteristics were considered to contribute to disease resistance in the organic product. In a similar comparative study, Perez-Lopez *et al.* (2007) reported that the concentrations of vitamin C, phenolics and carotenoids in organic peppers were higher than in conventionally grown fruit and increased during ripening, thus contributing to better nutritional value of the fruit.

Comparative studies on eggplant fruit quality under organic and conventional systems are not available. Overall, it seems that there are few concrete examples that organic tomatoes, peppers or eggplants differ significantly from conventionally grown produce in terms of nutritional value and quality characteristics and closely monitored, well-controlled research is still required in this field (Bourn and Prescott 2002; Magkos *et al*. 2006).

CONCLUSIONS AND FUTURE PERSPECTIVES

Tomato, pepper and to a lesser extent eggplant are three important candidates for cultivation by sustainable or organic growers. In particular tomato, both in a fresh and processed form, is one of the principal certified or organic vegetable products on the market today.

The production of certified produce presupposes an agency that legislates rules and updates them when the conditions demand. Moreover, there must be an inspection and certification service in each country so that the consumer may be certain that the produce he/she buys corresponds exactly to that described on the label. In consequence, inspection and certification inevitably constitute a somewhat bureaucratic process. In organic agriculture, there is a wider conception of environmental protection and a respect for sustainability. This is a most important approach for the future of crop production and the world as a whole, but it also increases the demands on the organic growers and the inspectorate. In the future, there will need to be a coordinated input of information technology and codification so as to make inspection and certification easier.

It is known that the addition of organic matter to the soil improves soil fertility, soil structure and properties, but perhaps above all it improves the biological activity of the soil. Intensive cultivation of the Solanaceous crops has a high nutrient demand, so when plant nutrition is based on organic matter, the latter must have a stable structure and composition, so that it may be safely used from the start of the cultivation, which is the stage of greatest susceptibility of the plant to toxins and disease. Therefore, techniques which reduce the time of composting and stabilize, or mature, the compost are especially important. Earthworms and microorganisms can play a significant role in this procedure, and further research in this area is foreseen.

The lower yields of organic crops (including the Solanaceae) in comparison with conventional ones can be attributed to two main factors: first, the difficulty of confronting pests and diseases, secondly, the exclusive use of organic matter for plant nutrition. Lower yields are compensated for by the higher prices of organically grown produce on the market. Consumer preference for organic produce, such as tomatoes, peppers and eggplants, is based primarily on the belied that such products are safer and healthier than those produced by conventional means. Unfortunately, many of the claims for increased nutritional value of organic produce are not derived from reliable scientific observation, and it is imperative in the near future that a greater research input should be made to clarify the benefits or not of organic production methods to produce composition and quality.

Research continues in all the areas of production of the Solanaceous and other vegetable crops. Each advance with respect to plant nutrition, plant protection, post-harvest management or even simple cultivation techniques (pruning and training methods, pollination assistance, etc.) encourages more farmers to turn to certified or even organic production.

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