G-Tech : Jurnal Teknologi Terapan
Vol. 9, No. 3, July 2025, p. 1348-1357
E-ISSN: 2623-064X | P-ISSN: 2580-8737

Potential and Characterization of Yeast from Soil Contaminated with Captan – Based Fungicide

Ratna Eka Sari Putri[1]✉, Chosa Zahro Fatiha[2], Novia Dwi Putri[3]

[1,2] Agrotechnology Study Program, Faculty of Agriculture, Universitas Pembangunan Nasional Veteran Jawa Timur , Indonesia
[3] Agroecotechnology Study Program, Faculty of Agriculture, Universitas Brawijaya, Indonesia

✉ **Corresponding Author :** Ratna Eka Sari Putri (e-mail: ratna.eka.fp@upnjatim.ac.id)

Article Information

Article History

Received : June 04, 2025
Revised : June 22, 2025
Published : July 10, 2025

***Keywords*:**

Bioremediation;
Yeast;
Fungicide Residues;
Captan

ABSTRACT

Captan is a fungicide that inhibits the growth of fungi such as *Alternaria porri*. This fungicide is non-systemic, forming a layer on the surface of leaves and fruit. The continuous use of captan fungicides can leave residues in the environment, especially in soil. One technique to reduce captan fungicide residues is bioremediation. Bioremediation is a way to remove fungicide residues by utilizing microorganisms. The purpose of the study was to obtain yeasts in land polluted with residues of fungicides made from active captan, knowing yeasts that are adaptive to various fungicide concentrations and have the potential to reduce the toxicity of fungicides made from active captan. This study includes soil sampling, isolation and characterization of yeasts morphologically and molecularly, yeast adaptation tests to fungicides, and degradation tests using a complete randomized design. In the adaptation test, all yeasts were able to grow on media added with various concentrations of fungicide product recommendations. Molecular identification of yeast includes DNA isolation, DNA amplification, PCR product sequencing, and molecular data analysis. In the treatment with the addition of yeast, the largest average diameter of *A. porri* on the seventh day of observation was in the treatment with the addition of *W. anomalus* and *W. onychis* yeast. The yeast with the highest ability to degrade fungicides containing the active ingredient captan is *W. onychis.*

INTRODUCTION

The contamination of soil is an issue that has affected the entire world, with origins stemming from both human activity and natural causes. Urbanization, industrialization, and the increased demand for food have led to the increased use of chemical compounds, substances, and agents. Over time, this leads to the dispersal and accumulation of pollutants in the environment. Common soil pollutants include heavy metals, polycyclic aromatic hydrocarbons (PAHs), and pesticides (Ibrahim A. Mirsal, 2008; Kim et al., 2017).

Some factors that can hinder the increase in agricultural yields include attacks by plant pathogens (such as fungal pathogens), decreased soil fertility, changes in microclimate, and the use of low-quality seeds (Dubois et al., 2024). To combat fungal pathogens, farmers rely heavily on pesticides, particularly fungicides. However, continuous fungicide use can have negative impacts, such as leaving residues in plants and soil. Fungicide use is also one cause of soil pollution because it reduces the activity of soil microorganisms (Zhang et al., 2024). One active ingredient in fungicides that is often used is captan, which acts as a contact fungicide and protects plants from

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pathogen infection. This fungicide effectively controls *Alternaria porri* on shallots and *Colletotrichum capsici* on chili plants (Gama et al., 2023).

The presence of fungicide residues in agricultural products damages the environment and poses a threat to human health. These residues can accumulate in the body and spread through the food chain. Humans, as the top consumers, receive the most exposure. One way to reduce these residues is bioremediation, which involves using microorganisms that produce enzymes to break down large molecules into smaller ones. Bioremediation is a technique for cleaning up contaminated land that utilizes the ability of microorganisms to degrade organic compounds (Alori et al., 2022).

Yeasts are microorganisms widely found in nature that play an important role in decomposing and mineralizing organic compounds in soil. Yeasts also contribute to cellulose hydrolysis in soil. These microorganisms are highly adaptable and can live in extreme environments, particularly in areas rich in organic matter. Common types of yeast found in soil ecosystems include species from the genera *Cryptococcus, Candida*, and *Debaryomyces* (Mohiuddin et al., 2024; Yurkov, 2018). Yeast can be grown in wide range of operating conditions such as very low pH, high salinity, and high concentrations of anorganics and antibiotics (Wang et al., 2011). Several methods have been developed to address the security and environmental issues caused by the above-mentioned hazardous components. The majority of yeast species are safe for living things, which is the primary benefit of employing them in biodetoxification procedures. These yeasts have a broad metabolic diversity and can grow on a variety of substrates (García-Béjar et al., 2020). Efforts are needed to reduce pollution caused by fungicide residues. One method that can be used is to employ microorganisms to break down fungicides into simple compounds. Therefore, this study aims to explore the potential of yeast in degrading fungicides in the laboratory.

RESEARCH METHODS

Study area

This research was conducted from November 2018 to April 2019. Soil samples were taken from shallot fields in Batu City, East Java, Indonesia. Isolation of yeast and identification in Plant Disease Laboratory, Department of Plant Pests and Diseases, Faculty of Agriculture, Universitas Brawijaya. The selection of sampling locations was conducted using purposive sampling. There are 5 sampling points and the sample was composited.

Sample collection

Soil sampling was carried out by taking soil as many as 5 sample points diagonally. Soil samples were taken using a pick with a depth of 0-15 cm as much as 100 grams and then composited. The soil that has been mixed is then put into a plastic bag and stored in a cold box (Subair Gaffar Baso et al., 2014).

Isolation and morphological character of yeast

Yeast was isolated from soil that contaminated with fungicide. 10 g of soil were put into Erlenmeyer 250 mL containing 100 ml distilled water and then shaken for 24 hours at 120 rpm. The obtained yeast suspension was serially diluted to 10^{-5}, subsequently grown on yeast malt agar (YMA) medium, and incubated at 23-30°C. Isolated yeast strains were maintained using potato dextrose agar (PDA). Pure culture of the yeasts was obtained by means of streaking techniques.

The evaluation of yeast colonies encompassed a comprehensive assessment of their color, surface characteristics, shape, and elevation. For microscopic identification, an Olympus CX-3 microscope is used. Single yeast cells are observed and measured for size and division pattern. Microscopic examination is performed by taking yeast colonies using an ose needle, then placing them on a glass slide that has been given one drop of sterile distilled water. The addition of distilled water aims to facilitate the yeast identification process (Al Halim et al., 2024).

Yeast molecular identification

The yeast DNA isolation process using method by (Bessadok et al., 2022) that modified. Yeast colonies were shaken using a shaker for two days, then 1.5 ml of the suspension was transferred to a microtube and centrifuged at 6000 rpm for two minutes. The resulting precipitate was added to 300 µl of STES buffer, then incubated at 65°C for 15–30 minutes with shaking every five minutes. After that, the mixture was centrifuged again at 13,000 rpm for 10 minutes. The supernatant is transferred to a new tube, mixed with CI at one volume, inverted, and centrifuged again for five minutes. The resulting supernatant is added with ammonium acetate (0.1x volume) and absolute ethanol (2.5x volume), then incubated at -20°C for 24 hours. After incubation, the pellet is washed with cold 70% ethanol, dried, and dissolved in 40 µl TE buffer, then stored at -20°C.

DNA amplification was carried out using the PCR (Polymerase Chain Reaction) technique with universal primers ITS4 and ITS5. The PCR process was conducted using TaKaRa PCR Thermal Cycler. A PCR mix consisted of 25 µl DNA Taq Polymerase, 0,8 µl forward primer ITS 4, 0,8 µl reverse primer ITS 5, 0,7 µl DNA template, and 22,7 µl Nuclease Free Water (NFW). DNA amplification involved with pre-denaturation at 95°C for 3 minutes, denaturation at 95°C for 30 seconds, annealing at 50°C for 30 seconds, elongation at 72°C for 2 minutes, and final elongation at 72°C for 7 minutes.

The PCR product was analyzed by electrophoresis agarose gel 1%. Agarose gel was prepared using 0,15 gr of agarose in 15 ml of 0.5x TBE buffer and heating for 60 seconds. To the warm agarose, 1µl DNA Gel Stain was added, mixed thoroughly and poured the suspension into gel tray until solidified. PCR products then tested by electrophoresis to determine the size of the DNA bands produced. 5 µl DNA samples loaded into agarose well. Additionally, 5 µL of a 1 kb DNA ladder (Thermo Scientific, USA) was loaded into the agarose well. Electrophoresis was conducted for 30 minutes at a voltage of 80V. The DNA bands were visualized using a UV-transilluminator. The PCR products were sent to third party, PT. Genetika Science Indonesia for sequencing.

The sequences were edited using BioEdit 7.2 software. Molecular data analysis was performed using bioinformatics methods with the Basic Local Alignment Search Tool (BLAST)at the National Center for Biotechnology Information (NCBI) website (https://blast.ncbi.nlm.nih.gov/Blast.cgi) to identify isolates at species level.

Testing Yeast Adaptation to Fungicides Containing the Active Ingredient Captan

Yeast adaptation test in fungicides using poisoned food technique (Simanjuntak et al., 2017). Yeast from single colonies was tested on liquid PDA media to which various concentrations of fungicides (1.5 g/L to 7.5 g/L) had been added. The experiment was designed using a completely randomized factorial design with two factors: yeast isolate and fungicide concentration level, each with three replicates. The fungicide-mixed medium was poured into Petri dishes and inoculated with yeast using the streaking method. Three days after inoculation, observations were made to measure colony growth.

In vitro degradation test of fungicides with captan as the active ingredient

This test used 12 treatments, consisting of 10 yeast treatments and two controls (positive and negative). The positive control contained PDA supplemented with fungicide, while the negative control contained neither yeast nor fungicide. One hundred milliliters of PDB medium were inoculated with three doses of pure yeast and shaken with a rotary shaker for three days. Then, 0.15 grams of captan fungicide were added, and the mixture was shaken again for 10 days to initiate the degradation process. After 10 days, two grams of agar were added to the medium, which was then poured into sterile Petri dishes. The pathogen *A. porri* was inoculated into the poisoned medium and incubated for seven days to measure its growth diameter. This experiment was designed using a completely randomized design with three replicates.

Data Analysis

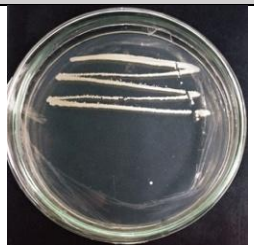
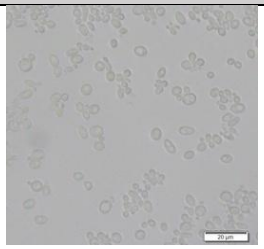
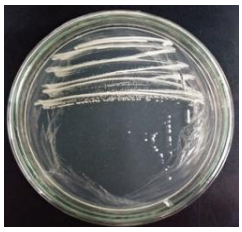
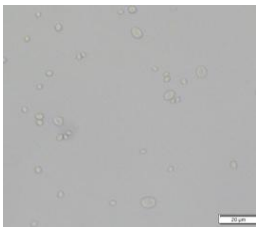
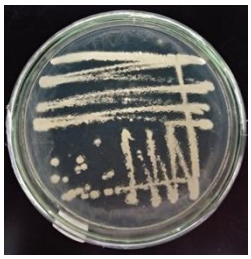
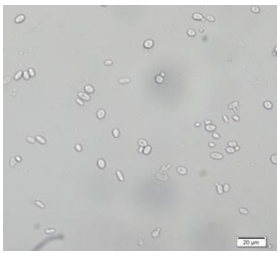
Data from the adaptation and degradation tests were analyzed using ANOVA with Microsoft Excel 2013 and DSAASTAT software. If significant differences were found, further testing was conducted using the Duncan Multiple Range Test (DMRT) at a 5% significance level to determine differences between treatments.

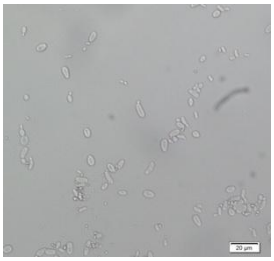
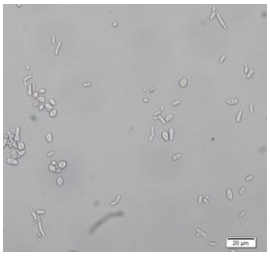
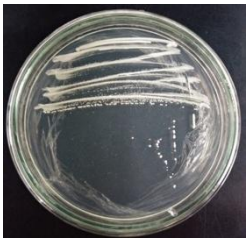
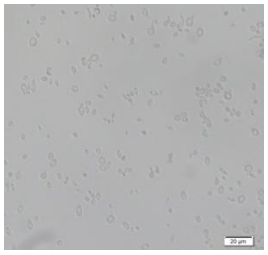
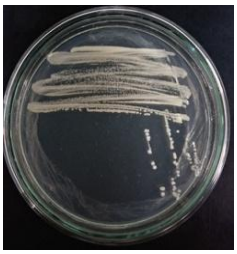
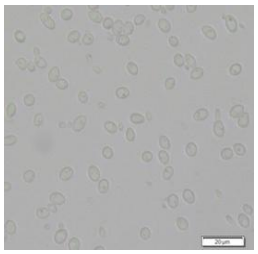
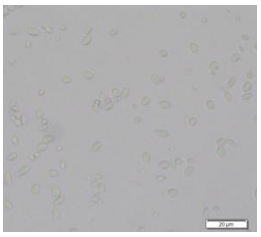
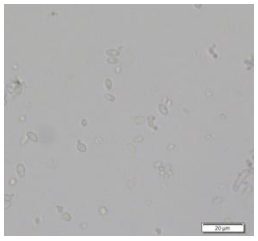
RESULTS AND DISCUSSION

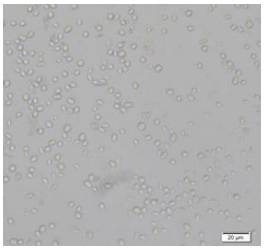
Yeast characterization

A total of 6 yeast were isolated from soil that contaminated with fungicide recidue. This research also using 4 yeast isolates from the collection of Pest and Plant Disease Department, Universitas Brawijaya. The yeast cells were identified and found to possess round, oval, and smooth surface indicated in Table 1. According to morphological characteristics, all of isolates could be categorized as yeast, The isolates has unicellular colonies, round and oval cell. The isolates has length of 2-5µm up to 3-9 µm (Al Halim et al., 2024).

Table 1. Morphological Characteristics of Yeast Isolates

Isolate Code	Colony Observation	Colony Observation	Description
B1			• Macroscopic White yeast colonies, granular texture, flat elevation, slightly shiny surface and flat colony edges. • Microscopic Ovoid-shaped yeast cells with a size of 2.24-5.17 x 3.08-7.23 µm and multilateral budding type.
B2			• Macroscopic The yeast is dull white in color, slightly raised elevation, slightly glossy surface, granular texture and flat edges. • Microscopic Cells are cylindrical or oval, single or paired cells with a size of 2.2-5.5 x 3.3-7.40 µm and multilateral budding type.
B3			• Macroscopic The yeast colony is white, granular in texture, with a flat elevation, a slightly shiny surface, and flat edges. Single cells are oval and cylindrical in shape. • Microscopic Single cells measuring 3.42–4.25 µm by 5–8.85 µm with multilateral budding.

B4			• Macroscopic The white yeast colony has a flat elevation, shiny surface, granular texture, and flat edges. • Microscopic Yeast cells are cylindrical and can be found either singly or in clusters. Single cells measure 2.85–4.47 × 4.39–9.91 µm and exhibit multilateral budding.
B5			• Macroscopic The yeast colony is dull white, slightly convex, slightly shiny, granular in texture, and flat on the surface. • Microscopic Single cells are round, oval, and cylindrical in shape. Single cells measure 2.92-5.19 x 4.93-5.84 µm with a multilateral budding type.
B6			• Macroscopic The yeast colony is white, granular in texture, with a non-glossy surface, flat elevation, and flat edges. • Microscopic The cells are round and measure between 2.41–5.68 x 3.62–6.89 µm.
C1			• Macroscopic White yeast colonies, slightly convex elevation, shiny surface, granular texture and fringed edges. • Microscopic The shape of yeast cells is ovoid with multilateral budding and can form pseudohyphae. Single cell size between 2.54-5.18 x 3.62-8.58 µm
C2			• Macroscopic The yeast colony is dull white, convex in elevation, non-glossy in surface, granular in texture, and wavy at the edges. • Microscopic Yeast cells are cylindrical in shape, with individual cells measuring 2.45–3.61 x 2.01–6.09 µm.
C3			• Macroscopic The yeast colony is dull white, convex in elevation, non-glossy in surface, granular in texture, and wavy at the edges. • Microscopic Yeast cells are oval or cylindrical in shape, with a single cell size of 3.14-4.52 x 5.27-7.10 µm.

C4			• Macroscopic pink yeast colony, convex elevation, shiny surface, grainy texture, and flat edges. • Microscopic Yeast cells are round and oval in shape, either single or clustered. Single cells measure 2.93-5.51 x 3.79-4.65 µm with a multilateral budding type.

Adaptability of Yeast to Fungicides Containing the Active Ingredient Captan

The adaptability of yeast was evaluated by measuring the length of colonies growing on PDA media mixed with fungicides containing the active ingredient captan at various concentrations according to the recommended dosage. Based on the results of the DMRT analysis at a significance level of 5% (Table 4), it was found that all yeast isolates exhibited adaptability to all fungicide concentration variations, ranging from 1.5 g/l to 7.5 g/l (equivalent to five times the recommended product dosage). This is evident from the presence of colony growth at each concentration level. However, as the fungicide concentration increases, there is a decrease in the yeast's adaptability, reflected in the reduced length of the formed colonies.

Table 2. Average Length of Yeast Colonies at Various Concentrations of Captan Fungicide

Yeast Isolates	Fungicide Concentration					
	0 g/l	1,5 (g/l)	3 (g/l)	4,5 (g/l)	6 (g/l)	7,5 (g/l)
B1	9,00a	5,67bcde	4,67bcde	3,17de	3,17de	3,00e
B2	9,00a	6,60abc	5,20bcde	4,67bcde	4,10bcde	4,03bcde
B3	9,00a	7,17ab	7,17ab	6,17abcde	5,40bcde	5,27bcde
B4	9,00a	5,83bcde	4,47bcde	3,57cde	3,50cde	3,47cde
B5	9,00a	5,43bcde	4,83bcde	4,50bcde	4,07bcde	3,27de
B6	9,00a	5,10bcde	4,60bcde	3,97cde	3,83cde	3,57cde
C1	9,00a	6,33abcd	5,50bcde	5,43bcde	3,67cde	3,67cde
C2	9,00a	6,50abc	5,77bcde	5,33bcde	4,33bcde	4,27bcde
C3	9,00a	6,53abc	5,33bcde	5,17bcde	4,50bcde	3,27de
C4	9,00a	5,83bcde	4,73bcde	4,33bcde	3,77cde	3,73cde

Note: According to Duncan's test, the average values followed by the same letters within each row are not significantly different at P< 0.05.

In the control treatment, all yeast isolates showed optimal growth with an average colony length of 9 cm. The application of fungicide at a concentration of 1.5 g/l did not have a significant effect on the average colony length of several yeast isolates such as B1, B3, C1, C2, and C3. However, at concentrations of 3 g/l and 4.5 g/l, there was a decrease in the average colony length of almost all isolates except B3, which still showed growth with colony lengths of 7.17 cm and 6.17 cm, respectively. When the fungicide concentration was increased to 6 g/l and 7.5 g/l, all yeast isolates showed smaller colony sizes compared to the control.

In general, the application of fungicides at low concentrations did not significantly affect yeast growth, but an increase in dose caused a decrease in growth, as indicated by incomplete colonies on the surface of the dish. The addition of pesticides to mineral media can reduce the growth ability of soil microbes. According to Sulistinah et al. (2011), some microorganisms are able to utilize pesticides as a carbon source, while others are unable to survive and are eliminated due to fungicide exposure. For example, *Rhodotorula* strains can completely degrade single aromatic hydrocarbons but are ineffective against polycyclic aromatic compounds, while Exophiala can degrade up to 80% of benzo[a]pyrene, 60% of phenanthrene, and about 50% of single-ring aromatic compounds (Ide-Pérez et al., 2020). In another study, *W. anomalus* has a higher tolerance rating for kadmium (Cd2+) than for chromium (Cr) or 4-bromodiphenyl ether

(BDE-3). *W. anomalus's* tolerance thresholds for BDE-3, Cd2+, and Cr are 30 mg/L, 500 mg/L, and 30 mg/L, respectively (Cai et al., 2022).

The Ability of Yeast to Degrade Captan Fungicide In Vitro

The ability of yeast to degrade fungicides with the active ingredient captan was tested by mixing yeast with the fungicide in PDB growth medium. A total of 12 treatments were applied in this test, consisting of 10 treatments using yeast and 2 control treatments, namely a positive control containing fungicide in PDA medium and a negative control without the addition of fungicide or yeast. Based on the DMRT test at a significance level of 5%, it was observed that the treatments had an effect on the diameter of *A. porri* colonies (Table 3). The larger the growth diameter of *A. porri*, the higher the yeast's ability to reduce the toxicity level of the captan-based fungicide.

Table 3. Average Diameter Length of *A. Porri* as an Indicator of Captan Fungicide Degradation by Yeast

Treatment	Observation Day (cm)						
	1	2	3	4	5	6	7
B1	0,63b	1,33d	2,00cd	2,77de	3,27de	3,97cde	4,33bc
B2	0,50a	0,97c	1,60b	2,27cd	2,87cde	3,30abcd	3,93bc
B3	0,83c	1,30d	2,17de	3,37e	4,07f	5,13f	5,60d
B4	0,60ab	0,70ab	1,07a	1,80bc	2,37bc	3,10abc	3,43ab
B5	0,63b	0,67ab	0,93a	1,37ab	2,10ab	2,80ab	3,13ab
B6	0,67b	1,47d	2,00cd	2,80de	3,47ef	3,90cde	4,27bc
C1	0,67b	1,23d	1,70bc	2,77de	3,50ef	4,27def	4,70cd
C2	0,67b	1,23d	2,07d	3,40e	4,13f	5,17f	5,57d
C3	0,60ab	0,87bc	1,20a	2,00e	2,80cd	3,77bcde	4,10bc
C4	0,67b	1,40d	2,03d	3,00e	3,47ef	4,33ef	4,70cd
Control +	0,50a	0,50a	0,97a	1,03a	1,57a	2,37a	2,60ab
Control -	1,00d	1,80e	2,47e	3,30e	4,10f	5,23f	6,73e

Note: According to Duncan's test, the average values followed by the same letters within each row are not significantly different at P< 0.05.

The lowest average growth diameter of *A. porri* was found in the positive control because the fungicide toxicity level was still high, while the largest diameter was found in the negative control, which did not contain fungicide and therefore did not inhibit pathogen growth. The addition of captan fungicide to the medium was able to suppress the growth of pathogens such as Aspergillus sp., Penicillium sp., and Mucor sp. originating from oil palm seeds (Simanjuntak et al., 2017).

On the first day of observation, most treatments with yeast addition showed significant differences compared to the positive control, except for yeast B1, B4, and C3 which did not show significant differences. On the second day, B4 and B5 also did not show significant differences compared to the positive control. On the third day, C3, B4, and B5 showed significant differences. On the fourth and fifth days, almost all yeast strains showed significant differences except B5. On the sixth day, B1, C1, C2, C3, C4, B3, and B6 yeast strains showed significant differences. On the final day, the yeast strains B3, C2, C1, C4 continued to show significant differences compared to the positive control.

Based on observations from the first to the seventh day, the most effective yeasts in reducing the toxicity of captan fungicide were C2, B3, C1, and C4. The larger the diameter of the *A. porri* colony, the lower the remaining fungicide toxicity. A study showed that *Candida pseudolambica* yeast isolated from contaminated agricultural soil was able to rapidly degrade the pesticide diazinon within 24 hours into simpler compounds (Ebadi et al., 2022). Another study by Megadi et al. (2010) revealed that the bacterium *Bacillus circulans* can break down the fungicide captan into simpler compounds such as cis-1,2,3,6-tetrahydrophthalimide, H_2S, CO_2, and HCl, and utilize the degradation products as a carbon source.

Based on adaptation and degradation tests, the yeast B3 demonstrated superior ability to adapt and reduce the toxicity of the fungicide captan. In general, yeast plays a crucial role in bioremediation technology for environments contaminated with heavy metals, both in soil and water. Several yeast genera such as *Candida, Pichia, Rhodotorula, Trichosporon*, and *Yarrowia* have been known to degrade various pollutants such as aliphatic hydrocarbons, crude oil, low-density polyethylene, industrial waste, and dyes from contaminated soil (Ataikiru et al., 2017; Elsamahy et al., 2023; Hashem et al., 2018; Rana et al., 2023).

Six *P. anomala* (formerly known as *Hansenula anomala*, currently renamed *W. anomalus*) strains that were isolated from contaminated lake water had a high capacity to collect several heavy metals, including cadmium and lead ions. The maximum Pb2+ ion concentrations that were tolerated were 200 mM, while the maximum Cd2+ ion concentration was 100 mM (Aibeche et al., 2022).

Yeast molecular identification

The result of seqeuences analysis using BLAST showed that yeast isolate B2, B3, B6 and C2 had a similarity with genus *Wickerhamomyces.* The BLAST results for the yeast isolates are presented in Table 2.

Table 4. Molecular identification of yeast isolates

Isolates Code	Accession Number	Blast	Homolog Presentation
C2	MT940583.1	*Wickerhamomyces anomalus* isolate NLN3i	99.64
B2	KY587120.1	*Wickerhamomyces anomalus* strain MY6	93.82
B3	EU877914.1	*Wickerhamomyces onychis*	95.31
B6	EU877914.1	*Wickerhamomyces onychis*	97.78

The results of DNA sequence analysis using the BLAST program showed that isolates B2, B3, B6 and C2 were 93-99% similar to *W. anomalus* and *W. onychis*. BLAST analysis with ≥90% homology indicated that the isolates were the same species.

CONCLUSION

Yeasts found in fungicide-contaminated land are capable of degrading fungicides. In adaptation tests, the yeasts were able to survive at concentrations up to five times the recommended concentration of fungicide products. *W. onychis* and *W. anomalus* isolate NLN3i has demonstrated significant potential as a bioremediation agent due to its ability to degrade various environmental pollutants, including pesticide residues and heavy metals. Yeast that can be applied to soil contaminated with fungicides using a specific concentration. Its resilience in diverse environmental conditions and metabolic versatility make it a promising candidate for application in contaminated soil or water treatment systems. To move beyond laboratory-scale studies, further research is needed to evaluate its effectiveness in real-world environments through controlled field trials. In addition, further research could be conducted to identify secondary metabolites produced by yeast.

REFERENCES

Aibeche, C., Selami, N., Zitouni-Haouar, F. E.-H., Oeunzar, K., Addou, A., Kaid-Harche, M., & Djabeur, A. (2022). Bioremediation potential and lead removal capacity of heavy metal-tolerant yeasts isolated from Dayet Oum Ghellaz Lake water (northwest of Algeria). *International Microbiology*, *25*(1), 61–73. https://doi.org/10.1007/s10123-021-00191-z

Al Halim, L. R. A., Hemeda, N. F., & Serag, A. M. (2024). Isolation, characterization, and screening of yeast biodiversity for multi- hydrolytic enzymes. *Journal of Umm Al-Qura University for Applied Sciences*, *10*(3), 474–484. https://doi.org/10.1007/s43994-023-00118-6

Alori, E. T., Gabasawa, A. I., Elenwo, C. E., & Agbeyegbe, O. O. (2022). Bioremediation techniques as affected by limiting factors in soil environment. *Frontiers in Soil Science*, *2*. https://doi.org/10.3389/fsoil.2022.937186

Ataikiru, T. L., Okorhi-Damisa, B. F., & Akpaiboh, J. I. (2017). Microbial community structure of an oil polluted site in Effurun, Nigeria. *International Research Journal of Public and Environmental Health*, *4*(3), 41–47. https://doi.org/10.15739/irjpeh.17.006

Bessadok, B., Jaouadi, B., Brück, T., Santulli, A., Messina, C. M., & Sadok, S. (2022). Molecular Identification and Biochemical Characterization of Novel Marine Yeast Strains with Potential Application in Industrial Biotechnology. *Fermentation*, *8*(10), 538. https://doi.org/10.3390/fermentation8100538

Cai, M., Zhou, J., Hao, T., & Du, K. (2022). Tolerance of phyllospheric Wickerhamomyces anomalus to BDE-3 and heavy metals. *Environmental Science and Pollution Research*, *29*(37), 56555–56561. https://doi.org/10.1007/s11356-022-19798-4

Dubois, T., Hadi, B. A. R., Vermeulen, S., Ballantyne, P., Dobermann, A., Fan, S., Garrett, K. A., Ibabao, X., Ismail, A., Jaramillo, J., Loboguerrero, A. M., McCutcheon, S., Njuki, J., Sharma, T. R., Tonnang, H. E. Z., & Pede, V. (2024). Climate change and plant health: impact, implications and the role of research for mitigation and adaptation. *Global Food Security*, *41*, 100750. https://doi.org/10.1016/J.GFS.2024.100750

Ebadi, T., Najafpour, G. D., Younesi, H., & Mohammadi, M. (2022). Rapid biodegradation of diazinon using a novel strain of Candida pseudolambica. *Environmental Technology and Innovation*, *25*. https://doi.org/10.1016/j.eti.2021.102218

Elsamahy, T., Sun, J., Elsilk, S. E., & Ali, S. S. (2023). Biodegradation of low-density polyethylene plastic waste by a constructed tri-culture yeast consortium from wood-feeding termite: Degradation mechanism and pathway. *Journal of Hazardous Materials*, *448*. https://doi.org/10.1016/j.jhazmat.2023.130944

Gama, A. B., Cordova, L. G., Baggio, J. S., Mertely, J. C., & Peres, N. A. (2023). Old but Gold: Captan Is a Valuable Tool for Managing Anthracnose and Botrytis Fruit Rots and Improving Strawberry Yields Based on a Meta-Analysis. *Plant Disease*, *107*(10), 3071–3078. https://doi.org/10.1094/PDIS-12-22-2781-RE

García-Béjar, B., Arévalo-Villena, M., Guisantes-Batan, E., Rodríguez-Flores, J., & Briones, A. (2020). Study of the bioremediatory capacity of wild yeasts. *Scientific Reports*, *10*(1), 11265. https://doi.org/10.1038/s41598-020-68154-4

Hashem, M., Alamri, S. A., Al-Zomyh, S. S. A. A., & Alrumman, S. A. (2018). Biodegradation and detoxification of aliphatic and aromatic hydrocarbons by new yeast strains. *Ecotoxicology and Environmental Safety*, *151*, 28–34. https://doi.org/10.1016/j.ecoenv.2017.12.064

Ibrahim A. Mirsal. (2008). *Soil Pollution*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-70777-6

Kim, K. H., Kabir, E., & Jahan, S. A. (2017). Exposure to pesticides and the associated human health effects. *Science of The Total Environment*, *575*, 525–535. https://doi.org/10.1016/J.SCITOTENV.2016.09.009

Megadi, V. B., Tallur, P. N., Mulla, S. I., & Ninnekar, H. Z. (2010). Bacterial degradation of fungicide captan. *Journal of Agricultural and Food Chemistry*, *58*(24), 12863–12868. https://doi.org/10.1021/jf1030339

Mohiuddin, O., P. Harvey, A., Orta Ledesma, M. T., & Velasquez-Orta, S. (2024). Bioremediation of waste by yeast strains. *Electronic Journal of Biotechnology*, *69*, 30–42. https://doi.org/10.1016/j.ejbt.2024.01.005

Rana, S., Handa, S., Aggarwal, Y., Puri, S., & Chatterjee, M. (2023). Role of Candida in the bioremediation of pollutants: a review. *Letters in Applied Microbiology*, *76*(9). https://doi.org/10.1093/lambio/ovad103

Simanjuntak, D., Faizah, R., Prasetyo, A. E., & Susanto, A. (2017). *Keefektifan Fungisida Terhadap Isolat Cendawan Terbawa Benih Kelapa Sawit The Effectiveness Of Fungicides Against Fungal Isolates Carried By Oil Palm Seeds.*

Subair Gaffar Baso, M., Hasanah, U., & Monde, A. (2014). *Variabilitas Sifat Fisika Tanah dan C-Organik Pada Lahan Hutan dan Perkebunan Kakao (Theobroma cacao L.) di Desa Sejahtera Kecamatan Palolo Kabupaten Sigi.*

Wang, X.-X., Zhao, Z.-H., Chang, T.-S., & Liu, J.-G. (2011). Yeast screening from avermectins wastewater and investigation on the ability of its fermentation. *Bioprocess and Biosystems Engineering*, *34*(9), 1127–1132. https://doi.org/10.1007/s00449-011-0563-6

Yurkov, A. M. (2018). Yeasts of the soil – obscure but precious. In *Yeast* (Vol. 35, Issue 5). John Wiley and Sons Ltd. https://doi.org/10.1002/yea.3310

Zhang, L., Zuo, Q., Cai, H., Li, S., Shen, Z., & Song, T. (2024). Fungicides reduce soil microbial diversity, network stability and complexity in wheat fields with different disease resistance. *Applied Soil Ecology*, *201*, 105513. https://doi.org/10.1016/J.APSOIL.2024.105513