

# Glossary of Terms

- Abiotic** Physical rather than biological; not derived from living organisms/relating to or resulting from physical phenomena.
- Etiology** The science of the causes of disease, especially the nature of the causal agent.
- AFLP** Amplified fragment length polymorphism.
- Alleles** Variants of a gene, occupying the same relative position on a chromosome and being separated during meiosis.
- Alternative host** A plant other than the main host on which the pathogen can survive.
- Anamorph** An asexual reproductive stage in a fungal life cycle.
- Anastomosis** The physical connect and mixing of two different fungal mycelia.
- Antagonistic** A biological structure or chemical agent that interferes with the physiological action of another.
- Anthraxnose** A plant disease typically caused by *Colletotrichum*, characterized by having limited necrosis and black sunken lesions.
- Applanate** Flattened.
- Appressed** Closely flattened down.
- Arriba** Cacao from the Guayas Basin of Ecuador, derived from the indigenous Nacional variety.
- Arthrospore** A specialized uninucleate cell functioning as a spore and derived from the disarticulation of cells of a formerly vegetative branch.
- Ascomycota** The largest fungal phylum for which the ascus is the diagnostic character.
- Ascospore** A spore produced in an ascus by “free cell formation.”
- Asexual** Not having or involving sexual union of gametes.
- Atypical** Different from what is common or typical.
- Basidiocarp** The multicellular structure of a basidiomycete fungus on which the spore-producing hymenium produced, a mushroom.
- Basidioma** A basidium-producing organ or fruit body.

- Basidiomycota** Phylum in the kingdom Fungi, producing basidiospores in the sexual phase; include, for example, mushrooms, bracket fungi, earth stars, jelly fungi.
- Basidiospore** Reproductive spores from basidiomycete fungi.
- Basidium (pl. basidia)** Cell produced by Basidiomycotina on which (generally four) basidiospores form.
- Bifactorial mating system** Each haploid nucleus has two mating-type loci; different alleles at each locus are needed for a sexual compatible interaction between hyphae from individuals of the same species.
- Biocontrol (Biological Control)** The use of living organisms to suppress the population density or impact of a specific pest organism, making it less abundant or less damaging than it would otherwise be.
- Biological control** Control of pathogens or pests using biological agents.
- Biological species concepts** In the chapter regarding *Ceratocystis* we utilize the phylogenetic species concept defining a species as the smallest aggregation of populations with a common lineage that share unique, diagnosable phenotypic and genetics characters.
- Biotic** Relating to or resulting from living organisms.
- Biotroph** An organism that acquires nutrients from a host without the death of the host tissues.
- Biotrophic** Obtaining nutrients from living host cells.
- Bottleneck** A sharp reduction in the size of a population due to environmental events or human activities that can change gene frequencies by sampling errors acting in a similar way to genetic drift.
- Budwood** Twigs with vegetative buds used for clonal propagation by grafting or budding.
- Cabruca system** Cultivation of cacao under thinned primary rain forest, as practiced in the Bahia region of Brazil.
- Cacao** Spanish corruption of the Nahuatl name for the tree (*Theobroma cacao*) and its product. In this text cacao is used specifically for the tree and its parts (i.e., cacao pod) and not for products produced from the tree (i.e., cocoa butter).
- Caducous** Separating easily or before the expected time.
- Catongo** Cacao variety possessing the anthocyanin inhibitor gene (shoots and beans lacking the purple coloration).
- Cheilocystidium** A sterile, distinctively shaped body occurring at the edge of an agaric basidioma (mushroom).
- Chemotropic response** Directed or oriented growth or movement in response to a chemical stimulus. The movement is either towards (positive) or away (negative) from the chemical stimulus.
- Cherelle** Immature pod of cacao, typically less than 2 months old.
- Chitinolytic** Being able to break down chitin.
- Chlamydospore** A thick-walled asexual resting spore that develops from a portion of a hyphal cell. The chlamydospore is a resistant propagule of indeterminate resting period.

- Chlorosis** Symptoms caused by the loss of chlorophyll, with characteristic paling, yellowing, or patchiness of leaf color.
- Chromosome** A unit package of DNA and proteins that is carried as hereditary material.
- Chupon** Vegetative offshoot of the stem allowing for the continual vertical growth of the plant.
- Clade** A group of organisms that consists of a common ancestor and all its lineal descendants, and represents a single branch on the tree of life.
- Cladogram** A diagram depicting possible branching lineages. Cladograms consist of clades and the branching points that differentiate clades and members are called nodes.
- Clamp connection** A hyphal outgrowth which at cell division and septum formation connects the resulting two cells; diagnostic of Basidiomycota.
- Clavate** Club-like.
- Clonal lineage** Organisms that share a common ancestor and have the same or highly similar DNA sequence.
- Coenocytic mycelium** Hyphal strands that have no dividing walls (aseptate) with a multinucleate cytoplasm.
- Coevolution** Cases where two (or more) species reciprocally affect each other's evolution. For example, an evolutionary change in the morphology of a plant might affect the morphology of its pathogen, which in turn might affect the evolution of the plant, which might affect the evolution of the pathogen. . .and so on.
- Colony pattern** A group of hyphae (mycelium) derived from single or multiple propagules that has a macroscopic recognizable shape or design as a whole during growth.
- Compatibility type** Versions of the same fungal species that can undergo sexual reproduction; mating types that are genetically similar but physiologically different and needing each other for sexual reproduction.
- Complex of species** A group of closely related species very similar in appearance, such that boundaries between them are often unclear.
- Concolorous** Of one color.
- Conidia** Sometimes termed asexual chlamydospores, or chlamydoconidia are asexual, non-motile spores of a fungus.
- Conidiogenous** Producing conidia.
- Conserved region** Stretch of DNA in which the sequence of nucleotides is unaltered.
- Conspecific** Belonging or referring to the same species.
- Convergent evolution** The independent evolution of similar features in species of different lineages, creating analogous characteristics that have similar form or function, but that were not present in the last common ancestor of those groups.
- Correlated** Concerning the relationship between two variables.
- Corticoid** Flattened, smooth (of basidiocarps).
- Cyst** A walled resting structure from single or multiple cells.

- Cystidium** Sterile body, frequently of a distinctive shape occurring at the surface of a basidioma, particularly the hymenium, from which it frequently projects.
- Decurrent** Of lamellae, running down the stipe.
- Diatoms** Algal form of plankton with siliceous walls occurring singly or in small clusters.
- Dieback** Disease form characterized by death of shoot or branch, beginning at or near the apex and spreading back to older tissues.
- Dikaryon (Dikaryotic)** Fungus in which the cells have two genetically distinct haploid nuclei.
- Dimidiate** Shield-like; appearing to lack one half or having one half very much smaller than the other.
- Diploid** Having twice the haploid content of the genome.
- Dissepiment** A partition, e.g., between pore of a polypore.
- Dolipore septum** Septum with pores located in thickened region characteristic of some Basidiomycotina species.
- Ectotrophic** Growing outside the root or between the cells.
- Effective microorganisms (EM)** Beneficial organism used as an amendment.
- Ellipsoid** An object that is elliptical in outline; oval with tapered ends and widest in center.
- Endophyte** Organism inhabiting internal plant tissues without causing apparent harm.
- Endospore** An asexual spore that is formed within a cell.
- Eukaryotic** An organism whose cells contain hereditary material enveloped in a membrane.
- Evolutionary forces** The forces of evolution are processes that change gene frequencies in populations and they include genetic drift, mutation, migration, and natural selection.
- Extragenic** Not under the control of genes.
- Fixation index** A comparative measure ranging from 0 to 1 of genetic variability within and among populations that indicates the ability of the populations to interbreed freely (zero value) or non-breeding (unity value) from not having any shared genetic diversity.
- Flower cushions** Compact inflorescences formed on woody tissue of suitable physiological age.
- Forastero** Original used to refer to a cacao variety foreign to or not native in the region of cultivation (mainly in Mesoamerica) but is now utilized to denote the cacao germplasm (both wild populations and cultivated forms) from South America other than Criollo and Trinitario.
- Founder effect** The loss of genetic variation that occurs when a new population is established by a very small number of individuals from a larger population, through sampling errors acting in a similar way to genetic drift.
- Gametangia** Hyphal structures acting as male (antheridia) or female (oogonia) reproductive structures.

- GenBank** An online repository of nucleic, protein, and organismal information.
- Gene diversity** The diversity of genetic forms of one or many genes in populations or species accounting for number and frequency of forms.
- Gene flow** Also called migration—any movement of individuals, and/or the genetic material they carry, from one population to another.
- Generative hyphae** Are branched, thin-walled, septate, and commonly with clamp connections.
- Genetic drift** Change in gene frequency of an allele in a population over time.
- Genome** Complete set of DNA containing all the genes for an organism.
- Germ tube** The germinating hypha from a spore.
- Germplasm** The living genetic resources such as seeds or tissue that is maintained for the purpose of animal and plant breeding, preservation, and other research uses.
- Glabrescent** Becoming smooth.
- Haploid** Having a complete but single unpaired set of genetic information.
- Haustoria** Are fungal mycelia structures that penetrate the host's tissue and draws nutrients from it.
- Haustorium** An outgrowth produced by some parasitic organisms that penetrates the host cell and acts as an absorptive organ.
- He (expected heterozygosity)** Theoretical maximum fractional number of mixed genic states of total genes of an individual or fraction of individuals in a population who show a mixed genic state at a particular gene.
- Hemibiotroph** A pathogen that lives on living tissues without killing those tissues for part of its life cycle but ultimately changes and kills and infects those tissues.
- Heterokaryotic** A condition where all of the nuclei in a multinucleate cell are genetically different
- Heterothallic** Mating system with compatible mating-type genes of a single type being present in a genome; hypha of the compatible mating type is therefore needed for sexual production.
- Holobasidiate** Metabasidium undivided.
- Holocarpic** The whole thallus (entire body) can become segmented into spores.
- Homogenous** Uniform composition; having the same type.
- Homoheteromixis** (secondary homothallism), in the basidiomycetes, a system whereby the basidiospore contains dikaryotic or diploid nuclei, resulting in dikaryotic or diploid hyphae upon germination that are phenotypically similar to homothallic hyphae instead of haploid hyphae as is the case with heterothallism.
- Homokaryotic** A condition where all of the nuclei in a multinucleate cell are genetically identical.
- Homologs** A gene related to a second gene because they are derived from a common ancestral DNA sequence.
- Homothallic** Mating system with mating-type genes of both types present in a genome; an individual is therefore self-fertile, thus able to reproduce without a partner of the opposite mating type, also referred to as selfing.

**Hormone** A chemical substance produced in one area and usually affecting metabolic activities elsewhere.

**Hyaline** Smooth, translucent.

**Hymenium** Spore-bearing layer of a fruit body.

**Hyperplasia** Overproduction of cells or tissues in reaction to a disease-producing agent.

**Hypertrophy** Increased size of cells or tissues in reaction to a disease-producing agent.

**Hyphae** The tubular structures that constitute the mycelium.

**ICGT (International Cocoa Genebank Trinidad)** A universal collection of cacao genetic resources that is the largest in the public domain. The collection is curated by the Cocoa Research Centre of The University of the West Indies and is located in central Trinidad in the country of Trinidad and Tobago in the Caribbean.

**Incubation period** The time taken between infection by a pathogen and development of observable symptoms in the host.

**Induced resistance** A plant defense state associated with an enhanced ability to resist pathogen attack by stronger activation of cellular defense responses.

**Induced Systemic resistance (ISR)** Induced resistance potentiated by plant growth-promoting rhizobacteria which does not involve the accumulation of pathogenesis-related proteins or salicylic acid but instead relies on pathways regulated by jasmonate and ethylene.

**Integrated Pest Management (IPM)** The attempt to prevent pathogens, insects, and weeds from causing economic crop losses by using a variety of management methods that are cost-effective and cause the least damage to the environment.

**Interfertility tests** *Ceratocystis* species is used with a diagnostic species to identify biological species and identify barriers to gene flow between species.

**Internal resistance** Host-induced resistance after pathogen ingress.

**Internal transcribed spacer region or ITS** A locus or region in the DNA that is found between the genes for Small Subunit Ribosomal RNA (SrRNA) and the Large Subunit Ribosomal RNA (LrRNA). It is used in taxonomy and molecular phylogeny as a universal DNA barcode marker for fungi because of a high degree of variation.

**Interspecific hybridization** The sexual mating between two distinct species.

**Irregular guttulate contents** Having one or more oil-like drops (guttules) inside.

**Isolate** (1) verb: To separate a microorganism from host or substrate and establish it in pure culture; (2) noun: a single spore or pure culture and the subcultures derived from it.

**Isozyme (or isoenzyme)** Proteins that perform the same enzymatic function but with different amino acid sequence.

**Isozyme analysis** Characterization of types of isozymes; genetic diversity studies based on frequency of isozymes.

**ITS (internal transcribed spacer)** Noncoding DNA sequence located between the small and large subunit ribosomal RNA genes.

**ITS polymorphism** Difference in DNA sequence of the ITS region.

- Koch's postulates** Four criteria which establish whether a pathogenic organism causes a particular disease.
- Limoniform** Shaped like a lemon.
- Mating types** Molecular mechanisms that regulate compatibility in fungi; genotypic diversity is generated through sexual recombination; this process is controlled in some *Ceratocystis* species by two alleles, MAT-1 and MAT-2, at the same mating-type locus.
- Meiosis** Specialized cell division prior to sexual reproduction that produces gametes with half of the initial chromosomal content.
- Mesophilic** Growing best at moderate temperatures.
- Microsclerotium** A small sclerotium or resting structure.
- Mitochondrion** An organelle in eukaryotic cells that is bounded with a double membrane.
- Mitotic recombination** Type of genetic rearrangement occurring in somatic cells.
- Monilioid hyphae** Shortened hyphae sometimes forming reproductive bodies.
- Monokaryon (Monokaryotic)** Fungus in which the cells have genetically identical haploid nuclei.
- Monomitic** Having hyphae of one kind (generative hyphae) as opposed to dimitric, having two kinds of hyphae (generative and skeletal) and trimetric, having three kinds of hyphae (generative, skeletal, and binding).
- Mt Cox I** Mitochondrially encoded cytochrome C oxidase I; one of three mitochondrial subunits of the respiratory complex IV enzyme.
- MtDNA restriction fragment length polymorphism** Genetic difference arising from differences in DNA sequence of mitochondrial DNA detected by the presence of restriction enzyme sites.
- Mutation** A permanent change of the nucleotide sequence of the genome of an organism.
- Mycelium** The mass of hyphae that forms the vegetative body of a fungus.
- Mycobiota** The total fungal inventory of an area.
- Mycolaminaran** A  $\beta$ -1,3;  $\beta$ -1,6 polysaccharide of D-glucose units.
- Mycoparasitism** Parasitism by a fungus of another fungus (one fungus living on another).
- Mycorrhiza** The association of a fungus with the roots of a vascular plant in a symbiotic to mildly parasitic relationship.
- Mycotoxin** A toxin or toxic metabolite derived from a fungus.
- Necrosis** The condition of premature death of plants cells.
- Necrotroph** Plant pathogen that kills the host cells and then utilizes the cells for feeding.
- Necrotrophic** Obtaining nutrients from dead host cells.
- Niche** The role and position a species has in its environment; how it meets its needs for food and shelter, how it survives, and how it reproduces. A species' niche includes all of its interactions with the biotic and abiotic factors of its environment.
- Nodulose** (of spores). Having broad based, blunt, wart-like excrescences.

- Non-agglutinated** Not fixed together.
- Nuclear polymorphism** Genetic difference in DNA sequence of the genetic material of the nucleus.
- Nursery** A place where young plants or trees are raised.
- Obovoid** Egg-shaped with a narrow end at the base.
- Obpyriform** Pear-shaped with a narrow end at the base.
- Obturbinate** A conical shape having a wider base at the bottom.
- Occluded pedicel** Closed off with walls; often used for the lumina of hyphae.
- Oomycete** Filamentous algae or fungi that are typically aquatic but with some terrestrial members; all oomycetes have a saprophytic or pathogenic life cycle.
- Ophiostomatoid fungi** Antique group that includes species of *Ceratocystis*, *Ophiostoma*, and *Ceratocystiopsis*.
- Ovoid** Shaped like an egg.
- Palindromic** Having the same sequence forward or backward.
- Panmictic** Random mating among members of a population without preference for certain traits.
- Papilla** Nipple-shaped protuberance.
- Parasexual recombination** An asexual form of genetic recombination that does not involve meiosis or the fusion of gametes.
- Parthenocarpic fruits** Fruits induced without fertilization and therefore seedless.
- Pathogen** A microorganism that can cause disease.
- Pathotype** A subdivision of a species distinguished by common characters of pathogenicity.
- Pedicel** Stalk of a single structure.
- Peduncle** Stalk of a compound structure.
- Perithecia** A flask-shaped sexual fruiting body produced by *Ceratocystis* species.
- Perithecial base** Basal segment in certain ascomycetous fungi, a flask-like case containing the spore sacs.
- Perithecium** Subglobose or flask-like structure which contains ascospores with an ostiole (opening) at end of the neck (associated with Ascomycetes).
- Persistent** Existing for an undetermined and longer period of time than expected.
- Petiole** Stalk of leaf.
- Phenological** Relationship of climatic conditions with periodic biological events.
- Phenotypic characters** Recognizable trait, feature, or property of an organism.
- Phyllosphere** The total aboveground portions of plants as habitat for microorganisms.
- Phylogenetics** The study of the evolutionary history, development, and relationships among groups of organisms (e.g., species or populations).
- Pileus** The hymenium supporting part of the basidioma on non-resupinate Agaricomycetes; the cap of a fruiting body.
- Plasma membrane** The cell membrane or plasmalemma that surrounds the protoplasm.
- Pleomorphic** Fungi having multiple independent forms.
- Polyene antibiotics** Antimicrobial compounds that contain many carbon-carbon double bonds.



- Polysaccharide** Extremely long chain containing repeat units of carbohydrate molecules.
- Post-penetration resistance** Host defense to pathogen after the external protective layers of the host have been breached; similar to internal resistance.
- Pre-breeding** Preliminary breeding to obtain suitable parent material that would be used in the final crosses to generate desirable varieties.
- Primers** Short stretches of nucleotide bases that will bind to a particular DNA region and allow the initiation of DNA polymerization.
- Pulvinus** A prominent swelling at the base of the petiole of a cacao leaf.
- Pyriform** Pear-shaped.
- QTLs** A quantitative trait locus (QTL) is a section of DNA (the locus) that correlates with variation in a phenotype (the quantitative trait).
- Quarantine pest** A pest of potential economic importance to a growing region that is not yet present, or present but not widely distributed and is officially controlled.
- RAPD** Randomly amplified polymorphic DNA.
- Refractario trees** Cacao cultivars from western Ecuador selected for “resistance” to pod diseases, based on escape from infection rather than genetic resistance.
- Reniform** Kidney-shaped.
- Repetitive sequence** Stretch of bases in DNA that is present as a set, multiple times with or without interruptions.
- Restriction digest** DNA after being subjected to enzymes that cut at specific base sequences in DNA.
- Resupinate** (of a basidioma or fruit body) Being flat on the substrate with the hymenium on the outer side.
- RFLP** Restriction fragment length polymorphism.
- Rhizobacteria** Root-colonizing bacteria.
- Rhizomorphs** Shoestring like aggregated hyphae, enabling fungi to move over a distance and often able to penetrate a host.
- Rhizosphere** The total belowground portions of plants and the soil immediately surrounding them as habitats for microorganisms.
- Saprotroph** An organism feeding on dead tissue, not forming part of a living host.
- Sclerotium** Firm, compact masses of hyphae, with or without addition of host tissue or soil, normally having no spores in or on it, acts a resting structure.
- Septum** A partition.
- Sequence** An ordered stretch of DNA.
- Serological diagnostic** Identification of foreign proteins by a process that matches with an antibody protein.
- Somatic incompatibility** Vegetative interaction between hyphae; incompatible reaction leads to cell death at the zone where hyphae from two incompatible strains are encountered.
- Speciation** The evolutionary process by which new biological species arise from an ancestor species.
- Spherical** Ball-shaped.

- Sporangial stalk** Filament that holds the sporangium.
- Sporangium** A structure in which spores are formed.
- Sporophore** Fruiting body.
- Stellate** Star-shaped.
- Sterigmata** Extensions (generally four) of the cell wall of the basidium on which basidiospores develop.
- Strain** A described/characterized purified isolate.
- Striate** Showing stripes or streaks.
- Subspherical** Nearly but not fully spherical.
- Sulcate** Grooved.
- Synonym** Another name for a species or group, especially a later name not currently employed for the taxon.
- Synonymy** Having the same name.
- Systemic Acquired Resistance (SAR)** A “whole-plant” resistance response that occurs following an earlier exposure to virulent, avirulent, or nonpathogenic microbes or to elicitor chemicals and which involves coordinated accumulation of pathogenesis-related proteins (and transcripts) and salicylic acid throughout the plant.
- Systemic** (of a pesticide) entering the plant and passing through the tissues or (of a pesticide) absorbed and circulated by a plant or other organism.
- Taxonomic status** The current standing valid/accepted name for a taxon by the 18th International Botanical Congress.
- Teleomorph** Sexual reproductive stage of a fungal life cycle.
- Tetrapolar** See bifactorial mating-type system.
- Thallus** A plant body that is not differentiated into roots, stems, and leaves and lacks a true vascular system.
- Tinsel flagellum** Threadlike projection, with multiple longitudinal rows of finer projections, that is capable of causing motion.
- Tomentose** Covered in soft matted hairs (downy).
- Torulose** Cylindrical but having swellings at intervals.
- Trama** The layer of hyphae in the central part of a lamella of an agaric.
- Transcriptome** An organism’s complete set of RNA used to identify expressed genes.
- Triazol** Refers to any of the heterocyclic compounds with molecular formula  $C_2H_3N_3$ , having a five-membered ring of two carbon atoms and three nitrogen atoms.
- Trichome** A small hair or other outgrowth from the epidermis of a plant, typically unicellular and glandular.
- Trinitario** Phenotypes derived from cacao populations in Trinidad.
- Turbinate** Shaped like a top; an inverted conical shape.
- Tylose** An outgrowth of xylem parenchyma cells which occlude xylem vessels acting as a resistance mechanism.
- Umbrinous** Umber in color.
- Unidirectional mating-type switching** A sexual reproduction mechanism described in a few fungal genera. The switching of mating type is irreversible

and results in the production of both self-fertile and self-sterile isolates by a homothallic species.

**Vegetative incompatibility** See Somatic incompatibility.

**Velutinate** Thickly covered in delicate hairs; velvet-like.

**Verrucose** Having a rough or warty surface.

**Verticillate** Having parts arranged in whorls.

**Vesicle** Any membrane-bound globule within the cytoplasm.

**Whiplash flagellum** Threadlike smooth projection capable of causing motion.

**Wilt disease** A disease characterized by chlorosis and wilting of the plant tissue due to the impairment of water supply as a result of the xylem infection by fungal pathogens.

**Zonate** Having concentric lines often forming alternating pale and darker zones near the margins.

**Zoospore** A motile asexual spore with one or more flagella and without a cell wall.

## Sources for Glossary Terms

Holliday, P. (1990). *A dictionary of plant pathology* (369 pp). Cambridge: Cambridge University Press.

Holliday, P. (2001). *A dictionary of plant pathology* (2nd ed., 536 pp). Cambridge: Cambridge University Press.

Kirk, P. M., Cannon, P. F., Winter, D. W., & Stalpers, J. A. (2008). *Dictionary of the fungi* (10th ed., 771 pp). Wallingford: CABI.

Martin, E. A. (1983). *Macmillan dictionary of life sciences* (2nd ed., 396 pp). London: The MacMillan Press.

Waller, J. M., Lenné, J. M., & Walker, S. J. (2002). *Plant pathologist's pocketbook* (3rd ed., 528 pp). Wallingford: CABI.

Oxford Dictionary Online. (2015). Oxford University Press. <http://www.oxforddictionaries.com/>

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