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Isolation, Identification, and Comparison of Microfungi on Stored Commercial Wheat and Einkorn Wheat in İhsangazi District of Kastamonu

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ABSTRACT

This study was conducted to investigate and compare fungal contamination in stored einkorn wheat (*Triticum monococcum* L.) and commercial wheat (*Triticum aestivum* L.) samples obtained from İhsangazi district of Kastamonu province following the 2022 harvest period. Twenty samples from each wheat type were analyzed using the dilution plating method on potato dextrose agar (PDA), and culture-based morphological methods were used to identify the isolates. As a result of the analyses, 22 different mold species belonging to 10 genera were isolated in einkorn wheat, and 28 different mold species belonging to 11 genera in commercial wheat. The dominant genera were *Penicillium, Mucor, Aspergillus*, and *Cladosporium*, with the highest species diversity in both wheat types belonging to the genus *Penicillium*. Chi-square and Mann-Whitney U tests showed statistically significant differences in the distribution of some mold species according to wheat types ($p < .05$). Specifically, *Mucor racemosus* and *Cladosporium cucumerinum* were detected only in einkorn wheat. In contrast, *Penicillium chrysogenum*, *P. glabrum, P. aurantiogriseum* and *Rhizopus arrhizus* were detected at higher frequencies in commercial wheat. The *Penicillium* genus was isolated in 100% commercial wheat samples (321 colonies) and 50% einkorn wheat samples (55 colonies). The findings suggest commercial wheat provides a more suitable substrate for mycotoxigenic molds. These fungi are potentially associated with the production of major mycotoxins, including aflatoxins, ochratoxin A, zearalenone, and fumonisins. In contrast, due to its dense husks and traditional production conditions, einkorn wheat poses a lower risk of contamination. These data highlight the importance of postharvest hygiene and demonstrate the advantages of einkorn wheat in terms of microbial food safety.

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Introduction

Turkey is a major genetic center for wheat diversity, with both traditional and modern varieties carrying economic and cultural value. Among these varieties, einkorn wheat (*Triticum monococcum* L.), with a history of approximately 10,000 years, is a significant part of our agricultural heritage. Its diploid structure (2n = 14), dense glumes, and durability allow it to grow in marginal soils and arid climates. It also has a higher oil and carotenoid content than modern wheat varieties (Atak, 2017).

Commercial wheat (*Triticum aestivum* L.), widely cultivated in modern agriculture, is an allohexaploid (2n = 6x = 42, AABBDD) species. Its complex genome, approximately 15.5 Gb, is estimated to contain between 75,000 and 150,000 genes, of which only 1.2–2.4% are functional protein-coding genes (Erayman et al., 2004). Commercial wheat, with its characteristics such as high yield, gluten content, grain uniformity, suitability for mechanization, and long shelf life, is widely preferred for industrial production and processing. The genetic diversity of this species also affects its response to different environmental conditions, and significant differences can occur in its quality parameters and physiological resistance traits (Güngör & Dumlupınar, 2019; Özdemir Dirik & Sakin, 2025). However, because this species has been subjected to modern breeding techniques and intensive agricultural practices, it may have limited nutritional diversity compared to some traditional varieties. It may develop different susceptibilities to microbial contamination.

Today, einkorn wheat is cultivated in Kastamonu province, particularly in the districts of İhsangazi, Seydiler, and Devrekani. Traditionally used in bulgur production, it has recently been used in products such as bread, noodles, and tarhana (Zengin, 2015; Atasoy & Hendek Ertop, 2017).

The increasing interest in healthy eating and local products has revitalized einkorn wheat. A limited amount of *T. dicoccum* is also grown in Kastamonu and is primarily used as animal feed. The storage process of wheat is a critical stage that directly affects quality. Many product losses during post-harvest storage are due to fungal contamination (Senbeta & Gure, 2014). In this context, field and storage molds are among the primary microbial spoilage agents observed in wheat. While field molds are transmitted during the product development or harvest period, storage molds develop during storage, causing significant declines in product quality. Environmental and physical factors, particularly temperature, humidity, storage duration, product content, and purity, are among the primary factors affecting mold development. Mycotoxins produced by microfungi such as *Aspergillus, Penicillium, Fusarium*, and *Alternaria* that thrive under storage conditions not only reduce product quality but also cause toxic effects on human and animal health (Joshaghani et al., 2013; Lohar & Sonawane, 2013). Mycotoxins are secondary metabolites with various biological effects, including carcinogenic, teratogenic, nephrotoxic, hepatotoxic, and neurotoxic (Sabuncuoğlu et al., 2008). The most widely known mycotoxins are aflatoxins, ochratoxin A, fumonisins, T-2 toxin, and zearalenone (Al-Kahtani, 2014). This study aimed to isolate, identify, and comparatively evaluate the species diversity of microfungi carried on stored commercial wheat and Einkorn wheat samples.

Materials and Methods

Procurement of Wheat Samples

Within this study's scope, 40 wheat samples (20 einkorn and 20 commercial wheat) were collected from warehouses in the İhsangazi district of Kastamonu province during the 2022 harvest season. Each 1-kg sample was taken from different locations in the warehouses with a metal scoop, placed in sterile polyethylene bags, labeled, and delivered to the laboratory within a maximum of 4 hours. Contact with the external environment was prevented during transport, and measures were taken to prevent moisture.

Einkorn and commercial wheat samples were taken simultaneously from each warehouse, ensuring that both varieties were exposed to the same temperature (22–25°C) and relative humidity (30–35%). The samples were harvested during the same agricultural season (July 2022) and stored directly in the warehouses without industrial processing. This method minimized the effects of environmental differences, providing a reliable basis for comparisons between species.

Isolation of Microfungi

From each 1 kg wheat sample delivered to the laboratory, five random 10-g subsamples were taken using the quartering method, and these subsamples were combined to form a homogeneous composite sample. The quartering method, commonly used for heterogeneous solid food samples, involves forming the sample material into a conical pile, dividing it into four equal portions, and repeating the process by selecting two opposite quarters (Codex Alimentarius Commission, 2009). To isolate surface mycoflora, each 10-g combined sample was transferred to 250-mL Erlenmeyer flasks containing 90 mL of sterile distilled water and shaken at 150 rpm for 30 minutes (Lohar & Sonawane, 2013). Serial dilutions up to 10^{-3} were prepared from the resulting suspensions, and 0.1 mL of each dilution was spread onto Potato Dextrose Agar (PDA) medium supplemented with 0.01% streptomycin. Petri dishes were incubated at 25°C in the dark for 5–14 days. The developed colony types were selected and purified based on morphological characteristics and stored in slant PDA medium at +4°C.

Identification of Microfungi

The isolated microfungi were identified by considering colony morphology, pigment production, spore structure, and conidial characteristics. Specific media such as Czapek Yeast Extract Agar (CYA), Malt Extract Agar (MEA), Yeast Extract Sucrose Agar (YES), and Creatine Sucrose Agar (CREA) were used for *Aspergillus* and *Penicillium* species; PDA and MEA were preferred for Dematiaceous hyphomycetes (darkly pigmented hyphal fungi). Cultures were incubated at 5°C, 25°C, 30°C, and 37°C for 5, 7, and 14 days. Additionally, colony shape, surface texture, upper and reverse coloration, and pigment diffusion were recorded as macromorphological characteristics, while micromorphological evaluations included hyphal septation, pigmentation, branching pattern, and hyphal surface features. Microscopic identification was carried out on preparations stained with lactophenol cotton blue. Classical mycological sources and species discrimination criteria were used for identification (Aydoğdu, 2016).

Statistical Analysis of the Data

Data were analyzed using SPSS 25.0. Relationships between species and wheat varieties were assessed using chi-square and Fisher's exact tests. Because the sample size was small, standard distribution assumptions were not met, so the Mann–Whitney U test was used for comparisons (Ghasemi&Zahediasl,2012).

Results

As a result of the analyses, 22 different fungal species were isolated from einkorn wheat samples, and 28 different species were isolated from commercial wheat samples. Ten different genera (*Penicillium, Mucor, Aspergillus, Cladosporium, Geotrichum, Alternaria, Rhizopus, Ulocladium, Trichoderma*, and *Epicoccum*) were identified in the einkorn samples. In comparison, eleven genera (*Penicillium, Acremonium, Aspergillus, Cladosporium, Mucor, Alternaria, Ulocladium, Geotrichum, Phoma, Fusarium*, and *Rhizopus*) were identified in the commercial wheat samples (Figure 1).

In this study, *Mucor racemosus* was isolated only from einkorn wheat (25%, n = 5), and not observed in commercial wheat (n = 0; 0%). This difference was statistically significant, $\chi^2(1, N = 40) = 5.71$, $p = .02$. Among *Penicillium* species, *P. aurantiogriseum* was found in 50% of commercial wheat (n = 10) and 10% of einkorn wheat (n = 2), $\chi^2(1, N = 40) = 7.62$, $p = .006$. *P. chrysogenum* was isolated from 85% of commercial wheat (n = 17) but not observed in einkorn wheat, $\chi^2(1, N = 40) = 29.57$, $p < 0.001$ (Table 1).

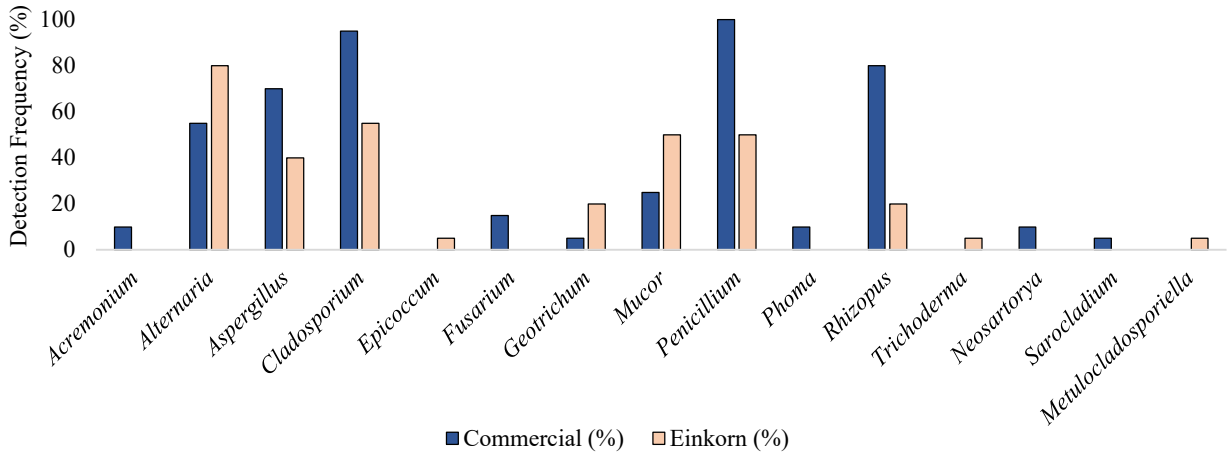


Figure 1. Comparison of Microfungi Detected in Commercial and Einkorn Wheat Samples in Percentages

Table 1. Microfungi Detected in Commercial and Einkorn Wheat Samples

Genus/Species name	Wheat type				χ^2 (1, N = 40)	p
	Commercial		Einkorn			
	n (20)	%	n (20)	%		
Acremonium charticola	2	10.00	0	0.00	2.11	0.244
Alternaria alternata	6	30.00	4	20.00	0.53	0.358
Alternaria chartarum	1	5.00	5	25.00	3.14	0.091
Alternaria citri	4	20.00	7	35.00	1.13	0.240
Alternaria	11	55.00	16	80.00	0.92	0.262
Aspergillus flavus	5	25.00	3	15.00	1.39	0.225
Aspergillus fumigatus	3	15.00	1	5.00	1.11	0.302
Aspergillus niger	5	25.00	4	20.00	0.14	0.500
Aspergillus ochraceus	1	5.00	0	0.00	1.03	0.500
Aspergillus	14	70.00	8	40.00	0.92	0.262
Cladosporium cladosporioides	11	55.00	7	35.00	1.62	0.170
Cladosporium cucumerinum	0	0.00	4	20.00	3.42	0.106
Cladosporium herbarum	4	20.00	0	0.00	4.44	0.053
Cladosporium macrocarpum	1	5.00	0	0.00	1.03	0.500
Cladosporium tenuissimum	3	15.00	0	0.00	3.24	0.115
Cladosporium	19	95.00	11	55.00	0.90	0.264
Epicoccum nigrum	0	0.00	1	5.00	1.03	0.500
Fusarium oxysporum	3	15.00	0	0.00	3.24	0.115
Geotrichum candidum	1	5.00	4	20.00	2.06	0.171
Mucor hiemalis	5	25.00	10	50.00	2.67	0.095
Mucor racemosus	0	0.00	5	25.00	5.71	0.024*
Mucor	5	25.00	10	50.00	2.67	0.095
Penicillium aurantiogriseum	10	50.00	2	10.00	7.62	0.006*
Penicillium brevicompactum	1	5.00	3	15.00	1.11	0.302
Penicillium chrysogenum	17	85.00	0	0.00	29.57	0.001*
Penicillium citrinum	9	45.00	3	15.00	4.29	0.041*
Penicillium commune	6	30.00	1	5.00	4.33	0.046*
Penicillium digitatum	8	40.00	2	10.00	4.80	0.032*
Penicillium expansum	1	5.00	1	5.00	0.00	0.756
Penicillium glabrum	16	80.00	2	10.00	19.80	0.001*
Penicillium oxalicum	2	10.00	0	0.00	2.11	0.244
Penicillium verrucosum	1	5.00	0	0.00	1.03	0.500
Penicillium	20	100.00	10	50.00	13.33	0.001*
Phoma herbarum	2	10.00	0	0.00	2.11	0.244
Rhizopus arrhizus	16	80.00	4	20.00	14.40	0.001*
Trichoderma harzianum	0	0.00	1	5.00	1.03	0.500
Neosartorya clavata	2	10.00	0	0.00	2.11	0.244
Sarocladium implicatum	1	5.00	0	0.00	1.03	0.500
Metulocladosporiella musae	0	0.00	1	5.00	1.03	0.500

*p<.05; #Percentages are given according to columns (wheat type). X^2: Chi-square Fisher test was performed.

Table 2 Comparison of Wheat Types with the Number of Samples Found

Genus/Species name	N	Commercial Wheat		Einkorn Wheat		U	p
		Rank Avg.	Avg. ±S.d	RankAvg.	Avg. ±S.d		
Acremonium charticola	20	21.50	2.00 ±0.31	19.50	0.00 ±0.00	180.00	0.152
Alternaria alternata	20	21.50	6.00 ±0.47	19.50	4.00 ±0.41	180.00	0.471
Alternaria citri	20	19.00	4.00 ±0.41	22.00	7.00 ±0.49	170.00	0.294
Alternaria chartarum	20	18.50	1.00 ±0.22	22.50	5.00 ±0.44	160.00	0.080
Alternaria	20	19.00	7.00 ±0.49	22.00	10.00±0.51	170.00	0.343
Aspergillus flavus	20	21.38	5.00 ±0.44	18.55	2.00 ±0.32	162.50	0.245
Aspergillus fumigatus	20	21.50	3.00 ±0.37	19.50	1.00 ±0.22	180.00	0.298
Aspergillus niger	20	21.00	5.00 ±0.44	20.00	4.00 ±0.41	190.00	0.708
Aspergillus ochraceus	20	21.00	1.00 ±0.22	20.00	0.00 ±0.00	190.00	0.317
Aspergillus	20	22.00	10.00 ±0.51	19.00	7.00 ±0.49	170.00	0.343
Cladosporium cladosporioides	20	22.50	11.00 ±0.51	18.50	7.00 ±0.49	160.00	0.209
Cladosporium cucumerinum	20	18.50	0.00 ±0.00	21.58	3.00 ±0.37	160.00	0.068
Cladosporium herbarum	20	22.50	4.00 ±0.41	18.50	0.00 ±0.00	160.00	0.037*
Cladosporium macrocarpum	20	21.00	1.00 ±0.22	20.00	0.00 ±0.00	190.00	0.317
Cladosporium tenuissimum	20	22.00	3.00 ±0.37	19.00	0.00 ±0.00	170.00	0.075
Cladosporium	20	22.00	12.00 ±0.50	19.00	9.00 ±0.51	170.00	0.348
Epicoccum nigrum	20	20.00	0.00 ±0.00	21.00	1.00 ±0.22	190.00	0.317
Fusarium oxysporum	20	22.00	3.00 ±0.37	19.00	0.00 ±0.00	170.00	0.075
Geotrichum candidum	20	19.00	1.00 ±0.22	22.00	4.00 ±0.41	170.00	0.157
Mucor hiemalis	20	18.00	5.00 ±0.44	23.00	10.00±0.51	150.00	0.107
Mucor racemosus	20	18.00	0.00 ±0.00	23.00	5.00 ±0.44	150.00	0.018*
Mucor	20	18.00	5.00 ±0.44	23.00	10.00±0.51	150.00	0.107
Penicillium aurantiogriseum	20	24.50	10.00 ±0.51	16.50	2.00 ±0.31	120.00	0.006**
Penicillium brevicompactum	20	19.50	1.00 ±0.22	21.50	3.00 ±0.37	180.00	0.298
Penicillium chrysogenum	20	29.00	17.00 ±0.37	12.00	0.00 ±0.00	30.00	0.001**
Penicillium citrinum	20	23.50	9.00 ±0.51	17.50	3.00 ±0.37	140.00	0.041*
Penicillium commune	20	23.00	6.00 ±0.47	18.00	1.00 ±0.22	150.00	0.040*
Penicillium digitatum	20	23.50	8.00 ±0.50	17.50	2.00 ±0.31	140.00	0.031*
Penicillium expansum	20	20.50	1.00 ±0.22	20.50	1.00 ±0.22	200.00	1.00
Penicillium glabrum	20	27.50	16.00 ±0.41	13.50	2.00 ±0.31	60.00	0.001**
Penicillium oxalicum	20	21.50	2.00 ±0.31	19.50	0.00 ±0.00	180.00	0.152
Penicillium verrucosum	20	21.00	1.00 ±0.22	20.00	0.00 ±0.00	190.00	0.317
Penicillium	20	25.50	20.00 ±0.00	15.50	10.00±0.51	100.00	0.001**
Phoma herbarum	20	21.50	2.00 ±0.31	19.50	0.00 ±0.00	180.00	0.152
Rhizopus arrhizus	20	26.50	16.00 ±0.41	14.50	4.00 ±0.41	80.00	0.001**
Trichoderma harzianum	20	20.00	0.00 ±0.00	21.00	1.00 ±0.22	190.00	0.317
Sarocladium implicatum	20	21.00	1.00 ±0.22	20.00	0.00 ±0.00	190.00	0.317
Neosartorya clavata	20	21.50	2.00 ±0.31	19.50	0.00 ±0.00	180.00	0.152
Metulocladosporiella musae	20	20.00	0.00 ±0.00	21.00	1.00 ±0.22	190.00	0.317

*p<.05; U: Mann-Whitney U Test

P. citrinum was found in 45% (n = 9) of commercial wheat and 15% (n = 3) of einkorn wheat, $\chi^2(1, N = 40) = 4.29$, p = .038. *P. commune* was isolated from 30% (n = 6) of commercial wheat and 5% (n = 1) of einkorn wheat, $\chi^2(1, N = 40) = 4.33$, p = .037. *P. digitatum* was found in 40% (n = 8) of commercial wheat and 10% (n = 2) of einkorn wheat, $\chi^2(1, N = 40) = 4.80$, p = .028. *P. glabrum* was isolated from 80% (n = 16) of commercial wheat and 10% (n = 2) of einkorn wheat, $\chi^2(1, N = 40) = 19.80$, $p < 0.001$. In general, the genus *Penicillium* was detected in 100% of commercial wheat samples (n = 20) and 50% of einkorn wheat samples (n = 10), $\chi^2(1, N = 40) = 13.33$, $p < 0.001$. Additionally, *Rhizopus arrhizus* was found in 80% (n = 16) of commercial wheat and 20% (n = 4) of einkorn wheat, $\chi^2(1, N = 40) = 14.40$, $p < 0.001$ (Table 1).

The Mann–Whitney U test was used to compare the distribution of mold species across wheat varieties (Table 2). According to the results, *Cladosporium herbarum* was found only in commercial wheat samples (n = 4), suggesting that commercial wheat may provide a more favorable habitat for this species than einkorn wheat. *Mucor racemosus* was isolated only from einkorn wheat (n = 5), indicating that this wheat variety offers a more suitable growth environment for this mold. When *Penicillium* species were examined, commercial wheat samples were more contaminated than einkorn wheat in all species, including *P. aurantiogriseum* (commercial: n = 10; einkorn: n = 2), *P. chrysogenum* (commercial: n = 17; einkorn: n = 0), *P. citrinum* (commercial: n = 9; einkorn: n = 3), *P. commune* (commercial: n = 6; einkorn: n = 1), *P. digitatum* (commercial: n = 8; einkorn: n = 2), and *P. glabrum* (commercial: n = 16; einkorn: n = 2), demonstrating that commercial wheat provides a more suitable substrate for *Penicillium* species. Similarly, *R. arrhizus* was isolated more frequently from commercial wheat samples (n = 16) than from einkorn wheat samples (n = 4), supporting the hypothesis that commercial wheat may offer a more favorable habitat for this mold. On the

other hand, no statistically significant differences were observed among wheat varieties for *Acremonium, Alternaria, Aspergillus, Cladosporium, Epicoccum nigrum, Fusarium oxysporum, Geotrichum candidum, Mucor spp., Phoma herbarum, Trichoderma harzianum*, and *Alternaria chartarum*. These findings suggest that some mold species may exhibit different colonization characteristics depending on the wheat variety. That commercial wheat, in particular, provides a more suitable environment for some mold species (Table 2).

The Mann–Whitney U test results, performed to compare microfungal colony counts between wheat varieties, revealed that particular mold species exhibited significant differences in their colonization patterns depending on wheat type. Specifically, *C. cucumerinum* formed no colonies on commercial wheat but 14 colonies on einkorn wheat, indicating that einkorn wheat provides a more favorable environment for this species. In contrast, *C. herbarum* formed eight colonies on commercial wheat and none on einkorn wheat, suggesting that commercial wheat is a more suitable host.

Similarly, *M. racemosus* was isolated exclusively from einkorn wheat (14 colonies) and was not observed in commercial wheat. Furthermore, the genus *Mucor* formed 14 colonies in commercial wheat and 47 colonies in einkorn wheat, supporting the conclusion that einkorn wheat provides a more favorable substrate for this genus. Among the *Penicillium* species, colony counts were consistently higher in commercial wheat samples: *P. aurantiogriseum* (47 colonies in commercial wheat vs. 8 in einkorn), *P. chrysogenum* (84 vs. 0), *P. citrinum* (41 vs. 14), *P. digitatum* (37 vs. 7), and *P. glabrum* (74 vs. 5). In total, *Penicillium* species formed 321 colonies on commercial wheat and only 55 on einkorn wheat, indicating a substantially greater colonization capacity in commercial wheat. Likewise, *R. arrhizus* exhibited a similar trend, forming 38 colonies on commercial wheat and nine on einkorn wheat (Table 3).

Table 3. Comparison of Total Colony Numbers and Wheat Types

Genus/Species name	N	Commercial Wheat		Einkorn Wheat		U	p
		Rank Avg.	Avg. ±S.d	Rank Avg.	Avg. ±S.d		
Acremonium charticola	20	21.50	3.00 ±0.49	19.50	0.00±0.00	180.00	.152
Alternaria alternata	20	22.00	20.00±0.59	19.00	9.00±0.94	170.00	.285
Alternaria citri	20	18.75	12.00±1.27	22.25	25.00±1.83	165.00	.228
Alternaria chartarum	20	18.43	2.00±0.45	22.58	15.00±1.41	158.50	.071
Alternaria	20	19.60	32.00±2.52	21.40	34.00±2.00	182.00	.588
Aspergillus flavus	20	21.53	12.00±1.10	19.48	7.00±0.88	179.50	.426
Aspergillus fumigatus	20	21.58	9.00±1.10	19.43	2.00±0.45	178.50	.264
Aspergillus niger	20	21.20	15.00±1.37	19.80	10.00±1.10	186.00	.604
Aspergillus ochraceus	20	21.00	2.00±0.45	20.00	0.00±0.00	190.00	.317
Aspergillus	20	22.43	42.00±2.67	18.58	19.00±1.28	161.50	.250
Cladosporium cladosporioides	20	22.05	35.00±1.65	18.95	28.00±2.21	169.00	.354
Cladosporium cucumerinum	20	18.50	0.00±0.00	22.50	14.00±1.45	160.00	.038*
Cladosporium herbarum	20	22.50	8.00±0.82	18.50	0.00±0.00	160.00	.037*
Cladosporium macrocarpum	20	21.00	1.00±0.22	20.00	0.00±0.00	190.00	.317
Cladosporium tenuissimum	20	22.00	5.00±0.64	19.00	0.00±0.00	170.00	.076
Cladosporium	20	21.35	49.00±2.31	19.65	43.00±2.54	183.00	.628
Epicoccum nigrum	20	20.00	0.00±0.00	21.00	1.00±0.22	190.00	.317
Fusarium oxysporum	20	22.00	8.00±0.99	19.00	0.00±0.00	170.00	.076
Geotrichum candidum	20	18.93	2.00±0.45	22.08	14.00±1.53	168.50	.138
Mucor hiemalis	20	17.68	14.00±1.26	23.33	33.00±1.84	143.50	.075
Mucor racemosus	20	18.00	0.00±0.00	23.00	14.00±1.26	150.00	.018*
Mucor	20	17.15	14.00±1.26	23.85	47.00±2.66	133.00	.036*
Penicillium aurantiogriseum	20	24.53	47.00±2.46	16.48	8.00±1.39	119.50	.007*
Penicillium brevicompactum	20	19.45	2.00±0.45	21.55	12.00±1.57	179.00	.275
Penicillium chrysogenum	20	29.00	84.00±1.88	12.00	0.00±0.00	30.00	.001*
Penicillium citrinum	20	23.73	41.00±2.35	17.28	14.00±2.11	135.50	.031*
Penicillium commune	20	22.85	25.00±2.00	18.15	6.00±1.34	153.00	.055
Penicillium digitatum	20	23.65	37.00±2.39	17.35	7.00±1.18	137.00	.025*
Penicillium expansum	20	20.53	4.00±0.89	20.48	3.00±0.67	199.50	.971
Penicillium glabrum	20	28.30	74.00±1.98	12.70	5.00±0.79	44.00	.001*
Penicillium oxalicum	20	21.50	6.00±0.92	19.50	0.00±0.00	180.00	.152
Penicillium verrucosum	20	21.00	1.00±0.22	20.00	0.00±0.00	190.00	.317
Penicillium	20	29.63	321.00±6.34	11.38	55.00±4.59	17.50	.001*
Phoma herbarum	20	21.50	2.00±0.31	19.50	0.00±0.00	180.00	.152
Rhizopus arrhizus	20	26.48	38.00±1.41	14.53	9.00±9.94	80.50	.001*
Trichoderma harzianum	20	20.00	0.00±0.00	21.00	1.00±0.22	190.00	.317
Neosartorya clavata	20	21.50	4.00±0.62	19.50	0.00±0.00	180.00	.152
Sarocladium implicatum	20	21.00	1.00±0.22	20.00	0.00±0.00	190.00	.317
Metulocladosporiella musae	20	20.00	0.00±0.00	21.00	1.00±0.22	190.00	.317

*p<.05; U: Mann-Whitney U Test

In contrast, no statistically significant differences ($p > 0.05$) were observed in colony numbers between wheat types for the following genera and species: *Acremonium, Alternaria, Aspergillus, Cladosporium* (all species), *E. nigrum, F. oxysporum, G. candidum, P.herbarum, T. harzianum*, and *U. chartarum* (Table 3).

Discussion

This study, through a comparative evaluation of the surface mycoflora of commercial and einkorn wheat varieties, revealed that some microfungal species exhibited specific colonization tendencies for each wheat species. The data obtained indicate that molds, particularly those of the genus *Penicillium*, were represented at a higher frequency and with a higher colonization density in commercial wheat samples than in einkorn wheat. Species such as *P. chrysogenum, P. glabrum*, and *P. aurantiogriseum* were more predominantly isolated from commercial wheat, suggesting that environmental and physical factors, such as the higher moisture retention capacity of commercial wheat, processing method, or storage conditions, provide a more favorable environment for the growth of these species. Furthermore, the isolation of some species, such as *M. racemosus* and *C. cucumerinum*, only from einkorn wheat suggests that the unique structure and composition of einkorn wheat may be more conducive to the survival of particular microfungal species. This is particularly supported by the *Mucor* genus's significantly higher total colony count in einkorn wheat (n=47).

Statistical analyses supported by Mann-Whitney U and Chi-square tests revealed that these differences were not random but that microbial colonization dynamics related to the wheat variety were significant ($p<.05$). The higher colonization density of species of the *R. arrhizus* and *Penicillium* genera in commercial wheat suggests that commercial wheat may be a more risky substrate for these microorganisms. These findings should be evaluated in terms of both food safety and mycotoxigenic risks. Furthermore, the fact that einkorn wheat offers a more resistant or less preferred environment for some microfungal species suggests that the microbiological resistance of traditional wheat varieties is also worth investigating.

The detection of *Aspergillus, Penicillium, Fusarium*, and *Alternaria* genera, which have the potential to produce mycotoxins in stored grains, can pose significant public health risks. As reported in the literature (Mathew et al., 2011; Sabuncuoğlu et al., 2008), mycotoxins produced by these species can exhibit hepatotoxic, nephrotoxic, and carcinogenic effects. In this context, commercial wheat toxigenic species such as *A. alternata, P. aurantiogriseum*, and *P. citrinum* should be carefully evaluated for consumer health concerns—similarly, the detection of *Fusarium* spp. Only in commercial wheat suggests that einkorn wheat may have developed a natural resistance mechanism against these species. The dense glume structure of einkorn wheat may reduce contamination by acting as a physical barrier against external factors. This finding supports the findings of researchers such as Atasoy and Hendek (2017) and Zengin (2015) on the resistance of einkorn wheat. Indeed, it can be argued that hulls may act as a barrier against external factors, preventing spores from adhering to the grain surface and reaching the inner tissue. These results highlight the importance of good agricultural and storage practices (GAP and GMP) implemented from harvest to consumer. In particular, measures such as proper post-harvest drying of grain, reducing moisture content to below 13%, removing broken and moldy grains, and ensuring storage at appropriate temperature and humidity can significantly reduce the risks of mold contamination and related mycotoxins.

Some studies on bread wheat varieties in Türkiye also parallel these results. Güngör and Dumlupınar (2019) emphasized that among the agronomic traits of bread wheat varieties, genetic variation, environmental factors, and processing methods are determinants of quality parameters. Similarly, Özdemir Dirik and Sakin (2025) evaluated the performance of wheat varieties under stress conditions, highlighting the impact of environmental factors on product quality. These studies support that differences between wheat varieties may be significant in yield, quality, and microbial colonization.

In conclusion, the findings indicate that fungal community composition varies significantly between different wheat varieties. This provides valuable information for monitoring fungal contamination and encourages the use of more resistant alternative wheat varieties. It is thought that various factors, such as genetic structure, grain surface characteristics, postharvest processing processes, and storage conditions, may influence these differences. Therefore, it is recommended that these parameters be considered in future research.

Furthermore, microfungi identification in this study was based solely on morphological characteristics. Using molecular methods such as the ITS region sequencing in subsequent studies will increase the accuracy of species-level identification.

Declarations

Ethical Approval Certificate

This study does not involve any experiments on human or animal subjects.

Author Contribution Statement

Ruhsen Aydın Karaagaç: Data collection, formal analysis, writing the original draft, project administration, methodology, and supervision.

Gülay Giray: Data collection, formal analysis, methodology, and supervision.

Abdullah Şimşek: Data collection and methodology.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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