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Antifungal Activity of Turmeric Extract (*Curcuma longa* Linn) Fortified with Silver Nanoparticles Against Pathogenic Fungi

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ABSTRACT

Trichophyton spp. is the most common etiological agent of human dermatophytosis worldwide. *T. mentagrophytes* and *T. rubrum* have various phenotypic virulence factors that allow the infection to establish and evolve. In traditional medicine and herbal remedies, medicinal plants have long played a significant role in producing secondary metabolites such as antimicrobial compounds. The main aim of this research is to investigate the effects of different forms of turmeric extract and silver nanoparticles on inhibiting the growth of certain pathogenic fungi, specifically *Trichophyton mentagrophytes* and *Trichophyton rubrum*. The study involved using aqueous and alcoholic extracts of turmeric, as well as an aqueous extract supplemented with silver nanoparticles. These extracts were mixed with a nutrient medium at various concentrations (5, 10, 15, and 20 mg/mL) to assess their effectiveness against fungal isolates. The inhibitory diameter for each concentration and type of extract (aqueous, alcoholic, and silver nanoparticle fortified) was measured to determine their inhibitory activity. Furthermore, the minimum inhibitory concentration for each type of extract was determined. The sensitivity of isolated fungi to the extracts varied, with *T. rubrum* showing a greater sensitivity than *T. mentagrophytes*. The results also revealed that alcoholic turmeric extract showed significant superiority over all other concentrations without nanoparticles, and also when adding 0.1 mg/mL of silver nanoparticles with the growth of the fungus *Trichophyton mentagrophytes* was lowest, it reached (12 and 8) mm without and with the addition of nanoparticles respectively. The findings highlight the potential antifungal properties of the different turmeric extracts tested in this study. For further research, the authors suggest exploring different concentrations or combinations with other nanoparticles.

1. INTRODUCTION

In traditional medicine and herbal remedies, medicinal plants have long played a significant role [1]. The World Health Organization (WHO) has also recorded the names of more than 20,000 species of medicinal plants and described medicinal plants as one of the potential sources of new drugs. More than 100 nations have developed regulations for medicinal plants. There are more than 1,140 plants with defined antimicrobial activity, and more than 30,000 antimicrobial compounds have been isolated from plants. Furthermore, 14% to 28% of higher plant species are projected to be medicinal and 74% of bioactive plant-derived compounds have been identified based on ethno-medicinal uses [2, 3].

However, newer methods, such as microwave-assisted extraction, have proven to be more effective [4]. The rich source of antimicrobial compounds in plants has boosted interest in their antibacterial capabilities [5]. *Curcuma longa* Linn, commonly known as turmeric, is in the Zingiberaceae family and has a history of medicinal properties against numerous diseases [6]. Numerous studies have shown a synergistic effect between AgNPs and curcumin, the extremely small size and large surface-to-volume ratio of this plant extracts conjugated nanoparticles form positively charged complexes, enhancing the penetration and efficiency of these bio-formulations. Pure curcumin-based nanoformulation was synthesized previously for better disease-resistance properties [7, 8]. These nano-curcumins are devoid of the other crucial bioactive compounds present in rhizome extract, which may perform better as nontoxic capping agents during green synthesis.

With many uses in microbiology and biotechnology, nanotechnology is a rapidly developing field of scientific study [9]. Silver nanoparticles, also known as AgNPs, are aggregations of comparatively few atoms; they can be smaller, with only a few atoms, or larger, with over 100,000 atoms. AgNPs have distinct chemical and physical characteristics, including fast diffusion rates, variable surface features, and adsorption capacities [10]. They are widely used in targeted

medication delivery, biosensors, cell structure imaging, and nanobiotechnology. In contrast to the large particles of bulk materials, nanoparticles have intriguing optical, electrical, biological, and chemical capabilities due to their unique size (1-100 nm) and high surface-to-volume ratio. Secondary metabolites can act as natural reducing and protecting agents in the formation of nanoparticles [9].

The majority of plant material analysis techniques use liquid extraction techniques to separate the constituents. The most popular usage of alcohols (methanol or ethanol) and their aqueous solutions is in the analytical aspects of phenolic component isolation from plants. Adducts with water and/or alcohol have just lately been found as one of the several derivatives that are produced when certain phenolics are extracted at high temperatures using alcoholic mixes with water [11].

The focus of this study is on the potential uses of an alcoholic and watery extract of the turmeric rhizome and and a composite material made of AgNPs using turmeric rhizome extract, which has a positive influence on individuals frequently exposed to *Trichophyton* fungi. These fungi are extremely contagious, can cause eczema and allergic reactions, require protracted treatment, and are particularly dangerous for those with sensitive skin. AgNP research is still in its infancy, but this work advances the use of nanoparticles by emphasizing their potential advantages for humanity.

The purpose of this study was to evaluate the efficiency of inhibiting fungus growth using turmeric extracts supplemented with silver nanoparticles. Aqueous and alcoholic extracts in various quantities were used in the study, as well as aqueous extracts enhanced with silver nanoparticles, to combat the pathogenic fungus *Trichophyton mentagr-ophytes* and *Trichophyton rubrum*. For each kind of extract and concentration, the inhibitory diameter and the minimum inhibitory concentration were calculated to determine the inhibitory impact. The findings of this study may offer important details about the possible use of turmeric extracts as a natural antifungal substitute for synthetic antifungal medications.

2. MATERIALS AND METHODS

2.1 Sabouraud Dextrose Agar (SDA) medium

Medium for Sabouraud Dextrose Agar in accordance with the manufacturer's (HIMEDIA) specifications, prepared by dissolving 65 gm of the prepared medium powder in a quantity of distilled water and bringing the volume to 1000 ml.

2.2 Littman Oxgall Agar

According to the manufacturer's instructions (HIMEDIA), Soak 55.01 grams in 1000 milliliters of distilled or purified water. Bring to a boil to fully dissolve the medium. Autoclave at 15 lbs pressure (121°C) for 15 minutes for sterilization.

2.3 Bromocresol purple indicator solutions

According to the manufacturer's instructions (HIMEDIA), dissolve 50 mg of bromocresol purple in 20 ml of 95% ethanol and 0.92 ml of 0.1 M sodium hydroxide. Once the solution has taken effect, add enough water to make 100 milliliters.

2.4 Keratin agar medium

As a source of keratin, chicken feathers were worked; a significant amount of chicken feathers were collected from a poultry farm, changed to a size of 1 cm, and cleaned with chloroform and methanol in a volume ratio of 1/1, followed by a wash with sanitized water and drying in the sun. The feathers were immersed in 10 ml of Dimethyl sulfoxide (DMSO) solution for 24 hours, followed by 10 ml of acetone for 30 minutes, before being filtered through filter paper, the filtrate was taken and added to the mineral salt agar medium covering 1.5 K_2HPO_4 g/L, 0.05 $MgSO_4.7H_2O$ g/L, $CaCl_2$ 0.025 g/L, 0.015 $FeSO_4.7H_2O$ g/L, 0.005 $ZnSO_4.7H_2O$ g/L, 2% agar, 100 ml sanitized water, and 7.5 pH was counteracted where it was incidental that the ability of fungi and modified by Barman et al. [12].

2.5 Fungi isolation and identification

In total, 55 patients (21 men and 34 women) with an age range of 18-55 years, who had dermal infections between their foot fingers, were used to take samples. The fungi were identified through the morphological characteristics observed via direct examination with lactophenol cotton blue and were preserved in tubes with SDA (HIMEDIA) and kept at 4°C [13].

2.6 Preparation of aqueous turmeric extract

The aqueous extract of turmeric rhizome follows the method defined by Rios et al. [14], and adapted by Xiong et al. [15]. Initially, 40 g of finely powdered was mixed with 160 ml of purified water. The mixture was then placed in a blender for 5 minutes with intermittent breaks. Subsequently, the mixture was stirred using an electric shaker for two hours to ensure a uniform blend. The combination was indorsed to soak at 4°C for 24 hours. The mixture was filtered through several layers of gauze. The filtrate was then exposed to centrifugation at 3000 rpm for 10 minutes. To further purify the extract, filtration was performed again using a Buchner funnel and Whatman No.2 filter paper. Following these steps, the crude aqueous extract of the turmeric rhizome explant was obtained. To remove moisture, the extracts were frozen using a freeze and then subjected to lyophilization under vacuum pressure and a temperature of -50°C using a lyophilizer device supplied by Edwards High Vacuum, UK.

2.7 Preparation of alcoholic turmeric extract

Alcoholic turmeric rhizome extract was prepared following the procedure described by Grand et al. [16], and modified by Borges et al. [17]. Initially, 20 g of the turmeric explant material was dissolved in 200 ml of 95% ethyl alcohol. The mixture was thoroughly mixed for 5 minutes with intermittent pauses to ensure proper mixing. The blended mixture was transferred to an airtight container and stirred for 2 hours using an electric shaker. After this, the container was placed at 4°C for 24 hours to allow adequate soak. The mixture was filtered through multiple layers of gauze to remove any solid particles. Subsequently, it was centrifuged at 3000 rpm for 10 minutes. To further purify the extract, the liquid was filtered again using a Buchner funnel with Whatman No.2 filter paper under vacuum conditions.

For final drying, the thick extract layer was freeze-dried using a lyophilizer under vacuum pressure and at a

temperature of -50°C. The resulting dried crude extracts were then stored in plastic containers with airtight lids in a freeze-dried state until ready for use.

2.8 Sterilizing the aqueous extract and alcoholic turmeric extract

To sterilize aqueous and alcoholic turmeric rhizome extract, one gram of dry plant extract was mixed with 5 ml of sterile distilled water for the aqueous extract and 5 ml of ethylene glycol for the alcoholic extract, resulting in a standard concentration of 200 mg/mL. This standardized concentration was then subjected to sterilization using 0.22-micron membrane filters under vacuum. This purified concentration served as the basis for preparing the various dilutions utilized in the study, following the dilution equation: C1 V1 = C2 V2, as described and modified by Gonçalves et al. [18].

2.9 Test the inhibitory effect of aqueous, alcoholic, and alcoholic turmeric rhizome extract supplemented with turmeric extract from silver nanoparticles

The inhibitory activity of the alcoholic turmeric rhizome extract against *Trichophyton mentagrophytes* and *Trichophyton rubrum* was evaluated using the following approach: Specific volumes of sterile extract were added to predetermine volumes of sterile Sabouraud Dextrose Agar (SDA) and supplemented with 0.1% silver nanoparticles (obtained from Sigma Aldrich, UK according to the properties of these particles their size used is < 110 nm and a molecular weight of 107.87g/mol) for nano treatment, before solidification, and the mixtures were thoroughly shaken to reach concentrations of 5, 10, 15, and 20 mg/mL for the aqueous extract and 2, 4, 8, and 16 mg/mL, for the alcoholic extract. Subsequently, the prepared mixtures were poured into three Petri dishes. Once the medium solidified, small discs measuring 0.5 cm in diameter were taken from the edges of one-week-old fungal colonies using a cork pourer. Then these discs were placed in the center of each dish under sterile conditions. The Petri dishes were inverted and incubated in an incubator at a constant temperature of 27°C for two weeks. Throughout the cultivation and incubation process, strict sterile conditions were maintained.

In the next week-long incubation period, the products were attained by determining the mean of the two vertical diameters for every fungal colony. The study comprised three replications for each treatment, with each repeat located in a separate plate. The method used for this study was adopted from the work of Pitt and Hocking [19], and modified by Udoh et al. [20].

2.10 Statistical analysis

All data were analyzed by one-way analysis of variance (one–way ANOVA) using the GraphPad prism9 statistical package, version 9.3.1 software. The results were expressed as means ± SD and the values were considered statistically significant at P <0.01. The Dunkin test was used to compare all different groups, while means that hold at least one common letter are not significant, while means that hold completely different letters are considered significantly different [21].

3. RESULTS AND DISCUSSION

3.1 Phenotypic characteristics of the fungus *Trichophyton rubrum*

The fungus displayed flat white colonies that had a slight elevation above the surface of Sabouraud Dextrose Agar medium (SDA). The texture of the colonies was soft, cottony, and loosely fluffy. On the reverse side of the colony, a yellowish-brown to reddish-brown color was observed [22]. The fungal culture exhibited a growth rate that resulted in a colony diameter of 8 cm after 14 days of incubation at a temperature of 25°C (Figure 1).

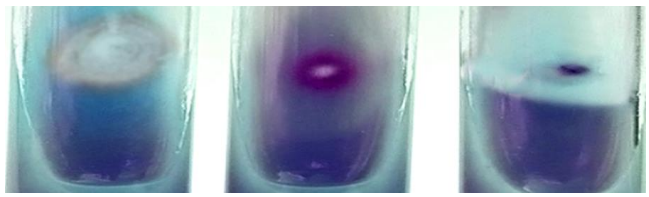

Figure 1. Colonies of *Trichophyton rubrum* isolated from the toenail: Primary isolation from gratings on Sabouraud's dextrose agar with cycloheximide, chloramphenicol, and gentamicin (14 d) (left); Green colonies on Littman Oxgall agar (14 d) (center); Constrained, red colony without pH change on Bromocresol Purple Milk Solids Glucose agar (10 d) (right)

3.2 Microscopic and macroscopic characteristics of the fungus

The isolates were inoculated on SDA and were incubated at 25°C for 7 days. The macroscopic and microscopic characteristics of the colonies were observed through micro-cultures, the fungus *Trichophyton mentagrophytes* displays specific microscopic characteristics: It forms septate hyphae that give rise to branched conidiophores. These conidiophores bear sessile (non-stalked) micro conidia, arranged in thick grape-like groups. The microconidia are globular to pyriform in shape, measuring approximately 2µm to 4µm in size. Additionally, the fungus produces macro conidia, which are cigar to club-shaped and may exhibit some distortion. The macroconidia have a smooth surface and thin walls, typically containing 3 to 8 cells within their interior. In younger cultures, macroconidia may be more abundant. It is important to note that the production of both micro and macro conidia may vary depending on the specific isolate. Some strains of *Trichophyton mentagrophytes* may also contain coiled or spiral hyphae, and certain constructions, defined as nodular forms or chlamydo spores, could be extant in certain strains.

Different reactions on bromocresol purple milk solids glucose agar (7 d). *T. mentagrophytes* shows an unobstructed growth with an alkaline (purple) color change, *T. rubrum* shows limited growth without a pH change, and *T. violaceum* produces feeble growth escorted by clearing the milk solids and a purple color change. Microscopic characteristics of the fungus: Microscopic examination showed abundant production of microconidia of spherical to pear shape and alternating arrangement along the mycelium and production of macroconidia of cylindrical shape resembling a cigar with thick smooth multicellular walls between 6-8 cells (Figure 2, Table 1).

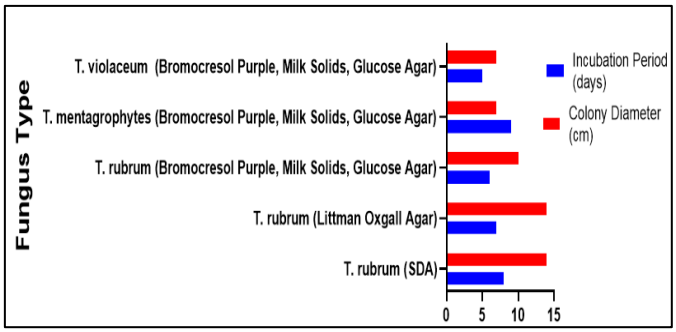

Figure 2. Growth graph of fungal colonies

The phenotypic characteristics of *Trichophyton mentagrophyte* shows that the fungus samples were established, the colonies looked in SDA medium, flat and domed in the midpoint and white, as shown in Figure 3, microscopic inspection presented the presence of Macro conidia separated by thin-walled septum's (4-5), microconidia seemed to gather.

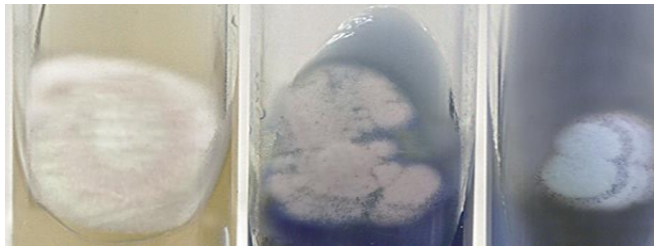

Figure 3. Colonies of *T. mentagrophytes* (left), *T. rubrum* (center), and *T. violaceum* (right)

Table 1. Growth characteristics of fungal colonies

Fungus Type	Medium	Colony Diameter (cm)	Incubation Period (days)	Incubation Temperature (℃)
T. rubrum	SDA	8	14	25
T. rubrum	Littman Oxgall Agar	7	14	
T. rubrum	Bromocresol Purple	6	10	
T. mentagrophytes	SDA	9	7	
T. violaceum		5	7	

Each value represents the average of three replicates.

Table 2. Microscopic characteristics of fungi

Fungus Type	Microconidia Shape	Microconidia Size (µm)	Macroconidia Shape	Macroconidia Size (µm)	Cell Count in Macroconidia
T. rubrum	Spherical to Pear-shaped	2-4	Cylindrical	40-60	6-8
T.mentagrophytes	Varied	3-5	cylindrical	50-70	10-12
T. violaceum	Varied	4-6	Cylindrical	60-80	15-18

Each value represents the average of three replicates.

Pathogenic fungi *Trichophyton* and *Microsporum* exhibit extracellular enzymatic activity, which allows them to produce enzymes capable of breaking down keratin, fat, and protein. Among these enzymes, *protease* stands out as the most effective, as evidenced by the diameter of the halo surrounding its activity. The enzyme's effectiveness increases with a longer incubation period. In dermal fungi, the production and secretion of the *protease* enzyme are stimulated in response to extracellular components such as keratin, particularly when they invade the epidermal layer. This *protease* enzyme can contribute to the ability of dermal cells to damage components of the deeper sheets of the dermis in patients with dermatomycosis [23, 24].

In a study by Al-Masaoodi et al. [25], they concluded that the fungus *Trichophyton rubrum* can produce the *protease* enzyme and the gene expression of this enzyme increased when exposed to filters of the fungus *Marasmius palmiyorus*. In another study by Pakshir et al. [26], it was demonstrated that various dermatophytes, including *T. mentagrophytes*, *T. verrucosum*, *T. tonsurans*, *T. Microsporum* canis, *T. rubrum*, *T. violaceum*, and *M. gypseum*, could produce the enzyme *protease*, but to varying degrees based on their virulence. Additionally, *Trichophyton* and *Microsporum* were found to secrete the *keratinase* enzyme, which allows them to infect and break down keratin in the skin, nails, or hair, making it a crucial virulence factor [27].

The *keratinase* enzyme primarily cleaves peptide bonds in hydrophobic aromatic amino acids (AAPF) and aliphatic amino acids (AAA) at the 1-P site of synthetic oligopeptides. Among the dermatophytes studied (*M. Audouinii*, *T. shoeleinni*, *T. mentagrophytes*, *T. rubrum*, and *E. floccosum*), it was found that *T. mentagrophytes* were the most effective in producing *keratinase* enzyme and efficiently breaking down keratin in hair. This is possibly due to its perforating organ, which facilitates the mechanical breakdown of keratin and aids mycelium growth [28]. Numerous virulence enzymes, including cellulase, lipase, and protease, with varying substrate specificities are secreted by dermatophytes. Numerous enzymes are secreted by dermatophytes in order to acquire the nutrients necessary for growth and survival [29]. Dermatophytes obtain their carbon, nitrogen, phosphorous, and sulfur from the macromolecules found in the host tissue. Furthermore, it has been proposed that the enzymes secreted by dermatophytes also function as antigens and cause varying degrees of inflammation [30].

3.3 Influences on microscopic properties

The results of the microscopic examinations revealed various internal abnormalities observed in the fungal cells. The most notable observation was the agglomeration of the protoplast within the fungal cells, while the cell wall remained unaffected. This indicates an impact on the cell membrane. Another noticeable effect was the significant formation of

chlamydial spores, suggesting that fungal cells were exposed to harsh environmental conditions, leading to the production of numerous chlamydial spores. This may be attributed to physiological variations within fungus cells and possibly the production of protective compounds in response to adverse conditions. In addition, these changes might disrupt vital processes within the fungus, leading to problems in protoplasm assembly, cell contraction, and collapse. It is possible that the presence of toxic substances could be poisoning the cells or increasing their osmotic pressure, ultimately leading to the destruction of the mycelium, which in turn affects the growth and increase of conidia (Table 2).

Some studies have indicated that silver nanoparticles can cause alterations in the fungal cell membrane, leading to cytoplasmic leakage and subsequent cell death, such as in fungi such as *Botrytis cinerea* and *Penicillium expansum* that silver nanoparticles caused deformation and destruction of the cell wall, severe damage to the plasma membrane, leakage of cell contents and disappearance of the nuclei, ultimately leading to cell death. These findings align with the work of Ghannoum and Rice [31], who showed that treatment of *T. rubrum* with TDT 067, which contained antifungal, resulted in distortions and ruptures in the mycelium and protoplasm shrinkage, leading to the formation of voids.

3.4 Effect of nanoparticle concentration in aqueous and alcoholic turmeric rhizome extracts on *T. rubrum* and *T. mentagrophytes* colony diameter

Tables 3 and 4 show that there is a clear effect of the aqueous and alcoholic extract on inhibiting the growth rates of the fungi included in the study, and the rate of inhibition increases with increasing concentration of the plant extract, the effect on both fungi also varied if *T. rubrum* was more sensitive than *T. mentogrophaytes*. This difference is due to the presence of genetic variance in both species.

The results of the microscopic investigations demonstrated that there were interior abnormalities observable within the fungal cells. In particular, the protoplast inside the cells aggregated without affecting the cell wall, indicating an impact on the cell membrane. Furthermore, the formation of chlamydial spores was significantly evident, suggesting that harsh environmental conditions led to the generation of numerous chlamydial spores, possibly as a protective response or as a result of physiological changes within fungus cells. These changes could result in disruption of vital processes, protoplasm assembly, cell contraction, and collapse. The smaller size of the fungal cells led to an increased accumulation of silver nanoparticles on their surfaces, enhancing the toxicity to microorganisms. This could affect the permeability of the cell's plasma membrane, ultimately leading to cell death [32].

The resistance of fungi to the effects of silver nanoparticles and their antifungal properties varied among different species. For example, *Trichophyton rubrum* showed more resistance compared to *Trichophyton mentagrophytes* in most treatments. This variation may be attributed to genetic differences between fungi, differences in the thickness and composition of their cell walls, and variations in the degree of hydrophobicity of their cell walls. The hydrophobicity of the cell wall affects the attachment of the fungi to the surfaces of the host cell, thus influencing their resistance. These findings are consistent with previous studies on dermatophytes that also showed variations in their resistance to silver nanoparticles and other antifungal agents [33].

It is clear from Table 3 that the concentration of 16 mg/mL of alcoholic turmeric extract showed significant superiority over all other concentrations without nanoparticles, and also when adding 0.1 mg/mL of silver nanoparticles Where the growth of the fungus *Trichophyton mentagrophytes* was lowest, it reached (12 and 8) mm without and with the addition of nanoparticles, respectively , while the concentration of 4 mg/mL of the turmeric extract with 0.1 of silver nanoparticles added showed significant superiority over the other treatments. This is considered the best combination for inhibiting the fungus *Trichophyton mentagrophytes* in this study because from an economic standpoint there is a big difference between the concentration of 16 mg/mL and 4 mg/mL of turmeric extract, meaning there is four times less.

Table 3. Effect of nanoparticle concentration in Aqueous and alcoholic turmeric rhizome extracts on the colony diameter with Silver nanoparticles (0.1 mg/mL) of *Trichophyton mentagrophytes*

Turmeric Rhizome Extract Type	Colony Diameter (mm) with Nanoparticles	Colony Diameter (mm) without Nanoparticles	Concentrate for Turmeric Rhizome Extract (mg/mL)
Aqueous	22 a	25 a	5
Aqueous	20 b	23 b	10
Aqueous	15 c	18 d	15
Aqueous	12 d	15 e	20
Alcoholic	15 c	20 c	2
Alcoholic	12 d	18 d	4
Alcoholic	10 e	15 e	8
Alcoholic	8 f	12 f	16

Values are means± SD. Comparisons are made between columns of the same row, and there are no comparison relationships between rows of the table. The similar letter = no significant, and the different letter = significant.

Data in Table 4 showed that the alcoholic extract has shown superiority over the aqueous extract for all concentrations, as the concentration of 16 mg/mL was significantly superior to all concentrations without and with the addition of nanoparticles of (6 and 5) mm, respectively. However, from an economic, environmental, and health standpoint, a concentration of 20 mg/mL of the aqueous extract with the addition of 0.1 mg/mL of silver nanoparticles was the best combination to inhibit the activity of the fungus *Trichophyton rubrum*, as its growth diameter reached only 7 mm.

Dermatophyte infections have received renewed interest during the last five years because of the emergence of recalcitrant, highly virulent species in Asia [34, 35]. The causative species was recently described as *T. mentagrophytes* group [36]. *T. rubrum* is still the predominant species among dermatophytes, similar to previously published data [37, 38]. Antifungal resistance has also been reported in *T. rubrum* [35] and thus, a potential public health problem is apparent. Since

many microbiological infections have become resistant to antibiotics, using curcumin in conjunction with various nanoparticles will be beneficial for treating them. Additionally, curcumin and nanoparticles coated with curcumin can be utilized to combat a variety of parasites [39].

Table 4. Effect of nanoparticle concentration in Aqueous and alcoholic turmeric rhizome extracts on the diameter of the colony with Silver nanoparticles (0.1 mg/mL) of *Trichophyton rubrum*

Turmeric Rhizome Extract Type	Colony Diameter (mm) with Nanoparticles	Colony Diameter (mm) without Nanoparticles	Concentrate for Turmeric Rhizome Extract (mg/mL)
Aqueous	15 a	20 a	5
Aqueous	12 b	15 c	10
Aqueous	9 cd	11 d	15
Aqueous	7 e	8 f	20
Alcoholic	12 b	18 b	2
Alcoholic	10 c	15 c	4
Alcoholic	7 e	10 de	8
Alcoholic	5 f	6 g	16

Values are means± SD. Comparisons are made between columns of the same row, and there are no comparison relationships between rows of the table. The similar letter = no significant, and the different letter = significant.

4. CONCLUSIONS

The results underscore the potential of turmeric rhizome extracts, especially when combined with silver nanoparticles, as promising antifungal agents. This research contributes to our understanding of the mechanisms by which these nanoparticles interact with fungal cells, causing damage to cell membranes, DNA replication, protein breakdown, and ultimately leading to cell death. These findings have significant implications for the development of novel and effective antifungal strategies to combat fungal infections, taking into account the genetic variations and resistance levels exhibited by different fungal species. To design more effective medications, it is essential to appreciate the physiopathology of dermatophytosis to understand the fungal activity. Because of their intrinsic importance in the pathophysiology of the disease, which promotes fungal invasion and spread via the host stratum corneum, keratinase is the most pertinent enzyme investigated as a virulence factor. Additionally, this study presents compelling evidence of a dose-dependent, beneficial biological response to turmeric-derived AgNPs in vivo. Therefore, it may be demonstrated that turmeric AgNPs are a safer substitute for the widely used chemically manufactured AgNPs. Turmeric-derived AgNPs can be commercialized after a more thorough toxicity investigation and synthesis standardization.

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