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A survey of bacteria and fungi occurring during composting and self-heating processes

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Abstract - Composting is a controlled self-heating, aerobic solid phase biodegradative process of organic materials. The process comprises mesophilic and thermophilic phases involving numerous microorganisms. In several successive steps, microbial communities degrade organic substrates into more stable, humified forms and inorganic products, generating heat as a metabolic waste product. Due to the complexity of substrates and intermediate products, microbial diversity and the succession of populations is a prerequisite to ensure complete biodegradation. Due to the dynamic process, both in time and space (microhabitats), which is reflected by constantly changing pH, humidity, oxygen partial pressure and temperature it is extremely difficult to detect, albeit isolate, all the microorganisms involved. Research on composts is also so difficult because the process can hardly be simulated in the laboratory since all major gas and temperature fluxes are to a large extent determined by the physical extension of the system. In this comprehensive survey of literature an inventory of the mesophilic and thermophilic bacteria, actinomycetes and fungi isolated during several phases of composting (including also self-heating organic materials) is presented.

Key words: self-heating material, compost, microbial diversity, bacteria, actinomycetes, fungi, degradation.

INTRODUCTION

Composting is, *sensu stricto,* a self-heating, aerobic solid phase biodegradative process of organic materials under controlled conditions, which distinguishes it from natural rotting or putrefaction. From an etymological viewpoint, *lat. compositum,* it is a mixture of substrates that is biodegraded by a mixed microbial

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community. The 'self-heating' is due to heat liberation from microbial metabolic activity:

$$\overset{-24e^-}{\overbrace{\phantom{C_6H_{12}O_{6\,(aq)}}}}\quad \underset{+24e^-}{\underbrace{\phantom{+\,6O_2 \rightarrow 6CO_{2aq} + 6H_2O}}}$$

$$C_6H_{12}O_{6\,(aq)} + 6O_2 \rightarrow 6CO_{2aq} + 6H_2O \qquad \Delta G = -677 \text{ kcal/mol}$$

The heating-up during a composting process is determined by the degradability and energy content of the substrates, the availability of moisture and oxygen, and the mode of energy conservation (insulation, convective losses) (Finstein and Morris, 1975; Haug, 1993).

The organic substrates and bulking agents used in composting are mainly derived from plant material. Carbon compounds serve as an energy source for microbial maintenance and growth. The yield coefficient, that is the amount of C incorporated into the cells per unit degraded C, ranges from 10% to 35%, depending on substrate energy content, degrading organism and environmental conditions.

Besides a C source, microorganisms require macronutrients such as N, P and K, and trace elements for their growth. Nitrogen is a critical element for microbial growth. If N is limiting during composting the degradation process will be slow. At excess supply, N may be lost from the system as ammonia gas or through leaching as nitrate. If we assume a microbial yield coefficient of 30%, and an average microbial C/N content of 10, the theoretical optimum substrate C/N ratio would be 30. Indeed, in practice the optimum C/N ratio has been reported to range between 25 and 35 (Shilesky and Maniotis, 1969; Gray *et al*., 1971; Savage *et al*., 1973; Finstein and Morris, 1975; de Bertoldi *et al*., 1985; Fogarty and Tuovinen, 1991; Golueke, 1991, 1992; Larsen and McCartney, 2000; Tuomela *et al*., 2000). During the process the C/N ratio decreases significantly (see Figure 1) (Thambirajah *et al*., 1995) because part of the C is lost as CO_2 upon microbial respiration while N is recycled (Shilesky and Maniotis, 1969; Golueke, 1992).

Decomposition by microorganisms occurs predominantly in the thin liquid films (biofilms) on the surface of the organic particles. If the moisture content drops below a critical level (<30%), microbial activity will decrease and the microorganisms will become dormant. On the other hand, a moisture content that is too high (>65%) can cause oxygen depletion and losses of nutrients through leaching. In subsequent anaerobic conditions the decomposition rate decreases and odor problems arise (de Bertoldi *et al*., 1985; Fogarty and Tuovinen, 1991; Golueke, 1991; Tiquia *et al*., 1996). However, even under optimal conditions, anaerobic microenvironments may develop. For example, Atkinson *et al*. (1996c) estimated that almost 1% of all the bacteria found in municipal solid waste compost are anaerobic.

Under optimal conditions the composting process can be divided into four phases: (i) an initial (first) mesophilic phase (10-42 °C), which may last for only a few hours or a couple of days; (ii) a thermophilic phase (temperature 45-70 °C), lasting a few days, several weeks (particularly in food wastes) or even months (particularly in wood wastes); (iii) second mesophilic phase during which mesophile organisms, often dissimilar to those of the first mesophilic phase, recolonize the substrates; and (iv) the maturation (or curing) and stabilization phase which can last for several weeks to several months (Hoitink and Boehm, 1999;

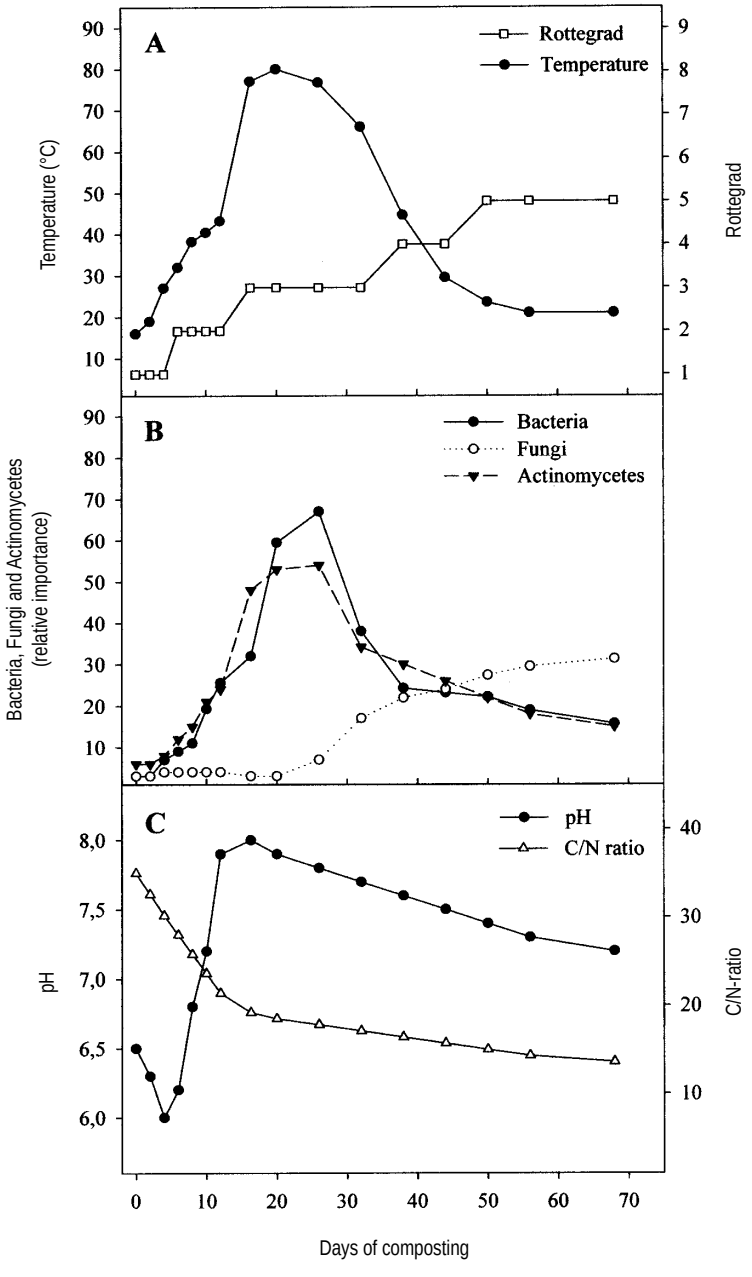

FIG. 1 – Typical process parameters and microbial abundance during composting. These curves, including extension of the time axis, may vary to a great degree depending on factors such as substrate, outside temperature, moisture availabilty and type of aeration or turning frequency.

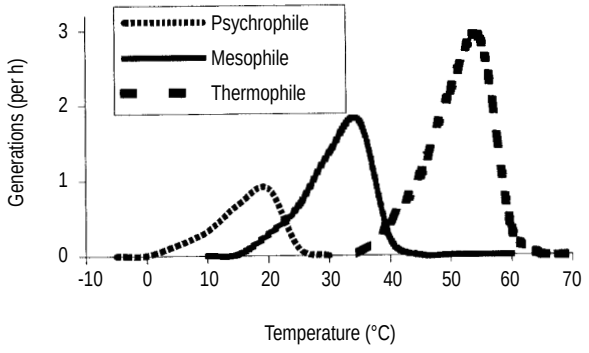

FIG. 2 – Temperature range of psychrotolerant, mesophile and thermophile organisms, and their generation time (from: Insam and de Bertoldi, 2003).

Tuomela *et al*., 2000; Insam and de Bertoldi, 2003). These phases may have considerable overlap based on temperature gradients and differential temperature effects on microorganisms (Fogarty and Tuovinen, 1991).

Different microbial communities predominate during the various composting phases, each of which being adapted to a particular environment (Gray *et al*., 1971; Bagstam, 1978; Crawford, 1983). Primary decomposers create a physico-chemical environment suited for secondary organisms, which cannot attack the initial substrates, while metabolites produced by the one group can be utilized by the other (crossfeeding) (Davis *et al*., 1992; Golueke, 1992). The initial rapid increase of temperature involves a rapid transition from mesophilic to thermophilic microflora (Niese, 1959; Corominas *et al*., 1987; Falcon, 1987; Ryckeboer *et al*., 2003). Often, however, a disruption of the process is observed at temperatures between 42 °C and 45 °C. The initial mesophilic microflora is inhibited by the high temperature, while the thermophilic populations have not yet developed and are below their temperature optimum (see Figure 2). Only after a sufficient number of thermophiles is generated, temperatures rise again. At temperatures exceeding 60 °C, the optimum for most thermophiles is reached, and the system starts to limit itself due to the inhibitory high temperatures (McKinley and Vestal, 1984). Heat may *per se* inhibit organisms (e.g. through enzyme inactivation) or may limit oxygen supply (O_2 solubility in water is temperature dependent). If a good management is provided (i.e. regular aeration or frequent turning), the thermophilic stage continues until the heat production becomes lower than the heat dissipation, due to the exhaustion of easily degradable substrates. High temperatures support degradation of recalcitrant organics such as lignocellulose, e.g. wood (Sjöström, 1993; Tuomela *et al*., 2000) and elimination of pathogenic and allergenic microorganisms (Wiley and Westerberg, 1969; Finstein and Morris, 1975; Bollen, 1993; Herrmann *et al*., 1994; Thambirajah *et al*., 1995; Beffa *et al*., 1996a, 1996b; Bollen and Volker, 1996; Ryckeboer *et al*., 2002a). During the second mesophilic (cooling) phase nutrients become a limiting factor, causing a decline in microbial activity and heat output. During the maturation phase, the substrate quality further declines and compounds such as lignin-humus complexes are formed that are not further degradable.

The length of the different composting phases depends on the nature of the organic matter being composted and the efficiency of the process, which is determined by several factors such as starting material, O_2 supply, moisture content, active turning and outside temperature.

Although composting is an ancient art, and very often works by itself, more knowledge on the involved microbiota will help to improve the process, both regarding its progress and the quality of the end-products that may be obtained.

Enumerations and isolations of microorganisms from composts have mostly been performed on rich organic complex media (Kane and Mullins, 1973; Finstein and Morris, 1975; Nakasaki *et al.*, 1985a, 1985b; Strom 1985a, 1985b; Hardy and Sivasithamparam, 1989; Davis *et al.*, 1991; Beffa *et al.*, 1996b; Choi and Park, 1998; Ryckeboer *et al*., 2003; Van Gestel *et al*., 2003). Later, techniques such as measuring of ATP content (Garcia *et al.*, 1992; Tseng *et al.*, 1996), microbial biomass (Derikx *et al.*, 1990) and of potential metabolic abilities such as metabolic fingerprinting became available (Insam *et al.*, 1996; Kersters *et al.*, 1997). More recently, methods have been introduced that do not require cultivation, e.g. direct analysis of phospholipid fatty acid (PLFA) (Hellmann *et al.*, 1997; Herrmann and Shann, 1997; Klamer and Baath, 1998) or DNA and RNA extraction (Hugenholtz *et al.*, 1998; Koschinsky *et al.*, 1998; Gurtner *et al.*, 2000; Ivors *et al.*, 2000; Alfreider *et al.*, 2002). Denaturing Gradient Gel Electrophoresis (DGGE) of PCR-amplified DNA fragments combined with the sequencing of relevant bands, Terminal Restriction Fragment Length Polymorphism analysis (T-RFLP) of 16S (prokaryotes) or 18S (eurkaryotes) rDNA genes and amplified ribosomal DNA restriction analysis (ARDRA) are examples of the most recent methodological developments in PCR-based detection techniques to analyze the diversity of microbial communities in self-heating materials (Ivors *et al*., 2002; McSpadden-Gardener *et al*., 2002; Michel *et al*., 2002; Minz *et al*., 2002; Riddech *et al*., 2002; Roberts *et al*., 2002; Alfreider *et al.*, 2002; Tiquia and Michel, 2002; Tiquia *et al*., 2002). The use of growth requiring culturing techniques is often disputed, while the culture-independent molecular screening techniques will definitely detect numerous unique microorganisms. Nevertheless, a few references clearly indicate that culturing studies still deliver non-overlapping information, consequently none of the two approaches can claim to be superior to the other yet (Brambilla *et al*., 2001).

MICROBIAL COMMUNITIES DURING COMPOSTING

Substrates and communities

Quantitatively, the main components of organic matter are carbohydrates (e.g. cellulose), proteins, lipids and lignin (as presented in Table 1). The capacity of microorganisms to assimilate organic matter depends on their ability to produce the enzymes needed for degradation of the substrate (Golueke, 1991, 1992; Davis *et al*., 1992; Tuomela *et al*., 2000). The composition of the microbial community during composting is determined by many factors (Davis *et al*., 1992; Golueke, 1992). Under aerobic conditions, temperature is the major selective factor for populations and determines the rate of metabolic activities. The reports on the number of organisms during the different phases of composting are contradictory (Table 2). While some authors state that the total number of microorganisms does not significantly

TABLE 1 – Major natural compounds which are the substrates for decomposition. These materials are found in plants animals and microorganisms. From: Insam and de Bertoldi (2003)

Compound	Composition	Function	P*	A*	M*	Degradability
Lignin	Polymerisates of phenylpropane derivatives, e.g. coniferyl alcohol	Structural compound	3	0	0	Very resistant, mainly by fungi
Glucose ($C_6 H_{10} O_5)_n$ polymers						
Cellulose	β-1,4 bonds	Structural compound (plant leaves, stems)	3	0	0	Easily, mainly by fungi, but also bacteria, Actinomycetes
Starch	Amylose: linear α-1,4 bonds; Amylo-pectin: branched α-1,4 bonds	Storage compound in seeds a nd roots	2	0	1	Good; Aerobically and anaerobically (*Clostridium*)
Glycogen	α-1,4 and α-1,6 bonds	In animal muscles	0	1	0	Good
Laminarin	β-1,3 bonds	Marine algae (Phaeophyta)	2	0	0	Fair
Paramylon	β-1,3 bonds	Algae (Euglenophyta and Xanthophyta)	1	0	0	Fair
Dextran	1,6 bonds	Capsules or slime layers of bacteria	0	0	1	Fair
Agar	Polymer of Galactose and galacturonic acid	Marine algae (Rhodophyta)	2			Resistant
Suberin, cutine	High polymeric esters of saturated and unsaturated fatty acids	Structural compound	1	0	0	Poor
Hemicelluloses						
Xylan Araban Mannan Galaktan	Low degree of polymerisation of sugar monomers (Pentoses and Hexoses) and Uronic acids; usually 20-100 monomers	Cell wall compound, in seeds, straw, wood, algae	3	0	0	Variable degradability, often together with lignin

(*continued*)

TABLE 1 – Major natural compounds which are the substrates for decomposition. These materials are found in plants animals and microorganisms. From: Insam and de Bertoldi (2003) (*follow the previous page*)

Compound	Composition	Function	P*	A*	M*	Degradability
Pectin	Polymer of galacturonic acids ($3\ 10^4$-$5\ 10^5$ monomers)	Dissolved, and in the cell wall, in seeds, fruits, and in young wood parts	2	0	0	Easy, by most microorganisms, among them often plant pathogens
Sucrose	Glucose-fructose disaccharide	Vacuoles	2	0	1	Very easy by most microorganisms
Lactose	Glucose-galactose disaccharide	Milk	0	1		Easy by lactic acid bacteria
Hyaluronic acid	Polysaccharide of glucuronic acid and N-acetylglucosamine	Connective tissue	0	1	0	Easy
Chlorophyll and other Pigments		Plastids	1	0	0	Easy
Alkaloids, tannins,	Sugars, mainly alpha-D-glucose	Vacuoles	1		0	Variable
Fats, waxes	Glycerine and fatty acids	Storage compound	1	3	1	Variable
DNS, RNS	Nucleic acids	Nuclei, Mitochondria	1	1	2	Easy
Poly-β-hydroxy butyric acid		Vacuoles, storage compound	0	0	2	Easy
Murein	Peptidoglycan	Cell wall of bacteria	0	0	3	Easy

* P: plants, A: animals, M: microorganisms. Figures indicate the relative importance (0... not found; 3... found in very high quantities).

TABLE 2 – Approximate numbers of microorganisms during different phases of composting (after Miller, 1993)

Organism	Number
Bacteria in mesophilic stage	10^9-10^{13} g^{-1} substrate
Bacteria in thermophilic stage	10^8-10^{12} g^{-1} substrate
Actinomycetes, thermophilic stage	10^7-10^9 g^{-1} substrate
Actinomycetes, mesophilic stage	10^8-10^{12} g^{-1} substrate
Fungi*, average value	10^5-10^8 g^{-1} substrate

* Due to the mycelial growth, actinomycete and fungal numbers are ambiguous.

change during composting (Atkinson *et al*., 1996a), other authors report higher numbers for the mesophilic stage. There is agreement, however, that the composition of the community can vary during the different phases of the composting process (Atkinson *et al*., 1996a; Ryckeboer *et al*., 2003). Only few studies describe the diversity of prokaryotes and/or fungi during an entire composting process. For example, Von Klopotek (1962) and Breitenbach (1998) examined the fungal diversity during the composting of (source-separated) municipal solid waste, while Strom (1985a, 1985b) and Beffa *et al*. (1996b) determined the diversity of prokaryotes during the composting of (source-separated) municipal solid wastes. Ryckeboer *et al*. (2003) examined diversity and population densities of prokaryotes and fungi throughout the whole composting process of source-separated household wastes, i.e. from starting material to mature compost. Since starting material and process conditions determine the community composition to a large degree, it is difficult to generalize. Below, it is attempted to summarize the most typical microbial features that characterize composting processes.

Starting phase - first mesophilic phase

Due to the heterogeneity of substrates, little is known on the original composition of the waste microbial community. Only few authors report on microbial diversity present in organic waste material. Von Klopotek (1962) isolated few mesophilic fungi from fresh municipal solid waste at a temperature of 36 °C. Ryckeboer *et al*. (2003) found few mesophilic fungi in source-separated household waste, but numerous thermophilic fungi and bacteria. During the initial phase of the composting process the substrates are at ambient temperature and the pH is usually slightly acidic (Figure 1). Mesophilic and/or thermotolerant fungi and bacteria are the dominant active degraders of fresh organic waste materials (20-40 °C). Food wastes containing vegetable residues often have a low initial pH (4.5 to 5.0), which stimulates the proliferation of fungi and yeasts (Choi and Park, 1998; Ryckeboer *et al.*, 2003). These microorganisms rapidly break down soluble and easily degradable carbon sources, resulting in a pH drop due to organic acids (Stutzenberger *et al*., 1970; Gray *et al*., 1971, Finstein and Morris, 1975; Beffa *et al*., 1996b).

Ammonification causes an increase of pH favourable for bacteria that subse-

quently out-compete fungi within a few hours or days. The high surface/volume ratio of bacteria allows a rapid transfer of soluble substrates into the cell. Bacteria are nutritionally also the most diverse group of compost organisms, using a broad range of enzymes to chemically degrade a variety of organic materials. Also, the average generation time of bacteria is much shorter than that of fungi which gives them a competititive advantage during those phases of the composting process that are characterized by rapid changes in substrate availability and other process parameters (temperature, moisture, aeration etc.). As a result, numbers of bacteria (including actinomycetes) are usually much higher than numbers of other microorganisms, e.g. fungi (if total numbers are comparable at all). Consequently, bacteria are responsible for most of the initial decomposition and heat generation in compost, provided that the major growth requirements are met. For bacteria, the optimal moisture content ranges from 50 to 60% (Fogarty and Tuovinen, 1991; Golueke, 1992), and they favor a near-neutral pH.

Actinomycetes develop more slowly than most bacteria and fungi and are rather ineffective competitors when nutrient levels are high (Lacey, 1973; Hardy and Sivasithamparam, 1989; Beffa *et al*., 1996b; Hoitink and Boehm, 1999). A wide range of prokaryotes produce amylase enzymes which enable them to degrade starch (Table 3), also important during the initial phase (Fagan and Fergus, 1984; Diaz-Ravina *et al.*, 1989; Domsch *et al*., 1993; Atkinson *et al.*, 1996b).

TABLE 3 – Overview of prokaryotes reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures

Organism*	Temperature phase**	Source material***	Reference
Achromobacter sp.	m, t	U, W	Strauch and de Bertoldi (1985); Ogawa *et al*. (1964)
Achromobacter xylosoxidans	m	A	Mergaert, unpublished data
Acidovorax facilis	m	A	Mergaert *et al*. (1994a)
Acidovorax sp.	m	U	Mergaert and Swings (1996)
Acinetobacter sp.	m, t	A, U	Mergaert, unpublished data; Droffner *et al*. (1995)
Actinomyces sp. °	t	P, U	Waksman *et al*. (1939a); Golueke (1977)
Alcaligenes faecalis	m, t	U, V	Corominas *et al*. (1987); Droffner *et al*. (1995)
Alcaligenes sp.	m	P, Y	Masanori and Kazuo (1998); Rocha et al. (2002)
Amphibacillus xylanus		I	Nimura *et al*. (1990)
Arthrobacter ilicis °	m	U	Mergaert *et al*. (1994a); Mergaert and Swings (1996)
Arthrobacter sp. °	m	A, V	Corominas *et al*. (1987); Beffa *et al*. (1996b)
Azotobacter sp.	m	Y	Rocha *et al*. (2002)

(continued)

TABLE 3 – Overview of prokaryotes reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Bacillus amyloliquefaciens	m, t	A	Ryckeboer *et al*. (2003)
Bacillus badius	m	A	Ryckeboer *et al*. (2003)
Bacillus cereus	m	A, M, P, V	Corominas *et al*. (1987); Hoitink and Fahy (1986); Kaneshiro *et al*. (1995); Ryckeboer *et al*. (2003)
Bacillus circulans	t	D	Strom (1985b)
Bacillus coagulans	t	A, D, O	Fermor *et al*. (1979); Strom (1985b); Koschinsky *et al*. (1998); Mergaert, unpublished data
"Bacillus denitrificans"	t	O	Koschinsky *et al*. (1998)
Bacillus licheniformis	m, t	A, D, G, O	Strom (1985b); Ivors *et al*. (2000); Ryckeboer *et al*. (2003)
Bacillus megaterium	m, t	U, V	Corominas *et al*. (1987); Mergaert *et al*. (1994a); Mergaert and Swings (1996); Mergaert, unpublished data
Bacillus mycoides		M	Hoitink and Fahy (1986)
Bacillus oleronius	m	A	Ryckeboer *et al*. (2003)
Bacillus pallidus	t	U	Blanc *et al*. (1997)
Bacillus pumilus	m, t	A, V	Corominas *et al*. (1987); Ryckeboer *et al*. (2003)
Bacillus schlegelii	t	A	Beffa *et al*. (1996a,1996b)
Bacillus smithii	t	A, O	Koschinsky *et al*. (1998); Ryckeboer *et al*. (2003)
Bacillus sp.	m, t	A, C, G, M, U, W, Y	Corominas *et al*. (1987); Hardy and Sivisithamparam (1989); Beffa *et al*. (1996b); Michel *et al*. (1997b); Blanc *et al*. (1998); Choi and Park (1998); Ogawa *et al*. (1998); Tuitert *et al*. (1998); Mannix *et al*. (2001); Rocha *et al*. (2002); Ryckeboer *et al*. (2003)
Bacillus sphaericus	m	A, D, N, V	Strom (1985b); Corominas *et al*. (1987); Seck and Kilbertus (1996); Ryckeboer *et al*. (2003)

(continued)

TABLE 3 – Overview of prokaryotes reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Bacillus subtilis	m, t	A, D, M, N, O, R, U, V	Fermor *et al.* (1979); Strom (1985b); Hoitink and Fahy (1986); Corominas *et al.* (1987); Phae *et al.* (1990); Asaka and Shoda (1996); Nakasaki *et al.* (1996); Seck and Kilbertus (1996); Ryckeboer *et al.* (2003)
Bacillus thuringiensis	m	A	Ryckeboer *et al.* (2003)
Bacteroides sp.	m	Y	Rocha *et al.* (2002)
Bradyrhizobium sp.		U	Mannix *et al.* (2001)
Brevibacillus brevis (syn.: *Bacillus brevis*)	t	D	Strom (1985b)
Brevibacillus agri	m	A	Ryckeboer *et al.* (2003)
Brevibacillus laterosporus (syn.: *Bacillus laterosporus)*	m	U	Mergaert, unpublished data
Brevibacillus thermoruber (syn.: *Bacillus thermoruber*)	t	O	Manachini *et al.* (1985)
Brevundimonas diminuta	m	A	Ryckeboer *et al.* (2003)
Brevundimonas sp.		U	Mannix *et al.* (2001)
Caryophanon latum	m	O	Ivors *et al.* (2000)
Caulobacter sp.		U	Mannix *et al.* (2001)
Cellulomonas cellulans °	m	A	Ryckeboer *et al.* (2003)
Cellulomonas flavigena °	m	A	Ryckeboer, unpublished data
Cellulomonas sp.	m	Y	Rocha *et al.* (2002)
Chromobacterium sp.	m	O	Fermor *et al.* (1979)
Chryseobacterium balustinum (syn.: *Flavobacterium balustinum*)	m	M	Hoitink and Fahy (1986); Hoitink (1990)
Chryseobacterium gleum (syn.: *Flavobacterium gleum*)	m	P	Kaneshiro *et al.* (1995)
Citrobacter freundii	t	U	Droffner *et al.* (1995)
Citrobacter sp.	m	P, U	Strauch (1987); Masanori and Kazuo (1998)
Clostridium sp.	m	W, U, Y	Ogawa *et al.* (1964); Mannix *et al.* (2001); Rocha *et al.* (2002)
Clostridium thermocellum	t	P	Henssen (1957)
Comamonas testosteroni	m	U	Mergaert *et al.* (1994a); Mergaert and Swings (1996)
Corynebacterium jeikeuim °	m	A	Andrews *et al.* (1994)

(continued)

TABLE 3 – Overview of prokaryotes reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Corynebacterium striatum °	m	A	Mergaert, unpublished data
Curtobacterium flaccumfaciens °	m	A	Mergaert, unpublished data
Cytophaga sp.	m	P	Waksman *et al.* (1939a)
Desulfotomaculum thermosapovorans	t	U	Fardeau *et al.* (1995)
Enterobacter cloacae	t	M	Hoitink and Fahy (1986); Droffner *et al.* (1995)
Enterobacter sp.	m	P, Y, U, G	Strauch (1987); Masanori and Kazuo (1998); Rocha *et al.* (2002)
Enterococcus gallinarum		U	Droffner *et al.* (1995)
Enterococcus sp.		U	Strauch (1987)
Escherichia coli	m	U, G	Strauch (1987); Droffner *et al.* (1995)
Flavimonas oxyzihabitans	m	A	Andrews *et al.* (1994)
Flavobacterium johnsoniae (syn.: *Cytophaga johnsonae*)	m	U	Mergaert *et al.* (1994a); Mergaert and Swings (1996)
Flavobacterium mizutaii	m	A	Ryckeboer *et al.* (2003)
Flavobacterium sp.	m	O	Fermor *et al.* (1979)
Geobacillus stearothermophilus (syn.: *Bacillus stearothermophilus*)	t	A, D, O, W	Fermor *et al.* (1979); Strom (1985b); Fujio and Kume (1991); Ryckeboer *et al.* (2003)
Geobacillus thermodenitrificans (syn.: *Bacillus thermodenitrificans*)	t	U	Blanc *et al.* (1997)
Geobacillus thermoglucosidasius (syn.: *Bacillus thermoglucosidasius*)	t	A, U	Blanc *et al.* (1997); Ryckeboer *et al.* (2003)
Hydrogenobacter sp.	t	A	Beffa *et al.* (1996a,1996b); Blanc *et al.* (1998)
Janthinobacterium lividum		M	Hoitink and Fahy (1986)
Klebsiella pneumoniae	m, t	A, U	Droffner *et al.* (1995); Andrews *et al.* (1994)
Klebsiella sp.		G, U	Strauch (1987)
Kocuria varians	m	A	Ryckeboer *et al.* (2003)
Methanothermobacter thermoautotrophicus (syn.: *Methanobacterium thermoautotrophicum*)	t	O	Derikx *et al.* (1989)
Methylobacterium extorquens	m	A	Andrews *et al.* (1994)
Methylobacterium organophilum	m	A	Ryckeboer *et al.* (2003)

(*continued*)

TABLE 3 – Overview of prokaryotes reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Methylobacterium sp.		U	Mannix *et al.* (2001)
Microbacterium flavcescens (syn.: *Aureobacterium flavescens*, *Arthrobacter flavescens*) °	m	N	Seck and Kilbertus (1996)
Micrococcus luteus °	m	A, N	Ryckeboer, unpublished data; Seck and Kilbertus (1996)
Micromonospora sp. °	t	P, U	Waksman *et al.* (1939a), Golueke (1977)
"Micromonospora vulgaris" °	t	F, K	Erikson (1952); Corbaz *et al.* (1963)
Moraxella bovis	m	A	Andrews *et al.* (1994)
Nitrobacter sp.	m	Y	Rocha *et al.* (2002)
Nitrosomonas sp.	m	Y	Rocha *et al.* (2002)
Nocardia brasiliensis °	t	O	Fergus (1964)
Nocardia otitidiscaviarium °	m	A	Ryckeboer *et al.* (2003)
Nocardia sp. °	m, t	P, Y	Henssen (1957); Rocha *et al.* (2002)
Paenibacillus lentimorbus	m, t	A	Ryckeboer *et al.* (2003)
Paenibacillus macerans	m, t	A, O	Ospina-Giraldo *et al.* (1996); Ryckeboer *et al.* (2003)
Paenibacillus pabuli	m	A	Ryckeboer *et al.* (2003)
Paenibacillus polymyxa	m	A, G	J. Ryckeboer, unpublished data; Ryckeboer *et al.* (2003)
Pantoea agglomerans (syn.: *Enterobacter agglomerans*)		M	Hoitink and Fahy (1986)
Paracoccus denitrificans	m	A	Beffa *et al.* (1996b); Ryckeboer *et al.* (2003)
Paracoccus versutus (syn.: *Thiobacillus versutus*)	m	A	Beffa *et al.* (1996b)
Paucimonas lemoignei (syn.: *Pseudomonas lemoignei*)	m	U	Mergaert *et al.* (1994a); Mergaert and Swings (1996)
Phyllobacterium rubiacearum	m	A	J. Mergaert, unpublished data
"Plectridia" sp.	t	P	Waksman *et al.* (1939a)
Propionibacterium sp.		U	Mannix *et al.* (2001)
Proteus hauseri (syn.: *Proteus vulgaris*)		U	Strauch (1987)
Proteus mirabilis		U	Strauch (1987)
Pseudoaltermonas haloplanktis (syn.: *Alteromonas haloplanktis*)	m	U	Mergaert and Swings (1996)

(*continued*)

TABLE 3 – Overview of prokaryotes reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Pseudomonas aeruginosa		M	Hoitink and Fahy (1986)
Pseudomonas alcaligenes	m	A, U	Mergaert *et al.* (1994a); Mergaert and Swings (1996); Ryckeboer *et al.* (2003)
Pseudomonas balearica	m	A	Ryckeboer *et al.* (2003)
Pseudomonas fluorescens	m	A, M	Hoitink and Fahy (1986); Andrews *et al.* (1994)
Pseudomonas mendocina	m	A, U	Mergaert and Swings (1996); J. Mergaert, unpublished
Pseudomonas pseudoalcaligenes	m	A, U	Droffner *et al.* (1995); J. Mergaert, unpublished
Pseudomonas putida	m	A, M	Hoitink and Fahy (1986); Andrews *et al.* (1994)
Pseudomonas sp.	m	A, G, M, O, P, U, V	Fermor *et al.* (1979); Corominas *et al.* (1987); Strauch (1987); Hardy and Sivisithamparam (1989); Beffa *et al.* (1996b); Masanori and Kazuo (1998); Tuitert *et al.* (1998); Mannix *et al*. (2001)
Pseudomonas stutzeri	m, t	A, M, O	Hoitink and Fahy (1986); Andrews *et al.* (1994); Koschinsky *et al.* (1998)
Pseudonocardia asaccharolytica °	m	M	Reichert *et al.* (1998)
Pseudonocardia sp. °	t	P	Henssen (1957)
Pseudonocardia sulfidoxydans °	m	M	Reichert *et al.* (1998)
Pseudonocardia thermophila °	t	O	Fergus (1964)
Psychrobacter immobilis	m	A	Andrews *et al.* (1994)
Rathayibacter tritici °	m	A	J. Mergaert, unpublished data
Rhodococcus rhodochrous °	m	A, G	Ryckeboer *et al.* (2003); J. Ryckeboer, unpublished data
Rhodococcus sp.	m	Y	Rocha *et al.* (2002)
Rhodovulum adriaticum	m	A	J. Mergaert, unpublished data
Saccharomonospora sp. °	t	O	Amner *et al.* (1988)
Serratia entomophila	m	A	Andrews *et al.* (1994)
Serratia marcescens	m	A, U	Andrews *et al.* (1994); Droffner *et al.* (1995)
Serratia sp.	m	O, U	Fermor *et al.* (1979), Strauch (1987)

(*continued*)

TABLE 3 – Overview of prokaryotes reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Sphingobacterium thalpophilum	m	P	Kaneshiro *et al.* (1995)
Staphylococcus intermedius	t	A	Ryckeboer *et al.* (2003)
Staphylococcus sp.	m	P, U	Kaneshiro *et al.* (1995); Mannix *et al.* (2001)
Stenotrophomonas maltophilia (syn.: *Xanthomonas maltophilia*)	m	A, M	Hoitink and Fahy (1986); Hoitink (1990); Andrews *et al.* (1994)
Streptomyces fradiae °	t	K	Corbaz *et al.* (1963)
Streptomyces griseoflavus °	t	K	Corbaz *et al.* (1963)
"Streptomyces rectus" °	m, t	O	Fergus (1964)
Streptomyces sp. °	m, t	A, D, O, U	Henssen (1957); Golueke (1977); Fermor *et al.* (1979); Strom (1985b); Strauch (1987); Amner *et al.* (1988); Mergaert *et al.* (1994a); Mergaert and Swings (1996); Breitenbach (1998); Ryckeboer *et al.* (2003)
Streptomyces thermoviolaceus °	t	B, O	Fergus (1969); Gangwar *et al.* (1997)
Streptomyces thermoviolaceus subsp. *apingens* °	t	K, O	Corbaz *et al.* (1963); Fergus (1964)
Streptomyces thermovulgaris °	t	O	Fergus (1964); Fermor *et al.* (1979)
Streptomyces violaceoruber °	m, t	O	Fergus (1964)
Symbiobacterium sp.	t	U	Ueda *et al.* (2002)
Symbiobacterium thermophilum	t	U	Ohno *et al.* (2000)
Terrabacter sp.	m	Y	Rocha *et al.* (2002)
"Thermoactinomyces glaucus" °	m, t	O	Fergus (1964)
Thermoactinomyces sp. °	t	D, O, P	Henssen (1957); Atrom (1985a, 1985b); Amner *et al.* (1988)
Thermoactinomyces vulgaris °	m, t	O	Fergus (1964); Fermor *et al.* (1979)
Thermobifida fusca (syn.: *Thermomonospora fusca*) °	m, t	G, O	Fergus (1964); Kleeberg *et al.* (1998)
Thermocrispum agreste	m, t	O	Korn-Wendisch *et al.* (1995)
Thermocrispum municipale	m, t	B	Korn-Wendisch *et al.* (1995)
Thermocrispum sp.	m, t	B	Korn-Wendisch *et al.* (1995)
Thermomonospora curvata °	m, t	B, O	Fergus (1964); Gangwar *et al.* (1997)

(*continued*)

TABLE 3 – Overview of prokaryotes reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Thermomonospora sp. °	t	O, P	Henssen (1957); Amner *et al.* (1988)
"Thermomonospora viridis" °	t	O	Fermor *et al.* (1979)
"Thermopolyspora polyspora"	t	K, O	Corbaz *et al.* (1963); Fergus (1964)
"Thermopolyspora glauca"	t	K	Corbaz *et al.* (1963)
"Thermopolyspora" sp.	t	P	Henssen (1957)
Thermus sp.	t	A, W	Fujio and Kume (1991); Beffa *et al.* (1996b, 1996c)
Thermus thermophilus	t	A	Blanc *et al.* (1998)
Variovorax paradoxus	m	U	Mergaert *et al.* (1994a); Mergaert and Swings (1996)
Xanthobacter sp.	m	A, Y	Beffa *et al.* (1996b); Rocha *et al.* (2002)

The majority of the species presented in this table were isolated on rich organic complex media.
* The most recent names are given. When older synonyms were cited in the referenced literature, these are given in parenthesis. Species names between brackets have not been listed on the Approved Names of Bacterial Names (Skerman *et al*., 1980) or have not been subsequently validly published or validated. Taxa (or their older synonyms) assigned to the actinomycetes by Goodfellow (1989) are marked with °.
** Temperature phase: m = mesophilic; t = thermophilic; prokaryotes are classified as mesophiles and thermophiles if their optimal growth temperatures are moderate (20-40 °C) or high (> 40 °C); respectively.
*** Source material: A = kitchen and garden waste (= vegetable, fruit and garden waste; leaves, grass and food waste; source-separated household waste); B = municipal solid waste; C = food waste and sawdust; D = kitchen waste and shredded newspapers; F = grass compost; G = garden waste; I = compost of manure, grass and rice straw; K = moldy hay; M = hardwood bark; tree bark; eucalyptus bark; N = peanut shells; O = mushroom compost; P = horse manure; dairy cattle manure; manure (several origins); Q = poultry litter; R = sludge, barks (chicken manure and wood chips) and garbage; U = compost (origin not defined); V = agricultural waste; W = sewage sludge; Y = cattle manure and forestry wastes.

Thermophilic phase

As soon as moisture decreases, temperature rises above 30 °C and the substrates become more alkaline, actinomycetes, in particular streptomycetes, strive. They cause the characteristic earthy smell of soil and compost by production of geosmine, which are sesquiterpenoid compounds. Actinomycetes compete with other organisms for nutrients and can inhibit microbial growth by production of antibiotics, lytic enzymes or even by parasitism. They play an important role in composting by degrading natural polymers and colonize organic material after bacteria and fungi have consumed easily degradable fractions. Their enzymes enable

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Absidia corymbifera (Cohn) Saccardo & A. Trotter 1912 (syn.: *Mucor corymbifer* Cohn 1884)	m, t	B, J, O, G	Von Klopotek (1962); Chang and Hudson (1967); Knoesel and Resz (1973); Upreti and Joshi (1984); Anastasi *et al.* (2002)
Absidia orchidis Vuillemin 1908	m	O	Upreti and Joshi (1984)
Absidia ramosa (Lindt) Lendner 1908	t	E, O	de Bertoldi *et al*. (1983); Upreti and Joshi (1984)
Absidia sp.	m	B	Von Klopotek (1962)
Acremoniella sp.	t	H	Waksman *et al.* (1939a)
Acremonium atrogriseum (Panasenko) W. Gams 1971	m	A	Breitenbach (1998)
Acremonium breve (Sukapure & Thirumalachar) W. Gams 1971		X	Anastasi *et al.* (2002)
Acremonium butyri (van Beyma) W. Gams 1971		O	Fagan and Fergus (1984)
Acremonium charticola (Lindau) W. Gams 1971		G	Anastasi *et al.* (2002)
Acremonium chrysogenum (Thirumalachar & Sukapure) W. Gams 1971	m	A, G, X	Breitenbach (1998), Anastasi *et al.* (2002)
Acremonium furcatum 1970 (F. & V. Moreau) ex W. Gams	m	A	J. Ryckeboer, unpublished data
Acremonium kiliense Grütz 1925 (syn.: *Cephalosporium kiliense* (Grütz) Hartmann)	m	A	Breitenbach (1998); J. Ryckeboer, unpublished data
Acremonium murorum (Corda) W. Gams 1971 (syn.: *Gliomastix murorum* (Corda) S. Hughes 1958)	m	E	de Bertoldi *et al*. (1983)
Acremonium sclerotigenum (F. & V. Moreau ex Valenta) W. Gams 1971		G, X	Anastasi *et al.* (2002)
Acremonium sp.	m	A, G, O, X	Fagan and Fergus (1984); Breitenbach (1998); Anastasi *et al.* (2002); Ryckeboer *et al.* (2003)
Acremonium strictum W. Gams 1971	m	A, G, H, X	Eastwood (1952); Breitenbach (1998); Anastasi *et al.* (2002)
Acremonium thermophilum W. Gams & Lacey 1972	m, t	A	J. Ryckeboer, unpublished data

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Acremonium verruculosum W. Gams & Veenbaas-Rijks 1971		X	Anastasi *et al.* (2002)
Acrodontium griseum (Fassatiová) de Hoog 1972		G	Anastasi *et al.* (2002)
Acrophialophora fusispora (S.B. Saksena) Samson 1970		G, X	Anastasi *et al.* (2002)
Actinomucor elegans (Eidam) C.R. Benjamin & Hesseltine 1957 (syn.: *A. repens* Schotstakowitsch. 1898)	m	A, G	Domsch (1960b); Von Klopotek (1962); Breitenbach (1998)
Actinomucor sp.	m	B	Von Klopotek (1962)
Agaricus bisporus (J. Lange) Imbach (syn.: *Agaricus brunnescens* Peck)		O	Fagan and Fergus (1984)
Aleurisma sp.	m	B	Von Klopotek (1962)
Alternaria alternata (Fries: Fries) von Keissler 1912 (syn.: *A. tenuis* Nees 1822)	m	A, B, E, F, G, J, X	Eastwood (1952); Von Klopotek (1962); Chang and Hudson (1967); de Bertoldi *et al*. (1983); Breitenbach (1998); Anastasi *et al.* (2002)
Alternaria sp.	m	P, Y	Waksman *et al.* (1939a); Rocha *et al.* (2002)
Aphanoascus terreus (Randhawa & Sandhu) Apinis		X	Anastasi *et al.* (2002)
Apiospora montagnei Saccardo 1875		X	Anastasi *et al.* (2002)
Armillaria mellea (Vahl: Fries) P. Kummer 1871		E	de Bertoldi *et al*. (1983)
Arthrinium phaeospermum (Corda) M.B. Ellis 1965		G	Domsch (1960a)
Arthrobotrys amerospora S. Schenck *et al.* 1976	m	A	Breitenbach (1998)
Arthrobotrys oligospora Fresenius 1850	m	A, E, G, O	de Bertoldi *et al*. (1983); Fagan and Fergus (1984); Domsch *et al*. (1993); Breitenbach (1998)
Arthrobotrys sp.	m	B, G	Von Klopotek (1962); Chamuris *et al.* (2000)
Ascodesmis microscopica (Crouan) Seaver		G	Anastasi *et al.* (2002)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Ascotricha sp.	m	B	Von Klopotek (1962)
Aspergillus candidus Link: Fries	m	A, G, J, X	Domsch (1960a); Chang and Hudson (1967); Anastasi *et al.* (2002); Ryckeboer *et al.* (2003); J. Ryckeboer, unpublished data
Aspergillus clavatus Desmazières 1834	m	B	Von Klopotek (1962)
Aspergillus erythrocephalus Berk. & Curtis 1869	m	F	Malik and Sandhu (1973)
Aspergillus flavipes (Bain. & Sart) Thom & Church	m	O	Upreti and Joshi (1984)
Aspergillus flavus Link 1821	m	O	Upreti and Joshi (1984)
Aspergillus flavus var. *columnaris* Raper & Fennell 1965		G, X	Anastasi *et al.* (2002)
Aspergillus flavus var. *flavus* Link: Fries 1809		G	Anastasi *et al.* (2002)
Aspergillus fumigatus Fresenius 1863	m, t	A, B, D, E, F, J, L, M, O, U	Eastwood (1952); Von Klopotek (1962); Fergus (1964); Chang and Hudson (1967); Stutzenberger *et al.* (1970); Knoesel and Resz (1973); Malik and Sandhu (1973); Golueke (1977); Fermor *et al.* (1979); de Bertoldi *et al.* (1983); Upreti and Joshi (1984); Strom (1985b); Campbell *et al.* (1990); Mergaert *et al.* (1994a); Beffa *et al.* (1996b); Lott Fischer (1996); Mergaert and Swings (1996); Breitenbach (1998); Chamuris *et al.* (2000)
Aspergillus fumigatus var. *ellipticus* Raper & Fennell 1965	m	A, G, X	Breitenbach (1998); Anastasi *et al.* (2002)
Aspergillus fumigatus var. *fumigatus* Fresenius 1863	m	A, G, X	Breitenbach (1998); Anastasi *et al.* (2002)
Aspergillus melleus Yukawa 1911 (syn.: *Aspergillus quercinus* (Bainier) Thom & Church 1926)	m	B	Von Klopotek (1962)
Aspergillus nidulans (Eidam) G. Winter 1884	m	A	Breitenbach (1998)

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TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Aspergillus niger van Tieghem 1867	m	B, F, G, O, X	Von Klopotek (1962); Malik and Sandhu (1973); Upreti and Joshi (1984); Chamuris *et al.* (2000); Anastasi *et al.* (2002)
Aspergillus orchraceous Wilhelm 1877	m	G, O, X	Upreti and Joshi (1984); Anastasi *et al.* (2002)
Aspergillus oryzae var. *oryzae* (Ahlburg) Cohn		G	Anastasi *et al.* (2002)
Aspergillus parasiticus Speare 1912	m	O	Upreti and Joshi (1984)
Aspergillus puniceus Kwon & Fennell 1965		X	Anastasi *et al.* (2002)
Aspergillus ruber (Kon. Spieck. & Bremer) Thom & Church 1926	m	O	Upreti and Joshi (1984)
Aspergillus sp.	m, t	A, B, E, F, G, M, N, P, X, Y	Eastwood (1952); Henssen (1957); Von Klopotek (1962); de Bertoldi *et al*. (1983); Chung and Hoitink (1990); Seck and Kilbertus (1996); Breitenbach (1998); Anastasi *et al.* (2002); Rocha *et al.* (2002); Ryckeboer *et al.* (2003); J. Ryckeboer, unpublished data
Aspergillus sulphureus (Fresenius) Thom & Church		X	Anastasi *et al.* (2002)
Aspergillus sydowii (Bain. & Sart) Thom & Church 1926	m	O	Upreti and Joshi (1984)
Aspergillus terreus Thom 1918	m, t	F, J, O	Eastwood (1952); Upreti and Joshi (1984)
Aspergillus terreus var. *africanus* Fennell & Raper 1955		G	Anastasi *et al.* (2002)
Aspergillus terreus var. *terreus* Thom		G, X	Anastasi *et al.* (2002)
Aspergillus versicolor (Vuillemin) Tiraboschi 1926	m	A, D, G, M	Domsch (1960b); Chang and Hudson (1967); Breitenbach (1998); Anastasi *et al.* (2002)
Aspergillus wentii Wehmer 1896		G	Anastasi *et al.* (2002)
Aureobasidium pullulans (de Bary) Arnaud 1910	m	F, G, O	Malik and Sandhu (1973); Fermor *et al.* (1979); Chamuris *et al.* (2000)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Aureobasidium pullulans var. *pullulans* (de Bary) Arnaud		X	Anastasi *et al.* (2002)
Aureobasidium sp.	m	J	Chang and Hudson (1967)
Beauveria bassiana (Balsamo) Vuillemin 1912		X	Anastasi *et al.* (2002)
Beauveria brongniartii (Saccardo) Petch 1926		X	Anastasi *et al.* (2002)
Beauveria felina (de Candolle: Fries) Carmichael 1980 (syn.: *Isaria cretacea* van Beyma)	m	B	Von Klopotek (1962)
Botryosporium sp.		U	Golueke (1977)
Botryotinia fuckeliana (de Bary) Whetzel 1945 (alternative state of *Botrytis cinerea* Persoon: Fries)		X	Anastasi *et al.* (2002)
Botryotrichum piluliferum Sacc. & March. 1885	m	A, E, O	de Bertoldi *et al.* (1983); Fagan and Fergus (1984); Breitenbach (1998)
Botryotrichum sp.		O	Fagan and Fergus (1984)
Botrytis cinerea Persoon Ex Nocca & Balb. 1822	m	A, G, O	Fermor *et al.* (1979); Breitenbach (1998); Chamuris *et al.* (2000)
Botrytis sp.	m	B	Von Klopotek (1962)
Candida krusei (Castellani) Berkhout 1923 (alternate state of *Issatchenkia orientalis* Kudrjanzev 1960)		Z	Peters *et al.* (2000)
Candida tropicalis (Castellani) Berkhout 1923		Z	Peters *et al.* (2000)
Cephaliophora irregularis Thaxter 1903	m	B	Von Klopotek (1962)
Cephaliophora sp.	m	A	Ryckeboer *et al.* (2003)
Cephaliophora tropica Thaxter 1903	m	B, E	Von Klopotek (1962); de Bertoldi *et al.* (1983)
Cephalosporium sp.	m	A, B, E, G, H, O, P	Waksman *et al.* (1939a); Eastwood (1952); Von Klopotek (1962); Fermor *et al.* (1979); de Bertoldi *et al.* (1983); J. Ryckeboer, unpublished data

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Chaetomidium fimeti (Fuckel) Saccardo 1882 (syn.: *Thielavia fimeti* (Fuckel) Malloch & Cain 1973)		G	Domsch (1960b)
Chaetomium bostrychodes Zopf 1877		X	Anastasi *et al.* (2002)
Chaetomium funicola Cooke 1873 (syn.: *Chaetomium dolichotrichum* L. Ames 1945)	m	B, X	Von Klopotek (1962); Anastasi *et al.* (2002)
Chaetomium globosum Kunze: Fries	m	F, J, X	Eastwood (1952); Malik and Sandhu (1973); Anastasi *et al.* (2002)
Chaetomium indicum Corda 1840	m	B	Von Klopotek (1962)
Chaetomium nigricolor L. Ames 1950		G	Anastasi *et al.* (2002)
Chaetomium olivaceum Cooke & Ellis 1878	m	O	Botha *et al.* (1990)
Chaetomium sp.	m	E, G, Y	de Bertoldi *et al*. (1983); Chamuris *et al.* (2000), Rocha *et al.* (2002)
Chaetomium thermophile var. *coprophile* Cooney & Emerson 1964	t	O	Upreti and Joshi (1984)
Chaetomium thermophile var. *dissetum* Cooney & Emerson 1964	t	O	Upreti and Joshi (1984)
Chaetomium thermophilum La Touche 1950	t	B, E, J, O, U	Von Klopotek (1962); Fergus (1964); Chang and Hudson (1967); Fergus (1969); Kane and Mullins (1973); Golueke (1977); Fermor *et al.* (1979); de Bertoldi *et al*. (1983)
Chrysosporium indicum (Randhawa & Sandhu) Garg 1965		X	Anastasi *et al.* (2002)
Chrysosporium merdarium (Link: Fries) Carmichael 1962		X	Anastasi *et al.* (2002)
Chrysosporium queenslandicum Apinis & Rees 1976		X	Anastasi *et al.* (2002)
Chrysosporium tropicum Carmichael 1962		X	Anastasi *et al.* (2002)
Circinella umbellata van Tieghem & le Monnier 1873	m	B	Von Klopotek (1962)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Cladosporium chlorocephalum (Fresenius) Mason & M.B. Ellis		G	Anastasi *et al.* (2002)
Cladosporium cladosporioides (Fresenius) de Vries 1952	m	A, B, G, O, X	Von Klopotek (1962); Upreti and Joshi (1984); Breitenbach (1998); Anastasi *et al.* (2002)
Cladosporium herbarum (Persoon: Fries) Link 1821	m	A, G, J, O, X	Chang and Hudson (1967); Fermor *et al.* (1979); Breitenbach (1998); Anastasi *et al.* (2002); J. Ryckeboer, unpublished data
Cladosporium oxysporum Berkeley & Curtis 1868		G, X	Anastasi *et al.* (2002)
Cladosporium sp.	m	B, Y	Von Klopotek (1962); Rocha *et al.* (2002)
Cladosporium sphaerospermum Penzig 1882		G, X	Anastasi *et al.* (2002)
Clitopilus pinsitus (Fries) Josserand	m	J	Chang and Hudson (1967)
Clonostachys rosea (Link: Fries) Schroers, Samuels, Seifert & W. Gams 1999	m	A	Breitenbach (1998)
Clonostachys solani (Harting) Schroers & W. Gams	m	A	Breitenbach (1998)
Coniothyrium fuckelii Saccardo 1878		G, X	Anastasi *et al.* (2002)
Coniothyrium sporulosum (W. Gams & Domsch) van der Aa 1977		G	Domsch (1960b)
Coonemeria crustacea (Apinis & Chesters) Mouch. 1997 (syn.: *Dactylomyces crustaceus* Apinis & Chesters 1964)	t	B	Kane and Mullins (1973)
Coprinus cinereus (Schaeffer: Fries) Gray 1928 (syn.: *Coprinus delicatulus* Apinis 1965)	m, t	E, J, O	Chang and Hudson (1967); de Bertoldi *et al.* (1983); Fagan and Fergus (1984); Straatsma *et al.* (1994); Tuomela *et al.* (2000)
Coprinus congregatus (Bulliard) Fries		O	Fagan and Fergus (1984)
Coprinus domesticus (Bolton: Fries) Gray 1821		O	Fagan and Fergus (1984)

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TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Coprinus sp.	m	B, J, O	Von Klopotek (1962); Chang and Hudson (1967); Fagan and Fergus (1984)
Corynascus sepedonium (C.W. Emmons) von Arx 1973 (syn.: *Thielavia sepedonium* Emmons 1932)	m	G, O, X	Fagan and Fergus (1984); Chamuris *et al.* (2000); Anastasi *et al.* (2002)
Cunninghamella elegans Lendner 1908		X	Anastasi *et al.* (2002)
Curvularia harveyi Shipton 1966	m	G	Chamuris *et al.* (2000)
Curvularia pallescens Boedijn 1933	m	O	Upreti and Joshi (1984)
Cylindrocarpon destructans (Zinssmeister) Scholten 1964	m	G	Chamuris *et al.* (2000)
Cylindrocarpon lichenicola (C.B. Massalongo) Hawksworth 1979 (syn.: *C. tonkinense* Bugnicourt 1939)	m	A	Breitenbach (1998)
Cylindrocarpon sp.	m	G	Chamuris *et al.* (2000); Anastasi *et al.* (2002)
Dactylaria sp.	m	A	Ryckeboer *et al.* (2003)
Doratomyces medius (Sacc.) Matsush. 1980	m	A	Breitenbach (1998)
Doratomyces microsporus (Saccardo) Morton & Smith 1963		G, O, P	Domsch (1960b); Fagan and Fergus (1984); Domsch *et al.* (1993); Anastasi *et al.* (2002)
Doratomyces purpureofuscus (Schweinitz: Fries) Morton & Smith 1963		B, O, X	Morton and Smith (1963); Fagan and Fergus (1984); Domsch *et al.* (1993); Anastasi *et al.* (2002)
Doratomyces sp.	m	E	de Bertoldi *et al*. (1983)
Doratomyces stemonitis (Persoon: Fries) Morton & G. Smith 1963 (syn.: *Stysanus stemonitis* (Persoon: Fries) Corda 1837	m	A, B, G, J	Domsch (1960b); Von Klopotek (1962); Chang and Hudson (1967); Breitenbach (1998)
Emericella nidulans (Eidam) Vuillemin 1927 (anamorph: *Aspergillus nidulans* (Eidam) Winter 1884)	m, t	E, G, J, O	Domsch (1960a); Chang and Hudson (1967); de Bertoldi *et al*. (1983); Upreti and Joshi (1984); Chamuris *et al.* (2000)
Emericella nidulans var. *nidulans* (Eidam) Vuillemin		X	Anastasi *et al.* (2002)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Emericella quadrilineata (Thom & Raper) C.R. Benjamin 1955 (anamorph: *Aspergillus quadrilineatus* Thom & Raper 1939)	m	B	Von Klopotek (1962)
Engyodontium album (Limber) de Hoog 1972		X	Anastasi *et al.* (2002)
Epicoccum nigrum Link ex Link 1825 (syn.: *E. purpurascens* Ehrenberg ex Schlecht 1824)	m	A, B, G, X	Domsch (1960b); Von Klopotek (1962); Breitenbach (1998); Anastasi *et al.* (2002)
Eremascus fertilis Stoppel 1907		G	Anastasi *et al.* (2002)
Eurotium amstelodami Mangin 1909 (syn.: *Aspergillus amstelodami* (Mangin) Thom & Church 1926)	m	E, G, J, X	Chang and Hudson (1967); de Bertoldi *et al*. (1983); Anastasi *et al.* (2002)
Eurotium chevalieri Mangin 1909		X	Anastasi *et al.* (2002)
Eurotium herbariorum (Wiggers: Fries) Link ex Gray 1821 (syn.: *E. repens* de Bary 1870; anamorph: *Aspergillus repens* (Corda) Saccardo 1882)	m	G, J	Domsch (1960a); Chang and Hudson (1967)
Eurotium intermedium Blaser 1975		X	Anastasi *et al.* (2002)
Eurotium montevideense (Talice & Mackinnon) Malloch & Cain 1972		G	Anastasi *et al.* (2002)
Eurotium rubrum König *et al.*		X	Anastasi *et al.* (2002)
Eutypella scoparia (Schweinitz: Fries) Ellis & Everhart 1892		G	Anastasi *et al.* (2002)
Exophiala moniliae de Hoog 1977		G	Anastasi *et al.* (2002)
Exophiala pisciphila McGinnis & Ajello 1974		X	Anastasi *et al.* (2002)
Exophiala sp.		X	Anastasi *et al.* (2002)
Fennellia nivea (Wiley & Simmons) Samson		X	Anastasi *et al.* (2002)
Fomes sp.	t	E	de Bertoldi *et al*. (1983)
Fusarium culmorum (W.G. Smith) Saccardo 1895	m	A, J	Chang and Hudson (1967); Breitenbach (1998)
Fusarium dimerum Penzig 1882		G	Domsch (1960a)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Fusarium filiferum (Preuss) Wollenw 1916	m	A	Breitenbach (1998)
Fusarium merismoides Corda Domsch (1960b) 8		G	Domsch (1960a)
Fusarium oxysporum Schlechtendahl: Fries 1824	m	G	Chamuris *et al.* (2000); Anastasi *et al.* (2002)
Fusarium solani (Martius) Saccardo 1881	m	A, F, G, O	Malik and Sandhu (1973); Fagan and Fergus (1984); Breitenbach (1998); Anastasi *et al.* (2002)
Fusarium sp.	m	A, B, G, H, N, O, S, X	Eastwood (1952); Von Klopotek (1962); Fagan and Fergus (1984); Hadar and Gorodecki (1991); Seck and Kilbertus (1996); Breitenbach (1998); Chamuris *et al.* (2000); Anastasi *et al.* (2002); J. Ryckeboer, unpublished data
Fusarium verticillioides (Saccardo) Nirenberg 1976 (syn.: *Fusarium moniliforme* Sheldon 1904)	m	O	Upreti and Joshi (1984)
Gelasinospora reticulata (Booth & Ebben) Cailleux 1972 (syn.: *Anixiella reticulata* (Booth & Ebben) Cain 1961)		O	Fagan and Fergus (1984)
Geomyces pannorum (Link) Sigler & Carmichael 1976	m	A	Breitenbach (1998)
Geomyces pannorum var. *pannorum* (Link) Sigler & Carmichael 1976		G, X	Anastasi *et al.* (2002)
Geomyces vinaceus Dal Vesco 1957		G	Anastasi *et al.* (2002)
Geosmithia sp.	t	M	Campbell *et al.* (1990)
Geotrichum candidum Link ex Leman 1821	m	A, B, E, U	Von Klopotek (1962); de Bertoldi *et al*. (1983); Strauch and de Bertoldi (1985); Breitenbach (1998); Ryckeboer *et al.* (2003); J. Ryckeboer, unpublished data
Geotrichum sp.	m	G, O, X, Y	Fagan and Fergus (1984); Chamuris *et al.* (2000); Anastasi *et al.* (2002); Rocha *et al.* (2002)

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TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Gilmaniella humicola Barron 1964	m	G, O	Bollen and Van der Pol-Luiten (1975); Fagan and Fergus (1984); Chamuris *et al.* (2000)
Gilmaniella macrospora Moustafa 1975		X	Anastasi *et al.* (2002)
Gliobotrys alboviridis von Höhnel	m	B	Von Klopotek (1962)
Gliocladium deliquescens Sopp.	m	O	Upreti and Joshi (1984)
Gliocladium penicillioides Corda 1870	m	F	Eastwood (1952)
Gliocladium roseum Bainier 1907	m	A, B	Von Klopotek (1962); Ryckeboer *et al.* (2003)
Gliocladium sp.	m	E, G	de Bertoldi *et al*. (1983); Anastasi *et al.* (2002)
Gliocladium viride Matruchot 1893	m	B	Von Klopotek (1962)
Gliomastix cf. *atrogriseum* (Panas.) Borowska 1986	m	A	Breitenbach (1998)
Gliomastix sp.	m	B	Von Klopotek (1962)
Gloeophyllum trabeum (Persoon: Fries) Murril 1908 (syn.: *Lenzites trabea* (Persoon) Bres. 1897)	m	E	de Bertoldi *et al*. (1983)
Graphium putredinis (Corda) S. Hughes 1958	m	A, X	Breitenbach (1998); Anastasi *et al.* (2002)
Graphium sp.	m	B	Von Klopotek (1962)
Gymnoascacea sp.		G	Anastasi *et al.* (2002)
Harpographium sp.	m	E	de Bertoldi *et al*. (1983)
Heterosporium sp.	m	B	Von Klopotek (1962)
Hormiscium sp.	m, t	B	Von Klopotek (1962)
Humicola fuscoatra Traaen 1914	m	A	Breitenbach (1998)
Humicola fuscoatra var. *fuscoatra* Traaen 1914		G, X	Anastasi *et al.* (2002)
Humicola grisea[d] Traaen	m, t	B, O	Von Klopotek (1962); Fergus (1969); Fermor *et al.* (1979); Campbell *et al.* (1990)
Humicola grisea var. *thermoidea*[a] Cooney & Emerson 1964	t	O, X	Fergus (1964); Fermor *et al.* (1979); Upreti and Joshi (1984); Anastasi *et al.* (2002)
Humicola insolens[a] Cooney & Emerson 1964	m, t	E, J, O	Fergus (1964); Chang and Hudson (1967); Fergus (1969); de Bertoldi *et al*. (1983); Upreti and Joshi (1984)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Humicola sp.	t	A, B, M, P	Waksman *et al.* (1939a); Henssen (1957); Von Klopotek (1962); Chung and Hoitink (1990); J. Ryckeboer, unpublished data
Hypocrea lutea (Tode) Petch 1937 (syn.: *Gliocladium deliquescens* Olsen-Sopp)	m	B	Von Klopotek (1962)
Hypomyces chrysospermus (Bulliard) Tulasne 1860		G	Domsch (1960a)
Kluyveromyces marxianus (E.C. Hansen) Van der Walt 1965	m, t	C	Choi and Park (1998)
Lentinus lepideus (Fries: Fries) Fries 1838	m	E	de Bertoldi *et al*. (1983)
Lenzites sp.	t	E	de Bertoldi *et al*. (1983)
Leptographium lundbergii Lagerberg & Melin	m	E	de Bertoldi *et al*. (1983)
Leptographium sp.		G, X	Anastasi *et al.* (2002)
Macrosporium sp.	m	B	Von Klopotek (1962)
Malbranchea cinnamomea (Libert) van Oorschot & de Hoog 1984 (syn.: *Malbranchea pulchella* (Miehe) Sigler & Carmichael 1976; *Thermoidium sulfureum* Miehe)	t	B, G, J, O, X	Von Klopotek (1962); Chang and Hudson (1967); Fergus (1969); Straatsma *et al.* (1994); Anastasi *et al.* (2002)
Melanocarpus albomyces (Cooney & Emerson) von Arx 1975 (syn.: *Myriococcum albomyces* Cooney & Emerson 1964)		O, U	Tuomela *et al.* (2000)
Metarhizium flavoviride W. Gams & Rozsypal 1973	m	A	J. Ryckeboer, unpublished data
Microascus cirrosus Curzi 1930		X	Anastasi *et al.* (2002)
Mollisia sp.	t	E	de Bertoldi *et al*. (1983)
Monilia sp.	m, t	A, O, P	Waksman *et al.* (1939a); Fermor *et al.* (1979); Breitenbach (1998)
Moniliella suaveolens var. *nigra* (Burri & Staub) de Hoog 1979		X	Anastasi *et al.* (2002)
Monotospora sp.	t	H, P	Waksman *et al.* (1939a); Eastwood (1952)
Mortierella alliacea Linnemann 1953		G	Anastasi *et al.* (2002)

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TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Mortierella alpina Peyronel 1913		G, X	Anastasi *et al.* (2002)
Mortierella chlamydospora (Chesters) van der Plaats-Niterink 1976		G	Anastasi *et al.* (2002)
Mortierella echinosphaera van der Plaats-Niterink 1976		G, X	Anastasi *et al.* (2002)
Mortierella exigua Linnemann 1941		G	Domsch (1960b)
Mortierella globalpina W. Gams & Veenbaas-Rijks 1976		G	Anastasi *et al.* (2002)
Mortierella humilis Linnemann ex W. Gams 1977		G	Anastasi *et al.* (2002)
Mortierella hyalina (Harz) W. Gams 1969 (syn.: *Mortierella hygrophila* Linnemann 1936)	m	A, G	Breitenbach (1998); *Anastasi et al. (2002)*
Mortierella indohii C.Y. Chien 1974		G	Anastasi *et al.* (2002)
Mortierella polycephala Coemans 1863		G	Domsch (1960a)
Mortierella reticulata van Tieghem & le Monnier 1873	m	A	Breitenbach (1998)
Mortierella sp.	m	B, G, X	Von Klopotek (1962); Anastasi *et al.* (2002)
Mortierella stylospora Dixon-Stewart 1932	m	A	Breitenbach (1998)
Mortierella turficola Ling Young 1930	m	A	Breitenbach (1998)
Mortierella vinacea Dixon-Stewart 1932	m	A	Breitenbach (1998)
Mucor abundans Povah 1917	m	H	Eastwood (1952)
Mucor caninus Persoon 1796	m	O	Upreti and Joshi (1984)
Mucor circinelloides van Tieghem 1875	m	A	Breitenbach (1998)
Mucor circinelloides f. *circinelloides* van Tieghem 1875	m	B, G, P	Domsch (1960a); Von Klopotek (1962); Domsch *et al.* (1993)
Mucor circinelloides f. *griseocyanus* (Hagem) Schipper 1970		X	Anastasi *et al.* (2002)
Mucor circinelloides f. *janssenii* (Lendner) Schipper 1971 (syn.: *Circinella tenella* (Ling Young) Zycha 1935)	m	B	Von Klopotek (1962)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Mucor fragilis Bainier sensu Zycha 1884	m	O	Upreti and Joshi (1984)
Mucor hiemalis Wehmer 1903	m	A	Breitenbach (1998)
Mucor microsporus Namyslowski 1910	m	A	Breitenbach (1998)
Mucor miehei Cooney & Emerson 1964	t	O	Upreti and Joshi (1984)
Mucor plumbeus Bonorden 1864 (syn.: *Mucor spinescens* Lendner 1907)	m	H	Eastwood (1952)
Mucor pusillus Lindt 1886	t	E, O	de Bertoldi *et al*. (1983); Upreti and Joshi (1984)
Mucor racemosus Fresenius 1850	m	A, O	Upreti and Joshi (1984); Breitenbach (1998)
Mucor racemosus f. *racemosus* Fresenius 1850 (syn.: *Mucor varians* Pišpek 1929)	m	H	Eastwood (1952)
Mucor sp.	m, t	A, B, M, O, U	Von Klopotek (1962); Fermor *et al.* (1979); Strauch (1987); Chung and Hoitink (1990); Ryckeboer *et al.* (2003)
Myceliophthora sp.		X	Anastasi *et al.* (2002)
Myceliophthora thermophila (Apinis) van Oorschot 1977 (syn.: *Sporotrichum thermophilum* Apinis)	t	J, X	Chang and Hudson (1967); Anastasi *et al.* (2002)
Mycena sp.	m	B	Von Klopotek (1962)
Mycogone nigra (Morgan) Jensen	m	B	Von Klopotek (1962); Golueke (1977)
Myrothecium sp.	m	O	Upreti and Joshi (1984)
Nectria inventa Pethybridge 1919		G	Domsch (1960a)
Nectria sp.		G	Anastasi *et al.* (2002)
Nectria ventricosa C. Booth 1971		G	Domsch (1960a)
Neosartorya spinosa (Raper & Fennell) Kozakiewicz 1989		X	Anastasi *et al.* (2002)
Neosartorya fischeri var. *fischeri* (Wehmer) Malloch & Cain		X	Anastasi *et al.* (2002)
Nigrospora sp.	m	N	Seck and Kilbertus (1996)
Oedocephalum glomerulosum (Bulliard: Fries) Saccardo	m	B, O	Von Klopotek (1962); Botha *et al.* (1990)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Oedocephalum sp.	m	A, B, O	Von Klopotek (1962); Fagan and Fergus (1984); Breitenbach (1998)
Oidiodendron griseum Robak 1934		G	Domsch (1960a)
Oïdium sp.	t	P	Waksman *et al.* (1939a)
Oospora variabilis (Lindner) Lindau	m	H	Eastwood (1952)
Paecilomyces farinosus (Holm: Fries) A.H.S. Brown & G. Smith 1957		G	Anastasi *et al.* (2002)
Paecilomyces fulvus Stolk & Samson 1971	m	A	Breitenbach (1998)
Paecilomyces inflatus (Burnside) Carmichael 1962	m	A	Breitenbach (1998)
Paecilomyces lilacinus (Thom) Samson 1974		G	Domsch (1960a)
Paecilomyces sp.	m, t	A, E, O, P	Henssen (1957); de Bertoldi *et al.* (1983); Breitenbach (1998); Tuomela *et al.* (2000)
Paecilomyces variotii Bainier 1907	m, t	A, B, G, O, X	Von Klopotek (1962); Knoesel and Resz (1973); Upreti and Joshi (1984); Breitenbach (1998); Anastasi *et al.* (2002)
Papulaspora immersa Hotson 1912	m	A, P	Domsch *et al.* (1993); Breitenbach (1998)
Panaeolus sp.	m	B	Von Klopotek (1962)
Penicillium albidum Sopp 1912	m	A	Breitenbach (1998)
Penicillium aurantiogriseum Dierckx 1901 (syn.: *Penicillium martensii* Biourge 1923)	m	A	Breitenbach (1998)
Penicillium aurantiogriseum var. *aurantiogriseum* Dierckx (syn: *P. verrucosum* var. *cyclopium* (Westling) Samson *et al.* 1976)		G, X	Domsch (1960a); Anastasi *et al.* (2002)
Penicillium brevicompactum Dierckx 1901		G, X	Domsch (1960a); Anastasi *et al.* (2002)
Penicillium canescens Sopp 1912		G	Anastasi *et al.* (2002)
Penicillium chermesinum Biourge 1923	m	U, X	Mergaert and Swings (1996); Anastasi *et al.* (2002)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Penicillium chrysogenum Thom 1910 (syn.: *Penicillium notatum* Westling 1911)	m	A, G, O, X	Upreti and Joshi (1984); Breitenbach (1998); Anastasi *et al.* (2002)
Penicillium citrinum Thom 1910		G, X	Anastasi *et al.* (2002)
Penicillium commune Thom 1910 (syn.: *P. palitans* Westling 1911)	m	A	Breitenbach (1998)
Penicillium corylophilum Dierckx 1901	m	A, G	Domsch (1960a); Breitenbach (1998)
Penicillium corymbiferum Westling 1911	m	A	Breitenbach (1998)
Penicillium crustosum Thom 1930	m	A	Breitenbach (1998)
Penicillium cyclopium Westling 1911	m	A	Breitenbach (1998)
Penicillium dierckxii Biourge		G	Anastasi *et al.* (2002)
Penicillium digitatum (Persoon: Fries) Saccardo 1882	m	B, G, X	Von Klopotek (1962); Anastasi *et al.* (2002)
Penicillium diversum Raper & Fennell 1948		G	Anastasi *et al.* (2002)
Penicilium dupontii Griffon & Maublank emend. Emerson 1949	t	B, E	Von Klopotek (1962); de Bertoldi *et al*. (1983)
Penicillium echinulatum var. *echinulatum* Raper & Thom ex Fassatiová		G, X	Anastasi *et al.* (2002)
Penicillium expansum Link 1821	m	A, G	Breitenbach (1998); Anastasi *et al.* (2002)
Penicillium glabrum (Wehmer) Westling 1911 (syn.: *Penicillium frequentans* Westling 1912)		G, X	Domsch (1960a); Anastasi *et al.* (2002)
Penicillium glandicola (Oudem.) Seifert & Samson 1986 (syn.: *Penicillium granulatum* Bainier 1905)		X	Anastasi *et al.* (2002)
Penicillium implicatum Biourge 1923		G, X	Anastasi *et al.* (2002)
Penicillium herquei Bainier & Sartory 1912		G, X	Anastasi *et al.* (2002)
Penicillium islandicum Sopp. 1912	m	O, X	Upreti and Joshi (1984); Anastasi *et al.* (2002)
Penicillium italicum Wehmer 1894		X	Anastasi *et al.* (2002)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Penicillium janczewskii Zaleski 1927 (syn.: *Penicillium nigricans* Bainier ex Thom 1930)	m	G, O, X	Domsch (1960a); Upreti and Joshi (1984); Anastasi *et al.* (2002)
Penicillium jensenii Zaleski 1927		G, X	Anastasi *et al.* (2002)
Penicillium melinii Thom 1930	m	A	Breitenbach (1998)
Penicillium miczynskii Zalewski 1927	m	A	Breitenbach (1998)
Penicillium minioluteum Dierckx 1901		G	Anastasi *et al.* (2002)
Penicillium ochrochloron Biourge 1923	m	A, G, U	Mergaert and Swings (1996); Breitenbach (1998); Anastasi *et al.* (2002)
Penicillium oxalicum Currie & Thom 1915	m	A, O	Fagan and Fergus (1984); Breitenbach (1998)
Penicillium paxilli Bainier 1907		G	Anastasi *et al.* (2002)
Penicillium piceum Raper & Fennell 1948		G, X	Anastasi *et al.* (2002)
Penicillium purpurescens (Sopp) Raper & Thom		X	Anastasi *et al.* (2002)
Penicillium purpurogenum Stoll 1904		G, X	Anastasi *et al.* (2002)
Penicillium restrictum Gilman & Abbott 1927		G, X	Anastasi *et al.* (2002)
Penicillium rolfsii var. *rolfsii* Thom		G	Anastasi *et al.* (2002)
Penicillium roqueforti Thom 1906	m	A, G	Breitenbach (1998); Anastasi *et al.* (2002)
Penicillium roseopurpureum Dierckx 1901		G, X	Anastasi *et al.* (2002)
Penicillium rubrum Stoll 1904		G	Domsch (1960a)
Penicillium rugulosum Thom 1910		X	Anastasi *et al.* (2002)
Penicillium simplicissimum (Oudemans) Thom 1930	m	G, U, X	Mergaert *et al.* (1994a); Mergaert and Swings (1996); Anastasi *et al.* (2002)
Penicillium sp.	m, t	A, B, E, G, H, J, M, N, O, S, U, X, Y	Eastwood (1952); Von Klopotek (1962); Chang and Hudson (1967); Fermor *et al.* (1979); de Bertoldi *et al.* (1983); Strauch and de Bertoldi (1985); Chung and Hoitink (1990); Hadar and Gorodecki (1991); Breitenbach (1998); Seck and Kilbertus (1996); Chamuris *et al.* (2000); Anastasi *et al.* (2002); Rocha *et al.* (2002); J. Ryckeboer, unpublished data

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Penicillium spinulosum Thom 1910	m	A, X	Breitenbach (1998); Anastasi *et al.* (2002)
Penicillium stoloniferum Thom 1910	m	A	Breitenbach (1998)
Penicillium velutinum van Beyma 1935	m	A	Breitenbach (1998)
Penicillium verrucosum var. *verrucosum* Dierckx 1901		G	Anastasi *et al.* (2002)
Penicillium viridicatum Westling 1911	m	A	Breitenbach (1998)
Penicillium waksmanii Zaleski 1927	m	A, G, X	Breitenbach (1998); Anastasi *et al.* (2002)
Peziza ostracoderma Korf 1961		G	Domsch (1960a)
Peziza vesiculosa Bulliard: Fries 1789		O	Fagan and Fergus (1984)
Phialemonium obovatum W. Gams & McGinnis 1983		G	Anastasi *et al.* (2002)
Phialophora cyclaminis van Beyma 1942		X	Anastasi *et al.* (2002)
Phoma exigua var. *exigua* Desmazières 1849		X	Anastasi *et al.* (2002)
Phoma glomerata (Corda) Wollenweber & Hochapfel 1936 (syn.: *P. alternariacea* Brooks & Searle)	m	B	Von Klopotek (1962)
Phoma herbarum Westendorp 1852	m	G	Domsch (1960a)
Phoma sp.	m	B, X, Y	Von Klopotek (1962); Anastasi *et al.* (2002); Rocha *et al.* (2002)
Phomopsis sp.		G, X	Anastasi *et al.* (2002)
Pichia sp.	m	Y	Rocha *et al.* (2002)
Piptocephalis sp.	m	B	Von Klopotek (1962)
Pithomyces sp.	m	N	Seck and Kilbertus (1996)
Plectosporium tabacinum (van Beyma) M.E. Palm, W. Gams & Nirenberg 1995 (syn.: *Fusarium tabacinum* (van Beyma) W. Gams 1968)	m	A, X	Breitenbach (1998); Anastasi *et al.* (2002)
Pleurotus ostreatus (Jacquin: Fries) Kummer	m	E	de Bertoldi *et al*. (1983)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Preussia fleischhakii (Auerswald) Cain 1961		G, X	Domsch (1960b); Anastasi *et al.* (2002)
Preussia sp.		X	Anastasi *et al.* (2002)
Pseudallescheria boydii (Shear) McGinnis *et al.* 1982 (syn.: *Petriellidium boydii* (Shear) Malloch 1970)	m	B, G, X	Von Klopotek (1962); Anastasi *et al.* (2002)
Pseudeurotium zonatum van Beyma 1937		G	Domsch (1960a)
Pseudogymnoascus roseus Raillo 1929 *(P. vinaceus* Raillo 1929)	m	B	Von Klopotek (1962)
Pullularia sp.	m	B	Von Klopotek (1962)
Pythium irregulare Buisman 1927	m	A	Breitenbach (1998)
Pythium oligandrum Drechsler 1930	m	A	Breitenbach (1998)
Rhinocladiella atrovirens Nannfeldt 1934	m	E	de Bertoldi *et al*. (1983)
Rhizomucor pusillus (Lindt) Schipper 1978 (syn.: *Mucor pusillus* Lindt 1886)	m, t	B, G, J, O, P	Von Klopotek (1962); Cooney and Emerson (1964); Fergus (1964); Chang and Hudson (1967); Fergus and Amelung (1971); Eicker (1972); Kane and Mullins (1973); Knoesel and Resz (1973); Fermor *et al.* (1979)
Rhizomucor sp.	t	M	Campbell *et al.* (1990)
Rhizopus arrhizus Fischer 1892	m	A	Breitenbach (1998)
Rhizopus chinensis Saito 1904	t	O	Upreti and Joshi (1984)
Rhizopus microsporus van Tieghem 1875	t	O	Upreti and Joshi (1984)
Rhizopus oryzae Went & Prinsen Geerligs 1895		G	Anastasi *et al.* (2002)
Rhizopus stolonifer (Ehrenb. ex Link) Lind 1913 (syn.: *Rhizopus nigricans* Ehrenberg 1820)	m	B, G, O	Domsch (1960a); Von Klopotek (1962); Upreti and Joshi (1984)
Rhodotorula sp.	m	N, Y	Strauch (1987); Seck and Kilbertus (1996); Rocha *et al.* (2002)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Rollandina capitata Patouillard		G	Anastasi *et al.* (2002)
Scedosporium apiospermum Saccardo ex Castellani & Chalmers (syn.: *Monosporium apiospermum* Saccardo 1911)	m	B	Von Klopotek (1962)
Scolecobasidium tshawytschae (Doty & Slater) McGinnis & Ajello 1974 (syn.: *Ochroconis tshawytschae* (Doty & Slater) Kyrylenko & Al-Achmed 1977)	m	B	Domsch *et al.* (1993)
Scopulariopsis brevicaulis (Saccardo) Bainier 1907	m	A, B, E, G	Domsch (1960a); Von Klopotek (1962); de Bertoldi *et al*. (1983); Upreti and Joshi (1984); Breitenbach (1998); Anastasi *et al.* (2002); Ryckeboer *et al.* (2003); J. Ryckeboer, unpublished data
Scopulariopsis brumptii Salvanet-Duval 1935	m	G, X	Domsch (1960a); Anastasi *et al.* (2002)
Scopulariopsis candida (Guéguen) Vuillemin 1911	m	A, G, X	Breitenbach (1998); Anastasi *et al.* (2002)
Scopulariopsis chartarum (G. Smith) Morton & Smith 1963	m	A, G	Breitenbach (1998); J. Ryckeboer, unpublished data
Scopulariopsis fusca Zach 1934	m	G	Domsch (1960a)
Scopulariopsis koningii (Oudemans) Vuillemin 1911		G, X	Anastasi *et al.* (2002)
Scopulariopsis sp.	m	A, B, E	Von Klopotek (1962); de Bertoldi *et al*. (1983); Ryckeboer *et al.* (2003); J. Ryckeboer, unpublished data
Scopulariopsis sphaerospora Zach 1934		X	Anastasi *et al.* (2002)
Scytalidium lignicola Pesante 1957		G	Anastasi *et al.* (2002)
Scytalidium thermophilum[a] (Cooney & Emerson) Austwick 1976 (syn.: *Torula thermophila*[a] Cooney & Emerson)	t	B, E, O	Fergus (1969); Kane and Mullins (1973); de Bertoldi *et al*. (1983); Upreti and Joshi (1984); Wiegant (1992); Straatsma and Samson (1993); Straatsma *et al.* (1994)
Sepedonium chrysospermum (Bulliard: Fries) Link 1832	m	G	Chamuris *et al.* (2000)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Sepedonium niveum Massee & Salmon	m	O	Botha *et al.* (1990)
Sepedonium sp.	m, t	B, P	Waksman *et al.* (1939a); Von Klopotek (1962)
Sistotrema brinkmannii (Bresadola) John Eriksson 1948 (syn.: *Corticium coronilla* von Höhnel & Litschauer 1906)	m	B	Von Klopotek (1962)
Sordaria fimicola (Roberge) Cesati & de Notaris 1863	m	G	Domsch (1960a)
Spicaria sp.	m	B	Von Klopotek (1962)
Sporotrichum sp.	t	P	Henssen (1957)
Sporotrichum thermophile Apinis 1963	m, t	E, O	de Bertoldi *et al.* (1983); Upreti and Joshi (1984); Campbell *et al.* (1990)
Sporothrix schenckii Hektoen & Perkins 1900	m	A	Breitenbach (1998)
Stachybotrys chartarum (Ehrenberg) S.J. Hughes 1958 (syn.: *Stachybotrys alternans* Bonorden)	m	B, G, X	Domsch (1960a); Von Klopotek (1962); Anastasi *et al.* (2002)
Stachybotrys sp.	m	E, U	Golueke (1977); de Bertoldi *et al.* (1983)
Staphylotrichum coccosporum J.A. Meyer & Nicot 1956		G, X	Anastasi *et al.* (2002)
Stemphylium sp.	m	B	Von Klopotek (1962)
Stereum hirsutum (Willdenow: Fries) Fries 1938	m	G	Chamuris *et al.* (2000)
Stereum sp.	m	G	Chamuris *et al.* (2000)
Stibella thermophila[b] Fergus	t	O	Fergus (1964); Campbell *et al.* (1990)
Stylopage sp.	m	B	Von Klopotek (1962)
Syncephalis sp.	m	A	Breitenbach (1998)
Syncephalastrum racemosum Cohn ex Schroeter 1886		X	Anastasi *et al.* (2002)
Talaromyces emersonii Stolk 1965 (misapplied name: *Talaromyces duponti* (Griffon & Maublanc) Apinis 1963)	t	E, J, O	Fergus (1964); Chang and Hudson (1967); Golueke (1977)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Talaromyces flavus (Klöcker) Stolk & Samson 1972 (anamorph: *Penicillium dangeardii* Pitt 1980)	t	G	Domsch (1960a)
Talaromyces flavus var. *flavus* (Klöcker) Stolk & Samson 1972		X	Anastasi *et al.* (2002)
Talaromyces helicus var. *helicus* (Raper & Fennell) C.R. Benjamin 1955		U, X	Domsch *et al.* (1993); Anastasi *et al.* (2002)
Talaromyces helicus var. *major* Stolk & Samson 1972		X	Anastasi *et al.* (2002)
Talaromyces thermophilus Stolk 1965	t	E, O	Fergus (1969); de Bertoldi *et al*. (1983); Straatsma *et al.* (1994)
Talaromyces wortmannii (Klöcker) C.R. Benjamin 1955	m	G	Domsch (1960a)
Thermoascus aurantiacus		B, U	Von Klopotek (1962); Kane and Mullins (1973); Domsch *et al.* (1993)
Thermomyces lanuginosus (Griffon & Maublanc) Tsiklinsky 1899 (syn.: *Humicola lanuginosa* (Griffon & Maublanc) Bunce 1961)	m, t	B, E, G, J	Von Klopotek (1962); Cooney and Emerson (1964); Fergus (1964); Chang and Hudson (1967); Kane and Mullins (1973); Knoesel and Resz (1973); Jodice *et al.* (1974); Golueke (1977); Fermor *et al.* (1979); de Bertoldi *et al.* (1983); Upreti and Joshi (1984); Anastasi *et al.* (2002)
Thermomyces sp.	t	M, P	Waksman *et al.* (1939a); Henssen (1957); Campbell *et al.* (1990)
Thielavia basicola Zopf 1871		X	Anastasi *et al.* (2002)
Thielavia heterothallica von Klopotek	t	J, J, U	Hedger and Hudson (1970); von Klopotek (1974); Domsch *et al.* (1993)
Thielavia terrestris (Apinis) Malloch & Cain 1972 (syn.: *Allescheria terrestris* Apinis 1963)	t	E, O	de Bertoldi *et al*. (1985); Straatsma *et al.* (1994)
Thielaviopsis basicola (Berkeley & Broome) Ferraris 1912 (syn.: *Chalara elegans* Nag Raj & Kendrick 1975)		G	Domsch (1960a)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Thielaviopsis sp.	m	G	J. Ryckeboer, unpublished data
Thysanophora penicillioides (Roumeguère) Kendrick 1961		X	Anastasi *et al.* (2002)
Torulopsis sp.		Y	Rocha *et al.* (2002)
Trametes versicolor (Linnaeus: Fries) Pilàt (syn.: *Polyporeus versicolor* (Linnaeus: Fries) Fries 1821)	m	E	de Bertoldi *et al*. (1985)
Trichocladium asperum Harz 1871	m	A, G	Breitenbach (1998); Domsch (1960a)
Trichoderma atroviride P. Karsten	m	A	Breitenbach (1998)
Trichoderma hamatum (Bonorden) Bainier 1906	m	G, M	Hoitink (1990); Anastasi *et al*. (2002)
Trichoderma harzianum Rifai 1969		G	Anastasi *et al*. (2002)
Trichoderma pseudokoningii Rifai 1969	m	A	Breitenbach (1998)
Trichoderma sp.	m	N	Seck and Kilbertus (1996)
Trichoderma viride Persoon: Fries 1829 (syn.: *Trichoderma lignorum* (Tode) Harz)	m	B, E, G, H, O	Eastwood (1952); Von Klopotek (1962); Cook *et al.* (1967); Fermor *et al.* (1979); de Bertoldi *et al*. (1985); Upreti and Joshi (1984); Anastasi *et al.* (2002)
Trichoderma virens (Miller *et al.*) von Arx 1987	m	A	Breitenbach (1998)
Trichosporon sporotrichoides (van Oorschot) van Oorschot & de Hoog 1981 (syn.: *Trichosporiella sporotrichoides* van Oorschot 1980)		X	Anastasi *et al.* (2002)
Trichophaea abundans (Karsten) Boudier 1907		O	Fagan and Fergus (1984)
Trichothecium sp.	m	A, P	Waksman *et al.* (1939a); Ryckeboer *et al.* (2003)
Trichothecium roseum (Persoon: Fries) Link ex Gray 1821	m, t	B, G, O	Domsch (1960a); Von Klopotek (1962); Fergus (1969); Botha *et al.* (1990); Chamuris *et al.* (2000)
Trichurus spiralis Hasselbring 1900	m	A, G, O	Domsch (1960a); Fagan and Fergus (1984); Breitenbach (1998)

(*continued*)

TABLE 4 – Overview of fungi reported in compost and self-heating organic materials at mesophilic and thermophilic temperatures (*follow the previous page*)

Organism*	Temperature phase**	Source material***	Reference
Trichurus terrophilus Swift & Povah 1929	m	B	Von Klopotek (1962)
Ulocladium sp.	m	N	Seck and Kilbertus (1996)
Ulocladium alternariae (Cooke) E.G. Simmons 1967		G	Anastasi *et al.* (2002)
Ulocladium consortiale (von Thümen) E. Simmons 1967 (syn.: *Stemphylium ilicis* Tengwall)	m	A, B	Von Klopotek (1962); Breitenbach (1998)
Verticillium lecanii (Zimmerman) A.W. Viégas 1939 (syn.: *Acrostalagmus albus-minus* A. & R. Sartory & Meyer)	m	A, G, H, X	Eastwood (1952); Breitenbach (1998); Anastasi *et al.* (2002)
Verticillium leptobactrum W. Gams 1971	m	A	Mergaert *et al.* (1994a)
Verticillium nigrescens Pethybridge 1919		X	Anastasi *et al.* (2002)
Verticillium sp.	m	A, B, G	Von Klopotek (1962); Chamuris *et al.* (2000); Ryckeboer *et al.* (2003)
Volutella ciliata (Albertini & Schweinitz: Fries) Fries 1832	m	G	Domsch (1960a)
Westerdykella dispersa (Clum) Cejp & Milko 1955		X	Anastasi *et al.* (2002)
Zygorhynchus sp.	m	P	Waksman *et al.* (1939a)
Zygorhynchus heterogamus (Vuillemin) Vuillemin 1903	m	B	Cook *et al.* (1967)
Zygorhynchus moelleri Vuillemin 1903	m	A, J	Eastwood (1952); Breitenbach (1998)

All species presented in this table, except *C. krusei* and *C. tropicalis*, were isolated on rich organic complex media.
* The most recent names are given. When older synonyms were cited in the referenced literature, these are given in parenthesis.
** Temperature phase: m = mesophilic; t = thermophilic; fungi are classified as mesophiles and thermophiles if their optimal growth temperatures are moderate (20-40 °C) or high (>40 °C), respectively.
*** Source material of compost: A = vegetable, fruit and garden waste; B = municipal solid waste; C = food waste and sawdust; D = kitchen waste and shredded newspapers; E = garden and kitchen waste and sewage sludge; F = grass (lawn cuttings); G = garden waste; H = lawn cuttings and barley straw; J = wheat straw, barley straw, straw compost; L = 70% green waste + 10% kitchen waste + 20% shredded wood; M = tree bark, hardwood bark, bark compost; N = peanut shells; O = mushroom compost; P = manure, horse manure; S = grape marc; U = unknown origin of compost; T = waste paper; X = vermicompost; Y = cattle manure and forestry wastes.
[a]*Scytalidium thermophilum*, *Humicola grisea* var. *thermoidea*, *Humicola insolens* and *Torula thermophila* are synonyms (Straatsma and Samson, 1993).
[b]*Stibella thermophila* is rediscribed and transferred to a new anamorph genus, *Remersonia* (Seifert *et al.*, 1997).

them to degrade tough debris such as woody stems, bark or newspaper. Cellulose and hemicellulose originating from plant material, chitin from fungi and soil fauna and possibly lignin and humus are their C and N sources (Lacey, 1973; Hardy and Sivasithamparam, 1989; Beffa *et al*., 1996b). There is also increasing evidence of their ability to degrade xenobiotic compounds (Goodfellow and Williams, 1983). Actinomycetes develop poorly in materials that are too wet (Finstein and Morris, 1975) or too dry (Festenstein *et al*., 1965). Most actinomycetes tolerate a higher pH than fungi, their optimum pH is situated between 7 and 8 (Fermor *et al*., 1979). Under adverse conditions actinomycetes survive as spores (Cross, 1968).

Thermal inactivation of pathogens is required to obtain safe products, both in terms of phytohygiene and human diseases. Thermal destruction of pathogens depends to a large degree on the species; lag-, exponential-, and asymptotic inactivation kinetics are known (Haug, 1993). Generally, the higher the temperature, the more efficient will be the destruction of pathogens (Ryckeboer *et al*., 2002a). On the other hand Millner *et al*. (1987) reported that *Salmonella spp*. was suppressed more efficiently in composts produced at 55 °C than in those produced at 70 °C, indicating that in certain cases antagonistic effects exerted through other microorganisms, in many cases actinomycetes, may be more important than a high temperature. Additionally, regrowth of mesophilic populations may be delayed if too high temperatures are maintained for a long time and if this temperature is reached throughout the composting material (which is a goal to provide proper hygienisation). Appropriate reinoculation schemes have to be used to avoid this problem.

In the early thermophilic composting phase microorganisms start to metabolize proteins, increasing liberation of ammonium and causing subsequent alkalinization (de Bertoldi *et al*., 1985; Thambirajah *et al*., 1995). Compared with the initial mesophilic phase, degradation is accelerated (Fogarty and Tuovinen, 1991). Mesophilic microorganisms are inactivated or killed during the initial thermophilic phase (temperatures between 40-60 °C), whereas the numbers and species diversity of thermophilic and/or thermotolerant bacteria, actinomycetes and fungi increase (Waksman, 1939a; Finstein and Morris, 1975; Beffa *et al.*, 1996b). However, overall bacterial species diversity drops significantly during the thermophilic phase (Finstein and Morris, 1975; Fogarty and Tuovinen, 1991).

Typical bacteria that are very active at temperatures around 50-60 °C are endospore-forming bacteria, e.g. *Bacillus* spp. (Strom, 1985a, b; Beffa *et al*., 1996c; Herrmann and Shann, 1997; Ryckeboer *et al*., 2003). At temperatures above 60 °C, the degradation process is performed essentially by thermophilic bacteria (Gray *et al.*, 1971; Finstein and Morris, 1975; Bagstam, 1979; Nakasaki *et al.*, 1985a; Strom, 1985a,b; Fujio and Kume, 1991; Beffa *et al.*, 1996b). Non-spore forming bacteria such as *Hydrogenobacter* spp. and *Thermus* spp. are the dominant active degraders in thermogenic composts at temperatures above 70 °C, even upto 82 °C (Beffa *et al*., 1996b, c; Blanc *et al*., 1999). The number and diversity of thermophilic actinomycetes increases significantly at temperatures of 45 to 55 °C which are optimal for their growth (Waksman, 1939a; Fergus, 1964; Finstein and Morris, 1975; Nakasaki *et al.*, 1985a; Amner *et al.*, 1988; Beffa *et al.*, 1996b). In the preparation of mushroom (*Agaricus*) substrates, the so-called "firefang period" at 45-48 °C is known when the substrate is covered by a white actinomycete mycelium. The main function is a reassimilation of ammonium, which does not occur in later stages. If the firefang period is too short or incomplete, ammonia will

later hamper the growth of *Agaricus*. To which extent similar processes occur in ordinary waste composting is not known. At temperatures above 60 °C, the number and diversity of actinomycetes decreases along with their importance in the degradation process.

Both thermophiles and mesophiles are reported to be good decomposers of cellulose, although the cellulose degrading ability of thermophiles was found to be exceedingly higher. The optimal temperature for cellulose degradation is around 65 °C, indicating that degradation is performed essentially by thermostable enzymes (Stutzenberger *et al*., 1970; Upreti and Joshi, 1984). In Table 5, several prokaryotes are listed which are known to have cellulolytic activity (Fergus, 1969; Stutzenberger *et al.*, 1970; Godden *et al*., 1989; Couglan and Mayer, 1992).

The ability of fungi to degrade cellulose and lignin is higher than that of actinomycetes, and bacteria in general (Crawford, 1983; Godden *et al*., 1992). Temperature is one of the most important factors affecting fungal growth. The majority of fungi is mesophilic (5 °C to 37 °C), with an optimum temperature of 25-30 °C. Although most fungi prefer a moderate level of N, a low N content is a prerequisite for lignin degradation. Fungi mostly prefer an acidic environment (Fogarty and Tuovinen, 1991), although they often tolerate a wide range of pH (Tuomela *et al*., 2000). Due to their extensive hyphal network, they can attack organic residues that are too dry, too acidic, or too low in nitrogen for bacterial decomposition (Finstein and Morris, 1975). Thermophilic fungi are generally less tolerant to high temperatures than actinomycetes. The optimal temperature for thermophilic fungi is 40 to 55 °C, with a maximum at 60 to 62 °C. At temperatures above 60 °C, fungi are killed or transiently present as spores (Eastwood, 1952; Von Klopotek, 1962; Kane and Mullins, 1973; Finstein and Morris, 1975; Rosenberg, 1975; Nakasaki *et al.*, 1985a; Fujio and Kume, 1991; Beffa *et al.*, 1996b; Ryckeboer *et al*., 2003; Van Gestel *et al*., 2003). Yeasts disappear during the thermophilic phase of composting, but when the temperature cools down to 54 °C, they can be found again (Choi and Park, 1998; Ryckeboer *et al.*, 2003). Table 6 lists several fungal genera which are able to degrade (crystalline) cellulose, carboxymethyl cellulose (CMC), hemicellulose, or more specific, xylan and arabinoxylan (Fergus, 1969; Fagan and Fergus, 1984; Botha *et al*., 1990; Domsch *et al*., 1993).

In mushroom compost, thermophilic fungi are responsible for the degradation of lignocellulose, which is prerequisite for the growth of the edible fungus (Sharma, 1989). The optimum temperature for thermophilic fungi from 40 to 50 °C is also the optimum temperature for lignin degradation in compost. The organisms most efficient at mineralizing lignin i.e. white-rot fungi, do not survive the thermophilic phase of composting, and thus cannot play a significant role in lignin degradation. A few Basidiomycota grow well at elevated temperatures, for example the white-rot fungus *Phanerochaete chrysosporium* (anamorph *Sporotrichum pulverulentum*) which has an optimum temperature around 36 to 40 °C and a maximum temperature of 46 to 49 °C (Tuomela *et al*., 2000). At mesophilic temperatures degradation is partly continued by mesophilic fungi, although several authors report that negligible degradation occurred during compost maturation (Chang, 1967; Tomati *et al*., 1995; Nusbaumer *et al*., 1996). Examples of fungi reported to degrade chitin, pectin or keratin are listed in Table 6 (Domsch *et al*., 1993).

The thermophilic phase *per se* is what composting differentiates from common degradation processes. Generally, higher temperatures accelerate biological

TABLE 5 – Known degradation capacity of genera of prokaryotes isolated from compost

Genus*	Degraded compound					
	Cellulose	Xylan	Lignin	Hydrocarbons	Pesticides	Bioplastics
Reference list**	a	b	c	d	e	f
Achromobacter				+	+	
Acidovorax						+
Acinetobacter				+		
Alcaligenes			+	+		
Amphibacillus		+				
Arthrobacter	+		+	+	+	
Bacillus	+		+			+
Brevibacillus						+
Brevibacterium	+					
Cellulomonas	+					
Clostridium	+					
Corynebacterium			+	+		
Cytophaga	+					
Enterobacter			+			
Flavobacterium	+			+	+	+
Klebsiella			+			
Micrococcus				+		
Micromonospora	+		+			
Nocardia			+	+		
Paenibacillus	+					
Pseudomonas			+	+	+	+
Pseudonocardia	+		+			
Rhodococcus			+	+		
Saccharomonospora			+			
Serratia	+					
Streptomyces	+		+			+
Thermoactinomyces	+					
Thermomonospora	+		+			

* Different species within the several genera may show different reactions for one or more of the substrates. Within a species great differences may exist between different isolates.
** a: Fergus (1969); Stutzenberger *et al.* (1970); Godden *et al.* (1989); Coughlan and Mayer (1992).
b: Bachmann and McCarthy (1989); Nimura *et al.* (1990).
c: Deschamps *et al.* (1980); Goodfellow and Williams (1983); Gonzalez *et al.* (1986); Corominas *et al.* (1987); Falcon *et al.* (1987); McCarthy (1987); Tuomela *et al.* (2000).
d: Raymond and Jamison (1971); Jensen (1975); Rosenberg *et al.* (1980); Goodfellow and Williams (1983); Dragun (1988).
e: Fogarty and Tuovinen (1991).
f: Mergaert *et al.* (1994a,1994b); Mergaert and Swings (1996).

TABLE 6 – Known degradation capacity of fungal genera isolated from compost

Genus*	Degraded compound												
	Starch	Cellulose	CMC-Cellulose	Hemi-Cellulose	Xylan	Arabinoxylan	Lignin	Wood	Chitin	Pectin	Keratin	Hydrocarbons	Bioplastics
Reference list**	a	b	c	d	e	f	g	h	i	i	i	j	k
Absidia			+		+	+			+				
Acremonium		+	+		+							+	+
Actinomucor	+				+								
Agaricus	+	+	+	+	+		+						
Alternaria	+	+			+	+	+	+		+		+	
Arthrinium, Scytalidium, Sordaria		+											
Arthrobotrys		+	+		+								
Aspergillus	+	+	+	+	+	+	+	+	+	+	+	+	+
Aureobasidium								+					
Beauvaria, Phanerochaete, Scolecobasidium												+	
Botryotrichum	+	+	+		+		+	+	+				
Botrytis			+			+	+						
Cephalosporium													+
Chaetomidium, Thermoascus		+						+					
Chaetomium	+	+	+	+	+			+				+	
Chrysosporium		+									+		
Cladosporium	+	+				+	+			+		+	+
Clitopilus, Sporotrichum		+		+									
Coniothyrium					+			+		+			
Coprinus		+	+	+			+						
Corynascus		+	+		+	+							
Doratomyces	+	+	+	+	+		+	+					
Emericella	+	+	+			+						+	
Epicoccum		+			+	+	+	+		+			
Fusarium	+	+	+	+	+	+	+	+		+	+	+	
Geotrichum		+	+									+	
Gilmaniella	+	+	+		+			+					
Gliocladium	+	+	+		+			+	+	+		+	
Humicola		+	+	+				+					
Malbranchea, Stibella		+	+										
Mortierella									+			+	
Mucor	+		+	+	+		+		+	+		+	+
Myceliophthora											+		
Nectria	+	+					+	+	+	+			
Oedocephalum	+	+	+		+								
Oidiodendron	+	+						+					
Paecilomyces	+	+			+		+	+	+		+	+	
Penicillium	+	+	+		+		+			+		+	+
Peziza, Volutella	+	+	+										
Phoma	+	+	+		+			+		+		+	

(*continued*)

TABLE 6 – Known degradation capacity of fungal genera isolated from compost (*follow the previous page*)

Genus*	Degraded compound												
	Starch	Cellulose	CMC-Cellulose	Hemi-Cellulose	Xylan	Arabinoxylan	Lignin	Wood	Chitin	Pectin	Keratin	Hydrocarbons	Bioplastics
Reference list**	a	b	c	d	e	f	g	h	i	i	i	j	k
Preussia							+						
Pseudeurotium, Pseudogymnoascus					+								
Rhizomucor	+	+				+				+			
Rhizopus	+	+		+					+	+			
Scopulariopsis	+	+			+	+	+		+		+	+	
Sepedonium	+	+	+	+	+								
Sporotrichum		+	+	+						+			
Stachybotrys		+						+	+	+			
Talaromyces	+	+	+	+			+	+				+	
Thermomyces		+		+		+							
Thielavia		+					+	+					
Trichocladium	+	+								+			
Trichoderma	+	+	+		+	+	+	+	+		+	+	
Trichophaea		+	+		+								
Trichothecium	+	+	+	+	+	+			+	+			
Trichurus	+	+	+		+			+				+	
Ulocladium		+				+		+					
Verticillium	+	+							+	+		+	+
Zygorhynchys				+						+			

* Different species within the several genera may show different reactions for one or more of the substrates. Within a species great differences may exist between different isolates.
** a: Fagan and Fergus (1984); Diaz-Ravina *et al.* (1989); Botha *et al.* (1990); Domsch *et al.* (1993); Atkinson *et al.* (1996b).
b: Chang (1967); Fergus (1969); Stutzenberger *et al.* (1976); Upreti and Joshi (1984); Fagan and Fergus (1984); Botha *et al.* (1990); Domsch *et al.* (1993); Tuomela *et al.* (2000); Rocha *et al.* (2002).
c: Fergus (1969); Fagan and Fergus (1984); Botha *et al.* (1990); Domsch *et al.* (1993); Tuomela *et al.* (2000).
d: Chang (1967); Fagan and Fergus (1984); Lynch and Wood (1985); Botha *et al.* (1990); Domsch *et al.* (1993); Tuomela *et al.* (2000).
e: Fagan and Fergus (1984); Botha *et al.* (1990); Domsch *et al.* (1993).
f: Domsch *et al.* (1993).
g: Fagan and Fergus (1984); Lynch and Wood (1985); Domsch *et al.* (1993); Tuomela *et al.* (2000); Chamuris *et al.* (2000).
h: Fagan and Fergus (1984); Domsch *et al.* (1993); Tuomela *et al.* (2000).
i: Domsch *et al.* (1993); Anastasi *et al.* (2002).
j: Llanos and Kjoller (1976); Davies and Westlake (1979); Dragun (1988); Aust (1990); McFarland *et al.* (1992); Domsch *et al.* (1993); Van Gestel *et al.* (2003).
k: Mergaert *et al.* (1994a); Mergaert and Swings (1996).

processes and improve hygienisation; thus, it may be assumed that the maximum temperatures should be as high as possible. However, there are some limitations. Oxygen can be supplied to the interior of composting piles by molecular diffusion and (more importantly) by mass movement through air pores (either through convection or forced aeration). Gas saturation constants decrease with increasing temperature so that O_2 availablity for the microbial cells is limited at high temperatures. Some authors state that at temperatures above 60°C functional biodiversity is reduced and thus degradation processes may be hampered (Jeris and Regan, 1973; Suler and Finstein, 1977; McKinely and Vestal, 1984; de Bertoldi *et al*., 1985; McKinely *et al*., 1985). For *Geobacillus stearothermophilus*, one of the most typical thermophiles in composts it is known that the cell size increases at high temperatures, while at the same time the thickness of the aqueous biofilms decreases. Thus, at some point, *G. stearothermophilus* activity may be impaired.

In the opinion of several researchers, exceeding optimal temperature during composting will not shorten the composting period neither will it eliminate nuisances nor improve product quality beyond the genetic capacity of the microorganisms (de Bertoldi *et al*., 1985; Golueke, 1992).

Cooling or second mesophilic phase

Once the activity of the thermophilic organisms ceases due to exhaustion of substrates, the temperature starts to decrease. Mesophilic organisms start to re-colonise the substrate, either originating from surviving spores, through spread from protected microniches, or from external inoculation. Upon initial temperature decrease the bacterial numbers may decrease by 1 to 2 orders of magnitude in comparison with the numbers present during the thermophilic phase (10^8-10^{11} g^{-1} dry wt), but the taxonomic and metabolic diversity increase. Several bacterial functions that are important for compost maturation and which are absent or not detected in the thermophilic phase appear during the cooling and maturation phase (Beffa *et al.*, 1996b). Metabolic studies revealed that several isolates were not simply organic oxidizers, but were involved in hydrogen-, ammonium-, nitrite- and sulfur-oxidation, nitrogen-fixation, sulfate-reduction, exopolysaccharide production, and nitrite production from ammonium under heterotrophic conditions (Diaz-Ravina *et al.*, 1989; Beffa *et al.*, 1996b). High numbers of diverse mesophilic and thermotolerant actinomycetes and yeasts reappear (Herrmann and Shann, 1997). The temperature decline, the lower water content and their ability to attack and/or degrade natural complex polymers (e.g. cellulose, hemicellulose, lignocellulose, lignin) also favor mesophilic and thermotolerant fungi during the cooling phase (Waksman *et al.*, 1939a; Savage *et al.*, 1973; Finstein and Morris, 1975; Breitenbach, 1998; Chamuris *et al.*, 2000; Ryckeboer *et al.*, 2003).

Maturation phase

Tree bark, yard wastes, agricultural wastes, etc. contain a high percentage of lignin, lignocellulose and other recalcitrant components (Corominas *et al*., 1987; Hoitink and Boehm, 1999). Paper may contain up to 20% of lignin (Tuomela *et al*., 2000). Mainly during the maturation phase, these more resistant compounds are degraded and partly transformed into humus (Gray *et al*., 1971; Crawford, 1983; Corominas *et al*., 1987; Falcon *et al*., 1987; Hoitink and Boehm, 1999; Tuomela *et al*., 2000). Most of the fungi, predominant cellulose and lignin degraders, are isolated during

the maturation phase (Von Klopotek, 1962). One problem arising with composting as a means of solid waste disposal is the presence of undegraded cellulosic material in the compost at the end of the process. This residual cellulose is probably inaccessible to enzymatic attack because of low water content or association with protective substances such as lignin (ligno-cellulose complexes) (Stutzenberger *et al*., 1970; Poincelot and Day, 1973).

Knowledge of the microbial composition and the microbial populations, involved in the nutrient cycles (i.e. C, N, S, P) in mature composts, is important to predict its potential impact on soil fertility and other biological parameters. Bacteria related to the genus *Arthrobacter* form a numerically important fraction of the natural bacterial flora of soils and their presence and numbers in mature composts could be used as an additional microbiological parameter for compost maturity evaluation. Species diversity seems to be correlated with stability of the end product (Beffa *et al.*, 1996b). Furthermore, the degree of maturity of the compost affects its successful utilization in agriculture. Immature composts induce high microbial activity in the soil some time after their incorporation, causing oxygen deficiency and a variety of indirect phytotoxicity problems to plant roots (Zucconi *et al.*, 1981a,1981b; Inbar *et al.*, 1990). Maturity tests are discussed in detail by Itävaara *et al*. (2002) and Insam and de Bertoldi (2003). Benefits of compost application, such as suppression of diseases caused by soilborne plant pathogens, in agricultural and horticultural crops have been reported previously (Lacey, 1973; Hoitink and Fahy, 1986; Dick and McCoy, 1993; Hoitink and Boehm, 1999; Ryckeboer *et al*., 1999; Ryckeboer, 2001).

AN INVENTORY OF COMPOST MICROORGANISMS

The majority of the microorganisms described in Tables 3 and 4 were isolated by culturing of extracts on agar media. Approximately half of the listed species in both tables grows at high temperatures. Most of the reported actinomycetes are thermophilic or thermotolerant, while most of the reported fungi are mesophilic. Knowledge on specific functions of taxonomic groups and species is still fragmentary. In cases where evidence for certain degradation capacities during a composting process is clear, this is indicated in Tables 5 and 6.

The inventory contains 155 species of prokaryotes (of which 33 strains were reported as actinomycetes) belonging to 66 genera, and 408 fungal species of 160 genera. The majority of isolates (approximately 80 species of prokaryotes and 295 fungal species) had been isolated from (source-separated) municipal, kitchen, grass, yard and agricultural wastes or their respective composts. Thirty-three species of prokaryotes and 82 fungal species were found in mushroom compost, while 121 fungal species were isolated from vermicompost. Eighteen species of prokaryotes and 18 fungal species have been found in manure. Sixteen species of prokaryotes and 12 fungal species were isolated from bark or bark compost, while 26 species of fungi have been found in straw or straw compost. A few more species of prokaryotes were found in sewage sludge and moldy hay, while a few fungal species are reported in grape marc, peanut shells and other food wastes. Some of the substrates also included considerable amounts of shredded newspaper or leaves. All these materials were major or minor input components of the composting process.

It needs to be emphasized that within the genera, different species may show different reactions for one or more of the substrates and also that within a species great differences may exist between different isolates.

CONCLUSIONS AND OUTLOOK

Several of the organisms may find applications as potential biocontrol agents of soilborne plant pathogens, among them bacteria (Table 3), e.g. *Flavobacterium balustinum*, *Bacillus subtilis*, *Bacillus cereus* and *Pseudomonas fluorescens* (Hoitink and Fahy, 1986; Hoitink, 1990; Phae and Shoda, 1990; Phae *et al*., 1990; Wei *et al*., 1991; Asaka and Shoda, 1996; Nakasaki *et al*., 1996; Raupach and Kloepper, 1998; Ryckeboer *et al*., 1999; Ryckeboer *et al*., 2002b) and fungi (Table 4) such as *Trichoderma* spp., *Gliocladium virens* and *Paecilomyces* spp. (Domsch, 1960a; Hoitink and Boehm, 1999; Ryckeboer *et al*., 1999; Ryckeboer *et al*., 2002b). Potential human pathogens e.g. *Alcaligenes faecalis*, *Clostridium* spp. and *Aspergillus fumigatus* (Eastwood, 1952; Von Klopotek, 1962; Fergus, 1964; Chang and Hudson, 1967; Stutzenberger *et al*., 1970; Kane and Mullins, 1973; Knoesel and Resz, 1973; Malik and Sandhu, 1973; Fermor *et al*., 1979; Strom, 1985b; Campbell *et al*., 1990; Beffa *et al*., 1996a; Lott Fischer *et al*., 1996) are also listed in Tables 3 and 4.

From the literature and the brief survey of the degradation capacities of prokaryotes and fungi listed above we can conclude that the ability to degrade monosaccharides, starch and lipids is almost universal among fungi and prokaryotes (Botha *et al*., 1990). Hemicelluloses and cellulose are also relatively fast degraded. More complex natural polymers (e.g. lignin and keratin), wood (lignocellulose), synthetic polymers (e.g. bioplastics) and hydrocarbons are mostly degraded by specialists of a limited number of genera. However, these abilities are mostly determined with single species tests, which often underestimate degradation capacities. Several reports on mixed populations clearly illustrated the synergistic effects of various organisms (Waksman and Hulpoi, 1939; Golueke, 1992; Tuomela *et al*., 2000). Furthermore, the use of indicator substrates is also questionable. For example, the use of a substrate such as carboxymethyl cellulose (CMC) as an indicator of cellulolytic acitivity may be far removed from the natural situation where the substrate is much more complex, e.g. lignocellulosic material in which lignin and cellulose must be depolymerised simultaneously (Deschamps *et al*., 1981; Davis *et al*., 1992).

Most publications were targeted on a few species and on their specific activities. Indeed, there are only a few microbiological studies in which a full process was followed in detail (Von Klopotek, 1962; Strom, 1985a, 1985b; Beffa *et al*., 1996b; Ryckeboer *et al*., 2003; Van Gestel *et al*., 2003).

Most of the former research was performed using culturing techniques (Kane and Mullins, 1973; Finstein and Morris, 1975; Nakasaki *et al*., 1985a; Strom 1985a, 1985b; Hardy and Sivasithamparam, 1989; Davis *et al*., 1991; Beffa *et al*., 1996a; Choi and Park, 1998). It is estimated for soils that less than 1% of the viable microbiota is cultivable with current techniques (Torsvik *et al*., 1990). For composts the percentage is unknown, and molecular techniques suggest that also in composts numerous microorganisms prevail that currently cannot be isolated (Ivors

et al., 2000). Peters *et al.* (2000) characterised several prokaryotes in a composting pile containing shredded maize plants, straw-bedded horse manure and wood chips, by direct analysis of DNA, i.e. without culturing on agar media. In this composting pile *Azotobacter salinestris, Bacillus badius, Bacillus coagulans, Bacillus fusiformis, Bacillus smithii, Clostridium stercorarium* subsp. *thermolacticum* (syn.: *Clostridium thermolacticum*), *Geobacillus caldoxylolyticus* (syn.: *Bacillus caldoxylolyticus*), *Geobacillus stearothermophilus* (syn.: *Bacillus stearothermophilus*), *Geobacillus thermocatenulatus* (syn.: *B. thermocatenulatus*), *Geobacillus thermoleovorans* (syn.: *B. thermoleovorans*), *Lactobacillus confuses, Lactobacillus panis, Pseudomonas citronellolis, Pseudomonas stutzeri, Streptomyces thermodiastaticus, Streptosporangium vulgare, Thermobispora bispora* (syn.: *Microbispora bispora*), *Thiobacillus denitrificans* (*B. denitrificans*) and *Xanthomonas campestris* were identified. However, of this list, only *B. badius, B. coagulans, B. smithii, G. stearothermophilus* and *P. stutzeri* were reported yet in composting materials after isolation on agar media (Table 3) (Strom, 1985b; Fermor *et al.*, 1979; Hoitink and Fahy, 1986; Fujio and Kume, 1991; Andrews and Trevors, 1994; Koschinsky *et al.*, 1998; Ryckeboer *et al.*, 2003; J. Mergaert, unpublished data).

From a few references we can conclude that the combination of cultivation-dependent and -independent approaches will yield complementary, non-overlapping information about the composition of the microbial community in compost (Gurtner *et al*., 2000; Ivors *et al*., 2000; Dees and Ghiorse, 2001, Mannix *et al*., 2001; van Elsas *et al*., 2002).

Contradictory reports exist concerning the usefulness of targeted inoculation of the starting material of composts to accelerate the composting process itself (Finstein and Morris, 1975). However, several studies have shown that it is possible under certain circumstances (Bagstam, 1979; Choi and Park, 1998). A better understanding of how the microbial communities change during composting and which environmental conditions they require could facilitate controlled composting. Such manipulations could be used to alleviate composting odours (Finstein and Morris, 1975), to increase available nutrients (Beffa *et al.*, 1996b; Ivors *et al.*, 2000), to increase efficacy of biofiltration techniques for removing toxic organic compounds from gaseous waste streams, e.g. benzene, toluene, xylenes and trichloroethylene (Watwood and Sukesan, 1995; Tahraoui and Rho, 1998; Juteau *et al.*, 1999), or even, speculatively, open the possibility to produce desired secondary metabolites. Composting could also be used to increase degradation of pesticides (Fogarty and Tuovinen, 1991; Lemmon and Pylypiw, 1992; Michel *et al.*, 1995, 1997a; Brown *et al.*, 1997; Buyuksonmez *et al.*, 2000), complex natural polymers, e.g. lignin (Lynch, 1987; Requena *et al*., 1996, 1997; Chamuris *et al.*, 2000; Tuomela *et al.*, 2000), bioplastics (Mergaert *et al*., 1994a,1994b; Mergaert and Swings, 1996; Kleeberg *et al.*, 1998; Rick *et al.*, 1998) and (polyaromatic) hydrocarbons (McFarland *et al.*, 1992; Berger and Schwartz, 1994; Civilini, 1994; Riggle, 1995; Kästner *et al.*, 1995; Silveira and Ganho, 1995; Civilini and Sebastianutto, 1996; Hupe *et al.*, 1996; Sukesan and Watwood, 1998; Löser *et al.*, 1999; Van Gestel *et al*., 2003). Among the various biological niches found during a composting process, there are likely some that facilitate the degradation of xenobiotic compounds. Care, however, has to be taken that temperature dependent volatilization of compounds is not mistaken as biodegradation (Van Gestel *et al*., 2003).

Polymers designed to undergo biological degradation are often proposed to solve problems arising from plastic waste. Standardized test methods using mixed cultures for the evaluation of biodegradability and compostability have been suggested, including *in-situ* composting tests as well as in vitro tests with pure cultures (Kleeberg *et al*., 1998). Examples of microorganisms reported to degrade bioplastics such as poly(3-hydroxybutyrate) are also listed in Tables 5 and 6 (Delafield *et al*., 1965; Mergaert *et al.*, 1994a,1994b; Mergaert and Swings, 1996).

A relatively new research field is the use of composts as an organic carrier for antagonists, i.e. microorganisms with biocontrol properties (Nakasaki *et al*., 1996; Ryckeboer *et al.*, 2002b). Such manipulations could be used to better suppress plant diseases (Kwok *et al*., 1987; Phae *et al.*, 1990; Hoitink *et al*., 1991; Grebus *et al*., 1994; Hoitink and Boehm, 1999; Ryckeboer *et al.*, 1999). The establishment of inoculated organisms requires abiotic factors to be at least within the tolerance range, and the appropriate niche to be either unfilled or filled with less efficient organisms (Finstein and Morris, 1975; Hoitink and Fahy, 1986).

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REFERENCES

Alfreider A., Peters S., Tebbe C.C., Rangger A., Insam H. (2002). Microbial community dynamics during composting of organic matter as determined by 16S ribosomal DNA analysis. Compost Sci. Util., 10: 303-312.

Amner W., McCarthy A.J., Edwards C. (1988). Quantitative assessment of factors affecting the recovery of indigenous and reseased thermophilic bacteria from compost. Appl. Environ. Microbiol., 54: 3107-3112.

Anastasi A., Varese G.C., Voyron S., Scannerini S., Marchisio V.F. (2002). Systematic and functional characterization of fungal biodiversity in compost and vermicompost. In: Michel F.C., Rynk R.F., Hoitink H.A.J., Eds, Proceedings of the 2002 International Symposium “Composting and Compost Utilization”. The JG Press Inc., Emmaus, pp. 171-182.

Andrews S.A., Lee H., Trevors J.T. (1994). Bacterial species in raw and cured compost from a large-scale urban composter. J. Ind. Microbiol., 13: 177-182.

Asaka O., Shoda M. (1996). Biocontrol of *Rhizoctonia solani* damping-off of tomato with *Bacillus subtilis* RB14. Appl. Environ. Microbiol., 62: 4081-4085.

Atkinson C.F., Jones D.D., Gauthier J.J. (1996a). Biodegradabilities and microbial activities during composting of municipal solid waste in bench-scale reactors. Compost Sci. Util., 4: 14-23.

Atkinson C.F., Jones D.D., Gauthier J.J. (1996b) Biodegradabilities and microbial activities during composting of oxidation ditch sludge. Compost Sci. Util., 4(1): 84-96.

Atkinson C.F., Jones D.D., Gauthier J.J. (1996c). Putative anaerobic activity in aerated composts. J. Ind. Microbiol., 16: 182-188.

Aust S.D. (1990). Degradation of environmental pollutants by *Phanerochaete chrysosporium*. Microbiol. Ecol., 20: 197-209.

Bachmann S.L., McCarthy A.J. (1989). Purification and characterization of a thermostable b-xylosidase from *Thermomonospora fusca*. J. Gen. Microbiol., 135: 293-299.

Bagstam G. (1978). Population changes in microorganisms during composting of spruce-bark. I. Influence of temperature control. Eur. J. Appl. Microbiol., 5: 315-330.

Bagstam G. (1979). Population changes in microorganisms during composting of spruce-bark. II. Mesophilic and thermophilic microorganisms during controlled composting. Eur. J. Appl. Microbiol., 6: 279-288.

Beffa T., Blanc M., Aragno M. (1996a). Obligately and facultatively autotrophic, sulfur- and hydrogen-oxidizing thermophilic bacteria isolated from hot composts. Arch. Microbiol., 165: 34-40.

Beffa T., Blanc M., Marilley L., Fischer J.L., Lyon P.-F., Aragno M. (1996b). Taxonomic and metabolic microbial diversity during composting. In: de Bertoldi M., Sequi P., Lemmes B., Papi T., Eds, The Science of Composting. Part 1, Chapman & Hall, London, pp. 149-161.

Beffa T., Blanc M., Lyon P.-F., Vogt G., Marchiana M., Fischer J.L., Aragno M. (1996c). Isolation of *Thermus* strains from hot composts (60 to 80 °C). Appl. Environ. Microbiol., 62: 1723-1727.

Belete L., Egger W., Neunhäuserer C., Caballero B., Insam H. (2001). Can community level physiological profiles be used for compost maturity testing? Compost Sci. Util., 9: 6-18.

Berger M., Schwartz L. (1994). Lab-scale composting and land treatment of contaminated soil from a former bulk fuel storage facility. Abstr. 94th General Meet. Am. Soc. Microbiol., 94: 396.

Blanc M., Marilley L., Beffa T., Aragno M. (1997). Rapid identification of heterotrophic, thermophilic, spore-forming bacteria isolated from hot composts. Int. J. Syst. Bacteriol., 47: 1246-1248.

Blanc M., Marilley L., Beffa T., Aragno M. (1999). Thermophilic bacterial communities in hot composts as revealed by most probable number counts and molecular (16S rDNA) methods. FEMS Microbiol. Ecol., 28(2): 141-149.

Bollen G.J., Van der Pol-Luiten B. (1975). Mesophilic heat-resistant soil fungi. Acta Bot. Neerl., 24: 254-255.

Bollen G.J. (1993). Factors involved in inactivation of plant pathogens during composting of crop residues. In: Hoitink H.A.J., Keener H.M., Eds, Science and Engineering of Composting: Desing, Environmental, Microbiological and Utilization Aspects. Renaissance Publications, Wortinghton, Ohio, USA, pp. 301-318.

Bollen G. J., Volker D. (1996). Phytohygienic aspects of composting. In: de Bertoldi M., Sequi P., Lemmes B., Papi T., Eds, The Science of Composting. Part 1, Chapman & Hall, London, pp. 233-246.

Botha W.J., Eicker A., De Meillon S. (1990). A comparative physiological study of four weed moulds of *Agaricus bisporus* mushroom compost. Phytophylactica, 22: 219-223.

Brambilla E., Hippe H., Hagelstein A., Tindall B., Stackebrandt E. (2001). 16S rDNA diversity of cultured and uncultured prokaryotes of a mat sample from Lake Fryxell, McMurdo Dry Valleys, Antartica. Extremophiles, 5: 23-33.

Breitenbach E. (1998). Phytosanitäre Qualitätsbeurteilung von gewerblich hergestellten Komposten anhand ihres Pilzspektrums. PhD Dissertation. Humboldt-Universität Berlin, Germany, p. 116.

Brown K.W., Thomas J.C., Whitney F. (1997). Fate of volatile organic compounds and pesticides in composted municipal solid waste. Compost Sci. Util., 5(4): 6-14.

Buyuksonmez F., Rynk R., Hess T.-F., Bechinski E. (2000). Occurrence, degradation and fate of pesticides during composting: Part II: Occurrence and fate of pesticides in compost and composting systems. Compost Sci. Util., 8(1): 61-81.

Campbell C.D., Darbyshire J.F., Anderson J.G. (1990). The composting of tree bark in small reactors - adiabatic and fixed-temperature experiments. Biol. Wastes, 31: 175-185.

Chamuris G.P., Koziol-Kotch S., Brouse, T.M. (2000). Screening fungi isolated from woody compost for lignin-degrading potential. Compost Sci. Util., 8(1): 6-11.

Chang Y., Hudson H.J. (1967). The fungi of wheat straw compost. I. Ecological studies. Trans. Brit. Mycol. Soc., 50: 649-666.

Chang Y., (1967). The fungi of wheat straw compost. II. Biochemical and physiological studies. Trans. Brit. Mycol. Soc., 50: 667-677.

Choi M.H., Park Y.-H. (1998). The influence of yeast on thermophilic composting of food waste. Lett. Appl. Microbiol., 26: 175-178.

Chung Y.R., Hoitink H.A.J. (1990). Interactions between thermophilic fungi and *Trichoderma hamatum* in suppression of Rhizoctonia damping-off in a bark compost-amended container medium. Phytopathology, 80: 73-77.

Civilini M. (1994). Fate of creosote compounds during composting. Microbiol. Eur., 2(6): 16-24.

Civilini M., Sebastianutto N. (1996). Degradation of naphtalene by microorganisms isolated from compost. In: de Bertoldi M., Sequi P., Lemmes B., Papi T., Eds, The Science of Composting. Part 2, Chapman & Hall, London, pp. 870-883.

Cook H.A., Cromwell D.L., Wilson H.A. (1967). Microorganisms in household refuse and seepage water from sanitary landfills. Proc. W. Va. Acad. Sci., 39: 107-114.

Cooney D.G., Emerson R., Eds (1964). Thermophilic Fungi. W.H. Freeman & Co., London.

Corbaz R., Gregory P.H., Lacey M.E. (1963). Thermophilic and mesophilic actinomycetes in mouldy hay. J. Gen. Microbiol., 32: 449-455.

Corominas E., Perestelo F., Perez M.L., Falcon M.A. (1987). Microorgansims and environmental factors in composting of agricultural waste of the Canary Islands. In: de Bertoldi M., Ferranti M.P., L'Hermite P., Zucconi F., Eds, Compost: Production, Quality and Use. Elsevier Applied Science, London, pp. 127-138.

Coughlan M. P., Mayer F. (1992). The cellulose-decomposing bacteria and their enzyme systems. In: Balows A., Trüper H. G., Dworkin M., Harder W., Schleifer K.-H., Eds, The Prokaryotes: A Handbook on the Biology of Bacteria. 2nd edn., Springer Verlag, New York, pp. 460-516.

Crawford J.H. (1983). Composting of agricultural wastes – A review. Process Biochem., 18: 14-18.

Cross T. (1968). Thermophilic actinomycetes. J. Appl. Bact., 31: 36-53.

Davies J.S., Westlake D.W.S. (1979). Crude oil utilization by fungi. Can. J. Microbiol., 25: 146-156.

Davis C.L., Hinch S.A., Donkin C.J., Germishuizen P. (1991). Changes in micobial population numbers during the composting of pine bark. Bioresour. Technol., 39: 85-92.

Davis C.L., Donkin C.J., Hinch S.A., Germishuizen P. (1992). The microbiology of pine bark composting: an electron-microscope and physiological study. Bioresour. Technol., 40: 195-204.

de Bertoldi, M., Vallini G., Pera A. (1983). The biology of composting: A review. Waste Manag. Res., 1: 157-176.

de Bertoldi M., Vallini G., Pera A., Zucconi F. (1985). Technological aspects of composting including modelling and microbiology. In: Gasser J.K.R., Ed., Composting of Agricultural and Other Wastes. Elsevier Applied Science, London, pp. 27-41.

Dees P.M., Ghiorse W.C. (2001). Microbial diversity in hot synthetic compost as revealed by PCR-amplified rRNA sequences from cultivated isolates and extracted DNA. FEMS Microbiol. Ecol., 35: 207-216.

Delafield F.P., Douderoff M., Palleroni J., Lusty C.J., Contopoulos R. (1965). Decomposition of poly-β-hydroxybutyrate by *Pseudomonas*. J. Bacteriol., 90: 1455-1466.

Derikx P.J.L., de Jong G.A.H., Op den Camp H.J.M., van der Drift C., van Griensven L.J.L.D., Vogels G.D. (1989). Isolation and characterization of thermophilic methanogenic bacteria from mushroom compost. FEMS Microbiol. Ecol., 62: 251-258.

Derikx P.J.L., Camp H.J.M.O., Van der Drift C., Van Griensven L.J.L.D., Vogels G.D. (1990). Biomass and biological activity during the production of compost used as a substrate in mushroom cultivation. Appl. Environ. Microbiol., 56: 3029-3034.

Deschamps A.M., Mahoudeau G., Lebeault J.M. (1980). Fast degradation of kraft lignin by bacteria. Eur. J. Appl. Microbiol. Biotechnol., 9: 45-51.

Deschamps A.M., Gillie J.P., Lebeault J.M. (1981). Direct delignification of untreated bark chips with mixed cultures of bacteria. Eur. J. Appl. Microbiol. Biotechnol., 13: 222-225.

Diaz-Ravina M., Acea M.J., Carballas T. (1989). Microbiological characterisation of four composted urban refuses. Biol. Wastes, 30: 89-100.

Dick W.A., McCoy E.L. (1993). Enchancing soil fertility by application of compost. In: Hoitink H.A.J., Keener H.M., Eds, Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects. Renaissance Publications, Wortinghton, Ohio, USA, pp. 622-644.

Domsch K.H. (1960a). Das Pilzspektrum einer Bodenprobe. 1. Nachweis der Homogenitaet. Arch. Mikrobiol., 35: 181-195.

Domsch K.H. (1960b). Das Pilzspektrum einer Bodenprobe. 3. Nachweis der Einzelpilze. Arch. Mikrobiol., 35: 310-339.

Domsch K.H., Gams W., Anderson T.H. Eds (1993). Compendium of Soil Fungi, Vol. 1, IHW-Verlag, Eching, Germany.

Dragun J. (1988). Microbial degradation of petroleum products in soil. In: Calabrese E.J., Kostecki P.T., Eds, Soils Contaminated by Petroleum; Environmental and Public Health Effects. Wiley-Interscience, New York, pp. 289-300.

Droffner M.L., Brinton W.F.Jr., Evans E. (1995). Evidence for the prominence of well characterized mesophilic bacteria in thermophilic (50-70 °C) composting environments. Biomass Bioenergy, 8: 191-195.

Eastwood D.J. (1952). The fungus flora of composts. Trans. Brit. Mycol. Soc., 35: 215-220.

Eicker A. (1972). Occurrence and isolation of South African thermophilic fungi. S. Afr. J. Sci., 68: 150-155.

Erikson D. (1952). Temperature/growth relationships of a thermophilic actinomycete, *Micromonospora vulgaris*. J. Gen. Microbiol., 6: 286-294.

Fagan S.M., Fergus C.L. (1984). Extracellular enzymes of some additional fungi associated with mushroom culture. Mycopathologia, 87: 67-70.

Falcon M.A., Corominas E., Perez M.L., Perestelo F. (1987). Aerobic bacterial populations and environmental factors involved in the composting of agricultural and forest wastes of the Canary Islands. Biol. Wastes, 20: 89-99.

Fardeau M.-L., Ollivier B., Patel B.K.C., Dwivedi P., Ragot M., Garcia J.-L. (1995). Isolation and characterization of a thermophilic sulfate-reducing bacterium, *Desulfotomaculum thermosapovorans* sp. nov. Internat. J. Sys. Bacteriol., 45: 218-221.

Fergus C.L. (1964). Thermophilic and thermotolerant molds and actinomycetes of mushroom compost during peak heating. Mycologia; 56: 267-284.

Fergus C.L. (1969). The cellulolytic activity of thermophilic fungi and actinomycetes. Mycologia, 61: 120-129.

Fergus C.L., Amelung R.M. (1971). The heat resistance of some thermophilic fungi on mushroom compost. Mycologia, 63: 675-679.

Fermor T.R., Smith J.F., Spencer D.M. (1979). The microflora of experimental mushroom composts. J. Hortic. Sci., 54: 137-147.

Festenstein G.N., Lacey J., Skinner F.A., Jenkins P.A., Pepys J. (1965). Self-heating of hay and grain in dewar flasks and the development of farmer's lung antigens. J. Gen. Microbiol., 41: 380-407.

Finstein M.S., Morris M.L. (1975). Microbiology of municipal solid waste composting. Adv. Appl. Microbiol., 19: 113-151.

Fogarty A.M., Tuovinen O.H. (1991). Microbial degradation of pesticides in yard waste composting. Microbiol. Rev., 55(2): 225-233.

Fujio Y., Kume S. (1991). Isolation and identification of thermophilic bacteria from sewage sludge compost. J. Ferment. Bioeng., 72: 334-337.

Gangwar M., Sodhi H.S., Agarwal R. (1997). Isolation of hypercellulolytic *Thermonospora curvata* strain TC-2 and its role in composting. Ann. Biol. (Hissar), 13(1): 233-238.

Garcia C., Hernandez T., Costa F., Ceccanti B., Ciardi C. (1992). Changes in ATP content, enzyme activity and inorganic nitrogen species during composting of organic wastes. Can. J. Soil Sci., 72: 243-253.

Godden B., Legon T., Helvenstein P., Pennincks M. (1989). Regulation of the production of hemicellulolytic and cellulolytic enzymes by a *Streptomyces* sp. growing on lignocellulose. J. Gen. Microbiol., 135: 285-292.

Godden B., Ball A.S., Helvenstein P., McCarthy A.J., Penninckx M.J., (1992). Toward elucidation of the lignin degradation pathway in actinomycetes. J. Gen. Microbiol., 138: 2441-2448.

Golueke C.G. (1977). Biological Reclamation of Solid Waste. Rodale Press, Emmaus, PA, USA, pp. 8-17.

Golueke C.G. (1986). Compost research accomplishments and needs. Biocycle, 27: 40-43.

Golueke C.G. (1991). Principles of composting. In: The Staff of Biocycle Journal of Waste Recycling. The Art and Science of Composting. The JG Press Inc., Pennsylvania, USA, pp. 14-27.

Golueke C.G. (1992). Bacteriology of composting. Biocycle, 33: 55-57.

Gonzalez B., Merino A., Almeida M., Vicna R. (1986). Comparative growth of natural bacterial isolates on various lignin-related compounds. Appl. Environ. Microbiol., 52: 1428-1432.

Goodfellow M., Williams S.T. (1983). The Ecology of actinomycetes. Annu. Rev. Microbiol., 37: 189-216.

Goodfellow M. (1989). Suprageneric classification of actinomycetes. In: Williams S.T., Sharpe M.E., Holt J.G., Eds, Bergey's Manual of Systematic Bacteriology. Vol. 4, Williams and Wilkins, Baltimore, MD, pp. 2333-2339.

Gray K.R., Sherman K., Biddlestone A.J. (1971). A review of composting - part I. Process Biochem., 6: 32-36.

Grebus M.E., Watson M.E., Hoitink H.A.J. (1994). Biological, chemical and physical properties of composted yard trimmings as indicators of maturity and plant disease suppression. Compost Sci. Util., 2: 57-71.

Gurtner C., Heyrman J., Pinar G., Lubitz W., Swings J., Rolleke S. (2000). Comparative analyses of the bacterial diversity on two different biodeteriorated wall paintings by DGGE and 16S rDNA sequence analysis. Int. Biodeterioration Biodegrad., 46: 229-239.

Hadar Y., Gorodecki B. (1991). Suppression of germination of sclerotia of *Sclerotium rolfsii* in compost. Soil Biol. Biochem., 23: 303-306.

Hardy G.E.St.J., Sivasithamparam K. (1989). Microbial, chemical and physical changes during composting of a eucalyptus (*Eucalyptus calophylla* and *Eucalyptus diversicolor*) bark mix. Biol. Fertil. Soils, 8: 260-270.

Haug RT (1993). Practical Handbook of Compost Engineering. Lewis Publishers, Boca Raton.

Hedger J.N., Hudson H.J. (1970). *Thielavia thermophila* and *Sporotrichum thermophile*. Trans. Brit. Mycol. Soc., 54: 497-500.

Hellmann B., Zelles L., Palojärvi A., Bai Q. (1997). Emission of climate-relevant trace gases and succession of microbial communities during open-windrow composting. Appl. Environ. Microbiol., 63(3): 1011-1018.

Henssen A. (1957). Über die Bedeutung der thermophilen Mikroorganismen für die Zersetzung des Stallmistes. Arch. Mikrobiol., 27: 63-81.

Herrmann I., Meissner S., Bächle E., Rupp E., Menke G., Grossmann F. (1994). Einfluss des Rotteprozesses von Bioabfall auf das Überleben von phytopathogenen Organismen und von Tomatensamen. Z. Pflanzenkr. Pflanzenschutz, 101: 48-65.

Herrmann R.F., Shann J.F. (1997). Microbial community changes during the composting of municipal solid waste. Microb. Ecol., 33: 78-85.

Hoitink H.A.J., Fahy P.C. (1986). Basis for the control of soilborne plant pathogens with composts. Annu. Rev. Phytopathol., 24: 93-114.

Hoitink H.A.J. (1990). Production of disease suppressive compost and container media, and microorganism culture for use therein. U.S. Patent 4,900,348.

Hoitink H.A.J., Inbar Y., Boehm M.J. (1991). Status of compost-amended potting mixes naturally suppressive to soilborne diseases of floricultural crops. Plant Dis., 75(9): 869-873.

Hoitink H.A.J., Boehm M.J. (1999). Biocontrol within the context of soil microbial communities: A substrate-dependent phenomenon. Annu. Rev. Phytopathol.; 37: 427-446.

Hugenholtz P., Goebel B.M., Pace N.R. (1998). Impact of culture-independent studies on the emerging phylogenetic view of bacterial diversity. J. Bacteriol., 180: 4765-4774.

Hupe K., Lueth J.C., Heerenklage J., Stegmann R. (1996). Enhancement of the biological degradation of soils contaminated with oil by the addition of compost. Acta Biotechnol., 16(1): 19-30.

Inbar Y., Chen Y., Hadar Y., Hoitink H.A.J. (1990). New approaches to compost maturity. Biocycle, 31: 64-69.

Insam H., Amor K., Renner M., Crepas C. (1996). Changes in functional abilities of the microbial community during composting of manure. Microbiol. Ecol., 31: 77-87.

Insam H., de Bertoldi M. (2003). Microbiology of the composting process. In: Golueke C., Bidlingmaier W., de Bertoldi M., Diaz L., Eds, Compost Science and Technology, Elsevier Science Ltd (in press).

Itävaara M., Venelampi O., Vikman M., Kapanen A. (2002). Compost Maturity – Problems Associated with Testing. In: Insam H., Riddech N., Klammer S., Eds, Microbiology of Composting. Springer Verlag, Heidelberg, pp. 383-396.

Ivors K.L., Collopy P.D., Beyer D.M., Kang S. (2000). Identification of bacteria in mushroom compost using ribsomal RNA sequence. Compost Sci. Util., 8(3): 247-253.

Ivors K., Beyer D., Wuest P., Kang S. (2002). Survey of Fungal Diversity in Mushroom Compost Using Sequences of PCR-Amplified Genes Encoding 18S Ribosomal RNA. In: Insam H., Riddech N., Klammer S., Eds, Microbiology of Composting. Springer Verlag, Heidelberg, pp. 18-24.

Jensen V. (1975). Bacterial flora of soil after application of oily waste. Oikos, 26: 152-158.

Jeris J.S., Regan R.W. (1973). Controlling environmental parameters for optimum composting. I. Experimental procedures and temperature. Compost Sci., 14: 10-15.

Jodice R., Ferrara R., Ceruti Scurti J., Fiussello N., Obert F., Cortellezzi G.C. (1974). Miceti termofili. 1. Contributo sull'isolamento, sul metabolismo e sulla capacità di degradazione di materiali organici. Allionia, 20: 53-74.

Juteau P., Larocque R., Rho D., Le Duy A. (1999). Analysis of the relative abundance of different types of bacteria capable of toluene degradation in a compost biofilter. Appl. Microbiol. Biotechnol., 52(6): 863-868.

Kane B.E., Mullins J.T. (1973). Thermophilic fungi in a municipal waste compost system. Mycologia, 65: 1087-1100.

Kaneshiro T., Nakamura L.K., Bagby M.O. (1995). Oleic acid transformations by selected strains of *Sphingobacterium thalpophilum* and *Bacillus cereus* from composted manure. Curr. Microbiol., 31: 62-67.

Kästner M., Lotter S., Heerenklage J., Breuer-Jammali M., Stegmann R., Mahro B. (1995). Fate of ^{14}C-labeled anthracene and hexadecane in compost-manured soil. Appl. Microbiol. Biotechnol., 43: 1128-1135.

Kersters I., Van Vooren L., Verschuere L., Vauterin L., Wouters A., Mergaert J., Swings J., Verstraete W. (1997). Utility of the Biolog System for the characterization of heterotrophic microbial communities. System. Appl. Microbiol., 20: 439-447.

Klamer M., Baath E. (1998). Microbial community dynamics during composting of straw material studied using phospholipid fatty acid analysis. FEMS Microbiol. Ecol., 27: 9-20.

Kleeberg I., Hetz C., Kroppenstedt R.M., Müller R.-J., Deckwer W.-D. (1998). Biodegradation of aliphatic-aromatic copolyesters by *Thermomonospora fusca* and other thermophilic compost isolates. Appl. Environ. Microbiol., 64: 1731-1735.

Knoesel D., Resz A. (1973). Pilze aus Müllkompost. Städtehygiene, 6: 6.

Korn-Wendisch F., Rainey F., Kroppenstedt R.M., Kempf A., Majazza A., Kutzner H.J., Stackebrandt E. (1995). *Thermocrispum* gen. nov., a new genus of the order *Actinomycetales,* and description of *Thermocrispum municipale* sp. nov. and *Thermocrispum agreste* sp. nov. Int. J. Syst. Bacteriol., 45: 67-77.

Koschinsky S., Schwieger F., Peters S., Grabbe K., Tebbe C.C. (1998). Characterizing microbial communities of composts at the DNA level. Med. Fac. Landbouww. Univ. Gent, 63: 1725-1732.

Kwok O.C.H., Fahy P.C., Hoitink H.A.J., Kuter G.A. (1987). Interactions between bacteria and *Trichoderma hamatum* in suppression of Rhizoctonia damping-off in bark compost media. Phytopathology, 77: 1206-1212.

Lacey J. (1973). Actinomycetes in soils, composts and fodders. In: Sykes G., Skinner F.A., Eds, Actinomycetales: Characteristics and Practical Importance. Academic Press, New York, pp. 231-251.

Larsen K.L., McCartney D.M. (2000). Effect of C:N ratio on microbial activity and N retention: Bench-scale study using pulp and paper biosolids. Compost Sci. Util., 8(2): 147-159.

Lemmon C.R., Pylypiw H.M. (1992). Degradation of diazinon, chlorpyrifos, isofenphos and pendimethalin in grass and compost. Bull. Environ. Contam. Toxicol., 48: 409-415.

Llanos C., Kjoller A. (1976). Change in the flora of soil fungi following oil waste application. Oikos, 27: 377-382.

Löser C., Ulbricht H., Hoffmann P., Seidel H. (1999). Composting of wood containing Polycyclic Aromatic Hydrocarbons. Compost Sci. Util., 7(3): 6-32.

Lott Fischer J., Lyon P.-F., Beffa T., Aragno M. (1996). Composting of organic garden and kitchen waste in open-air windrows: Influence of turning frequency on the development of *Aspergillus fumigatus*. In: de Bertoldi M., Sequi P., Lemmes B., Papi T., Eds, The Science of Composting. Part 1, Chapman & Hall, London, pp. 1207-1210.

Lynch J.M., Wood D.A. (1985). Controlled microbial degradation of lignocellulose: The basis for existing and novel approaches to composting. In: Gasser J.K.R., Ed., Composting of Agricultural and Other Wastes. Elsevier Applied Science Publishers, London, pp. 183-193.

Lynch J.M. (1987). Lignocellulolysis in composts. In: de Bertoldi M., Ferranti M.P., L'Hermite P., Zucconi F., Eds, Compost, Production, Qualitiy and Use. Elsevier Applied Science, London, pp. 178-189.

Malik K.A., Sandhu G.R. (1973). Some studies on the fungi of kallar grass (*Diplachne fusca*) compost. Pakist. J. Bot., 5: 57-63.

Manachini P.L., Fortina M.G., Parini C., Craveri R. (1985). *Bacillus thermoruber* sp. nov., nom. rev., a red-pigmented thermophilic bacterium. Int. J. Syst. Bacteriol., 35: 493-496.

Mannix S.P., Haruta S., Hazaka M., Shimada R., Yoshida C., Hiura K., Ishii M., Igarashi Y. (2001). Denaturing Gradient Gel Electrophoresis analyses of microbial community from field-scale composter. J. Biosci. Bioeng., 91: 159-165.

Masanori K., Kazuo A. (1998). Changes occurring in microbial flora during composting of mature derived from dairy cattle. J. Rakuno Gakuen Univ. Natural Sci., 22: 225-229.

McCarthy A. J. (1987). Lignocellulose-degrading actinomycetes. FEMS Microbiol. Rev., 46: 145-164.

McFarland M.J., Qiu X.J., Sims J.L., Randolph M.E., Sims R.C. (1992). Remediation of petroleum impacted soils in fungal compost bioreactors. Water Sci. Technol., 25(3): 197-206.

McKinley V.L., Vestal J.R. (1984). Biokinetic analyses of adaption and succession: microbial activity in composting municipal sewage sludge. Appl. Environ. Microbiol., 47: 933-941.

McKinley V.L., Vestal J.R., Eralp A.E. (1985). Microbial activity in composting. Biocycle, 26: 39-43.

McSpadden-Gardener B., Miller S.A., Kleinhenz M., Doohan D., Grewal P. (2002). Impact of compost and manure amendments on bacterial populations in the rhizospheres of tomato and cabbage. In: Michel F.C., Rynk R.F., Hoitink H.A.J., Eds, Proceedings of the 2002 International Symposium "Composting and Compost Utilization". The JG Press Inc., Emmaus, pp. 581-591.

Mergaert J., Anderson C., Wouters A., Swings J. (1994a). Microbial degradation of poly(3-hydroxybutyrate) and poly(3-hydroxybutyrate-co-3-hydroxyvalerate) in compost. J. Environ. Polymer Degrad., 2(3): 177-183.

Mergaert J., Wouters A., Swings J. (1994b). Estimation of the intrinsic biodiversity among poly(3-hydroxyalkanoates) degrading streptomycetes using gas chromatographic analysis of fatty acids. System. Appl. Microbiol., 17: 601-612.

Mergaert J., Swings J. (1996). Biodiversity of microorganisms that degrade bacterial and synthetic polyesters. J. Industrial Microbiol., 17: 463-469.

Michel F.C., Reddy C.A., Forney L.J. (1995). Microbial degradation and humification of the lawn care pesticide 2,4-Dichlorophenoxyacetic acid during the composting of yard trimmings. Appl. Environ. Microbiol., 61: 2566-2571.

Michel F.C., Reddy C.A., Forney L.J. (1997a). Fate of carbon-14 diazinon during the composting of yard trimmings. J. Environ. Quality, 26: 200-205.

Michel F.C., Top E.M., Marsh T.L., Reddy C.A., Forney L.J. (1997b). Novel 2,4-D degrading thermophilic bacilli isolated from yard trimmings compost. Abstr. General Meet. Am. Soc. Microbiol., 97: 520.

Michel F.C., Marsh T.L., Reddy C.A. (2002). Bacterial community structure during yard trimmings composting. In: Insam H., Riddech R., Klammer S., Eds, Microbiology of Composting. Springer Verlag, Heidelberg, pp. 25-42.

Miller F.C. (1993). Ecological process control of composting. In: Metting F.B., Jr., Ed., Soil Microbial Ecology. Marcel Dekker, New York, pp. 529-536.

Minz D., Green S.J., Kautsky L., Inbar E., Hadar Y. (2002). Effect of compost amendment on microbial community in soil, rhizosphere and roots. In: Michel F.C., Rynk R.F., Hoitink H.A.J., Eds, Proceedings of the 2002 International Symposium "Composting and Compost Utilization". The JG Press Inc., Emmaus, p. 592.

Morton F.J., Smith G. (1963). The genera *Scopulariopsis*, *Microascus* and *Doratomyces*. Mycol. Pap., 86: 1-96.

Nakasaki K., Sasaki M., Shoda M., Kubota H. (1985a). Change in microbial numbers during thermophilic composting of sewage sludge with reference to CO_2 evolution rate. Appl. Environ. Microbiol., 49(1): 37-41.

Nakasaki K., Shoda M., Kubota H. (1985b). Effect of temperature on composting of sewage sludge. Appl. Environ. Microbiol., 50: 1526-1530.

Nakasaki K., Sasaki M., Shoda M., Kubota, H. (1985c). Characteristics of mesophilic bacteria isolated during thermophilic composting of sewage sludge. Appl. Environ. Microbiol., 49(1): 42-45.

Nakasaki K., Kubo M., Kubota H. (1996). Production of functional compost which can suppress phytopathogenic fungi of lawn grass by inoculating *Bacillus subtilis* into grass clippings. In: de Bertoldi M., Sequi P., Lemmes B., Papi T., Eds, The Science of Composting. Part 1, Chapman & Hall, London, pp. 87-95.

Niese G. (1959). Mikrobiologische untersuchungen zur frage der selbsterhitzung organischer stoffe. Arch. Mikrobiol., 34: 285-318.

Niimura Y., Koh E., Yanagida F., Suzuki K.-I., Komagata K., Kozaki M. (1990). *Amphibacillus xylanus* gen. nov., sp. nov., a facultatively anaerobic sporeforming xylan-digesting bacterium which lacks cytochrome, quinone, and catalase. Int. J. Syst. Bacteriol., 40: 297-301.

Nusbaumer C., Job D., Aragno M. (1996). Etude de l'altération par les champignons de l'état physico-chimique des composés lignocellulosiques dans un processus naturel de compostage. Mycologia Helvetica, 8: 51-67.

Ogawa T., Asai Y., Ohno S., Tatsumoto H. (1998). Changes in sludge components and microflora during the composting of sewage treatment sludge. Biocontrol Sci., 3: 51-55.

Ohno M., Shiratori H., Park M.-J., Saitoh Y., Kumon Y., Yamashita N., Hirata A., Nishida H., Ueda K., Beppu T. (2000). *Symbiobacterium thermophilum* gen. nov., sp. nov., a

symbiotic thermophile that depends on co-culture with a *Bacillus* strain for growth. Int. J. Syst. Evol. Microbiol., 50: 1829-1832.

Ospina-Giraldo M.D., Royse D.J., Xi C., Romaine C.P. (1996). In vitro inhibition of *Trichoderma harzianum*, cause of mushroom green mold, by *Paenibacillus macerans*. Phytopathology, 86 (11 suppl.): p. 82.

Peters S, Koschinsky S., Schwieger F., Tebbe C.C. (2000). Succession of microbial communities during hot composting as detected by PCR-Single-Strand-Conformation-Polymorphism-based genetic profiles of small-subunit rRNA genes. Appl. Environ. Microbiol., 66: 930-936.

Phae C.G., Shoda M. (1990). Expression of the suppressive effect of *Bacillus subtilis* on phytopathogens in inoculated composts. J. Ferment. Bioeng., 70(6): 409-414.

Phae C.G., Sasaki M., Shoda M., Kubota H. (1990). Characteristics of *Bacillus subtilis* isolated from composts suppressing phytopathogenic microorganisms. Soil Sci. Plant Nutr., 36: 575-586.

Pinzari F., Tittarelli F., Benedetti A., Insam H. (2002). Use of CLPP for evaluating the role of different organic materials in composting. In: Insam H., Riddech N., Klammer S., Eds, Microbiology of Composting. Springer Verlag, Heidelberg, pp. 383-396.

Poincelot R.P., Day P.R. (1973). Rates of cellulose decomposition during the composting of leaves combined with several municipal and industrial wastes and other additives. Compost Sci., 14: 23-25.

Raupach G.S., Kloepper J.W. (1998). Mixtures of plant growth-promoting rhizobacteria enhance biological control of multiple cucumber pathogens. Phytopathology, 88: 1158-1164.

Raymond R.L., Jamison V.W. (1971). Biochemical activities of *Nocardia*. Adv. Appl. Microbiol., 14: 93-122.

Reichert K., Lipski A., Pradella S., Stackebrandt E., Altendorf K. (1998). *Pseudonocardia asaccharolytica* sp. nov. and *Pseudonocardia sulfidoxydans* sp. nov., two new dimethyl disulfide-degrading actinomycetes and emended description of the genus *Pseudonocardia*. Int. J. Syst. Bacteriol., 44: 293-299.

Requena N., Azcón R., Baca T.M. (1996). Chemical changes on humic substances from compost due to incubation with ligno-cellulolytic microorganisms and effects on lettuce growth. Appl. Microbiol. Biotechnol., 45: 857-863.

Requena N., Baca T.M., Azcón R. (1997). Evolution of humic substances from unripe compost during incubation with lignolytic or cellulolytic microorganisms and effects on the lettuce growth promotion mediated by *Azotobacter chroococcum*. Biol. Fertil. Soils, 24: 59-65.

Rick D.L., Davis J.W., Kram S.L., Mang M.N., Lickly T.D. (1998). Biodegradation of an epoxy-based thermoplastic polyester, poly(hydroxy ester ether) in a laboratory-scale compost system. J. Environ. Polymer Degrad., 6(3): 143-157.

Riddech N., Klammer S., Insam H. (2002). Characterisation of microbial communities during composting of organic wastes. In: Insam H., Riddech R., Klammer S., Eds, Microbiology of Composting. Springer Verlag, Heidelberg, pp. 43-52.

Riggle D. (1995). Succesful bioremediating with compost. Biocycle, 36(2): 57-59.

Roberts M.S., Klamer M., Frazier C., Garland J.L. (2002). Microbial community profiling of fungi and bacteria in an in-vessel composter. In: Michel F.C., Rynk R.F., Hoitink H.A.J., Eds, Proceedings of the 2002 International Symposium "Composting and Compost Utilization". The JG Press Inc., Emmaus, pp. 139-155.

Rocha M., Cordeiro N., Cunha Queda A.C.F., Capela R. (2002). Microbiological and chemical characterization during composting of cattle manure and forestry wastes – a

study in Madeira Island. In: Michel F.C., Rynk R.F., Hoitink H.A.J., Eds, Proceedings of the 2002 International Symposium “Composting and Compost Utilization”. The JG Press Inc., Emmaus, pp. 156-170.

Rosenberg S.L. (1975). Temperature and pH optima for 21 species of thermophilic and thermotolerant fungi. Can. J. Microbiol., 21: 153-154.

Rosenberg M., Gutnick D., Rosenberg E. (1980). Adherence of bacteria to hydrocarbons: a simple method for measuring cell-surface hydrophobicity. FEMS Microbiol. Lett., 9: 29-33.

Ryckeboer J., Deprins K., Coosemans J. (1999). The influence of biowaste and garden waste composts on diseases caused by *Pythium ultimum* and *Rhizoctonia solani* related to the antagonists *Trichoderma hamatum* and *Flavobacterium balustinum*. In: Bidlingmaier W., de Bertoldi M., Diaz L.F., Papadimitriou E.K., Eds, Orbit99: Organic Recovery and Biological Treatment. Proceedings of the International Conference ORBIT 99 on Biological Treatment of Waste and the Environment. Rhombos Verlag, Berlin, pp. 523-531.

Ryckeboer, J. (2001). Biowaste and yard waste composts: Microbiological and hygienic aspects - Suppressiveness to plant diseases. PhD Dissertation, Katholieke Universiteit Leuven, Belgium, 278 p.

Ryckeboer J., Cops S., Coosemans, J. (2002a). The fate of plant pathogens and seeds during anaerobic digestion and aerobic composting of source separated household wastes. Compost Sci. Util., 10(3): 204-216.

Ryckeboer J., Vaes K., Vanwynsberghe L., Coosemans J. (2002b). The suitability of mature biowaste and yard waste composts as carrier substrates for bacterial and fungal biocontrol agents. In: Michel F.C., Rynk R.F., Hoitink H.A.J., Eds, Proceedings of the 2002 International Symposium “Composting and Compost Utilization”. The JG Press Inc., Emmaus, pp. 1353-1365.

Ryckeboer J., Mergaert J., Coosemans J., Deprins K., Swings J. (2003). Microbiological aspects of biowaste during composting in a monitored compost bin. J. Appl. Microbiol., 94(1): 127-137.

Savage J., Chase T.Jr., Macmillan J.D. (1973). Population changes in enteric bacteria and other microorganisms during aerobic thermophilic windrow composting. Appl. Microbiol., 26: 969-974.

Seck M.A., Kilbertus G. (1996). Fresh and composted pea-nut shells microflora. In: de Bertoldi M., Sequi P., Lemmes B., Papi T., Eds, The Science of Composting. Part 1, Chapman & Hall, London, pp. 1322-1330.

Seifert K.A., Samson R.A., Boekhout T., Louis-Seize G. (1997). *Remersonia*, a new genus for *Stilbella thermophila*, a thermophilic mould from compost. Can. J. Bot., 75: 1158-1165.

Sharma H.S.S. (1989). Economic importance of thermophilous fungi. Appl. Microbiol. Biotechnol., 31: 1-10.

Shilesky D.M., Maniotis J. (1969). Mycology of composting. Compost Sci., 9: 20-23.

Silveira A.E., Ganho R.B. (1995). Composting wastes contaminated with naphtalene. Compost Sci. Util., 3(4): 78-81.

Sjöström E. (1993). Wood chemistry: Fundamentals and applications, 2nd edn., Academic Press, New York.

Skerman V.B.D, McGowan V., Sneath P.H.A. (1980). Approved Lists of Bacterial Names. Int. J. Syst. Bacteriol., 30: 225-420.

Straatsma G., Samson R.A. (1993). Taxonomy of *Scytalidium thermophilum*, an important thermophilic fungus in mushroom compost. Mycol. Resour., 97: 321-328.

Straatsma G., Samson R.A., Olijnsma T.W., Op den Camp H.J.M., Gerrits J.P.G., Van Griesven L.J.L.D. (1994). Ecology of thermophilic fungi in mushroom compost, with

emphasis on *Scytalidium thermophilum* and growth stimulation of *Agaricus bisporus* mycelium. Appl. Environ. Microbiol., 60: 454-458.

Strauch D., de Bertoldi, M. (1985). Microbial specifications of disinfected sewage sludge. In: L'Hermite P., Ed., Processing and Use of Organic Sludge and Liquid Agricultural Wastes. D. Reidel, Dordrecht, pp. 178-197.

Strauch D. (1987). Microbiological specifications of disinfected compost. In: de Bertoldi M., Ferranti M.P., L'Hermite P., Zucconi F., Eds, Compost: Production, Quality, and Use. Elsevier Applied Sciences, London, pp. 210-229.

Strauch D. (1996). Occurrence of microorganisms pathogenic for man and animals in source-separated biowaste and compost – Importance, control, limits, epidemiology. In: de Bertoldi M., Sequi P., Lemmes B., Papi T., Eds, The Science of Composting. Vol. 1, Chapman & Hall, London, pp. 224-232.

Strom P.F. (1985a). Effect of temperature on bacterial species diversity in thermophilic solid-waste composting. Appl. Environ. Microbiol., 50: 899-905.

Strom P.F. (1985b). Identification of thermophilic bacteria in solid-waste composting. Appl. Environ. Microbiol., 50: 906-913.

Stutzenberger F.J., Kaufman A.J., Lossin R.D. (1970). Cellulolytic activity in municipal solid waste composting. Can. J. Microbiol., 16: 553-560.

Sukesan S., Watwood M.E. (1998). Effects of hydrocarbon enrichment on trichloroethylene biodegradation and microbial populations in finished compost. J. Appl. Microbiol., 85(4): 635-642.

Suler D.J., Finstein M.S. (1977). Effect of temperature, aeration and moisture on CO_2 formation in bench-scale, continuously thermophilic composting of solid waste. Appl. Environ. Microbiol., 33: 345-350.

Tahraoui K., Rho D. (1998). Biodegradation of BTX vapors in a compost medium biofilter. Compost Sci. Util., 6(2): 13-21.

Thambirajah J.J., Zulkali M.D., Hashim M.D. (1995). Microbiological and biochemical changes during the composting of oil palm empty-fruit-bunches. Effect of nitrogen supplementation on the substrate. Bioresour. Technol., 52: 133-144.

Tiquia S.M., Tam N.F.Y., Hodgkiss I.J. (1996). Microbial activities during composting of spent pig-manure sawdust litter at different moisture contents. Bioresour. Technol.; 55: 201-206.

Tiquia S.M., Keener H.M., Elwell D., Ichida J.M., Burt E.H.Jr., Michel F.C.Jr. (2002). Microbial community structure during composting of waste feathers using terminal restriction fragment length polymorphisms of 16S rDNA. In: Michel F.C., Rynk R.F., Hoitink H.A.J., Eds, Proceedings of the 2002 International Symposium "Composting and Compost Utilization". The JG Press Inc., Emmaus (abstract).

Tiquia S.M., Michel F.C.Jr. (2002). Bacterial diversity in livestock manure composts as characterized by Terminal Restriction Fragment Length Polymorphisms (T-RLFP) of PCR-amplified 16s rRNA gene sequences. In: Insam H., Riddech R., Klammer S., Eds, Microbiology of Composting. Springer Verlag, Heidelberg, pp. 65-82.

Tomati U., Galli E., Pasetti L., Volterra E. (1995). Bioremediation of olive-mill wastewaters by composting. Waste Manag. Res., 13: 509-518.

Torsvik V.L., Goksoyr J., Daae F.L. (1990). High diversity in DNA of soil bacteria. Appl. Env. Microbiology, 56: 782-787.

Tseng D.Y., Chalmers J.J., Tuovinen O.H. (1996). ATP measurement in compost. Compost Sci. Util., 4: 6-17.

Tuitert G., Szczech M., Bollen G.J. (1998). Suppression of *Rhizoctonia solani* in potting mixtures amended with compost made from organic household waste. Phytopathology, 88: 764-773.

Tuomela M., Vikman M., Hatakka A., Itävaara M. (2000). Biodegradation of lignin in a compost environment: A review. Bioresour. Technol., 72(2): 169-183.

Ueda K., Ohno M., Yamamoto K., Nara H., Mori Y., Shimada M., Hayashi M., Oida H., Terashima Y., Nagata M., Beppu T. (2001). Distribution and diversity of symbiotic thermophiles, *Symbiobacterium thermophilum* and related bacteria, in natural environments. Appl. Environ. Microbiol., 67: 3779-3784.

Upreti J.C., Joshi M.C. (1984). Cellulolytic activity of mesophilic and thermophilic fungi isolated from mushroom compost. Indian Phytopathol., 37(3): 473-476.

Van Dees P.M., Ghiorse W.C. (2001). Microbial diversity in hot synthetic compost as revealed by PCR-amplified rRNA sequences from cultivated isolates and extracted DNA. FEMS Microbiol. Ecol., 35: 207-216.

Van Elsas J.D., Garbeva P., Salles J. (2002). Effects of agronomical measures on the microbial diversity of soils as related to the suppression of soil-borne plant pathogens. Biodegradation, 13: 29-40.

Van Gestel K., Mergaert J., Swings J., Coosemans J., Ryckeboer J. (2003). Bioremediation of diesel oil-contaminated soil by composting with biowaste. Environ. Pollut, 125: 361-368.

Von Klopotek A. (1962). Über das Vorkommen und Verhalten von Schimmelpilzen bei der Kompostierung städtischer Abfallstoffe. Antonie van Leeuwenhoek, 28: 141-160.

Von Klopotek A. (1974). Revision der thermophilen Sporotrichum-arten – *Chryosporium thermophilum* (Apinis) comb.nov. und *Chrysosporium fergusii* spec.nov. = status conidialis von *Corynascus thermophilis* (Fergus & Sinden) comb.nov. Arch. Mikrobiol., 98: 365-369.

Waksman S.A., Cordon T.C., Hulpoi N. (1939a). Influence of temperature upon the microbiological population and decomposition processes in composts of stable manure. Soil Sci., 47: 83-114.

Waksman S.A., Cordon T.C. (1939b). Thermophilic decomposition of plant residues in composts by pure and mixed cultures of microorganisms. Soil Sci., 47: 217-225.

Watwood M.E., Sukesan S. (1995). Biodegradation of trichloroethylene in finished compost materials. Compost Sci. Util., 3(4): 6-19.

Wei G., Kloepper J.W., Tuzun S. (1991). Induction of systemic resistance of cucumber to *Colletotrichum orbiculare* by select strains of plant growth-promoting Rhizobacteria. Phytopathology, 81: 1508-1512.

Wiegant W.M. (1992). Growth characteristics of the thermophilic fungus *Scytalidium thermophilum* in relation to production of mushroom compost. Appl. Environ. Microbiol., 58: 1301-1307.

Wiley B.B., Westerberg S. (1969). Survival of human pathogens in composted sewage. Appl. Microbiol., 18: 994-1001.

Zucconi F., Forte M. Monaco A., de Bertoldi M. (1981a). Biological evaluation of compost maturity. Biocycle, 22: 27-29.

Zucconi F., Pera A., Forte M., de Bertoldi M. (1981b). Evaluating toxicity of immature compost. Biocycle, 22: 54-57.