REPUBLIC OF AZERBAIJAN

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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

MYCOBIOTA AND ECOPHYSIOLOGY OF PATHOGENIC SPECIES ASSOCIATED WITH DRY SUBTROPICAL FRUIT CROPS IN AZERBAIJAN

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Applicant: **Gultakin Gara Arabova**

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The work was performed at the Laboratory of Microbial Biotechnology of the Institute of Microbiology, Ministry of Science and Education of the Republic of Azerbaijan.

Scientific supervisor:	Doctor of Biological Sciences, Professor **Konul Farrukh Bakhshaliyeva**
Official opponents:	Doctor of Biological Sciences, Professor **Khudaverdi Ganbar Ganbarov**
	Doctor of Philosophy in Biology, Associate Professor **Afag Latifagha Rzayeva**
	Doctor of Philosophy in Biology **Fikrat Tofig Aliyev**

Dissertation Counsil PhD 1.07 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Institute of Microbiology of the Ministry of Science and Education of the Republic of Azerbaijan.

Chairman of the Dissertation Counsil:	Corresponding Member of ANAS Doctor of Biological Sciences, Professor **Panah Zulfigar Muradov**
Scientific Secretary of the Dissertation Council:	Doctor of Philosophy in Biology **Vafa Yashar Hasanova**
Chairman of the Scientific Seminar:	Doctor of Biological Sciences, Professor **Gular Mirjafar Seyidova**

INTRODUCTION

Relevance and degree of development of the topic. One of the foundations of the development strategy of any country, including the Republic of Azerbaijan, is the provision of food to the country's population in accordance with the principle of sustainable development. Thus, due to the increasing demand for food, especially natural foods, which are considered more serious issues in modern times, these issues are the main focus of both the country's economy and experts conducting research in this field, and attention to them is increasing against the background of global problems of the globalized world.

Although the basis of human nutrition is made up of products of plant, animal, and microorganism origin, "*products derived from plants differ from others in terms of their biological value*"[1]. In addition, the role of plants in the development of other sources that contribute to the provision of human food is indispensable, not least because "*plants are the main source of meeting the demand for organic matter and molecular oxygen necessary for their development*"[2]. Plants are both cultivated and grow in the wild, and both types are included in the human diet. Nevertheless, people make greater use of cultivated plants, which differ from one another based on certain characteristics they possess. For example, there are medicinal plants, fodder plants, fruit plants, technical plants, essential oil plants, and so on. Some of the plants that fit this classification may possess all of the mentioned characteristics, while others may carry only one or several of them, and one such group is fruit plants, among which

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[1] Samtiya M., Aluko R.E., Dhewa T., Moreno-Rojas J.M. Potential Health Benefits of Plant Food-Derived Bioactive Components: An Overview. Foods. 2021 Apr 12;10(4):839. doi: 10.3390/foods10040839.

[2] Fernando W.G. Plants: An International Scientific Open Access Journal to Publish All Facets of Plants, Their Functions and Interactions with the Environment and Other Living Organisms. Plants (Basel). 2012 Feb 6;1(1):1-5. doi: 10.3390/plants1010001.

"*medicinal, nutritional, and essential oil-bearing plants*"[3] are included, some of which are able to develop better in specific climatic conditions, with dry subtropical fruit plants being of particular significance among them. According to the rules of artificial systematics of living organisms, fruits grouped under this name today have the ability to grow and show high productivity not only in areas with dry subtropical climatic conditions, but also in those with other climatic conditions, which necessitates their cultivation in wider areas.

In this regard, the development of agriculture, including its fruit growing sector, which is one of the main areas of the non-oil sector, is of particular interest in terms of both the development of the country's economy and meeting people's growing demand for food. For this reason, serious work is being carried out in this field in the world, as well as in the Republic of Azerbaijan as a part of it. However, the mere planting and cultivation of any product and obtaining the product does not mean the successful achievement of the set goal. In a period when the number of people is increasing and the demand for food is increasing against its background, proper planning, advance calculation of risks and problems play a key role in the proper development of the agricultural sector.

One of the works carried out in this field around the world in recent years is the "*establishment of super-intensive gardens*"[4,5], thanks to which crop growth has increased significantly. There ara several advantages of this type of gardens:

- In traditional orchards, trees would produce a full crop

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[3] Sadıqov Ə.N. Azərbaycanda yayılmış meyvə bitkiləri.Bakı: "Müəllim" nəşriyyatı-2023. 632 s

[4] Степанова Н. А. Ключевые направления развития садоводства в России // Вестник ОрелГАУ, -2019. №4 (79). -с.158-163

[5] Famiani, F., Cinosi, N., Paoletti, A. et al. Deflowering as a Tool to Accelerate Growth of Young Trees in Both Intensive and Super-High-Density Olive Orchards//Agronomy, 2022, *12*(10), 2319. https://doi.org/10.3390/agronomy12102319

after about 5-7 years, while in intensive orchards this process takes 2-3 years;

- High productivity: about 12 t/ha in traditional gardens, 60 t/ha in intensive;

- The small distance between planted seedlings and therefore the large number of trees planted in the field, etc.

However, despite all this, this does not mean that such intensive gardens are protected from all risks, on the contrary, the close distance between seedlings, early flowering and fruiting bring with them a number of problems, one of which is the "*pathologies created by microorganisms inhabiting substrates*"[6]. in any ecosystem, mainly of high nutritional value. In both traditional and intensively established orchards, any "*microbial disease that may arise can lead not only to yield losses but also to significant financial losses*"[7]. If we take into account that "*a number of intensive orchards have been established in the last decade in economic regions of Azerbaijan such as Guba-Khachmaz, Sheki-Zagatala, Daglig Shirvan, etc.*"[8], then it can be noted that it is equally important to conduct microbiological, mycological and phytopathological monitoring, take samples, and take necessary measures in time to prevent the disease from spreading to other trees in case it is detected, in order to timely detect the problems caused by microorganisms, which are one of the factors that will cause crop loss. It is true that a number of studies have been conducted in Azerbaijan in this direction in different years, but none of them have been devoted to studying

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[6] Bano, A., Gupta, A., Prusty, M. R., & Kumar, M. Elicitation of Fruit Fungi Infection and Its Protective Response to Improve the Postharvest Quality of Fruits. *Stresses*, 2023, *3*(1), 231-255. https://doi.org/10.3390/ stresses 3010018

7 Ristaino, J.B., Anderson, P.K., Bebber, D.P. et al. The persistent threat of emerging plant disease pandemics to global food security, *Proc. Natl. Acad. Sci. U.S.A.*, 2021, 118 (23) e2022239118, https://doi.org/10.1073/pnas. 2022239118

[8] Food and Agriculture Organization of the United Nations. Hazelnut sector in Azerbaijan Options for green energy interventions along the value chain. -Baku, -2023, -149p.

the mycobiota of dried subtropical fruits cultivated in intensively planted and traditional gardens and the ecophysiology of pathogenic species there.

Research aim and objectives. The aim of the presents work is to study the mycobiota of certain dry subtropical fruit plants cultivated in both intensive and traditional orchards established in some regions of Azerbaijan, more precisely, in the economic zones located within the Greater Caucasus, in terms of species composition and ecophysiological characteristics of pathogenic species recorded on these plants.

In order to achieve the aim of the study, the following objectives have been formulated:

- Determination of the species composition of dry subtropical fruit crops cultivated in the mentioned areas and selected as the object of study;
- Evaluation of the mycobiota of dry subtropical fruit plants selected as the object of research in terms of species composition and frequency of occurrence;
- Assessment of the species composition of pathogenic fungi identified on the studied dry subtropical plants, as well as the diseases they cause, based on their specific symptoms;
- Investigation of the ecophysiological characteristics of certain pathogenic species identified on the studied dry subtropical fruit plants.

Research methods. Since the research primarily aimed to clarify biologically based issues, the methods selected were accordingly aligned with this objective. Thus, sampling was conducted using planned route and permanent plot selection methods commonly applied in mycological and botanical studies, while both classical and modern techniques widely used in mycological research were employed to isolate fungi from the samples, obtain pure cultures, identify them, and study their ecophysiological characteristics. In the dissertation, the experiments conducted to obtain quantitative results were repeated 4 to 6 times, and statistical analysis was carried out accordingly. In addition, the precision of the instruments used in the experiments and the purity of the reagents were sufficient to ensure the accuracy of the obtained data.

The main provisions of the dissertation submitted for defence.

- The natural climatic and soil conditions of the Greater Caucasus determine both the distribution of dry subtropical fruit crops and the fact that this region is one of the areas where fungi associated with these plants are found;
- Due to the fact that many fungi involved in the formation of the mycobiota of dry subtropical fruit crops do not possess substrate specificity, the pathogens observed in these fungi tend to exhibit universal characteristics;
- The establishment of intensive gardens, the introduction of new high-yielding varieties into the country, as well as the increasing anthropogenic pressure on the environment, are the main reasons for the participation of new species in the formation of the mycobiota of both the country's nature and dry subtropical plants.
- The presence of phytopathogens among the fungi involved in the formation of the mycobiota of dry subtropical fruit plants, and the different nature and form of observation of their plant-fungus relationships are factors that influence the wide diversity of their ecophysilogical properties.

Scientific novelty of the research. In the conducted studies, the mycobiota of dry subtropical fruit plants belonging to the genera *Elaeagnus L., Pistacia L. Amygdalis L., Punica L., Ficus L. Olea L., and Ziziphus Mill.* distributed in the Republic of Azerbaijan was analyzed according to its species composition and it was determined that a total of 127 fungal species participate in the formation of their mycobiota, of which 8 species belong to the subphylum Mucormyceta, 15 species belong to the phylum Basidiomycota and 104 species to the phylum Ascomycota, of which *Alternaria consortialis* (Thum.) J.W.Groves & S.Hughes, *Cytospora amygdali* D.P.Lawr., L.A.Holland & Trouillas, *Gliomastix murorum* (Corda) S.Hughes., *Monilia pistaciae* Zaprom. and *Papularia rosea* Grebenjuk & Kusnezowa are the first species to be found in the nature of Azerbaijan.

It was determined that among the species involved in the formation of the mycobiota of the studied dry subtropical plants, 60 belong to eurytrophs, 42 to conditionally stenotrophs, and 25 to stenotrophs and although 83 of these species exhibit characteristics typical of phytopathogens, both general fungi and phytopathogens differ from each other in terms of their fungus–plant interactions. Thus, 9 species of phytopathogens belong to biotrophs, 30 species to necrotrophs, 44 species to hemibiotrophs, and of the remaining 10 species to endophytes, 12 species to epiphytes and 22 species to those of unknown status.

It has been determined that fungi recorded to be distributed on dry subtropical fruit plants are characterized by a wide diversity in terms of their ecophysiological properties. Thus, although the growth range of macromycetes in terms of pH lies between 2.7-9.5, and the cultivation temperature ranges from 3°C to 50°C, a pH of 5–6 and a temperature of 26–32°C are optimal for the growth of both macromycetes and micromycetes. All recorded fungi that could be isolated into pure culture exhibit characteristics typical of aerophilic organisms.

Theoretical and practical significance of research. The results obtained in the studies are factual material that serves to expand knowledge about the mycobiota characteristic of Azerbaijani nature.

The results obtained will be useful in development of control measures against diseases affecting dry subtropical fruit plants and in identifying pathogens observed in one or another plant.

Publication, approbation and application of the dissertation. 14 scientific works have been published related to the topic of the dissertation. The materials of the dissertation were presented at the XXV Republican Scientific Conference of Doctoral Students and Young Researchers (Baku, 2022), the I International Scientific-Practical Conference on “Innovative Biotechnologies for Environmental Protection: From Theory to Practice” (Belarus, Minsk, 2024), the International Scientific-

Practical Conference on “Modern Approaches in the Study of the Plant World” (Baku, 2023), the mycological forum (RF, Moscow, 2024), the Scientific-Practical Conference on “The Role of the National Leader Heydar Aliyev in Improving the Environment in Azerbaijan” (Baku, 2024), the forum on “Protection of Biological Diversity: Botany, Ecology and Green Cities” (Baku, 2024), the International Scientific Conference on “Ensuring Sustainable Agricultural Production through Mitigation and Adaptation to the Impacts of Global Climate Change” (Guba, 2024), XXVII Republican Scientific Conference of Doctoral Students and Young Researchers (Sumgait, 2024).

The organization where the dissertation was performed. The work was performed at the Laboratory of Microbial Biotechnology of the Institute of Microbiology, Ministry of Science and Education of the Republic of Azerbaijan.

Structure and volume of the dissertation. The dissertation consists of an introduction, four chapters, a final analysis of the research results, main conclusions, a list of literature and abbreviations used in the dissertation. All this consists of a total of 218650 characters.

CHAPTER I
GENERAL CHARACTERISTICS OF THE COMMON AND PATHOGENIC MYCOBIOTA OF DRY SUBTROPICAL FRUIT PLANT SPECIES DISTRIBUTED IN AZERBAIJAN

This chapter, prepared based on literature data, includes Section 1.1 which presents the general characteristics of dry subtropical fruit plants distributed in Azerbaijan, Section 1.2 evaluates the current state of research on the mycobiota of dry subtropical fruits cultivated in Azerbaijan and Section 1.3 analyzes information about phytopathogenic fungi distributed under Azerbaijani conditions and the diseases they cause in dry subtropical fruit plants, clarifying the key points to be addressed in order to achieve the set objectives.

CHAPTER II
RESEARCH MATERIALS AND METHODS

2.1. General characteristics of the researched areas

The research was conducted in several, more precisely, 4 economic regions (Absheron-Khizi, Guba-Khachmaz, Daglig Shirvan and Sheki-Zagatala) located in the Greater Caucasus of the Republic of Azerbaijan, which are characterized by both similar and different indicators due to natural soil and climatic conditions. This difference occurs even within the borders of the same economic region.

2.2.Methods used for analysis in the research

In the research, it was considered appropriate to collect samples from dry subtropical fruit plants belonging to the genera *Elaeagnus* L., *Pistacia* L., *Amygdalis* L., *Punica* L., *Ficus* L., *Olea* L., and *Ziziphus* Mill. Sampling was carried out according to the "*planned route and permanent site selection methods*"[9] widely used in mycological research. Laboratory analysis of the samples taken was continued until the fungal cultures were isolated in a clean manner. The purity of the culture was monitored using a microscope with a magnification capacity of up to 2500 times (OMAX 40X-2500X LED Digital Lab Trinocular Compound Microscope with USB Camera). These works were carried out according to "*known methods*"[10,11] accepted in mycology. To obtain pure cultures of fungi from the collected samples, nutrient media such as malt extract agar (MEA), potato dextrose agar (PDA), rice agar (RA), Czapek agar

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[9] Томашевич, М.А. Формирование патокомплексов растениц при интродукции в Сибири:/диссертации д.б.н./-Новосибириск, 2015, -с.462

[10] Методы экспериментальной микологии/Под. ред. Билай В.И. Киев: Наукова думка, -1982, -500с.

[11] Maheshwari, R. Fungi:Experimental Methods In Biology, 2th Edition. CRC Pres, 2016, 358 DOI:10.1201/9781420027648

(CA), and Sabouraud agar (SA) were used. The preparation, sterilization, filtration into Petri dishes, and inoculation of the samples were also carried out in accordance with the "*known methods and approaches*"[10] accepted in mycology.

The determination of the species composition of pure cultures obtained after inoculation of samples taken from dry subtropical fruit plants was carried out mainly according to classical mycological methods, using "determinants and atlases"[12,13,14] compiled according to the cultural-morphological and physiological characteristics of fungi. The taxonomic affiliation and names of the fungi were clarified in accordance with the system provided on the "*official website*"[15] of the International Mycological Association. The identification of fungal diseases and their causative agents was also carried out based on "*known determinants corresponding to classical phytopathological methods*"[16,17,18,19].

To determine the frequency of occurrence of fungi on the sampled plants, as well as the incidence rate of diseases caused by phytopathogens across different plant species, the following formula was used:

$$P=100n/N$$

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[12] Kirk, P.M, Cannon, P.F., Minter, D,W,, Stalpers. J.A. Dictionary of the fungi, 10th edn. CABI publishing – Wallingford (UK), 2008. 784p.

[13] Li D.W., Magyar D., Kendrick B. Color Atlas of Fungal Spores. A laboratory identification Guide. American CGIH, 2023, 852p.

[14] Seifert KA, Gams W. 2011. The genera of Hyphomycetes. Persoonia 27:119-29. doi: 10.3767/003158511X617435.

[15] https://www.mycobank.org/

[16] Левитин М. М. Сельскохозяйственная фитопатология. - М: Юрайт, 2018 - 282 с.

[17] Дьяков, Ю.Т., Еланский С.Н. Общая фитопатология: учебное пособие для академического бакалавриата. - Москва: Юрайт, 2017. - 230с

[18] Воробьева, М. В. Болезни древесных растений: учебное электронное пособие Екатеринбург : УГЛТУ, 2022. – 231с.

[19] Трейвас Л.Ю., Каштанова О.А. Атлас-определитель. Болезни и вредители плодовых растений. -Киев: Фитон, -2016, -352с.

P – frequency of occurrence of fungi in the samples (or incidence rate of the disease caused by the pathogen, expressed as a percentage), n– number of detected fungal isolates (or number of plant species showing disease symptoms), N– total number of samples (or total number of plant species studied in the research area).

In the research, well-known "*methods*"[20] were also used to study the ecophysiological characteristics of fungi that could be isolated into pure culture.

During the course of the research, all experiments aimed at obtaining quantitative data were conducted in 4–6 replicates, and the results were "*statistically processed*"[21].

CHAPTER III
GENERAL CHARACTERISTICS OF THE MYCOBIOTA OF DRY SUBTROPICAL FRUIT PLANTS DISTRIBUTED IN THE STUDIED AREAS

3.1. Species composition of the mycobiota of dry subtropical fruits distributed in the studied areas

The primary objective of the research was to determine the genus composition of the dry subtropical fruit plants whose mycobiota was to be studied. To clarify these issues, it was considered appropriate to take samples from trees belonging to the genera *Elaeagnus* L., *Pistacia* L., *Amygdalis* L., *Punica* L., *Ficus* L., *Olea* L. and *Ziziphus* Mill. During the research period, more than 700 samples were collected from these plants, analyzed for their fungal biota, and as a result, 127 fungal species

[20]Bakhshaliyeva K.F., Namazov N.R., Jabrailzade S.M. et al. Ecophysiological Features of Toxigenic Fungi Prevalent in Different Biotopes of Azerbaijan. Biointerface Research in Applied Chemistry (Romania), 2020, 10, 6: 6773 – 6782. https://doi.org/ 10. 33263/ BRIAC106.67736782

[21]Сиделев, С. И. Математические методы в биологии и экологии: введение в элементарную биометрию: учебное пособие – Ярославль : ЯрГУ, 2012. – 140 с.

were identified. Of these, 8 species belonged to the subkingdom *Mucormyceta*, 15 species to the phylum *Basidiomycota*, and 104 species to the phylum *Ascomycota*. The distribution of these fungi across different plant species is presented in general numerical form in Table 3.1.

Table 3.1

Numerical characteristics of the distribution of fungi recorded during the research on dry subtropical fruits

Plant	The recorded number of species	Share in the total recorded fungi, %
Elaeagnus L.(Oleaster)	32	25,2
Pistacia L. (Pistachio)	38	29,9
Amygdalis L. (Almond)	31	24,4
PunicaL.(Pomegranate)	23	18,1
Ficus L.(Fig)	35	27,6
Olea L.(Olive)	29	22,8
Ziziphus Mill.(Jujube)	27	21,3
Total	127	100

As can be seen, fruit plants differ from each other in the number of fungal species involved in the formation of their mycobiota, with plants belonging to the genus *Pistacia* L. having a relatively rich mycobiota, while plants belonging to the genus *Punica* L. are characterized by a poor mycobiota.

It should be noted that most of the fungal species recorded in these studies had also been documented in previous mycological research conducted in Azerbaijan at different times. However, species such as *Alternaria consortialis*, *Cytospora amygdali*, *Gliomastix murorum*, *Monilia pistaciae*, and *Papularia roseum* were recorded in Azerbaijan (Fig. 3.1), while species including *Alternaria pruni*, *Aspergillus amstelodami*, *Cephalosporium asperum*, *C. lecani*, *C. roseum*, *Chrysonilla sitophila*, *C. carposperma*, *C. leucosperma*, *C. punicae*, *C. rubescens*, *C. ziziphi*, *Fusarium culmorum*, *F. dimerum*, *F.*

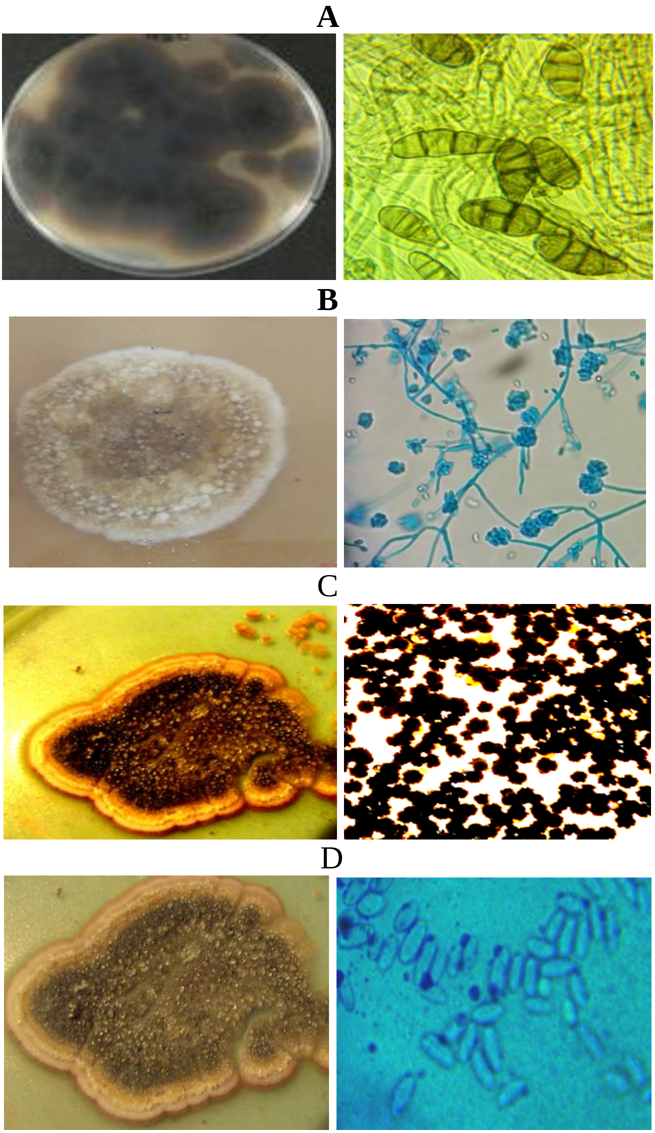

Figure 3.1. General view of the colonies and microscopic images of conidia of *Alternaria consortialis* (A), *Gliomastix murorum* (B), *Papularia roseum* (C), and *Cytospora amygdali* (E), species new to the flora of Azerbaijan

graminearum, Mycosphaerella fici-ovatae, Penicillium cyclopium, P. divergens, P. expansum, P. glacum, P. tardum, Trichocladium opacum, Trichosporon beigelii, Trichoderma asperellum, Venturia oleaginea, Verticillium dahile, and others were recorded for the first time on dry subtropical fruit plants.

3.2. Distribution of fungal species recorded in studies on individual dry subtropical fruit crops

As noted above, some fungi are widespread across many fruit plants, while others are found only in one or a few species. This, in turn, allows each plant to be characterized both by common species typical for dry subtropical fruit plants and by specific species unique to it. Therefore, the fungal communities involved in the formation of each plant's mycobiota are characterized by a wide diversity in various aspects. Consequently, fungi recorded on different plants, particularly phytopathogens, differ from one another in terms of their relative abundance, ecotrophic relationships, and manifestations of ecotrophic specialization, which in turn allows plants to be distinguished based on these characteristics. More precisely, each plant is characterized by a somewhat specific mycobiota, so that the recorded fungi can be classified into three groups based on this aspect:

1. Non-substrate-specific fungi, that is, those found on the majority of the studied plants (more than 2/3 of the plants studied), known as eurytrophs (ET). Research has confirmed that a total of 60 species (*Actinomucor elegans, Alternaria alternata, A.solani, A.tenuissima, Armilaria mellea, Ascochyta caricae, Aspergillus flavus, A.fumigatus, A.glaucus, A.nidulans, A.niger, A.ochraceus, A.versicolor, Bjerkandera adusta, Botrytis cinerea, Cephalosporium asperum, Cladosporium cladosporides, C.herbarium, Coniophora puteana, Cytospora carposperma, Erysiphe communis, Fomes fomentarius, Fomitopsis pinicola, Fusarium culmorum, F.graminerum, F.moniliforme, F.solani, F.verticillioides, Ganoderma applanatum, Macrosporium*

cladosporioides, Monilia fructigena, M.laxa, Mortierella alpina, Mucor circinelloides, M.hiemalis, M.mucedo, M.rasemous, M.sinensis, Nectria cinnabarina, Paecilomyces variotii, Penicillum crysogenum, P.expansum, P.tardum, Phellinus igniarus, Phoma fallens, Ph.cressina, Phyllactinia suffulta, Pleurotus ostreatus, Rhisopus stolonifera, Rhizoctina solani, Schizophyllum commune, Stereum hirsitum, Talaromyces purpurogenus, Trichotectum roseum, Trametes hirsuta, T.versicolor, Tricoderma harzianum, T.viride, Verticillium alboartrum and *V.dahile)* fit this characteristic.

2. Those with relative substrate specificity (found in 20-50% of the studied plants), that is, they are conditional stenotrophs (CS), the number of species corresponding to this characteristic is 42 (*Alternaria dianthi, A.pruni, Ascochyta fagi, Asc.olaea, Aspergillus amstelodami, Aureobasidium pullulans, Cephalosporium lecani, C.roseum, Chrysonilla sitophila, Colletotrichum gloeosporioides, Cytospora leucosperma, C.rubescens, Diplodia amygdali, D.elaeagni, Fusarium dimerum, Gliocladium roseum, Gliomastix murorum, Gleosporium carpini, Humicola olivacea, Laetiporus sulphureus, Macrosporium bifurcum, M.commune, Melampsora fagi, Papularia roseum, Penicillium cyclopium, P.divergens, P.glacum, P.olivaceum, Phoma purpurea, Phomopsis prunorum, Phyllactinia acaciae, Podosphaera fusca, Polystigma ochraceum, Sclerotinia laxa, S.sclerotiorum, Sphaerulina pruni, Stemphylium botryosum, Trichocladium opacum, Trichoderma asperellum, T.hamatum, T.koningii, Trichosporon beigelii*).

3. Those with substrate specificity (found on only one of the studied plant species), referred to as true stenotrophs (TS), were represented by 25 species (*Ascochyta amygdali, Alternaria consortialis, Cytospora amygdali, C.elaeagni, C.punicae, C.ziziphi, Diaporthe elaeagni, Exoascus amygdale, Fusicladium fici, F.pisfacia, Mycosphaerella fagi, M.fici-ovatae, Monilia olivacea, M.pistaciae, Phyllosticta elagni, Ph.fici-caricae, Ph.oleae, Ph.ziziphi, Ph.punicae, Podosphaera pistacia, Septoria amygdali, S.oleae, S.pistaciae, S.ziziphi* and *Venturia oleaginea*)

as determined during the course of the research.

When the recorded fungi are characterized according to this classification, along with the number of phytopathogenic micromycetes involved in the formation of the general mycobiota, it becomes evident that the number of universal species is higher than that of the other groups, whereas the number of specific species is relatively low and this ratio remains generally consistent across all studied plants (Tab. 3.2). With regard to the relative abundance of phytopathogens, some variation is also observed between the different plant species. Although phytopathogens account for 65.4% of the total recorded fungal species, their relative proportion in the formation of the mycobiota of individual plant species ranges from 51.9% to 65.6%. In this context, the highest value was recorded in oleaster and the lowest in jujube.

83 of the recorded fungi belong to phytopathogens (Tab. 3.2), which have different characteristics depending on the nature

Table 3.2

Quantitative characterization of micromycetes recorded in the studies based on their phytopathogenicity and substrate association

Plant	Number of species according to substrate association			Number of phytopathogens
	ET	CS	TS	
Elaeagnus L.	17	12	3	32/21
Pistacia L.	19	14	5	38/23
Amygdalis L.	14	13	4	31/18
Punuca L.	12	9	2	23/12
Ficus L.	17	14	4	35/22
Olea L.	14	10	5	29/19
Ziziphus Mill.	15	9	3	27/14
Total	60	42	25	127/83

of the diseases they cause and the observed symptoms. Therefore, phytopathogens are also characterized from this perspective, and certain approaches are used in their classification. It is true that these systems are mostly conventional, so that fungi cannot sometimes be characterized within a specific group due to their lack of comprehensive study and their high adaptive properties. Moreover, the differences observed between macro- and micromycetes further reinforce the conditional nature of these classification systems. For this reason, the recorded fungi were first characterized at the macro- and micro-mycelial levels.

Based on the analysis of literature data and our own observations, it was considered appropriate to characterize the total of 112 micromycete species (Ascomycota – 104 and Mucormyceta – 8), recorded during the research, according to the following system:

1. Biotrophic fungi - synthesize substances with suppressor or effector effects on host plants, the entry of which into plant tissues leads to a weakening of the plant immune system. Six micromycete species (*Erysiphe communis, Exoascus amygdale, Phyllactinia acaciae, Ph. suffulta, Podosphaera fusca, and P. pistacia*) recorded in the studies belong to this group.

2. Necrotrophs are organisms that, through their vital activity, cause the destruction of individual host plant cells by producing toxic substances. Studies have confirmed that the number of species that meet this characteristic is 27 (*Alternaria alternata, A.consortialis, A.dianthi, A.pruni, A.solani, A.tenuissima, Ascochyta amygdali, Asc.caricae, Asc.fagi, Asc.oleae, Botrytis cinerea, Colletotrichum gloeosporioides, Macrosporium bifurcum, M.cladosporioides, M.commune, Phoma fallens, Ph.cressina, Ph.purpurea, Phomopsis prunorum, Polystigma ochraceum, Septoria amygdali, S.oleae, S.pistaciae, S.ziziphi, Trichocladium opacum, Trichosporon beigelii, Trichotectum roseum*).

3. Hemibiotrophs are organisms that occupy an intermediate position between biotrophs and necrotrophs, part of their life cycle takes place in living plants, while another part occurs in the dead remains of plants and other organisms. The number of fungi belonging to this group has amounted to 37

species (*Cytospora amygdali, C.carposperma, C.elaeagni, C.leucosperma, C.punicae, C.rubescens, C.ziziphi, Diaporthe elaeagni, Diplodia amygdali, D.elaeagni, Fusarium culmorum, Fusarium dimerum, F.graminerum, F.moniliforme, F.solani, F.verticillioides, Fusicladium fici, F.pisfacia, Mycosphaerella fagi, M.fici-ovatae, Monilia fructigena, M.laxa, M.olivacea, M.olpistaciae, Nectria cinnabarina, Phyllosticta elaeagni, Ph.fici-caricae, Ph.oleae, Ph.ziziphi, Ph.punicae, Sclerotinia laxa, S.sclerotiorum, Sphaerulina pruni, Stemphylium botryosum, Venturia oleaginea, Verticillium alboartrum, V.dahile*).

4. Endophytes are organisms that are not known to cause any disease in plants, but their mycelia penetrate plant tissues and produce metabolites that stimulate plant functions. Species such as *Cephalosporium asperum, C.lecani, C.roseum, Gliocladium roseum, Gleosporium carpini, Trichoderma asperellum, T.hamatum, T.harzianum, T.koningii* and *T.viride* have been confirmed in studies to posses these characteristics.

5. Epiphytes are organisms associated with plants, primarily feeding on their dead tissues and on exudates produced by living organisms. It has been determined that this group includes 10 species (*Actinomucor elegans, Aureobasidium pullulans, Gliomastix murorum, Humicola olivacea, Mortierella alpina, Mucor circinelloides, M.hiemalis, M.mucedo, M.rasemous, M.sinensis)*.

6. Those who clearly do not belong to any of the groups mentioned above, or more precisely, whose status is unknown. The number of mushroom species belonging to this group is 22 (*Aspergillus amstelodami, A.flavus, A.fumigatus, A.glaucus, A.nidulans, A.niger, A.ochraceus, A.versicolor, Chrysonilla sitophila, Cladosporium cladosporides, C.herbarium, Paecilomyces variotii, Papularia roseum, Penicillum crysogenum, Penicillium cyclopium, P.divergens, P.expansum, P.glacum, P.olivaceum, P.tardum, Rhisopus stolonifera, Talaromyces purpurogenus*).

It would also be appropriate to touch on a point regarding those whose status is unknown, which is related to the fact that the status of some mushrooms is currently uncertain. As can be seen, based on the results of the studies, fungi belonging to genera such as *Aspergillus*, *Cladosporium*, *Mucor*, *Penicillium*, and others have been included in this group. This is due to the fact that, based on the analysis of literature data as well as our observations during the periods in which the studies were conducted, it has not been definitively confirmed that these fungi either cause significant pathology or exhibit clear characteristics typical of endophytes or epiphytes.

When characterizing the 15 species of macromycetes recorded in the studies, it becomes evident that one of them causes rust (*Melampsora fagi*), one causes rhizoctoniosis or root rot (*Rhizoctonia solani*), ten (*Armillaria mellea*, *Bjerkandera adusta*, *Fomes fomentarius*, *Ganoderma applanatum*, *Phellinus igniarius*, *Pleurotus ostreatus*, *Schizophyllum commune*, *Stereum hirsutum*, *Trametes hirsuta*, *T. versicolor*) are white rot pathogens, and three (*Coniophora puteana*, *Fomitopsis pinicola*, *Laetiporus sulphureus*) are brown rot pathogens. The fungi *A. mellea*, *F. fomentarius*, and *M. fagi* are true biotrophs, *Sch. commune* and *T. versicolor* are saprotrophs, while the remaining species are facultative (polytrophic) fungi.

Thus, when characterizing the common fungi recorded during the research, that is, both macromycetes and micromycetes, together, it becomes clear that 9 of the recorded fungal species belong to biotrophs, 30 to necrotrophs, 44 to hemibiotrophs, 10 to endophytes, 12 to epiphytes, and 22 to those whose status is unknown.

It would also be appropriate to clarify one point here, which is related to the true biotrophs among the common fungi recorded. As mentioned, 9 of the total fungi are true biotrophs, although their biotrophic characteristics differ from one another. Thus, the biotrophy of macromycetes such as *Armilaria mellea* and *Fomes fomentarius* is ecological, while the biotrophy of the fungi *Erysiphe communis*, *Exoascus amygdale*, *Melampsora fagi*, *Phyllactinia acaciae*, *Ph. suffulta*, *Podosphaera fusca* and *P.*

pistacia is physiological. Ecological and physiological biotrophy differ from each other in that fungi with ecological biotrophy can be cultured in pure form in standard and nutrient media, while for others this is practically impossible. For this reason, fungi with physiological biotrophy and the diseases they cause are evaluated not in pure culture, but based on the structural elements they form at different stages of their life cycles and the symptoms of the diseases they cause.

3.3. Annotated list of fungi recorded in the studies

As a rule, it is also common to compile an annotated list of fungi recorded in mycological studies; however, the criteria used in compiling these lists change over time, or rather, there is no unified approach to their compilation. In this regard, taking into account the analysis of literature data, as well as the changes accepted in the systematics of living organisms, it was considered appropriate to use the following in compiling an annotated list of fungi recorded in the presented work:

1. The current name of the fungus on the official website of the IMA, its systematic status (division), as well as the indication of the names of the last fungus currently considered its synonym, rather than its current name, in articles related to the dissertation;
2. The name of the substrate on which the fungus is found, some cultural and morphological information about the newly recorded fungi and illustrative materials.

CHAPTER IV
ECOPHYSIOLOGICAL FEATURES OF PHYTOPATHOGENIC FUNGI RECORDED IN DRY SUBTROPIC FRUIT PLANTS OF AZERBAIJAN

4.1. Ecophysiological characteristics of phytopathogenic species involved in the mycobiota of dry subtropical fruit plants

In studies, understanding the growth and development conditions of 127 fungal species commonly found in dry subtropical fruit plants is important for limiting or completely preventing their phytopathogenic activity. Considering this, it was deemed appropriate to clarify certain ecophysiological characteristics of phytopathogens in the next stage of the research.

The results showed that, for optimal growth of the recorded fungi in standard nutrient media, a slightly acidic initial pH (pH = 5.0–6.0) and a temperature range of 26–32°C (optimal for mesophiles) are considered favorable and all of them are mesophiles in relation to oxygen, which can be confirmed by the information provided in Table 4.1 in a generalized form. However, as can be seen from the table, there are certain differences between micromycetes and macromycetes in terms of the mentioned indicators, which is reflected in the ability of micromycetes to function over a wider range of pH and temperature.

Thus, based on the data obtained from the conducted studies, it can be noted that the fungi forming the mycobiota of dry subtropical fruit crops cultivated under Azerbaijani conditions are characterized by a wide diversity, and among them, the full spectrum of phytopathogens is found, namely biotrophs, hemibiotrophs, and necrotrophs. Among the fungi involved in the formation of the mycobiota of the studied plants, the relatively high proportion of universals, hemibiotrophs, and necrotrophs, and the low number of biotrophs, can be considered a negative situation from a phytosanitary point of view.

Thus, unlike biotrophs, fungi belonging to other groups, primarily those without substrate specificity, have higher adaptation capabilities, which can create conditions for their wide distribution, which currently poses a necessary task of developing preventive control measures aimed at limiting and completely preventing the pathogenic activities of fungi that are the cause of the disease.

Table 4.1.

The influence of environmental factors on the growth of phytopathogenic fungi recorded in dry subtropical fruit plants

Parameters	Indicators	Macro-mycetes	Micro-mycetes
Initial pH of the medium	Minimum	3,0	2,7
	Optimal	5,0-6,0	4,5-6,0
	Maximum	9,0	9,5
Cultivation temperature	Minimum	4-6	3-5
	Optimal	26-28	26-32
	Maximum	37-42	40-50
Response to molecular oxygen	Aerophilic	15	64
	Microaerophilic	0	0
	Anaerobic	0	0

FINAL ANALYSIS OF RESEARCH RESULTS

Although the agricultural sector has always played a leading role in providing people with plant and animalbased products, it is a present-day reality that the demand for this sector and especially for its products will continue to grow in the future. As the global population continues to grow, this occurs against the backdrop of a decreasing amount of land available for agriculture on the Earth's surface, which remains constant in size. As a result, people's demand for food products is increasing, which creates certain problems in providing it. Addressing these problems is among the essential tasks to be solved by modern biology and agricultural sciences. Various aspects of research are being conducted to solve this problem, which primarily reflects issues related to the creation of new productive plant varieties, the use of innovative technologies in their cultivation, etc. However, even with the cultivation of high-yield and disease-resistant varieties, the expected production is not always achieved, and there are a number of reasons for this. Eliminating these factors and creating conditions that ensure increased crop production are among the current research priorities of modern biology and agricultural sciences. One of the factors that causes a decrease in crop production in crop production is pathologies caused by various living organisms, as a result of diseases caused by such organisms, the productivity of agricultural crops generally decreases by up to 25% every year. Fungi are of particular significance among the organisms responsible for this decline, as they differ from other phytopathogenic organisms in both the total number of diseases they cause and their overall contribution to crop losses. For this reason, the study of fungi, especially those that cause various plant diseases, is currently one of the most relevant research areas in the world.

Dry subtropical fruit crops, which represent a group of fruit plants cultivated in the Republic of Azerbaijan, are considered to be of particular interest due to their nutritional value, chemical composition, and economic importance. These plants are also subject to yield losses caused by various factors, including diseases induced by different organisms, particularly fungi. However, there is currently a lack of essential research data necessary for proper assessment of the situation in this area. For this reason, the present study is dedicated to evaluating the species composition of the mycobiota of dry subtropical fruit plants distributed in the Republic of Azerbaijan, primarily in the territories located in the Greater Caucasus region, with a focus on the proportion of phytopathogens and the ecophysiological characteristics of species that can be isolated in pure culture.

In the studies conducted in 2022-2024, dry subtropical fruit plants belonging to the genera Elaeagnus L., Pistacia L. Amygdalis L., Punica L., Ficus L. Olea L., and Ziziphus Mill. were studied for both the species composition of their general and phytopathogenic mycobiota, ecotrophic relationships, the nature of plant-fungal relationships, and the ecophysiological characteristics of phytopathogens. As a result, scientifically and practically significant data were obtained that are useful for ensuring the mycological and phytopathological safety of dry subtropical fruit crops and for developing preventive control measures against fungal diseases. All of these findings are reflected in the following six-point conclusion and three-point practical recommendations.

RESULTS

1. In the conducted studies, the species composition of the mycobiota of dry subtropical fruit plants belonging to the genera *Elaeagnus* L., *Pistacia* L., *Amygdalus* L., *Punica* L., *Ficus* L., *Olea* L., and *Ziziphus* Mill., which are distributed in the Republic of Azerbaijan, was analyzed. It was determined that a total of 127 fungal species participate in the formation of their mycobiota, of which 8 species belong to the subphylum Mucormyceta, 15 to the phylum Basidiomycota, and 104 to the phylum Ascomycota [1-6, 12-14].

2. Itwas determined that fungi such as *Alternaria consortialis* (Thum.) J.W. Groves & S. Hughes, *Cytospora amygdali* D.P. Lawr., L.A. Holland & Trouillas, *Gliomastix murorum* (Corda) S. Hughes, *Monilia pistaciae* Zaprom., and *Papularia rosea* Grebenjuk & Kusnezowa were recorded for

the first time in the natural environment of Azerbaijan, while species such as *Alternaria pruni*, *Aspergillus amstelodami*, *Cephalosporium asperum*, *C. lecanii*, *C. roseum*, *Chrysonilia sitophila*, *Cytospora carposperma*, *C. leucosperma*, *C. punicae*, *C. rubescens*, *C. ziziphi*, *Fusarium culmorum*, *F. dimerum*, *F. graminearum*, *Mycosphaerella fici-ovatae*, *Penicillium cyclopium*, *P. divergens*, *P. expansum*, *P. glacum*, *P. tardum*, *Trichocladium opacum*, *Trichosporon beigelii*, *Trichoderma asperellum*, *Venturia oleaginea*, *Verticillium dahliae*, and others were identified for the first time as occurring on dry subtropical fruit plants [1-6, 10, 14].

3. It was established that 60 of the species participating in the formation of the mycobiota of the studied dry subtropical plants have characteristics typical of eurytrophs (found in at least 2/3 of the identified plant genera), 42 are conditional stenotrophs (found in 20-50% of the studied plant genera), and 25 are stenotrophs (found in only one genus of the studied plants)[8-10].

4. It was revealed that although 83 species of fungi participating in the formation of the general mycobiota of dry subtropical plants have characteristics typical of phytopathogens, both general fungi and phytopathogens differ from each other in terms of their fungal-plant relationships. Thus, 9 species of them belong to biotrophs, 30 species to necrotrophs, 44 species to hemibiotrophs, 10 species to endophytes, 12 species to epiphytes, and 22 species to those of unknown status[8-11].

5. Although the biotrophy of 7 of the 9 species recorded in the studies (*Erysiphe communis*, *Exoascus amygdale*, *Melampsora fagi*, *Phyllactinia acaciae*, *Ph. suffulta*, *Podosphaera fusca and P. pistacia*) is physiological in nature, in 2 (*Armilaria mellea and Fomes fomentarius*) it is ecological in nature [6, 8, 10].

6. It was determined that the fungi recorded on dry subtropical fruit plants are also characterized by a wide diversity in terms of their ecophysiological characteristics.

Thus, although the pH range for the growth of macromycetes is between 2.7-9.5, a pH of 5-6, and a cultivation temperature of 3-50°C, are optimal for the growth of both macromycetes and micromycetes. All fungi that have been recorded and successfully isolated in pure culture exhibit characteristics typical of aerophiles [5-6, 8, 10].

PRACTICAL RECOMMENDATIONS

1. The criteria used for selection in planting orchards should also include an assessment of their resistance to local mycopathocomplexes.
2. Measures to combat pathogens in any plant, including dry subtropical fruit plants, should be based on identifying the specific nature of the pathologies they cause.
3. In developing control measures against phytopathogenic species involved in the formation of the mycobiota of dry subtropical fruit plants, greater emphasis should be placed on biological control, particularly through the use of endophytes naturally present in their mycobiota.

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2. Bakhshaliyeva K.F., Arabova G.G. Species composition of mycobiota of some fruit plants common in Azerbaijan// Modern science: current problems of theory and practice. Series: Natural and technical sciences, 2022, 12/2, p.13-16
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12. Arabova G.G. Phytotoxic Activity of Endogenous and Exogenous Metabolites of Fungi Detected in Fruit Gardens Cultivated in the Territory of Guba-Khachmaz

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The defense will be held on 24 september 2025 at 10.00 at the meeting of the Dissertation Council FD 1.07 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at the Institute of Microbiology, the Ministry of Science and Education of the Republic of Azerbaijan.

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