ISSN-print: 2073-0764

ISSN-online: 2959-4340

TuJNaS

Thamar University Journal of Natural & Applied Sciences

A peer-reviewed Scientific Journal

Volume 10

Issue (1)

June 2025

Thamar University Publications

Thamar University Journal of
Natural and Applied Sciences (*TUJNAS*)

Thamar University Journal of Natural & Applied Sciences (TUJNAS) is a peer-reviewed journal. It is an open-access journal published by Thamar University, Dhamar, Yemen twice a year. The aim of the journal is to publish original and review articles in the fields of science, agriculture, engineering, medicine, environment, and computer science. The journal is published in English only.

The journal has the following international standard codes:

ISSN-print: 2073-0764

ISSN-online: 2959-4340

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Volume 10, Issue 1, June 2025

Articles

TuJNaS

Thamar University Journal of Natural & Applied Sciences ***10****(1) (2025) 1– 7*

DOI: https://doi.org/10.59167/tujnas.v10i1.2672

Original Article

Prevalence and Risk Factors for Intestinal Parasitosis among Internally Displaced Yemeni Children in Sana'a City

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Received: 11 January 2025. Received (in revised form): 17 May 2025. Accepted: 24 May 2025. Published: 28 June 2025

Abstract

Objective: This study was conducted as preliminary research to determine the prevalence and risk factors for intestinal parasitosis (IP) among internally displaced Yemeni children (IDYC) in Sana'a city.

Methods: Using a cross-sectional study, a total of 400 children, 210 (52.5%) males and 190 (47.5%) females, aged 1-12 years, with a mean age of 7.9 ± 2.8 years, were recruited from five displaced camps of Sana'a city. Relevant data were enrolled by means of a questionnaire. Single fecal specimens were collected, processed, and examined by direct" saline & Iodine," formol-ether concentration, and modified Ziehl-Neelsen staining techniques for detecting IP.

Results: The overall prevalence of IP was found to be 63.8% (255/400). Infection with protozoa was higher than helminths (42.8% vs. 26.3%, respectively). *G. lamblia* was the most frequently detected protozoan (18.5%), followed by *E. histolytica/ dispar* (16.2%), whereas the coccidia of *Cryptosporidium spp.* and *C. belli* were the lowest (6.8% and 1.2% respectively). *A. lumbricoides* ranked the first helminth (11.2%), followed by *H. nana* (7.8%), while the Hookworm was the lowest (0.3%). Age group of 6-12 years old (AOR=2.7; *P*=0.003), behavioral factors related to not washing hands before meals (AOR=2.0; *P*=0.043) and not trimming nails (AOR=2.5; *P*=0.017) were risk factors "independent predictors" for IP among displaced children.

Conclusion: It can be concluded that the prevalence of IP among internally displaced Yemeni children in Sana'a city is substantial. This was mainly due to protozoa. Age-related demographics and behavioral factors concerning handwashing and nail trimming were the independent-significant risk factors for IP among displaced children.

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Keywords: Intestinal Parasitosis; Prevalence; Risk Factors; Displaced Children; Sana'a

1. Introduction

Intestinal parasites are organisms that can infect the gastrointestinal tract (GIT) of humans and other animals [1]. Such parasites belong to two main groups: protozoa and helminths. Protozoa prevalently include *Entamoeba histolytica*, *Giardia lamblia*, and *Cryptosporidium parvum*, and helminths mainly involve *Hymenolepis nana*, *Enterobius vermicularis*, *Ascaris lumbricoides*, *Trichuris trichiura*, hookworm species, and *Schistosoma mansoni* [1,2]. Humans get infected with these parasites through autoinfection, ingestion of food, drinking of water contaminated with cysts, oocysts, eggs, and/or penetration of skin by infective larvae [3]. Intestinal parasitosis (IP) represents a global health problem, particularly among children in developing countries, leading to morbidity and mortality [4]. IP creates a variety of symptoms in those affected, most of which manifest themselves in general weakness and GIT manifestations. These symptoms comprise abdominal pain, nausea, diarrhea, dysentery, and skin irritation around the anus and vulva [5]. Complications of IP negatively affect nutritional status, including decreased absorption of micronutrients and intestinal blood loss that can often lead to anemia, besides lack of appetite, weight loss, and delayed growth consequences. It may also cause physical and mental disabilities [6]. The infection rate is the highest among children living in the poorest communities of developing nations [7,8]. Yemen is one of the poorest countries in the world. The current war, which began in March 2015, has also exacerbated the situation; 21.6 million Yemenis (two-thirds of the population) are estimated to be under the national poverty line and are dependent on humanitarian assistance. Years of devastating and unrelenting conflict have led to a protection and displacement crisis: more than 4.5 million people have been internally displaced [9]. These people were displaced from their native homes to live in other safe areas like Sana'a city. Internally displaced persons (IDPs) camps become the main shelter for those people [7,10,11]. As a result of poor hygienic conditions and lack of proper sanitation in the camps, many IDPs, particularly children, have become victims of infections, mainly with intestinal parasites [10]. The rate of IP among IDPs could be attributed to a lack of potable water supply and low levels of sanitation and socioeconomic status [11]. The prevalence rate of IP varies considerably from one area to the other according to various risk factors that include sociodemographic, behavioral, and

environmental [12,13]. The profile of IP among Yemeni people has been reported [14]. However, few researchers have dealt with the category of children in Sana'a, and they are missing studies on such a problem and its factors among displaced ones. The objective of this study was to assess the prevalence and risk factors for intestinal parasitosis among internally displaced Yemeni children in Sana'a city.

2. Subjects and Methods

2.1 Study Area, Design, and Population

This study was carried out at Sana'a city, which is made into a separate placement of its own called Amanat Al-Asimah. The city is the capital of Yemen, at an altitude of 2,200 m above sea level and located in the northern part of the country. It covers a surface area of 5,552 km^2 with a population of more than three million [15]. It is administratively divided into ten districts. The study was conducted in five selected districts hosting IDP camps. A cross-sectional study was conducted during October 2020 through October 2021 among 400 IDYC, 210 (52.5%) males and 190 (47.5%) females, aged 1 to 12 years (mean age 7.9 ± 2.84 years), selected randomly from the five districts as the study population. A pre-designed questionnaire administered via face-to-face interview was given to each child or guardian to collect data on the following factors: demographic (age and gender); socio-economic (parents' education status and family size); behavioral (handwashing before meals, handwashing after defecation, wearing shoes on soil, and nail hygiene); and environmental (drinking-water source and sanitation facilities). Data on nail hygiene, either trimmed or non-trimmed, were collected by direct observation. Inclusion criteria were subjects of both genders, aged 1–12 years, residents of the five districts, displaced for six months or longer, and guardian consent. Exclusion criteria were subjects older than 12 years; recent or current anti-parasitic medication; guardian refusal; or guardian unable to confirm age.

2.2 Sample Size and Sampling Method

2.2.1 Sample Size

The required sample size was estimated using a single population proportion standard formula Epi Info software, version 6 (Centers for Disease Control and Prevention, USA), and as per:

$$\boldsymbol{n = \left(z^2 p(1-p)\right)/d^2} \quad (1)$$

where (n) represents the sample size, (z) is the z-score corresponding to the desired confidence level, (d) is the acceptable margin of error (absolute precision), and (p) is the expected prevalence of infection.

The prevalence (p) of IP among internally displaced Yemeni persons was not known, wherefore the p rate was taken to be 50% (0.5). Besides, a 95% confidence interval (z), equivalent to 1.96, and a 5% (0.05) margin of error (d) were used. Therefore: n = $(1.96)^2$ 0.5 (1-0.5)/ 0.05^2. This would minimally give a sample size of 384. With an additional 5% as a potential contingency or as non-responses, the total sample size required was 403. The response rate of children was about 95% of the minimum sample size. In this context, the sample size that could be achieved was four hundred (400), 210 males and 190 females.

2.2.2 Sampling Method

Districts hosting displaced camps are dispersed in Sana'a city. So, a cluster sampling method was followed. It is a multi-stage cluster sampling method that was completed in two stages. 1st stage was the random selection of districts, where five districts were chosen as clusters. 2nd stage was random selection of a limited number of displaced children within each district's camp using a simple random sampling whereby a sampling frame was prepared from the subjects' males & females' enrollment list in each camp, then children were chosen randomly by the lottery method.

2.3 Stool Collection and Examination

Prior to the collection of samples, basic instructions on collection were primarily given and clarified to guardians and children so that every child could place their specimen immediately and directly into the specified cup. Fresh single fecal sample of 5 g was collected from every child in a sterile, labeled, plastic-covered cup, including: "name, number, date of collection, and district's location". All samples were betimes transported to the lab of the Parasitology Department, Faculty of Medicine and Health Sciences, University of Sana'a. Each sample was preserved in 10% formalin, then processed and examined by the following methods of direct wet preparation, using saline and iodine, formol-ether sedimentation, and modified Ziehl-Neelsen stain for diagnosing IP, including coccidian protozoa.

2.4 Wet Mount Method

A drop of normal saline was placed on a clean slide, and a drop of iodine was added too. A small amount of material was taken from the interior and surface of each stool sample. The sample was mixed with saline and iodine using an applicator stick until a suitable thickness of wet mount smear preparation was achieved, whereby a good microscopic contrast and picture were obtained. The smear was then rapidly covered with a coverslip to avert dryness during the time of microscopic examination. The entire smear zone was systematically inspected using the microscopic low-power magnification of the objective 10X and then using the high magnification of the objective 40X. Using 40X, various microscopical fields for each smear were examined prior to deciding the sample as a negative [16].

2.5 Formol-Ether Sedimentation Method

A small part of each fecal sample was taken into a centrifuge tube of 15mL capacity and mixed with 7 mL of 10% formalin-water solution. The sample was sieved through two layers of medical gauze into a wide beaker, and the sieved liquid was poured into a centrifuge tube, and 3mL of ether was added. The sample tube was stoppered, shaken vigorously, and then centrifuged at 1500 rpm for three minutes. Four layers were formed. In ascending order, the layers consisted of a small amount of sediment at the bottom, a layer of formol-water, a plug of fecal debris, and a layer of ether at the top. The plug of debris was separated by moving an applicator stick, and the supernatant was discarded. The sediment was resuspended, and one drop was placed on a clean slide and examined microscopically using the 10X and 40X objectives [16, 17].

2.6 Modified Ziehl-Neelsen Staining Technique

After concentration of fecal specimens in the formol-ether method, a thin smear was prepared from one drop of each fecal sample sediment, and it was fixed in absolute methanol for three minutes. Smear was stained with cold carbol fuchsin for 15 minutes; then the stain was rinsed off in tap water. The smear was decolorized using 3% HCl in 95% ethanol until no more color flooded from the smear. The decolorizer was rinsed off in clean tap water. The smear was counterstained with 0.3% methylene blue for about 30 seconds. The counter stain was rinsed off in tap water and then blotted dry. The smear was examined microscopically using 40X and oil immersion (100X) objectives to identify the oocysts of intestinal coccidian parasites [16]. All samples were examined microscopically for cysts and oocysts of protozoa, and also for eggs and larvae of helminths under a light microscope. Samples were considered positive if cysts, oocysts or eggs and/or larvae were detected by any of the parasitological methods used.

2.7 Statistical Data Analysis

Data was primarily checked for consistency, coded and entered into the computer, and validation was made in Microsoft Excel spreadsheets. The data were then exported to the SPSS version 20.0 program for analysis. In univariate analysis, categorical variables were phrased and expressed in a descriptive pattern as frequencies, whereas continuous variables were expressed in arithmetic mean and standard deviation, and prevalence for IP was listed. Pearson's Chi-square was used to explore the possible association between categorical variables. Odds ratio (OR) was used to explore the potential association between exposure to different independent variables (factors) and the outcome/dependent variable (IP). Bivariate analysis was used to assess the association between each factor and IP. Such a test was basically used to estimate unadjusted "Crude odds ratio (COR or OR)" together with its corresponding 95% CI. Variable(s) showing a statistically significant P-value less than five (<0.05) were entered into a multivariable analysis model. This model was used to identify factors associated with IP. Besides, adjusted odds ratio (AOR) together with its corresponding 95% CI were used to assess the strength of associations. The cutoff value for statistical significance was considered at P-value <0.05.

2.8 Ethical Consideration

Ethical approval was obtained from the Ethical Committee in the Faculty of Medicine and Health Science, Sana'a University. An authorization letter for conducting the study was obtained from the health office of Amanat Al-Asimah, Sana'a. The goal of the work was explained to children and their parents, and informed consent was taken from every.

3. Results

The results showed that 255 displaced children were infected with at least one intestinal parasite, which constituted an overall prevalence of

63.8%. Infections with protozoa were more prevalent (42.8%) than helminths (26.3%) (Table 1 and Figure 1).

Table 1: Prevalence of intestinal parasitosis "including protozoa and helminths" among internally displaced Yemeni children in Sana'a City

Parasitic group	Intestinal Parasitosis	
	No.*	%
Protozoa	171	42.8
Helminths	105	26.3
Total	**255****	**63.8**

*No.: number of infected children; %: percentage of infected children.
**Some children were infected with more than one parasite.

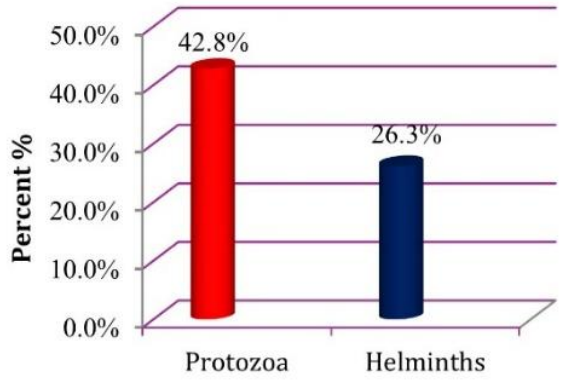

Figure 1: Percentage of infection with protozoa and helminths among internally displaced Yemeni children in Sana'a City (N = 400)

The highest percentage of infection with intestinal protozoa was for *G. lamblia* (18.5%), followed by *E. histolytica/dispar* (16.2%). Infection with *Cryptosporidium species* and *C. belli* represented the lowest percentages (6.8% and 1.2% respectively). The highest percentage of infection with helminths was for *A. lumbricoides* (11.2%), followed by *H. nana* (7.8%). Infection with *S. mansoni*, *E. vermicularis*, *T. trichiura*, *Taenia species,* and Hookworm represented the lowest percentages (2.5%, 1.8%, 1.5%, 1.2%, and 0.3% respectively) (Table 2).

Table 2: Distribution of intestinal parasitosis among internally displaced Yemeni children in Sana'a City according to parasite type

Type of parasite	No.	%
Protozoa*		
Giardia lamblia	74	18.5
Entamoeba histolytica/dispar	65	16.2
Cryptosporidium species	27	6.8
Cystoisospora belli	5	1.2
Helminths*		
Ascaris lumbricoides	45	11.2
Hymenolepis nana	31	7.8
Schistosoma mansoni	10	2.5
Enterobius vermicularis	7	1.8
Trichuris trichuira	6	1.5
Taenia species	5	1.2
Hookworm	1	0.3

No: number of infected children; %: percentage of infected children; *E. coli* was detected in 56(14.0%) of children; *Some children had been infected with more than one parasite.

Children who harbored one parasite 'single infection' accounted for the majority of infected children 240 (94.1%), and 9 (3.5%) were infected with two parasites 'double infection'; however, those who infected with three parasites 'triple infection' represented a minority of them 6 (2.4%) (Table 3).

Table 3: Multiplicity of intestinal parasitosis among internally displaced Yemeni children in Sana'a City

Infection multiplicity	No.	(%)
One parasite*	240	94.1
Two parasites**	9	3.5
Three parasites***	6	2.4
Total	**255**	**100%**

***Single infections:** *G. lamblia* 25.5%, *E. histolytica/dispar* 24.7%, *A. lumbricoides* 16.5%, *H. nana* 11.4%, *Cryptosporidium* spp. 7.8%, *E. vermicularis* 2.7%, *S. mansoni* 2.4%, *T. trichiura* 1.6%, *Taenia* spp. 1.2%, *C. belli* 0.3%. **Double infections** included: *G. lamblia* + *H. nana*, *G. lamblia* + *T. trichiura*, *Cryptosporidium* spp. + *S. mansoni* (each 0.8%); *E. histolytica/dispar* + *S. mansoni*, *Cryptosporidium* + *C. belli*, *S. mansoni* + *Taenia* spp. (each 0.4%). ***Triple infections**: *G. lamblia* + *Cryptosporidium* spp. + *C. belli* (0.8%), *G. lamblia* + *Cryptosporidium* spp. + *A. lumbricoides* (0.4%), *G. lamblia* + *E. histolytica/dispar* + *A. lumbricoides* (0.4%), *G. lamblia* + *A. lumbricoides* + *Taenia* spp. (0.4%), *Cryptosporidium* spp. + *C. belli* + *A. lumbricoides* (0.4%).

The rate of IP among males was slightly higher than that among females (65.7% vs. 61.6% respectively), and the difference between both genders and IP was not statistically significant. Concerning age, the age of children ranged between one and twelve (1 and 12) years. A higher rate of IP was found among children aged 6–12 years (74.7%) than those aged 1– < 6 years (22.6%). The risk of infection was higher in the older group, and the association was statistically significant (OR = 3.3, 95% CI: 1.7 – 6.8; P = 0.001). The percentage of infection was somewhat higher among children whose mothers were non-educated (65.9%) than those whose mothers were educated (59.7%). The association between the mother's education status and IP was not statistically significant (P=0.132). Though in the father's education status, the proportions of infection among children whose fathers were non-educated and educated were convergent (66.7% & 62.2% respectively). Also for family size and crowding index, the rates of infection among children belonged to > 5 group 'more than five family members living in each tent' and those who belonged to ⩽ 5 group 'less than or equal to five family members living in each tent' were convergent (65.1% & 59.8% respectively) (Table 4).

Table 4: Association of socio-demographic factors with intestinal parasitosis among internally displaced Yemeni children in Sana'a City (N = 400)

Variable	No.	IP	*P*-value
		n (%)	
Gender:			
Females	190	117(61.6)	
Males	210	138(65.7)	0.225
Age (years)			
1– < 6	84	19 (22.6)	
6 –12	316	236 (74.7)	0.001*
Mother's education status			
Educated#	139	83(59.7)	
Non educated¥	261	172(65.9)	0.132
Father's education status			
Educated#	259	161(62.2)	
Non educated¥	141	94(66.7)	0.216
Family size*			
≤5 members	102	61(59.8)	
>5 members	298	194(65.1)	0.200

No. : number of examined; n: number of infected; IP: intestinal parasitosis; #Educated: primary, secondary or university; ¥Non educated: illiterate or just read and write;; *Crowding index: a high crowding index was estimated as per the family size and for (> 5 members group) in which more than five family members living in each tent with an approximate size of 4x4 meters.

Infection percentage among children who did not practice handwashing "washing hands" before meals was higher than among those who did (92.4% vs. 36.3% respectively). The association between washing or not washing hands before meals and IP was statistically significant (OR = 2.6, 95% CI: 1.3–4.9; P = 0.010). For washing hands after defecation, the percentage of infection among children who did not practice handwashing "washing hands" after defecation was insignificantly higher than among those who did (73.3% vs. 63.0% respectively; P = 0.175). It was actually

observed that children who had non-trimmed nails were at a higher risk rate of infection than those who had trimmed nails (87.7% vs. 29.3% respectively). The association between nail hygienic status of non-trimmed nails, "non-trimming nails," and IP was statistically significant (OR = 3.1, 95% CI: 1.5 – 6.2; P = 0.001). About wearing shoes when walking on the ground soil or outside, children who did not practice wearing shoes had an insignificantly higher infection rate than those who did (67.2% vs. 60.8% respectively; P = 0.111). children who used unfiltered water as a source of drinking had an insignificant higher percentage of infection than those who used filtered water (64.6% vs. 54.5% respectively; P = 0.168). Infection percentage among subjects who used the unsanitary system was relatively higher than those who used the sanitary system (74.2% vs. 62.9%, respectively), in spite of non-statistically significant association (P = 0.143) (Table 5).

Table 5: Association of behavioral and environmental factors with intestinal parasitosis among internally displaced Yemeni children in Sana'a City (N = 400)

Variable	No.	IP	*P* -value
		n (%)	
Washing hands before meals:			
Yes	204	74(36.3)	0.010*
No	196	181(92.4)	
Nails hygienic status:			
Trimmed	164	48(29.3)	0.001*
Non trimmed	236	207(87.7)	
Wearing shoes when walking on the ground soil or outside:			
Yes	217	132(60.8)	0.111
No	183	123(67.2)	
Source of drinking water:			
Filtered water	33	18(54.5)	0.168
Unfiltered water	367	237(64.6)	
Sewage disposal system:			
Sanitary	369	232(62.9)	0.143
Unsanitary	31	23(74.2)	

Bivariate analysis was conducted for all variables. It was basically used to test, explore, and predict the association of each independent categorical variable with IP. Three variables, "factors (or predictors)," were statistically associated with infection. That indicated, the prevalence of IP or risk of infection among children increased with 2.6 to 3.3 times due to the association of the following: age group of 6–12 years old (OR = 3.3, 95% CI: 1.7–6.8; P = 0.001), not washing hands before meals (OR = 2.6, 95% CI: 1.3 – 4.9; P=0.010) and not trimming nails (OR = 3.1, 95% CI: 1.5 – 6.2; P = 0.001) (Table 6).

A multivariable analysis was used to adjust and identify the most significant risk factors or independent predictors associated with IP. After adjustment, it was confirmed that, age group of 6–12 years old (AOR = 2.7, 95% CI: 1.4 – 5.2; P = 0.003); not washing hands before meals (AOR=2.0, 95% CI: 1.1 – 3.5; P = 0.043) and not trimming nails (AOR = 2.5, 95 % CI: 1.2–4.4; P=0.017) were the independent predictors that statistically associated with infection (Table 7).

4. Discussion

Results of the current study were discussed with reference to the existing literature as much as possible; the required literature was cited to present either a convergence or a divergence in view of the explanation and interpretation of these results. In general, the results have been discussed with much support from the literature. Eventually, the inferences emerging from the discussion were also presented [18].

The findings of the present study indicated that the prevalence of IP was high and can be considered a health problem. Such inference was evident from Table 1, wherein the overall prevalence of pathogenic IP among internally displaced Yemeni children in Sana'a city was 63.8%. A nearly similar rate (63.0%) was reported from a previous study conducted among displaced subjects in Sudan [13]. This is somewhat consistent with another study carried out in Pakistan (65.3%) [7]. A high prevalence rate of IP in this study could be attributed to many factors including: environmental faecal contamination, poverty, poor quality of life and poor personal hygiene of children as well as lack of safe water supply, illiteracy and overcrowding, all of the above-mentioned factors were behind the high rate of IP [7,13]. Further, a much higher rate of 79.5% was reported from Nigeria [11]. In contrast, lower prevalence rates of 17.0%, 21.8%, and 20.6% were documented from Sudan [19], Nigeria [20], and Italy [21], respectively. A much lower rate of 5.8% was reported from Iraq [22]. The rates of IP may have differed according to multiple factors: type of study, hospital or community-based, demographic, socioeconomic, sanitary, and environmental conditions. On top of that, the parasitological techniques applied in each study could affect the results [23].

Table 6: Bivariate analysis of factors associated with intestinal parasitosis among internally displaced Yemeni children in Sana'a City (N = 400)

Variable	No.	IP	OR (95% CI)	*P*-value
		n (%)		
Gender:				
Females	190	117(61.6)	R	
Males	210	138(65.7)	1.2(0.8–1.8)	0.225
Age (years):				
1– < 6	84	19 (22.6)	R	
6 –12	316	236 (74.7)	3.3(1.7–6.8)	0.001*
Mother's education status:				
Educated	139	83(59.7)	R	
Non educated	261	172(65.9)	1.3(0.9–2.0)	0.132
Father's education status:				
Educated	259	161(62.2)	R	
Non educated	141	94(66.7)	1.2(0.8–1.9)	0.216
Family size*:				
≤5 members	102	61(59.8)	R	
>5 members	298	194(65.1)	1.3(0.8–2.0)	0.200
Washing hands before meals:				
Yes	204	74(36.3)	R	
No	196	181(92.4)	2.6(1.3–4.9	0.010*
Washing hands after defecation:				
Yes	370	233(63.0)	R	
No	30	22(73.3)	1.6(0.7–3.7)	0.175
Nails hygienic status:				
Trimmed	164	48(29.3)	R	
Non trimmed	236	207(87.7)	3.1(1.5–6.2)	0.001*
Wearing shoes when walking in the ground soil:				
Yes	217	132(60.8)	R	
No	183	123(67.2)	1.3(0.9–2.0)	0.111
Source of drinking water:				
Filtered water	33	18(54.5)	R	
Unfiltered water	367	237(64.6)	1.5(0.7–3.1)	0.168
Sewage disposal system:				
Sanitary	369	232(62.9)	R	
Unsanitary	31	23(74.2)	1.7(0.7–3.9)	0.143

No.: number of examined; n: number of infected; IP: intestinal parasitosis; non trimmed nails as a hygienic status was considered as one behavior of this study and it was named "not trimming nails"; OR: odds ratio; CI: confidence interval; R: reference category; *significant association (*P* < 0.05).

Table 7: Multivariable analysis of factors associated with intestinal parasitosis among internally displaced Yemeni children in Sana'a City (N = 400)

Variable	IP		
	AOR	95% CI	*P*- value
Age group of 6–12 years old	2,7	1.4–5.2	0.003*
Not washing hands before meals	2.0	1.1–3.5	0.043*
Not trimming nails	2.5	1.2–4.4	0.017*

IP: intestinal parasitosis; non-trimmed nails as a hygienic status was considered as one behavior of this study, and it was named "not trimming nails"; AOR: adjusted odds ratio; CI: confidence interval; *significant association (P< 0.05).

In the present study, intestinal protozoa were more prevalent than helminths (42.8% vs. 26.3%, respectively). Intestinal protozoan parasites are considered to be directly transmitted from one child to another via the faeco-oral route, contributing to the high rate of infection because of poor hygiene, close contact, and overcrowding. Infection with these protozoa occurs without the need for an external cycle or intermediate host. Discharge of infective cysts in stool results in environmental contamination, whereby such cysts are ingested by another host [13]. Nevertheless, helminths (excluding principally *Hymenolepis nana* and *Enterobius vermicularis*) are considered indirectly transmitted parasites.

These helminths require certain environmental conditions of soil, climate, intermediate host, and factors that would limit their spread [24]. The helminth passes its oval stage in the stool of an infected individual, and this stage needs an external cycle or growth period in an intermediate host or environment to be infective and transmitted to a susceptible person [25]. Immature eggs of STHs, such as *Ascaris lumbricoides*, *Trichuris trichiura*, and *Ancylostoma duodenale*, require proper environmental conditions, including temperature, humidity, shade, etc., to develop in soil either into infective eggs or larvae [24]. Also, the oval stage of *Schistosoma mansoni* necessitates a snail as an intermediate host to grow into an infective cercarial stage. For the above-mentioned clarification, the probability of infection with protozoa might be higher than with helminths [22].

As for the protozoa in the present results, *Giardia lamblia* was the most prevalent (18.5%), followed by *Entamoeba histolytica/dispar* (16.2%). A comparable order was reported from Sudan [13]. Anywise, infection percentages vary according to several factors. Socio-economic, sanitary and environmental conditions are among the most common contributing factors [13,10]. Consistent with the present findings, the rate of *G. lamblia* was reported from Iraq (17.5%) [22]. A higher rate of 59.8% was documented from Nigeria [26]. In contrast, lower rates of *G. lamblia* were reported from other studies: 1.1% in Nigeria [11] and 2.5% in Italy [21].

In the present study, *E. histolytica/dispar* was detected in 16.2%. This is in agreement or somewhat lower compared with 14.3% and 23.5% from Sudan and Nigeria respectively [11,13]. Further, much higher rates (69.9% and 67.9%) were recorded from Iraq and Nigeria respectively [22,26]. According to this study, infection with *E. histolytica/dispar* was high and it was the second intestinal parasite detected after *G. lamblia*. It is worth mentioning that prevalence estimates of *E. histolytica* are variable and that non-pathogenic strains—mainly *E. dispar*, and to a lesser extent *E. hartmanni*—could lead to overestimation of rates [27]. Identification of such strains may require more specific and sensitive methods and use of strain-specific immuno-molecular testing [28]. In contrast, a lower rate of *E. histolytica/dispar* (6.0%) was reported from Pakistan [7]. Moreover, much lower rates (0.4% and 1.7%) were documented from Sudan and Iraq respectively [19,29].

In the current findings, infection with the coccidian *Cryptosporidium* spp. was 6.8%. A much higher rate of 16.3% was reported from Iraq [30]. However, a later study in the same country revealed a lower rate of 1.4% [29]. *Cystoisospora belli* was another coccidian detected in this study, at 1.2%. A nearly similar rate (1.6%) was reported from Nigeria [26]. An extremely lower rate (0.1%) was recorded from Iraq [30]. According to this study, infections with *Cryptosporidium* spp. and *C. belli* represented the lowest percentages of protozoa detected. These protozoa have been documented as opportunistic parasites, more prevalent in immunocompromised individuals [31-33].

Concerning helminths in the present results, infection percentages for *A. lumbricoides*, *T. trichiura* and hookworm (STHs) were 11.2%, 1.5%, and 0.3%, respectively. In accordance with this study, 11.2% of children were infected with *A. lumbricoides*. Higher rates (18.0% and 19.7%) were reported from Pakistan and Nigeria respectively [7,11]. A much higher rate (34.2%) was documented from Nigeria [26]. Conversely, a lower rate of 5.5% was found in another previous study from Nigeria [20].

In our findings, *T. trichiura* was detected at 1.5%. This was supported by a study in Colombia, which reported 2.1% [10]. Much lower rates of 0.2%, 0.5% and 0.3% were documented from Sudan, Nigeria and Italy respectively [19-21]. On the other hand, a higher rate of 17.9% was reported from Nigeria [26]. In the present work, the rate of *T. trichiura* was relatively low compared to other studies. This may be attributable to climatic and/or hygienic practice differences [10,26].

Hookworm infection in the current results was detected in one case only (0.3%). A nearly similar rate (0.2%) was reported from Iraq. A slightly higher rate (1.6%) was recorded from Italy [21]. A higher rate of 6.1% was reported from Nigeria [11], and another Nigerian study reported 32.1% [26]. In this study, the rate of hookworm was the lowest; *Strongyloides stercoralis* larvae were absent, which was not unexpected since the Harada–Mori method was not used to detect hookworm or *S. stercoralis* larvae [10,29].

In current findings, infection rate with *Hymenolepis nana* was 7.8%. A comparable rate (5.3%) was reported from Sudan [13]. However, higher rates of 32.6% and 15.0% were documented from Nigeria and Pakistan respectively [20,7]. Moreover, an extremely high rate (95.7%) was reported from Sudan [36]. In contrast, lower rates of 0.6% and 1.7% were presented from Colombia and Italy respectively [10,21]. *H. nana* is considered a directly transmitted parasite; in this study, the lifestyle of displaced children may explain this. Living in such conditions perhaps increases spread of this parasite [11,34].

No data about participants' original residence (urban or rural) was collected—among the study's limitations. The infection rate of *S. mansoni* was 2.5% among children who likely emigrated from rural areas. They probably acquired infection through swimming in canal or pond water infested with schistosome cercariae [35]. Lower rates (0.7% and 1.1%) were recorded from Sudan and Italy, respectively [13,21]. In contrast, a higher rate of 22.0% was reported from Nigeria [11].

Regarding *Taenia* species, high rates were reported from Sudan and Pakistan (2.9% and 9.0%) [36,7]. This disagrees with present findings, where *Taenia* species eggs were detected in five cases (1.2%). This low rate is consistent with a Nigerian study (1.1%) [11]. Lower rates of 0.6% and 0.9% were reported in Italy and Iraq respectively [21,22]. Tapeworm infection is transmitted by eating undercooked meat. Yemeni families usually cook food well, which may explain the low infection rate in this study [37]. For *E. vermicularis*, infection rate was clearly low. One limitation was not using Scotch tape to diagnose enterobiasis [10,22].

The results showed that 94.1% of infected children had one parasite; 3.5% had two; 2.4% had three. Previous studies show that multiplicity of parasitic infections in children depends on socioeconomic factors including education and income [38,10,25]. One Nigerian study reported 50.8% with single parasite infection, 29.5% double, and 18.2% triple infection; this mirrors low socioeconomic conditions [11].

The current study also assessed socio-demographic and behavioral factors associated with IP. Age group 6–12 years was an independent predictor of infection (AOR = 2.7) vs. 1–< 6 years ($p < 0.05$). The likelihood of infection increased with age, possibly due to more outdoor activity and poor hygiene practices—consistent with studies from Italy and Iran [38,25], but conflicting with reports from Sudan, Peru, and Ethiopia [19,39,40]. Conversely, lower infection rates in younger children may be due to limited mobility and exposure [38].

Behavioral factors: not washing hands before meals was a significant predictor (AOR = 2.0), supporting findings from previous studies [13,7]. Contaminated hands facilitate transmission of *G. lamblia*, *E. histolytica*, and *H. nana* [11]. However, inconsistent associations were found in other studies [36,11]. Washing hands after defecation showed no significant association—potentially due to self-reporting bias [41].

Not trimming nails was the second independent predictor (AOR = 2.5). Children with non-trimmed nails had 2.5 times higher infection risk than those with trimmed nails—consistent with a study from Ethiopia [40]. Fingernail hygiene is important since *G. lamblia*, *E. histolytica* cysts, and *H. nana* eggs can survive under nails [42]. This contradicts some studies reporting no significant association [10].

Some socio-demographic, behavioral, and environmental variables showed no association with IP—possibly due to limitations of the study design and self-report biases [41]. Data analysis models can identify associations but not causation [41]. These findings align with some studies from Ethiopia [40] and conflict with others from Sudan [36].

5. Limitations of the Study

The present work undoubtedly shares all the limitations of a cross-sectional study design. In this context, social–desirability bias was a potential for self-reported responses. In addition, the study research is based on secondary information from the internet, books, journals, and different websites. Contextually, there was a limitation in collecting and citing considerable references because previous displacement-based studies were very scarce, there was also a block in undertaking and examining direct wet mount in the camps, and a barrier in proceeding with scotch adhesive tape for correct and actual diagnosis of enterobiasis among children. Besides, there are a lot of challenges, especially resources and constraints, that obstacle of performing more specific and sensitive techniques for the real and exact pinpointing of IP rate.

6. Conclusion

It can be concluded that the prevalence of IP among internally displaced Yemeni children in Sana'a city is decisive and conclusive; age-related demographics and behavioral factors concerning handwashing and nails trimming were the independent-significant risk factors for IP among displaced children. This study is a primarily "timely primal" report on enteric parasites in internally displaced Yemeni children.

Data Availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical Approvals

This study was approved by the Institutional Review Board of the Ethics Committee at the Faculty of Medicine and Health Sciences, Sana'a University, Yemen (Approval No. REC-48-2021). All procedures were conducted in accordance with the ethical standards outlined in the Declaration of Helsinki.

Subject Consent

Verbal informed consent was obtained from the parents or legal guardians of all participating children after a full explanation of the study's purpose and procedures. Participation was voluntary, and consent was reaffirmed prior to data collection. All collected data were anonymized and used solely for research purposes.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

SAQ conceived the research idea, designed the study protocol, collected and analyzed the data, interpreted the findings, and drafted the manuscript. SAQ supervised the overall project.

Acknowledgments

The first author sincerely thanks the participants, their parents, and the authorities of displaced persons in Sana'a city for their cooperation during fieldwork, including the collection of data and samples for this study. Finally, she would also like to express her sincere gratitude to the technicians at the Department of Medical Parasitology, Faculty of Medicine and Health Sciences, Sana'a University, for their encouragement and assistance during the implementation of the practical aspects of this study.

References

[1] Tamomh, A.G., Ali, M.O., Walana, W., Mohammed, N.M., Hassan, I.M., Hamed, M.E., Alkab, M.J., Mohammed, G.I., Albashir, E.A., Mahmoud, R.O., Ahmed, M.S. (2025) Intestinal Parasitic Infections and Associated Risk Factors Among Children in an Internally Displaced Center (IDC) in Kosti City of the White Nile State, Sudan, *Journal of Parasitology Research* **2025**: 5542680.

[2] Shetty, A.K. (2019) Infectious diseases among refugee children, *Children* **6**: 129.

[3] Amuta, E., Iboyi, M., Ajangem, S. (2017) A comparative study of gastrointestinal parasites among secondary school students in the rural and urban communities of Makurdi local government, *International Journal of Tropical Disease & Health* **25**: 1-9.

[4] Butera, E., Mukabutera, A., Nsereko, E., Munyanshongore, C., Rujeni, N., Mwikarago, I.E., Moreland, P.J., Manasse, M.N. (2019) Prevalence and risk factors of intestinal parasites among children under two years of age in a rural area of Rutsiro district, Rwanda–a cross-sectional study, *Pan African Medical Journal* **32**: 1-9.

[5] Hartati, H., Destriani, D., Victoria, A.R. (2018) Worm Disease Profile of Primary School Children. IOP Conference Series: Materials Science and Engineering, **296**: *IOP Publishing*, pp. 012009.

[6] Al Saadawy, A.S., Al Karyony, I.M., Bayoumy, A.M., Abd El Raheem, M.A., Hashim, A.H.A. (2018) Parasitic profile among primary school children in a rural area at Beheira Governorate, Egypt, *The Egyptian Journal of Hospital Medicine* **70**: 2042-2049.

[7] Ahmed, W., Ahmad, M., Shah, F. (2015) Pervasiveness of intestinal protozoan and worm incursion in IDP's (North Waziristan agency, KPK-Pakistan) children of 6-16 years, *JPMA. The Journal of the Pakistan Medical Association* **65**: 943-945.

[8] WHO (2023) *Soil-transmitted helminth infections*, [Fact sheet], World Health Organization (WHO), https://www.who.int/news-room/fact-sheets/detail/soil-transmitted-helminth-infections (accessed December 2024).

[9] UNICEF (2017) *Falling through the cracks: The children of Yemen*, United Nations International Children's Emergency Fund (UNICEF), https://www.unicef.org/yemen/reports/falling-through-cracks-children-yemen?utm_source=chatgpt.com (accessed October 2024).

[10] Bouwmans, M.C., Gaona, M.A., Chenault, M.N., Zuluaga, C., Pinzón-Rondon, Á.M. (2016) Prevalence of intestinal parasitic infections in preschool-children from vulnerable neighborhoods in Bogotá, *Revista de la Universidad Industrial de Santander. Salud* **48**: 178-187.

[11] Ayuba, K., Oti, V., Okwoli, A., Ioannou, M., Chindo, I. (2019) High prevalence of human gastrointestinal parasitic infections in an Internally Displaced Persons (IDPs) camp in Nasarawa State, Nigeria: a cross-sectional study, *South Asian Journal of Parasitology* **3**: 1-8.

[12] Faria, C.P., Zanini, G.M., Dias, G.S., da Silva, S., de Freitas, M.B., Almendra, R., Santana, P., Sousa, M.d.C. (2017) Geospatial distribution of intestinal parasitic infections in Rio de Janeiro (Brazil) and its association with social determinants, *PLoS Neglected Tropical Diseases* **11**: e0005445.

[13] El-Mekki, M.A., Abd Elmajed, H.E., Elhassan, M.M. (2014) Prevalence rate of intestinal parasites with interaction of other factors among displaced people in Khartoum state, *Journal of Natural and Medical Sciences* **15**: 53-59.

[14] Qasem, E.A., Edrees, W.H., Al-Shehari, W.A., Alshahethi, M.A. (2020) Frequency of intestinal parasitic infections among schoolchildren in Ibb city-Yemen, *Universal Journal of Pharmaceutical Research* **5**: 42-46.

[15] United Nations Statistics Division (2020) *Demographic Yearbook 2020*, United Nations, Department of Economic and Social Affairs, https://unstats.un.org/unsd/demographic-social/products/dyb/ (accessed December 2024).

[16] Cheesbrough, M. (2005) District laboratory practice in tropical countries, part 2, ed., *Cambridge University Press*, Cambridge, UK, pp. 200-208.

[17] Ritchie, L.S. (1948) An ether sedimentation technique for routine stool examinations, *Bulletin of the United States Army Medical Department* **8**: 326.

[18] Kamimura, T. (2014) Citation Behaviors Observed in Japanese EFL Students' Argumentative Writing, *Journal of Pan-Pacific Association of Applied Linguistics* **18**: 85-101.

[19] Mohamed, M.M., Ahmed, A.I., Salah, E.T. (2009) Frequency of intestinal parasitic infections among displaced children in Kassala Town, *Khartoum Medical Journal* **2**: 175 - 177.

[20] Hamidu, I., Habiba, J., Nathan, D., Saleh, A., Mohammed, A., Kankop, W. (2016) Incidence of intestinal parasites among internally displaced persons (IDPs) in Maiduguri, Borno State, *International Journal of Applied Research* **2**: 220-224.

[21] Sulekova, L.F., Ceccarelli, G., Pombi, M., Esvan, R., Lopalco, M., Vita, S., Mattiucci, S., Gabrielli, S., Bellanca, G., Cavallari, E.G., Gangarossa, G., Kehbuma Dinga, C., Spaziante, M., Amato, E., Bujor, M., Dimitrova, E., Durante, D., Pereda Figueroa, G., Pinna, N., Velez, L., Walter, I. (2019) Occurrence of intestinal parasites among asylum seekers in Italy: A cross-sectional study, *Travel Medicine and Infectious Disease* **27**: 46-52.

[22] Hassan, A., Mero, W. (2020) Prevalence of intestinal parasites among displaced people living in displacement camps in Duhok Province/Iraq, *The Internet Journal of Microbiology* **17**: 1–8.

[23] Hussein, A.H., Rashed, S.M., El-Hayawan, I.A., Aly, N.S., Abou Ouf, E.A., Ali, A.T. (2017) Intestinal parasite infections and accuracy of direct thin and thick smear, formol-ether sedimentation, centrifugal flotation, and mini-FLOTAC techniques among patients with gastrointestinal tract disorders from the Greater Cairo region, Egypt, *The American Journal of Tropical Medicine and Hygiene* **96**: 589–594.

[24] Taher, H.M. (2017) Soil contamination with intestinal parasites eggs in public parks and playgrounds in Kirkuk city, *Tikrit Journal of Pure Science* **22**: 52-55.

[25] Mesgarian, F., Sofizadeh, A., Shoraka, H.R., Rahimi, H.R., Hesari, A., Soheili, N., Badiei, F. (2017) Prevalence of Intestinal Parasite Infections among Children in the Day Care Centers of Gonbad-e Kavus County, North-Eastern Iran, *Zahedan Journal of Research in Medical Sciences* **19**: e11633.

[26] Edosomwan, E.U., Evbuomwan, I.O., Agbalalah, C., Dahunsi, S.O., Abhulimhen-Iyoha, B.I. (2020) Malaria coinfection with neglected tropical diseases (NTDs) in children at internally displaced persons (IDP) camp in Benin city, Nigeria, *Heliyon* **6**: e04604.

[27] Villamizar, X., Higuera, A., Herrera, G., Vasquez-A, L.R., Buitron, L., Muñoz, L.M., Gonzalez-C, F.E., Lopez, M.C., Giraldo, J.C., Ramírez, J.D. (2019) Molecular and descriptive epidemiology of intestinal protozoan parasites of children and their pets in Cauca, Colombia: a cross-sectional study, *BMC infectious diseases* **19**: 1-11.

[28] Cheepsattayakorn, A., Cheepsattayakorn, R. (2014) Parasitic Pneumonia and Lung Involvement, *BioMed Research International* **2014**: 1-18.

[29] Salman, Y.J., Al-Taee, A.-R.A., Abid, A.M. (2016) Prevalence of *Giardia lamblia* among Iraqi displaced peoples in Kirkuk Province, *International Journal of Current Microbiology and Applied Sciences* **5**: 753-60.

[30] Salman, Y.J., Sadek, W.S., Rasheed, Z.K. (2015) Prevalence of *Cryptosporidium parvum* among Iraqi displaced people in Kirkuk city using direct microscopy, flotation technique and ELISA-copro antigen test, *International Journal of Current Microbiology and Applied Sciences* **4**: 559-572.

[31] Sow, S.O., Muhsen, K., Nasrin, D., Blackwelder, W.C., Wu, Y., Farag, T.H., Panchalingam, S., Sur, D., Zaidi, A.K., Faruque, A.S. (2016) The burden of *Cryptosporidium* diarrheal disease among children< 24 months of age in moderate/high mortality regions of sub-Saharan Africa and South Asia, utilizing data from the Global Enteric Multicenter Study (GEMS), *PLoS Neglected Tropical Diseases* **10**: e0004729.

[32] Wang, Z.-D., Liu, Q., Liu, H.-H., Li, S., Zhang, L., Zhao, Y.-K., Zhu, X.-Q. (2018) Prevalence of *Cryptosporidium*, microsporidia and *Isospora* infection in HIV-infected people: a global systematic review and meta-analysis, *Parasites & Vectors* **11**: 28.

[33] Khan, A., Shams, S., Khan, S., Khan, M.I., Khan, S., Ali, A. (2019) Evaluation of prevalence and risk factors associated with *Cryptosporidium* infection in rural population of district Buner, Pakistan, *PLoS One* **14**: e0209188.

[34] Herrick, J.A., Nordstrom, M., Maloney, P., Rodriguez, M., Naceanceno, K., Gallo, G., Mejia, R., Hershow, R. (2020) Parasitic infections represent a significant health threat among recent immigrants in Chicago, *Parasitology Research* **119**: 1139-1148.

[35] Kuete, T., Yemeli, F.L.S., Mvoa, E.E., Nkoa, T., Somo, R.M., Ekobo, A.S. (2015) Prevalence and risk factors of intestinal helminth and protozoa infections in an urban setting of Cameroon: the case of Douala, *American Journal of Epidemiology and Infectious Disease* **3**: 36-44.

[36] Eljack, I.(2015) *Prevalence and associated risk factors of Intestinal Helminths infections among pre-school children (1 to 5 years old) in IDPs settlements of Khartoum state, Sudan*. https://www.researchgate.net/publication/307138777_Prevalence_and_Associated_Risk_Factors_of_Intestinal_Helminth_Infections_Among_PreSchool_Children_1_To_5_Years_Old_in_IDPs_Settlements_of_Khartoum_State_Sudan/citations

[37] Best-Country.com (2019) Yemen food, *Short information*, Web Resource https://www.best-country.com/en/asia/yemen/food, (10 December 2024)

[38] Manganelli, L., Berrilli, F., Di Cave, D., Ercoli, L., Capelli, G., Otranto, D., Giangaspero, A. (2012) Intestinal parasite infections in immigrant children in the city of Rome, related risk factors and possible impact on nutritional status, *Parasites & Vectors* **5**: 265.

[39] Bailey, C., Lopez, S., Camero, A., Taiquiri, C., Arhuay, Y., Moore, D.A.J. (2013) Factors associated with parasitic infection amongst street children in orphanages across Lima, Peru, *Pathogens and Global Health* **107**: 52-57.

[40] Abebaw, A., Alemu, G., Ayehu, A. (2020) Prevalence of intestinal parasites and associated factors among children from child centres in Bahir Dar city, northwest Ethiopia, *Tropical Doctor* **50**: 194-198.

[41] Puhan, M.A., Akl, E.A., Bryant, D., Xie, F., Apolone, G., Riet, G.t. (2012) Discussing study limitations in reports of biomedical studies- the need for more transparency, *Health and Quality of Life Outcomes* **10**: 23.

[42] Alo, M., Ugah, U., Elom, M. (2013) Prevalence of intestinal parasites from the fingers of school children in Ohaozara, Ebonyi State, Nigeria, *American Journal of Biological, Chemical and Pharmaceutical Sciences* **1**: 22-27.

TuJNaS

Original Article

Thamar University Journal of Natural & Applied Sciences ***10****(1) (2025) 8– 11*

DOI: https://doi.org/10.59167/tujnas.v10i1.2673

Changes in Udder Compartments (Alveolar and Cisternal) Depending on Lactation Stage and Parity in Crossbred Cows

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Received: 2 January 2025. Received (in revised form): 3 April 2025. Accepted: 22 June 2025. Published: 28 June 2025.

Abstract

This study investigates morphological and compositional variations in the mammary gland of crossbred dairy cows, with specific attention to the udder cisterns and alveoli across different stages of lactation and parities. The primary objectives were: (1) to assess the dimensional changes in the udder cisterns and alveoli in relation to lactation stage and parity, and (2) to analyze variations in milk composition within the cisternal and alveolar compartments. Twenty-eight crossbred dairy cows, comprising both primiparous and multiparous individuals, were evaluated across three distinct lactation phases: early (1–3 months), mid (4–6 months), and late (7 months to drying off). The investigation spanned an 11-month period from January to November 2022. Milk samples from the udder and teat cisterns were analyzed using thermogravimetric methodology.

Findings revealed that cisternal milk constituted approximately 31.35–31.95% of total udder milk in both primiparous and multiparous cows. In contrast, the alveolar compartments in multiparous and primiparous cows contributed up to 70% and 72% of total milk fat, respectively ($P < 0.05$). Notably, no statistically significant differences ($P > 0.05$) were observed in average fat, protein, lactose, and solids-not-fat (SNF) percentages between the cisternal and alveolar compartments in primiparous cows. Cisternal milk volume increased during early and mid-lactation but declined in late lactation, whereas alveolar milk volume demonstrated an inverse trend. A significant decrease of 18% ($P < 0.05$) in alveolar milk volume was observed from early to late lactation, with no further reduction noted from mid to late stages. Cisternal milk volume remained stable from early to mid-lactation but declined by 16% ($P < 0.05$) in the late phase.

In conclusion, the crossbred dairy cows exhibited favorable udder morphology, characterized by medium-sized cisterns and teats, suggesting suitability for mechanical milking. Multiparous cows showed superior performance in both cisternal and alveolar milk yield compared to primiparous counterparts. These findings underscore the productive potential of crossbred cows, although enhancements in nutritional management are recommended to optimize milk composition. Further investigations with larger sample sizes are warranted to substantiate these preliminary observations.

Keywords: Cisternal; Alveolar; Stage lactation; Milk fraction; Crossbreed cow

1. Introduction

Milk storage within the bovine udder is commonly conceptualized through a two-compartment model, comprising the cisternal and alveolar regions [1,2]. The cisternal compartment encompasses the large ducts, gland cisterns, and teat cisterns, while the alveolar compartment refers to milk secreted and retained within the small ducts and alveoli. Species-specific differences in the proportional distribution of milk between these compartments have been well documented. In dairy cows, less than 30% of the total milk volume is typically stored in the cisternal region [3], whereas in dairy goats, this figure ranges between 57% and 88% [4]. Among sheep, the proportion exceeds 50% in dairy breeds [5,6] but falls below 30% in meat breeds [7], following conventional milking intervals of 8 to 16 hours.

The compositional characteristics of milk are significantly influenced by its site of storage within the udder. Numerous studies have indicated that the relative distribution of cisternal and alveolar milk fractions fluctuates depending on the milking interval [3,8]. The hormone oxytocin (OTH) plays a pivotal role in facilitating milk ejection, primarily by inducing the contraction of myoepithelial cells encasing the alveoli, thereby promoting the transfer of alveolar milk into the cistern [9,10]. An understanding of how lactation stage and parity affect the volume of the cisternal compartment is essential, particularly in light of the milk yield

losses that may occur during the interval between milk ejection and complete evacuation. Prolonging milking intervals has been proposed as a strategy to enhance the efficiency of milk removal and to stimulate additional milk synthesis.

Accordingly, the present study aims to: (1) examine morphological changes in the size of udder cisterns and alveoli across different lactation stages and parities, and (2) evaluate the compositional differences in milk collected from the alveolar and cisternal compartments in crossbred dairy cows.

2. Materials and Methods

2.1 Animals and Management

This study was conducted at the University of Khartoum Educational Farm using twenty-eight crossbred dairy cows maintained under uniform nutritional and managerial conditions. The experimental cohort included cows at varying parities: twelve primiparous cows (six in their first lactation and six in their second), and sixteen multiparous cows (eight in their sixth lactation and eight in their seventh). All animals were categorized into three lactation stages: early (1–3 months postpartum, *n* = 28), mid (4–6 months, *n* = 28), and late (7–9 months, *n* = 28). The observational period spanned 11 months, from January to November 2022.

2.2 Experimental Procedures

A completely randomized design (CRD) was employed to assess the effects of parity and lactation stage. Measurements of cisternal and alveolar milk volumes were performed at 12:00 PM, approximately 12 hours after the morning milking session, to ensure clear differentiation between milk compartments [11,12]. To inhibit premature milk ejection and thereby avoid overestimation of cisternal milk volume, cows were intravenously administered Atosiban at a dosage of 10 µg/kg body weight, an oxytocin receptor antagonist, in line with the protocol described by [14].

Cisternal milk was subsequently extracted from each quarter using a sterile teat cannula (10 cm in length), and its volume was recorded. Ten minutes following the cisternal milk removal, each cow received an intravenous injection of oxytocin (10 IU) to negate the effects of Atosiban and stimulate the ejection of alveolar milk. Alveolar milk was then manually collected and measured. For each udder quarter, milk fractions were weighed individually, and a 50 mL representative sample was collected and preserved for laboratory analysis.

2.3 Milk Composition Analysis

Milk samples were transferred to the Dairy Laboratory of the Department of Dairy Production, College of Animal Production (Shambat), where they were analyzed using a Milko Scan ultrasonic analyzer. Prior to testing, the 50 mL milk samples were equilibrated to room temperature and homogenized to prevent stratification of milk fat. The analyzer provided digital readings for key compositional parameters, including fat, protein, lactose, solids-not-fat (SNF), and density.

2.4 Statistical analysis

Data were subjected to analysis using the General Linear Model (GLM) framework as specified below:

$$\tilde{\varepsilon}_{ijl} = \mu + a_i + b_j + \varepsilon_{ijl}$$

where μ represents the general mean, a_i is the effect of parity (primiparous or multiparous), b_j is the influence of stage lactation (early, mid, and late), and ε_{ijl} is the random error term. Differences between treatment means were evaluated using Duncan's multiple range test, with statistical significance determined at $P < 0.05$ [15].

3. Results and Discussion

The findings of this study revealed no statistically significant effect of parity ($P > 0.05$) on cisternal size, cisternal milk percentage, alveolar size, or alveolar milk percentage in crossbred dairy cows (Table 1). On average, cisternal milk constituted approximately 31.35–31.67% of total udder milk, regardless of parity.

These results align with earlier studies reporting minimal influence of parity on cisternal milk yield and its proportional contribution to total udder milk. For instance, [15] observed that cisternal milk fractions tend to be lower in primiparous cows, while multiparous cows typically exhibit increased cisternal volumes and yield. Similarly, [16] documented that primiparous cows demonstrated reduced cisternal milk output and proportion, corroborating the present study's findings.

The physiology underlying these observations may be attributed to the structural development of the udder over successive lactations. Cows with relatively smaller cisternal capacity experience faster filling, which increases intramammary pressure. This, in turn, can exert a suppressive effect on alveolar milk secretion, as reported by [17]. Consequently, cows with smaller cisterns often exhibit a more pronounced milk yield response to increased milking frequency (e.g., thrice-daily milking) than those with larger cisternal reservoirs [18], likely due to the alleviation of inhibitory pressure on the alveolar tissue.

Table 1: Effect of parity on cisternal and alveolar milk volumes and composition in crossbred dairy cows.

Traits	Cistern		Alveolar	
	Multiparous	Primiparous	Multiparous	Primiparous
Milk production, (L/AM)				
Milk volume-12h, L	1.74±0.05[b]	1.42±0.05[b]	3.75±0.09[a]	3.08±0.10[a]
Milk volume-12h, %*	31.64[b]	31.67[b]	68.36[a]	68.38[a]
Milk compositions (%)				
Fat	2.89±0.27[b]	2.54±0.23[b]	7.04±0.50[a]	7.27±0.43[a]
Protein	3.69±0.11	3.56±0.09	3.22±0.06	3.64±0.05
Lactose	5.03±0.08	4.97±0.07	4.48±0.09	4.54±0.08
SNF	9.39±0.16	9.24±0.14	8.67±0.20	8.49±0.18
Density	33.54±0.56[a]	33.36±0.48[a]	28.68±0.88[b]	27.66±0.76[b]

[a,b] Means in the same row within each period carrying different superscripts differ ($p < 0.05$). *Percentage values transformed to arcsine before statistical analysis. SNF: non-fat souled.

The results of this study demonstrated that parity did not exert a statistically significant effect ($P > 0.05$) on the relative distribution of cisternal and alveolar milk volumes in crossbred dairy cows (Table 1). On average, cisternal milk comprised approximately 31.64–31.67% of total udder milk, while alveolar milk accounted for 68.36–68.38%, irrespective of parity. However, multiparous cows produced significantly greater volumes of both cisternal and alveolar milk compared to primiparous cows, indicating enhanced secretory capacity and udder development in later lactations.

A positive correlation was observed between cisternal milk volume and total milk yield ($P < 0.05$), suggesting that cisternal size may serve as a predictive marker for overall milk production potential in crossbred cows. This aligns with earlier reports which indicate that cows with larger cisternal capacity produce more milk, milk faster, and adapt better to extended milking intervals [3, 23].

Regarding milk composition, fat content was significantly higher in alveolar milk than in cisternal milk across both parity groups ($P < 0.05$), with alveolar compartments accounting for up to 70% of total milk fat in multiparous cows and 72% in primiparous cows. These findings are consistent with prior research in dairy cows [19] and ewes [5], and can be explained by the physicochemical properties of milk fat. Specifically, the alveolar compartment tends to retain a larger proportion of milk fat due to the higher viscosity and larger size of fat globules [21]. A similar pattern has been reported in dromedary camels [20], as well as in Najdi and Naeimi sheep, where alveolar milk fat concentrations were 41% and 37% higher, respectively, than in the cisternal fraction [22].

Cisternal milk also exhibited significantly higher density values compared to alveolar milk in both primiparous and multiparous cows, likely reflecting differences in component concentration and distribution. This difference has practical implications for milk processing and storage stability.

In contrast, protein, lactose, and solids-not-fat (SNF) contents did not significantly differ ($P > 0.05$) between the cisternal and alveolar fractions. This uniformity in composition supports the notion that these components are more homogeneously distributed within the colloidal phase of milk and less influenced by anatomical compartmentalization [20, 26]. Similar patterns have been observed in both cows and sheep, where protein levels

remained stable following a 12-hour milking interval, and protein yield changes were predominantly associated with overall milk volume [5, 21, 24, 25].

Collectively, these findings emphasize that while parity influences the absolute volumes of milk produced, it does not significantly alter the proportional or compositional characteristics between udder compartments, apart from fat content. Moreover, the data reinforce the relevance of cisternal volume as an indicator of milk yield efficiency and its potential utility in selective breeding for improved dairy traits

Lactation stage had a statistically significant effect on both the absolute volumes and the relative proportions of cisternal and alveolar milk in crossbred cows (Table 2). Total milk yield over a 12-hour interval declined progressively from early (5.54 ± 0.08 L) to mid (5.10 ± 0.07 L) and late lactation (4.61 ± 0.04 L). Alveolar milk volume decreased by 18% between early and late lactation ($P < 0.05$), while cisternal milk volume remained relatively stable between early and mid-lactation but declined by 16% from mid to late lactation ($P < 0.05$). These shifts corroborate prior findings that show a marked decline in milk volume stored in the cistern as lactation advances [19, 27].

Table 2: Effect of lactation stage on the cisternal and alveolar milk volumes in crossbred cows.

Traits	Milk volume-12h, L			Milk volume-12h, %*	
	Cisternal	Alveolar	Total	Cisternal	Alveolar
Early 1-3 months	1.76±0.05[a]	3.78±0.07[a]	5.54±0.08[a]	31.89[b]	68.09[b]
Mid 4-6 months	1.74±0.04[a]	3.36±0.05[b]	5.10±0.07[b]	34.24[a]	65.76[c]
Late 7- end of drying	1.31±0.02[b]	3.30±0.04[b]	4.61±0.04[c]	28.79[c]	71.20[a]

*: Percentage values transformed to arcsine before statistical analysis.
[a,b] Means in the same Colum within each period carrying different superscripts differ ($p < 0.05$).

Notably, cisternal milk as a percentage of total udder milk increased from 31.89% in early lactation to 34.24% in mid-lactation, before decreasing sharply to 28.79% in late lactation. This temporal pattern aligns with observations in dairy cows and sheep, where cisternal milk proportions generally range from 20% to 35% during a 12-hour milking interval [4, 15, 19]. It contrasts with the findings of [3], who reported a lower cisternal proportion of 17% under similar conditions. Conversely, [1] reported an incremental increase in cisternal proportion over the course of lactation, attributing this to a sharper decline in alveolar milk.

The reduction in both cisternal and alveolar milk volumes during late lactation can be attributed to physiological changes, particularly the apoptosis of secretory epithelial cells, which reduces the capacity for milk synthesis [16, 28]. Similar reductions in cisternal milk storage have been documented in dairy sheep using ultrasonography, affirming this pattern across species [6].

These findings emphasize the dynamic interplay between lactation stage and udder compartmental storage. The temporary increase in cisternal proportion during mid-lactation may reflect adaptive responses in milk storage mechanisms, possibly to compensate for declining alveolar activity. As lactation progresses, the udder undergoes structural and functional regression, leading to an overall reduction in secretory capacity and milk yield. Understanding these shifts is essential for optimizing milking schedules and assessing mammary gland health across lactation.

4. Conclusion

This study found that cisternal milk constituted roughly 31–32% of total udder milk in crossbred cows, with no significant difference due to parity. However, cisternal volume was positively associated with total milk yield ($P < 0.05$), indicating its potential as a marker of productivity. Fat content was predominantly concentrated in the alveolar compartment, accounting for up to 70% in multiparous and 72% in primiparous cows. This confirms the alveolar region's primary role in fat storage. As lactation progressed, both alveolar and cisternal milk volumes declined significantly. Cisternal milk proportion peaked during mid-lactation but dropped in late lactation, whereas the alveolar percentage increased. Alveolar milk volume decreased by 18% from early to late lactation. Cisternal volume remained stable between early and mid-lactation but decreased by 16% between mid- and late-lactation stages. Overall, these results highlight the interplay between lactation stage, udder morphology, and milk composition, suggesting that management and breeding strategies should take these dynamics into account to optimize yield.

Acknowledgment

I would like to express my heartfelt gratitude to Prof. Dr. Abdelmoneim M. Abu Nikhaila, my supervisor, whose guidance and expertise were instrumental throughout the research process. I'm also sincerely thankful to Dr. Tarig Abdelrouf Ahmed Eltayeb, my co-supervisor, for her unwavering support and thoughtful insights that greatly enriched this study. A special thanks goes to the academic staff in my department, whose readiness to assist at every turn did not go unnoticed. I also extend my appreciation to the Department of Dairy Production, the Faculty of Animal Production, and the University of Khartoum Farm for their logistical and institutional support.

Author Contributions

Conceptualization, methodology, validation, formal analysis, and investigation were carried out by Al-Hayani A.A. The original draft was prepared by Al-Hayani A.A., with review and editing contributions from Al-Hayani A.A., Abu Nikhaila A.M., and Tarig A.A. Visualization was led by Al-Hayani A.A., under the supervision of Abu Nikhaila A.

Funding statement

This study was conducted without the support of any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest Declaration

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Ethical standards

Not applicable.

References

[1] Wilde, C.J., Knight, C.H., Peaker, M. (1996) Autocrine Regulation of Milk Secretion, in: Phillips, C.J., (Ed.), Progress in Dairy Science, *CAB International*, Wallingford, UK, pp. 311–332.

[2] Stelwagen, K. (2001) Effect of Milking Frequency on Mammary Functioning and Shape of the Lactation Curve, *Journal of Dairy Science* **84**: E204-E211.

[3] Ayadi, M., Caja, G., Such, X., Knight, C.H. (2003) Use of ultrasonography to estimate cistern size and milk storage at different milking intervals in the udder of dairy cows, *Journal of Dairy Research* **70**: 1-7.

[4] Knight, C.H., Hirst, D., Dewhurst, R.J. (1994) Milk accumulation and distribution in the bovine udder during the interval between milkings, *Journal of Dairy Research* **61**: 167-177.

[5] McKusick, B.C., Thomas, D.L., Berger, Y.M., Marnet, P.G. (2002) Effect of Milking Interval on Alveolar Versus Cisternal Milk Accumulation and Milk Production and Composition in Dairy Ewes, *Journal of Dairy Science* **85**: 2197-2206.

[6] Rovai, M., Such, X., Caja, G., Piedrafita, J. (2002) Changes in cisternal and alveolar milk throughout lactation in dairy sheep, *Journal of Dairy Science* **85**: 4-4.

[7] Caja, G., Such, X., Ruberte, J., Carretero, A., Navarro, M. (1999) The use of ultrasonography in the study of mammary gland cisterns during lactation in sheep, in: Barillet, F., Zervas, N.P., (Ed.), Milking and Milk Production of Dairy Ewe and Goats, *EAAP Publication*, Wageningen, The Netherlands, pp. 91-93.

[8] Stelwagen, K., Knight, C.H., Farr, V.C., Davis, S.R., Prosser, C.G., McFadden, T.B. (1996) Continuous versus single drainage of milk from the bovine mammary gland during a 24 hour period, *Experimental Physiology: Translation and Integration* **81**: 141-149.

[9] Blum, J.W., Schams, D., Bruckmaier, R. (1989) Catecholamines, oxytocin and milk removal in dairy cows, *Journal of Dairy Research* **56**: 167-177.

[10] Bruckmaier, R.M. (2001) Milk ejection during machine milking in dairy cows, *Livestock Production Science* **70**: 121-124.

[11] Knight, C.H., Dewhurst, R.J. (1994) Once daliy milking of dairy cows: Relationship between yield loss and cisternal milk storage, *Journal of Dairy Research* **61**: 441-449.

[12] Bruckmaier, R.M., Wellnitz, O., Blum, J.W. (1997) Inhibition of milk ejection in cows by oxytocin receptor blockade, α-adrenergic receptor

stimulation and in unfamiliar surroundings, *Journal of Dairy Research* **64**: 315-325.

[13] Wellnitz, O., Bruckmaier, R.M., Albrecht, C., Blum, J.W. (1999) Atosiban, an oxytocin receptor blocking agent: pharmacokinetics and inhibition of milk ejection in dairy cows, *Journal of Dairy Research* **66**: 1-8.

[14] SAS (2012) *SAS User's Guide: Release 9.1.3*; SAS Institute Inc, Cary, North Carolina, USA.

[15] Pfeilsticker, H.-U., Bruckmaier, R.M., Blum, J.W. (1996) Cisternal milk in the dairy cow during lactation and after preceding teat stimulation, *Journal of Dairy Research* **63**: 509-515.

[16] Dewhurst, R.J., Knight, C.H. (1993) Changes in the sites of milk storage over the lactation cycle of primiparous and multiparous dairy cows. Proceedings of the British Society of Animal Production (1972), **1993**: *Cambridge University Press*, pp. 38-38.

[17] Wilde, C.J., Peaker, M. (1990) Autocrine control in milk secretion, *The Journal of Agricultural Science* **114**: 235-238.

[18] Dewhurst, R.J., Knight, C.H. (1994) Relationship between milk storage characteristics and the short-term response of dairy cows to thrice-daily milking, *Animal Production* **58**: 181-187.

[19] Caja, G., Ayadi, M., Knight, C.H. (2004) Changes in Cisternal Compartment Based on Stage of Lactation and Time Since Milk Ejection in the Udder of Dairy Cows, *Journal of Dairy Science* **87**: 2409-2415.

[20] Ayadi, M., Aljumaah, R.S., Musaad, A., Samara, E.M., Abdelrahman, M., Alshaikh, M., Saleh, S.K., Faye, B. (2013) Relationship between udder morphology traits, alveolar and cisternal milk compartments and machine milking performances of dairy camels (*Camelus dromedarius*), *Spanish Journal of Agricultural Research* **11**: 790-797.

[21] Ayadi, M., Caja, G., Such, X., Rovai, M., Albanell, E. (2004) Effect of different milking intervals on the composition of cisternal and alveolar milk in dairy cows, *Journal of Dairy Research* **71**: 304-310.

[22] Alhayani, A.A.N., Ayadi, M.A., Matar, A.M., Aljumaah, R.S. (2022) Udder Morphology Traits and Milk Production of Najdi and Naeimi Ewes under Intensive Condition, *International Journal of Current Microbiology and Applied Sciences* **11**: 235-243.

[23] Castillo, V., Such, X., Caja, G., Casals, R., Albanell, E., Salama, A.A.K. (2008) Effect of Milking Interval on Milk Secretion and Mammary Tight Junction Permeability in Dairy Ewes, *Journal of Dairy Science* **91**: 2610-2619.

[24] Stelwagen, K., Farr, V.C., McFadden, H.A., Prosser, C.G., Davis, S.R. (1997) Time course of milk accumulation-induced opening of mammary tight junctions, and blood clearance of milk components, *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* **273**: R379-R386.

[25] Auldist, M., Prosser, C. (1998) Differential effects of short-term once-daily milking on milk yield, milk composition and concentrations of selected blood metabolites in cows with low or high pasture intake. Proceedings of the New Zealand Society of Animal Production 58th Annual Conference, Massey University, **58**, pp. 41-43.

[26] Davis, S.R., Farr, V.C., Copeman, P.J.A., Carruthers, V.R., Knight, C.H., Stelwagen, K. (1998) Partitioning of milk accumulation between cisternal and alveolar compartments of the bovine udder: relationship to production loss during once daily milking, *Journal of Dairy Research* **65**: 1-8.

[27] Bruckmaier, R.M., Blum, J.W. (1998) Oxytocin Release and Milk Removal in Ruminants, *Journal of Dairy Science* **81**: 939-949.

[28] Wilde, C.J., Quarrie, L.H., Tonner, E., Flint, D.J., Peaker, M. (1997) Mammary apoptosis, *Livestock Production Science* **50**: 29-37.

TUJNAS

Original Article

Thamar University Journal of Natural & Applied Sciences 10(1) (2025) 12– 15

DOI: https://doi.org/10.59167/tujnas.v10i1.2674

Outcomes of Single-Session ERCP and Cholecystectomy in the Management of Choledocholithiasis: A Pilot Retrospective Analysis

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Received: 9 January 2025. Received (in revised form): 21 February 2025. Accepted: 22 February 2025. Published: 28 June 2025.

Abstract

Background: Choledocholithiasis—the presence of gallstones in the common bile duct—remains a significant clinical concern. While ERCP and cholecystectomy are standard treatments, their sequential scheduling can increase hospitalization and costs.

Objective: This pilot study evaluates the feasibility, outcomes, and complication rates of performing single-session ERCP and cholecystectomy in a resource-limited hospital setting.

Methods: A retrospective analysis of 21 patients treated at Taiba Consultative Hospital (2023–2024) was conducted. Demographic, clinical, procedural, and follow-up data were analyzed.

Results: ERCP had a success rate of 92.5% with a 6.8% complication rate. Cholecystectomy had an 89.3% success rate and 4.2% complication rate. The combined procedure achieved an 87.6% success rate with an 8.1% complication rate.

Conclusion: Single-session ERCP and cholecystectomy are feasible and effective, especially in rural or resource-constrained settings. However, slightly elevated complication rates call for broader multicenter studies and standardization.

Keywords: Choledocholithiasis; ERCP; Cholecystectomy; Complications; Procedural Outcomes; Single-Session Management; Pilot Study.

1. Introduction

Choledocholithiasis, the presence of gallstones in the common bile duct (CBD), is a significant cause of morbidity and mortality worldwide. It accounts for approximately 10–20% of patients with symptomatic gallstones and can lead to severe complications such as cholangitis, pancreatitis, and obstructive jaundice if left untreated [1]. The mortality rate associated with choledocholithiasis ranges from 1% to 2% in uncomplicated cases but can rise to 10% in cases complicated by severe cholangitis or pancreatitis [2].

Endoscopic retrograde cholangiopancreatography (ERCP) is the gold standard for diagnosing and treating choledocholithiasis. However, ERCP is not without risks, with complications including pancreatitis (3–5%), bleeding (1–2%), perforation (0.5–1%), and infection (1%) [3]. Cholecystectomy, often performed in the same session as ERCP, also carries risks such as bile duct injury (0.3–0.5%) and postoperative infections[2].

Despite advances in diagnostic and therapeutic techniques, challenges remain. Misdiagnosis of choledocholithiasis can occur due to overlapping symptoms with other biliary and pancreatic diseases, leading to delayed or inappropriate treatment[4]. Additionally, the failure rate of ERCP in clearing the CBD can range from 5% to 15%, often due to the presence of large or impacted stones, anatomical variations, or operator inexperience [5].

2. Rationale for Single-Session Management

Single-session ERCP and cholecystectomy aim to reduce hospital stays, healthcare costs, and patient discomfort by addressing both ductal and gallbladder pathology in one setting. However, this approach requires meticulous coordination between endoscopists and surgeons, particularly in resource-limited environments [6]. This pilot study analyzes the feasibility and outcomes of this strategy, focusing on procedural success rates, complications, and challenges unique to combined interventions.

3. Subjects and Methods

3.1 Ethical Approval

The protocol of this study was approved by the Thamar University Medical Ethics Committee (TUMEC-24014) [7].

3.2 Study Design

A retrospective pilot analysis was conducted on 21 patients diagnosed with choledocholithiasis who underwent single-session ERCP and cholecystectomy at Taiba Consultative Hospital between January 2023 and December 2024.

3.3 Inclusion Criteria

- Confirmed choledocholithiasis via lab investigations, ultrasound, CT, or MRCP.
- Other patient selection criteria (e.g., ASA score, absence of severe comorbidities).
- A number of patients were excluded due to incomplete data.
- Patients deemed fit for combined ERCP and cholecystectomy.

3.4 Data Collection

- Demographics: Age, gender, clinical presentation.
- Procedural Outcomes: Success rates, procedural time, complications.
- Follow-up: Postoperative recovery and readmission rates.

3.5 Statistical Analysis

Data were analyzed using SPSS v28 [8]. Descriptive statistics (mean, percentages) and Chi-square tests were used to assess associations between variables. The numbers on the age group of the histogram, presented in Figure 1, represent the following ages: 2 (20-39), 3 (40-59), 4 (60-79), and 5 (more than 80). We have no mortality directly related to our procedures in this study; the mortality mentioned in Table 1 refers to general procedures for comparison purposes.

4. Results

4.1 Demographics and Clinical Presentation

The study cohort consisted of 21 patients with a mean age of 35 years (range, 20–75 years). The majority of patients (38.1%) were in the 20–39 age group, while 42.8% were aged 60 years or older. Females predominated (85.7%), consistent with the higher prevalence of gallstone disease in women [9]. The most common clinical presentation was abdominal pain (85.7%), followed by jaundice (4.8%) and a combination of symptoms (9.5%).

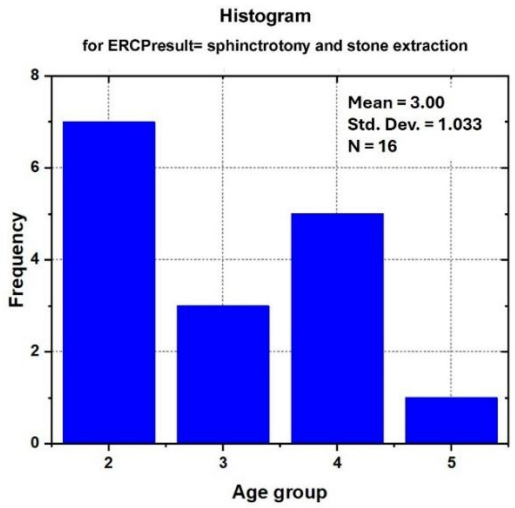

Figure 1: Histogram showing the relationship between age groups and procedural success rates

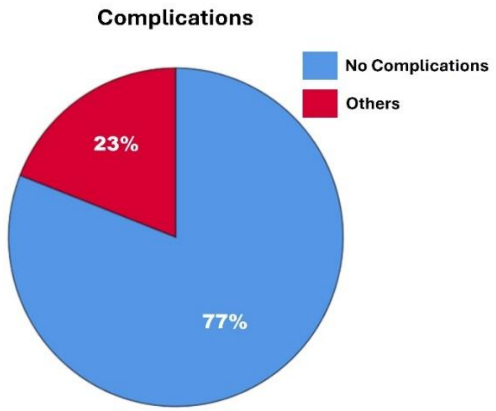

Figure 2: Distribution of complications associated with ERCP and cholecystectomy

4.2 Procedural Outcomes

- ERCP Success Rate: 92.5% (19/21 patients) achieved complete CBD stone clearance. Complications occurred in 6.8% of cases (1 case of pancreatitis, 1 case of mild bleeding) [10].
- Cholecystectomy Success Rate: 89.3% (18/21 patients) underwent uneventful open cholecystectomy or laparoscopic cholecystectomy, with a 4.2% complication rate (1 wound infection) [11].
- Combined Procedure Success Rate: Single-session ERCP and cholecystectomy had an 87.6% success rate (18/21 patients). Complications occurred in 8.1% of cases (1 post-ERCP pancreatitis, 1 bile leak) [12]. All these outcomes can be presented in Table 1.

Table 1: Procedural Outcomes

Variable	Success Rate (%)	Complication Rate (%)	Mortality Rate (%)
ERCP	92.5	6.8	0.5
Single-Session Cholecystectomy	89.3	4.2	0.3
Combined ERCP + Cholecystectomy	87.6	8.1	0.7

4.3 Challenges and Complications

The complications associated with ERCP and cholecystectomy are presented in Figure 2. Challenges and complications for the current study can be listed as follows:

- Anatomical Variants: Large duodenal diverticula and hidden ampullary orifices posed challenges in 9.5% of cases (2/21), necessitating advanced techniques such as guidewire-assisted cannulation and biliary balloon dilation [13].
- Missed Diagnoses: One case of cholangiocarcinoma and one case of Mirizzi syndrome were identified intraoperatively, underscoring the limitations of preoperative imaging in detecting rare biliary pathologies [14].
- Large/Impacted Stones: Three patients (14.3%) had stones >15 mm, requiring adjunctive interventions such as mechanical lithotripsy [15].

4.4 Statistical Analysis

- Chi-Square Tests: No significant associations were found between gender, age, and procedural outcomes ($p > 0.05$). However, the small sample size limited the statistical power to detect subtle differences [16].
- Overall Complication Rate: 19% (4/21 patients), with no mortality reported.

5. Discussion

5.1 Feasibility of Single-Session Management

The results of this study demonstrate a high success rate for ERCP (92.5%) and a single-session cholecystectomy rate of 89.5%. This is consistent with findings from regional studies in the Middle East, including many regional countries, while the combined success rate of 87.6% in this study still aligns with regional reports from Saudi Arabia (90%) [17] and Egypt (88%) [18] but falls slightly below European benchmarks (94%)[19]. %). We appreciate the reviewer's insight. While we acknowledge the existence of local studies, such as the referenced Sana'a study, which the first reviewer mentioned, we were unable to access its full text despite conducting rigorous online searches. We were actively collaborating with specialists in Sana'a to obtain further details and will incorporate comparative data in future work. Our study focuses on a rural population (Thamar and neighboring districts), where resource constraints and patient logistics often prefer single-session interventions. This unique context may explain differences in outcomes compared to urban settings.

5.2 Key Contributing Factors

The key contributing factors for this study can be summarized as follows:

- Operator Workload: Extended procedural time and technical complexity in single-session interventions [20].
- Patient Selection: Suboptimal preoperative assessment of anatomical variants (e.g., duodenal diverticula) [21].
- Resource Constraints: Limited access to advanced imaging (e.g., MRCP) for preoperative planning [2].

5.3 Addressing Challenges

Challenges for the current study can be listed as follows:

- Anatomical Variants: Guidewire-assisted cannulation and biliary balloon dilation improved success rates in cases with challenging anatomy [22].
- Large Stones: Mechanical lithotripsy or ESWL should be considered for stones >15 mm, as recommended by the European Society of Gastrointestinal Endoscopy (ESGE) [23].
- Missed Diagnoses: Preoperative MRCP reduces diagnostic errors by 25% compared to ultrasound, particularly for conditions like Mirizzi syndrome [24].

5.4 Clinical and Economic Implications

Single-session management reduces hospital stays by 2–3 days compared to staged procedures, making it cost-effective in resource-limited settings [25]. However, the higher complication rate underscores the need for:

(i) Standardized Protocols: Adopting guidelines from the American Society for Gastrointestinal Endoscopy (ASGE) for patient selection [26].

(ii) Enhanced Training: Structured programs focusing on ERCP-cholecystectomy coordination, as advocated by the World Gastroenterology Organisation [27].

6. Limitations

- Small Sample Size: Limits generalizability and detection of rare complications (e.g., bile duct injury) [28].
- Single-Center Design: The results may not accurately reflect outcomes in hospitals with varying resource levels.
- Retrospective Bias: Potential underreporting of minor complications.

7. Conclusions and Recommendations

This pilot study demonstrates the feasibility of performing single-session ERCP and cholecystectomy in the management of choledocholithiasis.

The Conclusion explicitly states:

- Single-session procedures reduce costs and hospital stays, which is critical for rural populations if the facility and a skilled surgeon or a skilled multidisciplinary team are available.
- Feasibility is demonstrated with 0% mortality and manageable minor complications.
- Outcomes are comparable to regional studies, though further multicenter collaboration is needed.

While success rates are promising, the slightly higher minor complication rates highlight the need for:

1. Larger Multicenter Studies: To validate outcomes across diverse populations.
2. Preoperative MRCP: To confirm or exclude the presence of expected challenges like Mirizzi syndrome and anatomical variants.
3. Standardized Continuous Education Programs: For endoscopists and surgeons.
4. Hospital-Based Multidisciplinary Teams: To address expected challenges and complications.

Ethical Approval

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Ethical approval was obtained from the Medical Ethics Committee of the Faculty of Medicine, Thamar University, Yemen (Approval ID: TUMEC-24014).

Patient Consent

All participants provided verbal and written informed consent prior to inclusion in the study. The purpose, procedures, potential risks, and benefits of the combined ERCP and cholecystectomy approach were clearly explained. Confidentiality and anonymity were assured, and participation was entirely voluntary.

Data Availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study.

Acknowledgements

The authors acknowledge Prof. Abdussalam Almachdad, General Director of Alwahda Teaching Hospital, for his support. Special thanks to Sister Basma Alharbi and Mr. Abdulla Alhajji for assistance with data collection. Appreciation is extended to the staff and management of Taiba Consultative Hospital.

Funding

This research received no external funding.

References

[1] Williams, E., Taylor, S., Fairclough, P., Hamlyn, A., Logan, R., Martin, D., Riley, S., Veitch, P., Wilkinson, M., Williamson, P. (2007) Risk factors for complication following ERCP; results of a large-scale, prospective multicenter study, *Endoscopy* **39**: 793-801.

[2] Maple, J.T., Ben-Menachem, T., Anderson, M.A., Appalaneni, V., Banerjee, S., Cash, B.D., Fisher, L., Harrison, M.E., Fanelli, R.D., Fukami, N. (2010) The role of endoscopy in the evaluation of suspected choledocholithiasis, *Gastrointestinal Endoscopy* **71**: 1-9.

[3] Gurusamy, K.S., Davidson, B.R. (2014) Gallstone disease, in: McDonald, J.W., Feagan, B.G., Jalan, R., Kahrilas, P.J., (Ed.), Evidence-based Gastroenterology and Hepatology *John Wiley & Sons*, New York, USA, pp. 342-352.

[4] Cotton, P., Lehman, G., Vennes, J., Geenen, J., Russell, R., Meyers, W., Liguory, C., Nickl, N. (1991) Endoscopic sphincterotomy complications and their management: an attempt at consensus, *Gastrointestinal Endoscopy* **37**: 383-393.

[5] Mallick, R., Rank, K., Ronstrom, C., Amateau, S.K., Arain, M., Attam, R., Freeman, M.L., Harmon, J.V. (2016) Single-session laparoscopic cholecystectomy and ERCP: a valid option for the management of choledocholithiasis, *Gastrointestinal Endoscopy* **84**: 639-645.

[6] Jones, M., Johnson, M., Samourjian, E., Slauch, K., Ozobia, N. (2013) ERCP and laparoscopic cholecystectomy in a combined (one-step) procedure: a random comparison to the standard (two-step) procedure, *Surgical Endoscopy* **27**: 1907-1912.

[7] Baron, T.H., Petersen, B.T., Mergener, K., Chak, A., Cohen, J., Deal, S.E., Hoffinan, B., Jacobson, B.C., Petrini, J.L., Safdi, M.A. (2006) Quality indicators for endoscopic retrograde cholangiopancreatography, *The American College of Gastroenterology* **101**: 892-897.

[8] Freeman, M.L., Nelson, D.B., Sherman, S., Haber, G.B., Herman, M.E., Dorsher, P.J., Moore, J.P., Fennerty, M.B., Ryan, M.E., Shaw, M.J. (1996) Complications of endoscopic biliary sphincterotomy, *New England Journal of Medicine* **335**: 909-919.

[9] Tse, F., Yuan, Y., Moayyedi, P., Leontiadis, G. (2013) Guide wire-assisted cannulation for the prevention of post-ERCP pancreatitis: a systematic review and meta-analysis, *Endoscopy* **45**: 605-618.

[10] Sharma, A., Dahiya, P., Khullar, R., Soni, V., Baijal, M., Chowbey, P. (2012) Management of common bile duct stones in the laparoscopic era, *Indian Journal of Surgery* **74**: 264-269.

[11] Park, D.H., Kim, M.-H., Lee, S.K., Lee, S.S., Choi, J.S., Lee, Y.S., Seo, D.W., Won, H.J., Kim, M.-Y. (2005) Can MRCP replace the diagnostic role of ERCP for patients with choledochal cysts?, *Gastrointestinal Endoscopy* **62**: 360-366.

[12] Costamagna, G., Tringali, A., Shah, S., Mutignani, M., Zuccala, G., Perri, V. (2002) Long-term follow-up of patients after endoscopic sphincterotomy for choledocholithiasis, and risk factors for recurrence, *Endoscopy* **34**: 273-279.

[13] Andriulli, A., Loperfido, S., Napolitano, G., Niro, G., Valvano, M.R., Spirito, F., Pilotto, A., Forlano, R. (2007) Incidence rates of post-ERCP

complications: a systematic survey of prospective studies, *The American College of Gastroenterology* **102**: 1781-1788.

[14] Loperfido, S., Angelini, G., Benedetti, G., Chilovi, F., Costan, F., De Berardinis, F., De Bernardin, M., Ederle, A., Fina, P., Fratton, A. (1998) Major early complications from diagnostic and therapeutic ERCP: a prospective multicenter study, *Gastrointestinal Endoscopy* **48**: 1-10.

[15] Dumonceau, J.-M., Andriulli, A., Elmunzer, B.J., Mariani, A., Meister, T., Deviere, J., Marek, T., Baron, T.H., Hassan, C., Testoni, P.A. (2014) Prophylaxis of post-ERCP pancreatitis: European Society of Gastrointestinal Endoscopy (ESGE) guideline–updated June 2014, *Endoscopy* **46**: 799-815.

[16] Chandrasekhara, V., Khashab, M.A., Muthusamy, V.R., Acosta, R.D., Agrawal, D., Bruining, D.H., Eloubeidi, M.A., Fanelli, R.D., Faulx, A.L., Gurudu, S.R. (2017) Adverse events associated with ERCP, *Gastrointestinal Endoscopy* **85**: 32-47.

[17] Baillie, J., Cairns, S., Putman, W., Cotton, P. (1990) Endoscopic management of choledocholithiasis during pregnancy, *Surgery, Gynecology & Obstetrics* **171**: 1-4.

[18] Testoni, P.A., Vailati, C., Giussani, A., Notaristefano, C., Mariani, A. (2010) ERCP-induced and non-ERCP-induced acute pancreatitis: Two distinct clinical entities with different outcomes in mild and severe form?, *Digestive and Liver Disease* **42**: 567-570.

[19] Cotton, P.B., Garrow, D.A., Gallagher, J., Romagnuolo, J. (2009) Risk factors for complications after ERCP: a multivariate analysis of 11,497 procedures over 12 years, *Gastrointestinal Endoscopy* **70**: 80-88.

[20] Al Mofleh, I.A. (2008) Severe acute pancreatitis: pathogenetic aspects and prognostic factors, *World Journal of Gastroenterology* **14**: 675.

[21] Dumonceau, J.-M., Andriulli, A., Devière, J., Mariani, A., Rigaux, J., Baron, T., Testoni, P.A. (2010) European Society of Gastrointestinal Endoscopy (ESGE) Guideline: prophylaxis of post-ERCP pancreatitis, *Endoscopy* **42**: 503-515.

[22] Sugiyama, M., Atomi, Y. (2000) Endoscopic sphincterotomy for bile duct stones in patients 90 years of age and older, *Gastrointestinal Endoscopy* **52**: 187-191.

[23] Isayama, H., Nakai, Y., Itoi, T., Yasuda, I., Kawakami, H., Ryozawa, S., Kitano, M., Irisawa, A., Katanuma, A., Hara, K. (2019) Clinical practice guidelines for safe performance of endoscopic ultrasound/ultrasonography-guided biliary drainage: 2018, *Journal of Hepato-Biliary-Pancreatic Sciences* **26**: 249-269.

[24] Strasberg, S.M., Hertl, M., Soper, N.J. (1995) An analysis of the problem of biliary injury during laparoscopic cholecystectomy, *Journal of the American College of Surgeons* **180**: 101-125.

[25] Buxbaum, J.L., Fehmi, S.M.A., Sultan, S., Fishman, D.S., Qumseya, B.J., Cortessis, V.K., Schilperoort, H., Kysh, L., Matsuoka, L., Yachimski, P. (2019) ASGE guideline on the role of endoscopy in the evaluation and management of choledocholithiasis, *Gastrointestinal Endoscopy* **89**: 1075-1105.e15.

[26] Gurusamy, K.S., Davidson, C., Gluud, C., Davidson, B.R. (2013) Early versus delayed laparoscopic cholecystectomy for people with acute cholecystitis, *Cochrane Database of Systematic Reviews* **6**: 1-46.

[27] Kadokura, M., Takenaka, Y., Yoda, H., Yasumura, T., Okuwaki, T., Tanaka, K., Amemiya, F. (2021) Asymptomatic common bile duct stones are associated with increased risk of post-endoscopic retrograde cholangiopancreatography pancreatitis, *Japan Medical Association Journal* **4**: 141-147.

[28] Thaker, A.M., Mosko, J.D., Berzin, T.M. (2015) Post-endoscopic retrograde cholangiopancreatography pancreatitis, *Gastroenterology Report* **3**: 32-40.

TuJNaS

Original Article

Thamar University Journal of Natural & Applied Sciences 10(1) (2025) 16– 24

DOI: https://doi.org/10.59167/tujnas.v10i1.2675

Design and Photocatalytic Evaluation of CdO–ZnO–Co_3O_4 Ternary Nanocomposite Synthesized by Co-precipitation Method

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Received: 6 May 2025. Received (in revised form): 25 May 2025. Accepted: 29 May 2025. Published: 28 June 2025.

Abstract

A CdO–ZnO–Co_3O_4 ternary nanocomposite was synthesized via the co-precipitation method. Transmission electron microscopy (TEM) confirmed the spherical morphology of the nanoparticles, with average particle sizes of 60.8 nm (CdO), 51.8 nm (ZnO), 33.3 nm (Co_3O_4), and a significantly reduced size of 13.82 nm for the nanocomposite. Crystallographic analysis revealed cubic structures for CdO and Co_3O_4, and a hexagonal structure for ZnO. Elemental composition was validated through total reflection X-ray fluorescence (TXRF). Diffuse reflectance spectroscopy (DRS) was employed to assess the optical properties, including reflectance and band gap energies. CdO and ZnO exhibited direct band gaps of 2.0 eV and 3.15 eV, respectively, whereas Co_3O_4 presented two band gap transitions at 1.0 eV and 1.43 eV, corresponding to charge transfers from O^{2-} to Co^{3+} and Co^{2+} ions. The ternary nanocomposite demonstrated a narrowed band gap of 1.4 eV. Photocatalytic testing against methylene red (MR) dye under UV irradiation showed a notable degradation efficiency of 33.5% within 30 minutes. These results suggest that the CdO–ZnO–Co_3O_4 nanocomposite holds strong potential for application in wastewater treatment.

Keywords: XRD; TXRF; Band gap energy; Photocatalyst; CdO-ZnO-Co_3O_4 Nanocomposite.

1. Introduction

Photolysis refers to the chemical decomposition of a molecule triggered by the absorption of light energy. In the context of nanocomposites, photolysis plays a vital role in understanding both the degradation of the polymer matrix and the light-induced release of embedded nanoparticles. This phenomenon is particularly significant for nanocomposites containing semiconductor particles like TiO_2, CeO_2, or ZnO, which exhibit photocatalytic behavior under light exposure. Such materials find applications in self-cleaning coatings, environmental remediation, and water purification. Researchers have explored a variety of parameters that influence photodegradation, including polymer type, nanofiller content, and light wavelength. Of particular concern is the release potential of nanoparticles from polymer matrices under illumination, which carries both functional and environmental implications [1].

Transition metal oxides (TMOs) have garnered extensive research interest due to their tunable synthesis pathways and ability to form multiple crystalline phases with varied metal-to-oxygen ratios. These structural variations impact their physical properties and broaden their application range [2,3]. Metal oxide-based nanocomposites are now widely studied for their roles in energy-related technologies, including solar cells, gas sensors, UV detectors, fuel cells, and batteries [4,5].

Cadmium oxide (CdO) is a well-known n-type semiconductor with a direct band gap in the range of 2.2–2.5 eV. Its notable features—such as low electrical resistivity and high transparency in the visible spectrum—make it a strong candidate for various optoelectronic and catalytic applications. These include solar energy devices, gas sensing, UV absorption, and catalytic oxidation [6].

Zinc oxide (ZnO), another widely used n-type semiconductor, has been extensively investigated for its potential in environmental and energy applications owing to its high photoreactivity, non-toxicity, chemical stability, and low cost. However, its relatively large band gap of 3.2 eV limits its photocatalytic activity to the UV region, which accounts for

less than 5% of the solar spectrum. One effective strategy to enhance visible light absorption and improve charge separation efficiency is the formation of p–n heterojunctions by combining ZnO with other semiconductors of narrower band gaps. ZnO's versatility and tunable nanoscale morphology have made it an ideal material for optoelectronics, piezoelectric devices, nanosensors, and antibacterial surfaces. Its surface characteristics, defects, and crystallinity significantly influence its photocatalytic efficiency [7].

Cobalt oxide (Co_3O_4), a p-type semiconductor with a spinel structure, exhibits multiple oxidation states (Co^{2+}, Co^{3+}, and Co^{4+}), enabling a wide range of functional properties. Co_3O_4 nanoparticles possess direct band gaps around 1.48 eV and 2.19 eV and have been used in catalysis, gas sensors, energy storage systems, and low-temperature CO oxidation. Their multifunctional behavior arises from excellent optical, electrical, and magnetic properties [8].

Recent studies have highlighted the synergistic effects of ternary metal oxide nanocomposites in enhancing photocatalytic and antimicrobial properties. For example, Saadabasi et al. synthesized a ZnO–CeO_2–MgO composite using Ocimum basilicum L seed extract for biological and photocatalytic studies [9]. Similarly, Kannan et al. explored a CdO–CuO–ZnO nanocomposite synthesized via microwave irradiation, demonstrating notable antimicrobial and dye degradation performance [10]. Munawar et al. reported the antimicrobial activity of a NiO–CdO–ZnO nanocomposite prepared through homogeneous co-precipitation [4].

Several synthesis methods have been employed to fabricate such composites, including sol–gel [11], mechanical grinding [12], hydrothermal [13], microwave-assisted [14], solid-state reaction [15], and co-precipitation techniques [16]. Among these, the co-precipitation method stands out for its simplicity, cost-effectiveness, ambient synthesis conditions, and suitability for scaling [17].

In this study, we aim to investigate the structural, optical, and photocatalytic properties of a CdO–ZnO–Co_3O_4 ternary nanocomposite synthesized via co-precipitation. By optimizing the synthesis conditions and analyzing the resulting material, we explore its potential for use in photocatalytic wastewater treatment applications.

2. Experimental Procedure

2.1. Materials

The following analytical-grade reagents were used without further purification: cadmium nitrate tetrahydrate $Cd(NO_3)_2{\cdot}4H_2O$ (99%, HIMEDIA), zinc nitrate hexahydrate $Zn(NO_3)_2{\cdot}6H_2O$ (99%, HIMEDIA), cobalt nitrate hexahydrate $Co(NO_3)_2{\cdot}6H_2O$ (98%, HIMEDIA), sodium hydroxide NaOH (98%, HIMEDIA), and distilled water (DW).

2.2. Synthesis of CdO, ZnO, and Co_3O_4 Nanoparticles

To synthesize CdO nanoparticles, 0.03 M of $Cd(NO_3)_2{\cdot}4H_2O$ was dissolved in 100 mL of distilled water. A 0.1 M NaOH solution was added dropwise to the mixture until the pH reached 7, followed by stirring for one hour at room temperature. The resulting solution was stored overnight in a sealed container. The precipitate was then washed repeatedly with distilled water, dried at 100 °C for one hour, and ground using a mortar and pestle to obtain a fine powder. This powder was subsequently annealed at 500 °C for two hours to form CdO nanoparticles. The same procedure was repeated using $Zn(NO_3)_2{\cdot}6H_2O$ and $Co(NO_3)_2{\cdot}6H_2O$ to synthesize ZnO and Co_3O_4 nanoparticles, respectively.

2.3. Synthesis of CdO–ZnO–Co_3O_4 Nanocomposite

For the ternary nanocomposite, equal molar amounts (0.03 M each) of cadmium, zinc, and cobalt nitrates were dissolved in 300 mL of distilled water under continuous stirring for 10 minutes. The synthesis followed the same procedure described for the individual oxides. Before heat treatment, the resulting precipitate appeared blue, turning black after calcination. A schematic representation of the synthesis process is provided in Figure 1.

2.4. Characterization

X-ray diffraction (XRD) analysis was conducted using an XD-2 diffractometer (CuKα radiation, λ = 1.54 nm; 36 kV, 20 mA; China) at the Yemeni Geological Survey and Mineral Resources Board to determine the crystal structure. Elemental analysis was carried out using total reflection X-ray fluorescence (TXRF) spectroscopy (S8 TIGER, Bruker, Germany). The particle sizes and morphology of the synthesized samples were evaluated via transmission electron microscopy (TEM, JEM-2100, JEOL, Japan). Image analysis was performed using ImageJ software.

Optical properties were assessed using a UV-Vis-NIR spectrophotometer (Cary 5000, Model DRA-2500, JASCO V-750, Japan) in the 400–700 nm wavelength range to obtain diffuse reflectance spectra (DRS). Photocatalytic activity was studied using a UV-VISIBLE spectrophotometer (UV-1650 PC, SHIMADZU, Japan) covering the 190–1100 nm range, conducted at the Department of Chemistry, Faculty of Science, Suez Canal University.

2.5. Photocatalytic activity

The photocatalytic efficiency of the synthesized samples was evaluated by degrading methylene red (MR) dye under UV irradiation. In a typical test, 20 mg of each nanoparticle (CdO, ZnO, Co_3O_4, and the ternary nanocomposite) was added to 100 mL of a 10 ppm MR aqueous solution in a beaker. MR dye was selected due to its effective coloring properties, relative environmental safety, and high biodegradability, making it a more sustainable alternative to conventional dyes.

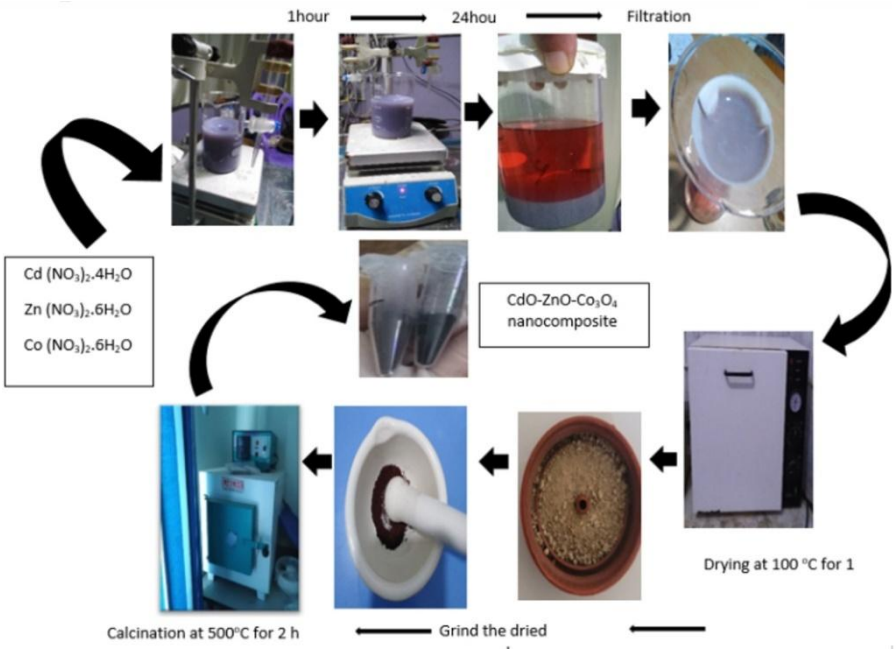

Figure 1: Schematic illustration of the CdO–ZnO–Co_3O_4 nanocomposite synthesis procedure.

The suspension was stirred magnetically in a custom-built photocatalytic reactor for two hours to establish adsorption–desorption equilibrium. A 320-watt UV lamp positioned 30 cm above the solution was then used to initiate photocatalysis. Aliquots of 5 mL were collected at 30-minute intervals, centrifuged, and analyzed via UV-Vis spectrophotometry to monitor the decrease in dye concentration through absorbance measurements.

3. Results and Discussion

3.1 Structural Analysis

The XRD patterns of CdO, ZnO, Co_3O_4 nanoparticles, and their CdO–ZnO–Co_3O_4 nanocomposite were recorded in the 2θ range of 30°–80° (Fig. 2). The diffraction peaks are indicative of distinct crystal planes. Peaks at 33.4°, 38.8°, 55.8°, 66.3°, and 69.7° correspond to (111), (200), (220), (311), and (222) planes, respectively, and match the JCPDS card #01-1049, confirming the cubic structure of CdO [5,18]. For ZnO, peaks at 32.5°, 34.8°, 36.7°, 48°, 57°, 63.3°, 66.6°, 68.4°, 69.5°, and 73° align with (100), (002), (101), (102), (110), (103), (200), (112), (201), and (004) planes per JCPDS card #01-1136, confirming a hexagonal structure [17,19]. Co_3O_4 shows peaks at 31.6°, 37.2°, 38.8°, 45.2°, 59.7°, and 65.6°, which correspond to (220), (311), (222), (400), (511), and (440) planes, confirming a cubic spinel structure consistent with JCPDS card #042-1467 [1].

In the nanocomposite, ZnO exhibited the most intense peaks, while CdO showed the weakest, suggesting that Co_3O_4's low crystallinity notably influenced the overall structural integrity. The crystallite sizes (D) were calculated using the Scherrer equation [20]:

$$D = \frac{0.9\lambda}{\beta \cos\theta} \quad (1)$$

where λ is the X-ray wavelength, β is the full width at half maximum in radians, and θ is the Bragg angle.

Lattice constants for cubic and hexagonal systems, respectively, were determined using Bragg's law [21]:

$$\frac{1}{d^2} = \frac{h^2 + k^2 + l^2}{a^2} \quad (2)$$

$$\frac{1}{d^2} = \frac{4}{3}\left[\frac{h^2 + hk + k^2}{a^2}\right] + \frac{l^2}{c^2} \quad (3)$$

Unit cell volumes were calculated as [22, 23]:

$$V = a^3 \quad \textbf{(cubic)} \quad (4)$$

$$V = 0.866\, a^2 c \quad \textbf{(hexagonal)} \quad (5)$$

Microstrain (ε) and dislocation density (δ) were estimated as [24]:

$$\varepsilon = \frac{\beta}{4 \tan\theta} \quad (6)$$

$$\delta = \frac{1}{D^2} \quad (7)$$

Results are summarized in Table 1. The nanocomposite exhibited a pronounced decrease in crystallite size, attributed to an increase in dislocation density and strain. This reduction is attributed to greater nucleation sites, interfacial disruptions, and impurity incorporation, which hinder grain growth and stabilize smaller crystalline domains [1].

Table 1: Structural parameters of CdO, ZnO, Co_3O_4 NPs, and CdO–ZnO–Co_3O_4 nanocomposite.

Samples	D (nm)	a (Å)	c (Å)	V (Å^3)	ε ($\times10^{-3}$)	δ ($\times10^{-3}$) (Lines/nm^2)
CdO NPs	37.73	4.64	–	99.9	1.6	0.702
ZnO NPs	31.79	3.20	5.14	45.5	3.9	0.989
Co_3O_4 NPs	32.84	8.13	–	537.3	6.4	0.927
CdO-ZnO-Co_3O_4 Nanocomposite						
CdO	26.25	4.63	–	99.25	4.7	1.541
ZnO	14.27	3.20	5.15	45.67	8.8	4.790
Co_3O_4	13.45	8.06	–	523.6	15.5	5.527

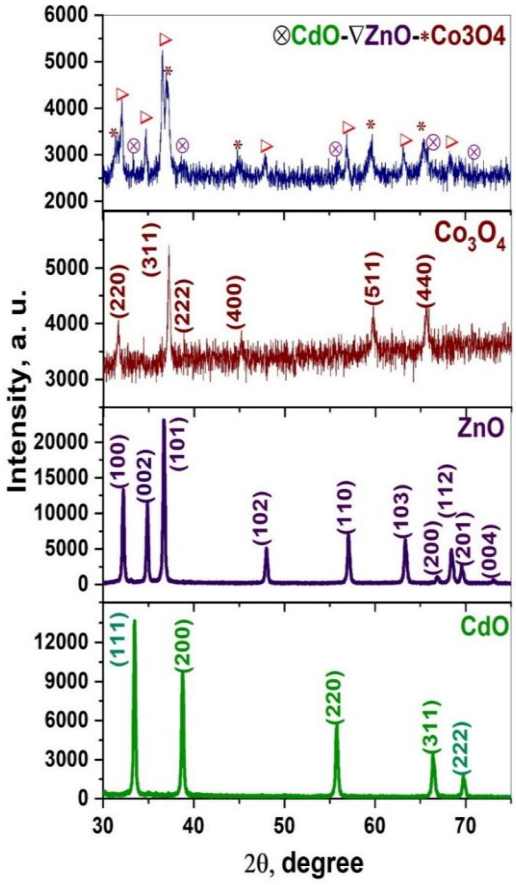

Figure 2: XRD patterns of CdO, ZnO, Co_3O_4 nanoparticles and CdO–ZnO-Co_3O_4 nanocomposite.

3.2. Elemental Analysis

TXRF analysis confirmed the elemental composition of the CdO–ZnO–Co_3O_4 nanocomposite. Results are summarized in Table 2. The percentages align closely with the intended stoichiometry, indicating successful incorporation of all three metal oxides.

Table 2: TXRF elemental analysis of CdO–ZnO–Co_3O_4 nanocomposite.

Element	% Metal	Compound	% Compound
Cd	18.79	CdO	23.8
Zn	38.66	ZnO	48.42
Co	21.35	Co_3O_4	27.2
O_2	20.62	–	–
Impurities: (P, Si, S, Ca, Fe)	0.58	–	0.58
Total	**100**	**–**	**100**

3.3. TEM Analysis

Figure 3 shows TEM images for CdO, ZnO, Co_3O_4 nanoparticles, and the ternary nanocomposite. Spherical to semi-spherical particles were observed across all samples. Using ImageJ, average particle sizes were calculated: CdO (60.8 nm), ZnO (51.8 nm), Co_3O_4 (33.3 nm), and nanocomposite (13.8 nm).

Transmission electron microscope (TEM) images, as shown in Figure 3, display CdO, ZnO, and Co_3O_4 nanoparticles, as well as a CdO–ZnO–Co_3O_4 nanocomposite. The TEM images show nanoparticles of varied shapes and sizes. The TEM images of the samples in Figure 3 clearly show the spherical and semispherical shapes of the prepared nanoparticles. Their particle sizes were determined using the ImageJ program. The histogram is plotted in Figure 4. The CdO–ZnO–Co_3O_4 nanocomposite and CdO, ZnO, and Co_3O_4 nanoparticles have particle sizes of 13.8 nm, 60.8 nm, 51.8 nm, and 33.3 nm, respectively. The comparison selected area electron diffraction (SAED) pattern for CdO, ZnO, and Co_3O_4 nanoparticles, as well as the CdO–ZnO–Co_3O_4 nanocomposite, is shown in Figure 5. The planes

corresponding to different rings were found by using the ImageJ program to calculate the d-spacing, which agrees well with the results of TXRF and XRD. The circular fringes in SAED patterns indicate the polycrystalline nature of the samples, and the diffraction rings matched with the XRD d-spacing of CdO, ZnO, Co_3O_4 nanoparticles, and CdO–ZnO–Co_3O_4 nanocomposite. This outcome aligns with that of Aziz *et al.* [17].

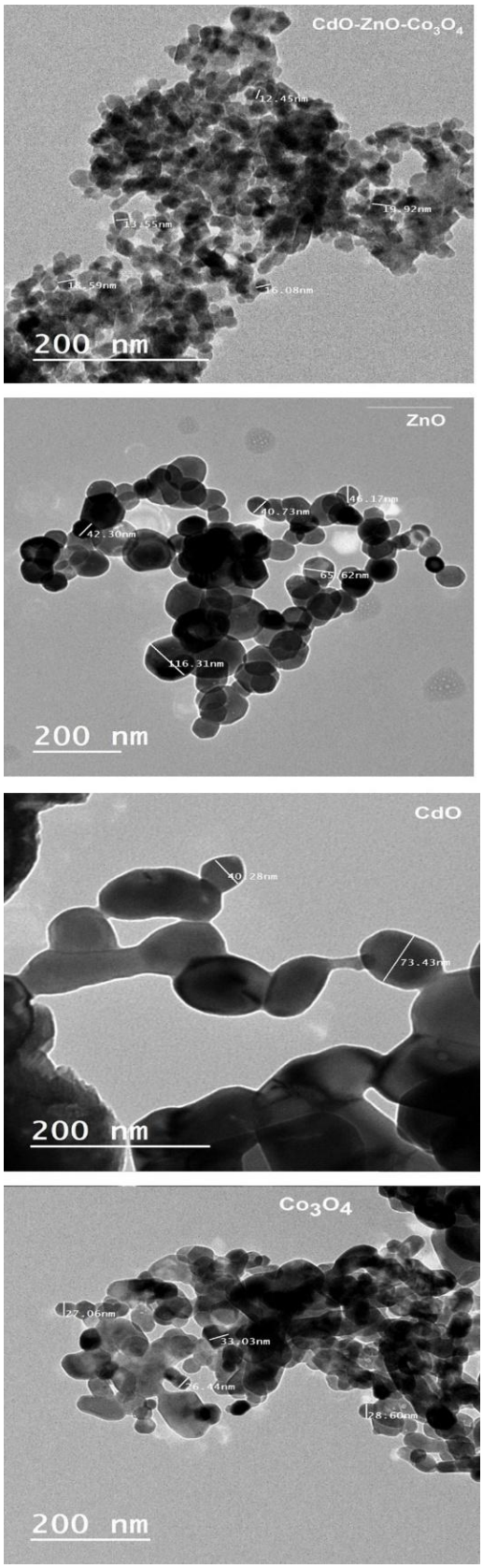

Figure 3: TEM image of CdO, ZnO, and Co_3O_4 nanoparticles and CdO–ZnO–Co_3O_4 nanocomposite.

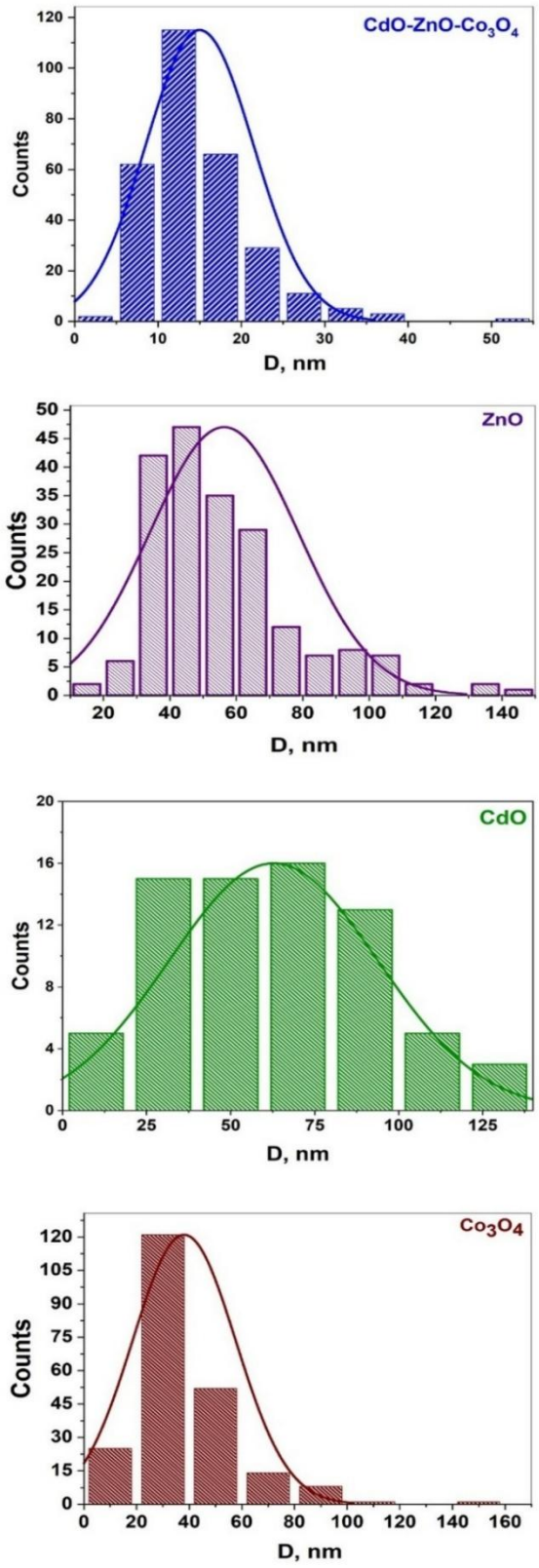

Figure 4: Histograms calculated from TEM images for the of CdO, ZnO, and Co_3O_4 nanoparticles and CdO–ZnO–Co_3O_4 nanocomposite

3.4. Optical Properties

Diffuse reflectance spectra (Figure 6) revealed differences in reflectance across the samples, with CdO and the nanocomposite exhibiting higher reflectance than ZnO and Co_3O_4. For the CdO–ZnO–Co_3O_4 nanocomposite, the onset of reflectance occurred around 400 nm, within the visible range.

The optical band gap (E_g) was estimated using the Kubelka-Munk function [25, 26]:

$$F(R_\infty) = \frac{(1 - R_\infty)^2}{2R_\infty} \quad (8)$$

where $F(R_\infty)$ is called the remission or Kubelka–Munk function and the diffuse reflectance (R_∞) of the examined samples $R_\infty = R_{sample}/R_{standard}$ [27]. Band gap values were determined from Tauc plots using:

$$(F(R_\infty) \times h\nu)^2 = A(h\nu - E_g) \quad (9)$$

The values of the optical band gap (E_g) are obtained by plotting the variation of $(F(R_\infty) \times h\nu)^2$ versus E (or $h\nu$) and extending the straight-line range of these plots on the E axis and the obtained. Values are shown in Table 3.

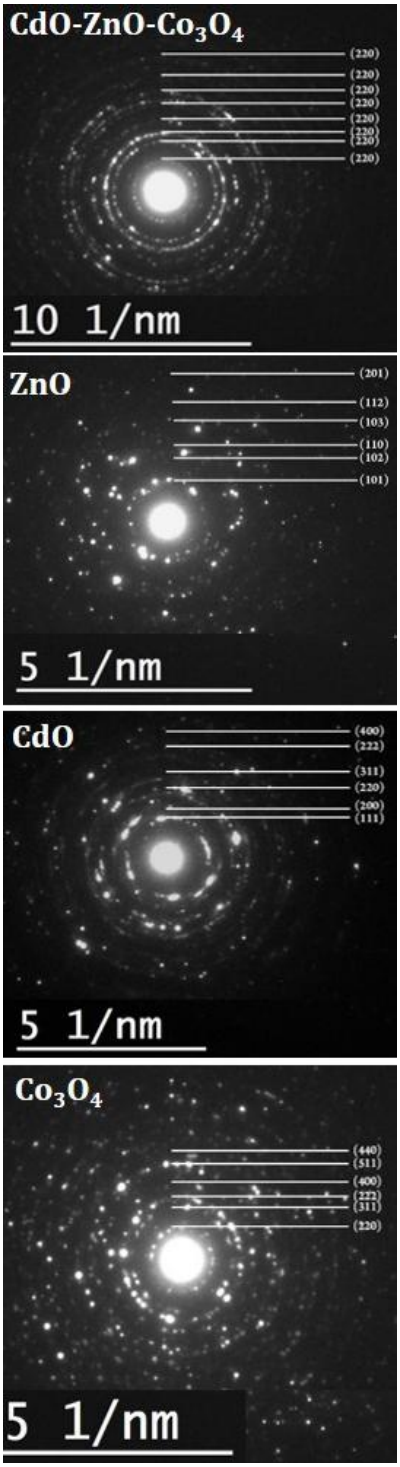

Figure 5: SAED patterns of CdO, ZnO, and Co_3O_4 nanoparticles and CdO–ZnO–Co_3O_4 nanocomposite.

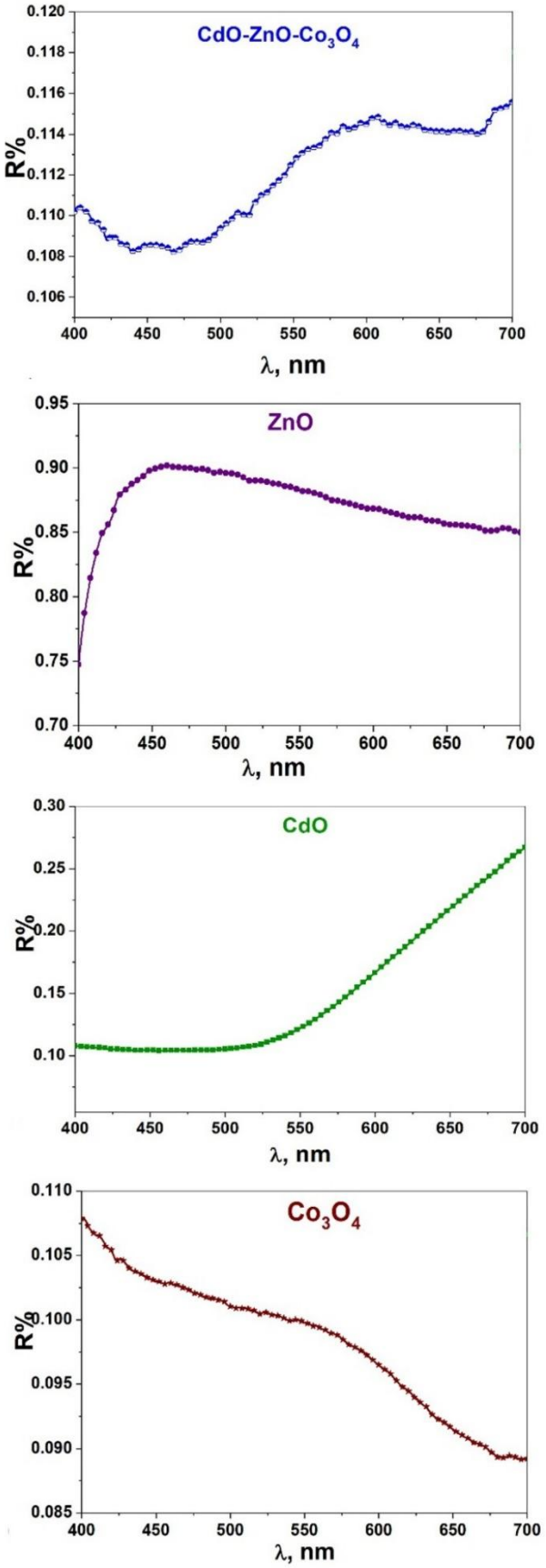

Figure 6: Diffuse reflectance spectrum (R%) of the CdO, ZnO, and Co_3O_4 nanoparticals and CdO–ZnO–Co_3O_4 nanocomposite

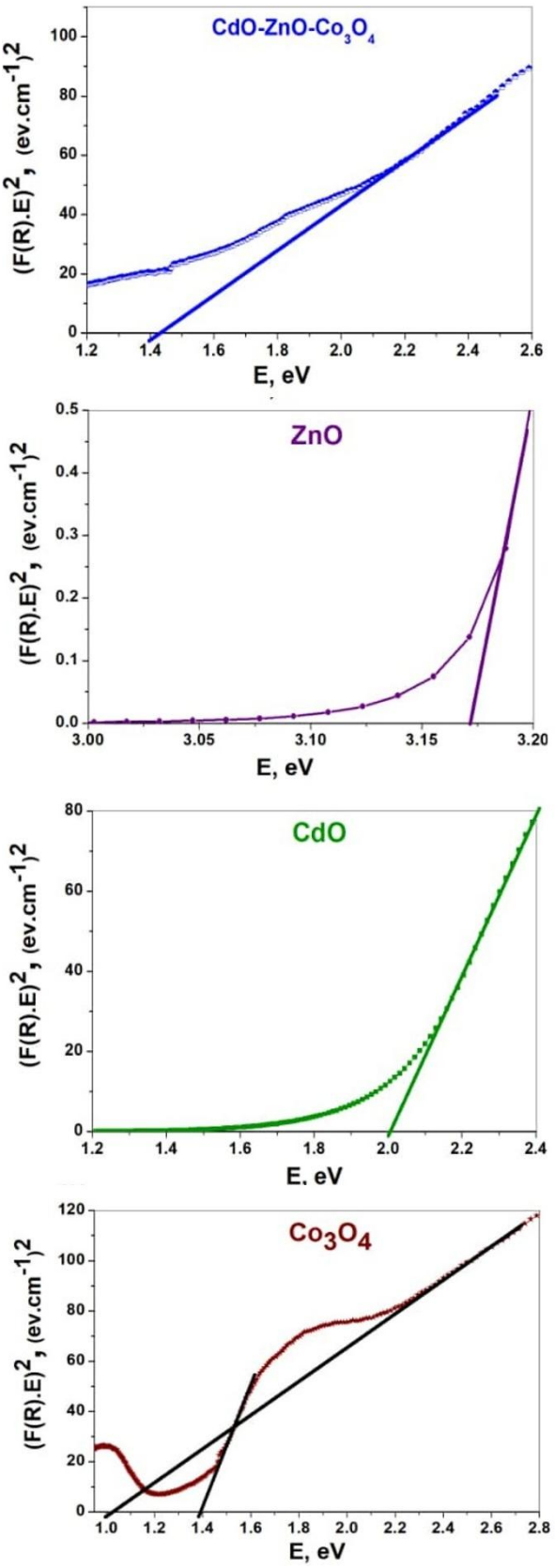

Figure 7: The plot of $(F(R)\hbar\nu)^2$ vs $E(eV)$ for the direct band gap energy for the prepared samples.

As shown in Figure 7 and Table 3, the optical band gap of CdO NPs was 2 eV, corresponding to the direct transition from the valence band O **2p** states to the shallow cores of **d** states of **4d** for Cd [28, 29]. ZnO NPs explored an optical band gap value of 3.17 eV, which is attributed to the transitions from the filled valence O **2p** orbitals to the empty conduction Zn **4s** orbitals, with the possibility of some Zn **4p** orbitals [25, 30]. For the Co_3O_4 NPs, Co^{2+} and Co^{3+} ions contribute to their electrical characteristics. Different charge transfer processes can be attributed to the two band gap energy values (E_{g1} and E_{g2}). The first one (E_{g1}), which is 1 eV, is associated with the charge transfer transition from O^{2-} ions to Co^{3+} ions. The excitation of electrons from the valence band to a higher energy state associated with Co^{3+} makes this transition significant. The second value (E_{g2}), approximately 1.43 eV, is associated with the change in ions from O^{2-} to Co^{2+}, suggesting that, unlike the Co^{3+} transition, the lower energy transition involves a distinct electronic configuration and energy state.

Table 3: Optical band gap energy values of CdO, ZnO, Co_3O_4 nanoparticles, and CdO–ZnO–Co_3O_4 nanocomposite.

Sample	E_g (eV)
CdO	2.00
ZnO	3.17
Co_3O_4	1.00, 1.43
CdO-ZnO-Co_3O_4	1.40

Although it is coupled to crystal size, it is not always directly correlated with the band gap, which suggests that for certain materials, other factors, such as surface states or structural integrity, may have a more significant or negligible impact on the effects of particle size on optical characteristics [31]. The CdO–ZnO–Co_3O_4 nanocomposite has a band gap value close to the second optical band gap of the Co_3O_4 NPs, which was 1.4 eV. This result may be related to the fact that the Co_3O_4 oxide is the dominant oxide in the nanocomposite. Besides the optical band gap of the nanocomposite, which is equal to that of Co_3O_4, the crystallinity of the nanocomposite is as weak as that of Co_3O_4.

On the other hand, ZnO oxide has the highest percentage, as determined by TXRF measurements, and it also exhibits the highest peak intensity in the X-ray pattern of the nanocomposite. These two results may be related to the preparation conditions that led to the formation of ZnO in the nanocomposite with a higher content than other oxides. Therefore, the dominant oxide in the nanocomposite is Co_3O_4 and not ZnO. At the interfaces of several metal oxides, new energy states may form, which could explain the shift in the band gap (E_g) of the nanocomposite relative to that of the individual metal oxides.

Photocatalytic activity is increased when the energy gap is reduced. Photocatalysts with narrow band gap values can absorb a broader range of visible light, which is important because the majority of solar radiation falls within the visible spectrum, and photocatalytic activity is directly correlated with efficient light absorption [1].

3.5. Photocatalytic Activities

3.5.1. Photocatalytic Mechanism

The photocatalytic mechanism of the CdO–ZnO–Co_3O_4 nanocomposite under UV light irradiation is illustrated in Figure 8. Upon exposure to UV photons with energy equal to or greater than the bandgap of the nanocomposite, electrons (e^-) in the valence band (VB) of each component semiconductor (CdO, ZnO, Co_3O_4) are excited to their respective conduction bands (CB), leaving behind positively charged holes (h^+) in the VB. The charge separation and subsequent migration are facilitated by the formation of heterojunctions between the n-type (CdO and ZnO) and p-type (Co_3O_4) semiconductors.

In this ternary system, ZnO with its higher conduction band edge serves as an electron donor to CdO and Co_3O_4, while Co_3O_4 effectively accepts holes due to its suitable VB position. This directional movement of photogenerated charge carriers minimizes recombination rates and enhances photocatalytic activity.

The photogenerated holes (h^+) react with water molecules or surface hydroxyl groups to form hydroxyl radicals (•OH), which are highly oxidative. Simultaneously, conduction band electrons reduce adsorbed molecular oxygen (O_2) to generate superoxide radicals ($O_2^{\bullet-}$). These radicals further interact to form additional reactive oxygen species (ROS) such as hydrogen peroxide (H_2O_2) and more hydroxyl radicals, significantly contributing to the degradation of organic pollutants like

methylene red (MR). The comprehensive mechanism includes the following reactions [32]:

$$CdO–ZnO–Co_3O_4 + h\nu \rightarrow e^- + h^+ \quad (10)$$

$$h^+ + H_2O \rightarrow \bullet OH + H^+ \quad (11)$$

$$e^- + O_2 \rightarrow O_2\bullet^- \quad (12)$$

$$O_2\bullet^- + H^+ \rightarrow \bullet HO_2 \rightarrow H_2O_2 \rightarrow \bullet OH \quad (13)$$

$$\bullet OH + \text{dye (MR)} \rightarrow \text{degradation products} \quad (14)$$

This synergistic interaction among the three oxides enhances the generation of active radicals, thereby improving the overall photocatalytic performance of the nanocomposite.

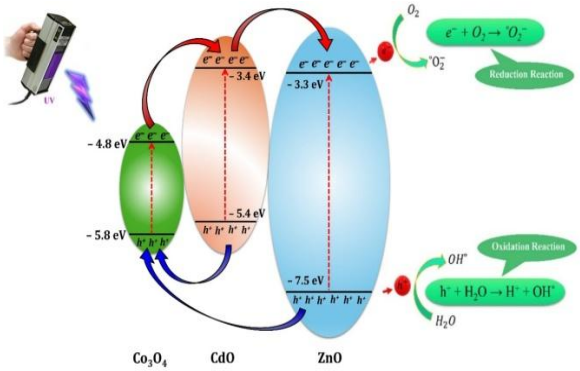

Figure 8: The mechanism of the photocatalytic process for the CdO–ZnO–Co_3O_4 nanocomposite under UV irradiation.

3.5.2. Photodegradation and Catalyst Concentration Effect

The photodegradation behavior of MR dye under UV irradiation at 320 nm in the presence of the CdO–ZnO–Co_3O_4 nanocomposite catalyst was assessed over varying time intervals. As depicted in Figure 9, the absorbance of the MR solution gradually decreased, indicating progressive degradation of the dye. The maximum absorption peak at 419.8 nm, characteristic of MR, diminished significantly after 30 minutes of exposure.

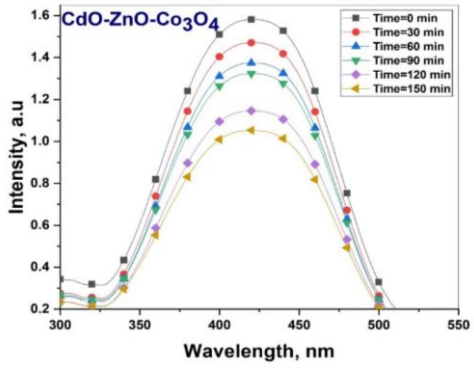

Figure 9: Absorbance spectrum of the CdO- ZnO-Co_3O_4 nanocomposite for MR dye under UV irradiation.

The degradation efficiency was quantified using the relation [33]:

$$\textbf{Degradation}\ \% = \left[\frac{(A_o - A_t)}{A_o}\right] \times 100 \quad (15)$$

where A_o is the initial absorbance (at time zero) and A_t represents absorbance after a particular time. The data revealed a degradation efficiency of approximately 33.4% within 30 minutes (Figure 10A). This modest degradation rate may be attributed to factors such as limited active site availability, suboptimal light penetration due to the MR concentration, and recombination of charge carriers. Several factors, including catalyst concentration, influence the observed photocatalytic performance. At optimal concentrations, more active sites are available for photon absorption and redox reactions. However, excessive catalyst loading can lead to light scattering and shielding effects, which reduce photon penetration and the overall reaction rate. Because light shielding effects caused by higher pollutant concentrations can result in reduced efficiency, as not all dye molecules are exposed to the light required for degradation [34]. The present photocatalytic degradation efficiency is compared with some metal oxide nanocomposites (Table 4).

Table 4: Comparison of photocatalytic activity of some metal oxide nanocomposites

Sample	Dye*	Light Source	Efficiency	Time (min)	Ref.
CeO_2/PAM	MB	UV	65%	15	[35]
CeO_2/GO/PAM	MB	UV	53%	15	[35]
CeO_2/GO/PAM/AO	MB	UV	49%	15	[35]
CeO_2/GO/PAM/$AgNO_3$	MB	UV	46%	15	[35]
ZnO/CeO_2 (99:01)	MO	Visible light	39.5%	30	[36]
ZnO/CeO_2(99:01)	MB	Visible light	34.7%	30	[36]
ZnO/CeO_2(99:01)	Phenol	Visible light	33.5%	30	[36]
CdO–NiO	RhB	UV	78%	20	[37]
CdO–ZnO–Co_3O_4	MR	UV	33.4%	30	This study

MB: Methyl Blue, MO: Methyl Orange, RhB: Rhodamine B, and MR: Methyl Red.

Reaction kinetic models can be used to explain the time-dependent relationship between system operating parameters and the rate at which organic pollutants degrade or microorganisms become inactive. We can use the following relationship [1] to calculate pseudo-first-order kinetics.

$$\ln\left(\frac{C_t}{C_0}\right) = Kt \quad (16)$$

where C_o is the concentration before light irradiation, C_t is the concentration at the time, and K is a first-order constant. When $ln\ (\frac{C_0}{C_t})$ is plotted against time, t (Figure 10B), the slope of the straight-line segment yields the value of K. A linear relationship was observed when plotting $ln\ (\frac{C_0}{C_t})$ versus time (Fig. 10b), with the rate constant K calculated as 0.00271 min^{-1}. This value suggests a relatively slow degradation rate under the tested conditions, which could be improved through modifications such as increased catalyst loading, optimized dye concentration, or adjusting the light intensity.

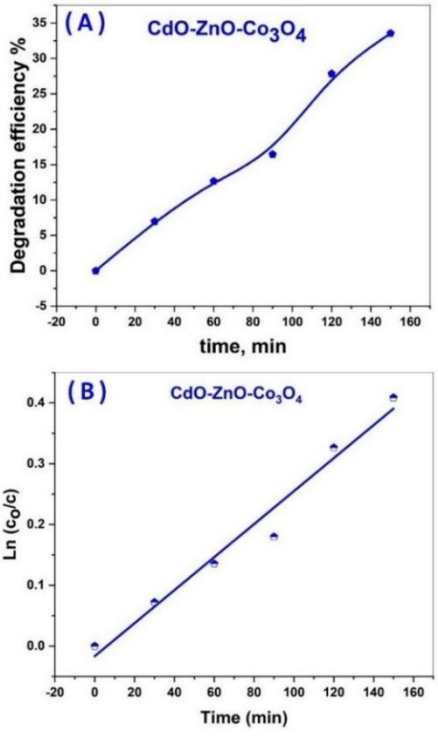

Figure 10: (A) MR degradation%, (B) Photodegradation kinetics plots of MR.

When compared with other nanocomposite systems (as shown in Table 4), the current photocatalyst demonstrates moderate activity. However, its ease of synthesis, structural stability, and reduced band gap energy highlight its potential for further development and application in wastewater treatment.

4. Conclusion

In this study, CdO, ZnO, and Co_3O_4 nanoparticles, along with their mixed ternary oxide nanocomposite CdO–ZnO–Co_3O_4, were successfully synthesized via the co-precipitation method. XRD analysis revealed a significant reduction in crystallite size for the nanocomposite compared to the individual nanoparticles, indicating effective integration of the phases. The elemental composition, as confirmed by TXRF analysis, aligned with the structural phases observed in XRD. TEM imaging showed uniformly distributed spherical particles, while SAED patterns validated the polycrystalline nature of the samples. Optical characterization using diffuse reflectance spectroscopy revealed that the nanocomposite exhibited a reduced band gap of 1.4 eV, enhancing its ability to harness UV light. Photocatalytic performance testing against methylene red dye demonstrated a degradation efficiency of 33.5% within 30 minutes of UV exposure, affirming the potential of CdO–ZnO–Co_3O_4 as a promising UV-active photocatalyst for wastewater treatment applications.

Data Availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study.

Funding

This research received no external funding.

Acknowledgment

The authors gratefully acknowledge Thamar University, Genius University for Sciences & Technology (Yemen), and Suez Canal University (Egypt) for their technical support throughout this study.

References

[1] Singh, R.P., Singh, P., Singh, K.R.,(2021) Introduction to Composite Materials: Nanocomposites and Their Potential Applications, in: Sachdeva, A., Singh, P.K., Rhee, H.W., (Ed.), Composite Materials, *CRC Press*, Boca Raton, USA, pp. 1-28.

[2] Weldegebrieal, G.K., Hinsene, D.H., and Sibhatu, A.K. (2023) Photocatalytic activity of CdO/ZnO nanocomposite for methylene blue dye and parameters optimisation using response surface methodology, *International Journal of Environmental Analytical Chemistry* **103**: 6146-6168.

[3] Guo, T., Yao, M.-S., Lin, Y.-H., Nan, C.-W. (2015) A comprehensive review on synthesis methods for transition-metal oxide nanostructures, *CrystEngComm* **17**: 3551-3585.

[4] Munawar, T., Iqbal, F., Yasmeen, S., Mahmood, K., Hussain, A. (2020) Multi metal oxide NiO-CdO-ZnO nanocomposite–synthesis, structural, optical, electrical properties and enhanced sunlight driven photocatalytic activity, *Ceramics International* **46**: 2421-2437.

[5] Aziz, S.N., Abdulwahab, A., Aldeen, T.S. (2024) Synthesis and Characterization of (CdO-CuO-Co_3O_4) Mixed Metal Oxides Nanocomposite, *Sana'a University Journal of Applied Sciences and Technology* **2**: 116-123.

[6] Taufik, A., Tju, H., Prakoso, S.P., Saleh, R. (2018) Different routes of synthesized CdO nanoparticles through microwave-assisted methods and photocatalytic study, *AIP Conference Proceedings* **2023**: 020035-1-020035-5.

[7] Chimupala, Y., Phromma, C., Yimklan, S., Semakul, N., Ruankham, P. (2020) Dye wastewater treatment enabled by piezo-enhanced photocatalysis of single-component ZnO nanoparticles, *RSC Advances* **10**: 28567-28575.

[8] Vennela, A.B., Mangalaraj, D., Muthukumarasamy, N., Agilan, S., Hemalatha, K.V. (2019) Structural and Optical Properties of Co_3O_4 Nanoparticles Prepared by Sol-gel Technique for Photocatalytic Application, *International Journal of Electrochemical Science* **14**: 3535-3552.

[9] Saadabadi, R.H., Tehrani, F.S., Darroudi, M., Sabouri, Z. (2024) Plant-based synthesis of ZnO–CeO_2–MgO nanocomposite using *Ocimum Basilicum* L seed extract: Biological effects and photocatalytic activity, *Materials Chemistry and Physics* **314**: 128919.

[10] Kannan, K., Radhika, D., Gnanasangeetha, D., Lakkaboyana, S.K., Sadasivuni, K.K., Gurushankar, K., Hanafiah, M.M. (2021) Photocatalytic and antimicrobial properties of microwave synthesized mixed metal oxide nanocomposite, *Inorganic Chemistry Communications* **125**: 108429.

[11] Singh, L.P., Bhattacharyya, S.K., Kumar, R., Mishra, G., Sharma, U., Singh, G., Ahalawat, S. (2014) Sol-Gel processing of silica nanoparticles and their applications, *Advances in Colloid and Interface Science* **214**: 17-37.

[12] Yamanaka, S., Suzuma, A., Fujimoto, T., Kuga, Y. (2013) Production of scallop shell nanoparticles by mechanical grinding as a formaldehyde adsorbent, *Journal of Nanoparticle Research* **15**: 1573.

[13] Li, J., Wu, Q., Wu, J.,(2016) Synthesis of nanoparticles via solvothermal and hydrothermal methods, in: Aliofkhazraei, M., (Ed.), Handbook of Nanoparticles, *Springer international publishing Switzerland*, Cham, Switzerland, pp. 295-328.

[14] Hasanpoor, M., Aliofkhazraei, M., Delavari, H. (2015) Microwave-assisted Synthesis of Zinc Oxide Nanoparticles, *Procedia Materials Science* **11**: 320-325.

[15] Zhu, Y., Zhou, Y. (2008) Preparation of pure ZnO nanoparticles by a simple solid-state reaction method, *Applied Physics A* **92**: 275-278.

[16] Vaidyanathan, G., Sendhilnathan, S., Arulmurugan, R. (2007) Structural and magnetic properties of $Co_{1-x}Zn_xFe_2O_4$ nanoparticles by co-precipitation method, *Journal of Magnetism and Magnetic Materials* **313**: 293-299.

[17] Aziz, S.N., Abdulwahab, A.M., Aldeen, T.S., Alqabili, D.M.A. (2024) Synthesis, characterization, and evaluation of antibacterial and antifungal activities of CuO-ZnO-Co_3O_4 nanocomposites, *Heliyon* **10**: e37802.

[18] Hedayati, K. (2023) Synthesis, characterization and photocatalytic properties investigation of $CuFe_2O_4$/CdO nanocomposite, *Nano Science and Technology Journal* **1**: 49-55.

[19] Dhal, J.P., Mishra, B.G., Hota, G. (2015) Hydrothermal synthesis and enhanced photocatalytic activity of ternary Fe_2O_3/$ZnFe_2O_4$/ZnO nanocomposite through cascade electron transfer, *RSC Advances* **5**: 58072-58083.

[20] Abdulwahab, A.M., Al-Adhreai, A.a.A., Ahmed, A.A.A. (2021) Influence of Ni-Co dual doping on structural and optical properties of CdSe thin films prepared by chemical bath deposition method, *Optik* **236**: 166659.

[21] Othman, A.A., Al-Hammadi, A., Khoreem, S.H. (2023) Fabrication and Study of the Effect of Mn-Substituted Ba-Zn Nanoferrites on the Enrichment of Structural Properties, *Sana'a University Journal of Applied Sciences and Technology* **1**: 168-74.

[22] Al-Sharabi, A., Sada'a, K.S.S., Al-Osta, A., Abd-Shukor, R. (2022) Structure, optical properties and antimicrobial activities of MgO–$Bi_{2-x}Cr_xO_3$ nanocomposites prepared via solvent-deficient method, *Scientific Reports* **12**: 10647.

[23] Yathisha, R.O., Nayaka, Y.A., Vidyasagar, C.C. (2016) Microwave combustion synthesis of hexagonal prism shaped ZnO nanoparticles and effect of Cr on structural, optical and electrical properties of ZnO nanoparticles, *Materials Chemistry and Physics* **181**: 167-175.

[24] Al-Mushki, A.A.A., Ahmed, A.A.A., Abdulwahab, A.M., Qaid, S.A.S., Alzayed, N.S., Shahabuddin, M., Abduljalil, J.M.A., Saad, F.A.A. (2023) Effect of the molar ratio of (Ni^{2+} and Fe^{3+}) on the magnetic, optical and antibacterial properties of ternary metal oxide CdO–NiO–Fe_2O_3 nanocomposites, *Scientific Reports* **13**: 9021.

[25] Ahmed, A.A.A., Talib, Z.A., Hussein, M.Z.b., Zakaria, A. (2012) Improvement of the crystallinity and photocatalytic property of zinc oxide as calcination product of Zn–Al layered double hydroxide, *Journal of Alloys and Compounds* **539**: 154-160.

[26] Ahmed, A.A.A., Talib, Z.A., Hussein, M.Z. (2015) Influence of sodium dodecyl sulfate concentration on the photocatalytic activity and dielectric properties of intercalated sodium dodecyl sulfate into Zn–Cd–Al layered double hydroxide, *Materials Research Bulletin* **62**: 122-131.

[27] Torrent, J., Barrón, V.,(2002) Diffuse reflectance spectroscopy of iron oxides, in: Hubbard, A.T., (Ed.), Encyclopedia of surface and Colloid Science, *Marcel Dekker, Inc.*, New York, USA, pp. 1438-1446.

[28] Guerrero-Moreno, R.J., Takeuchi, N. (2002) First principles calculations of the ground-state properties and structural phase transformation in CdO, *Physical Review B* **66**: 205205.

[29] Lims, S.C., Jose, M., Aswathappa, S., Dhas, S.S.J., Kumar, R.S., Pham, P.V. (2024) Co-precipitation synthesis of highly pure and Mg-doped CdO nanoparticles: from rod to sphere shapes, *RSC Advances* **14**: 22690-22700.

[30] Sampath, S.K., Cordaro, J.F. (1998) Optical Properties of Zinc Aluminate, Zinc Gallate, and Zinc Aluminogallate Spinels, *Journal of the American Ceramic Society* **81**: 649-654.

[31] Andrade, A.B., Ferreira, N.S., Valerio, M.E.G. (2017) Particle size effects on structural and optical properties of BaF_2 nanoparticles, *RSC Advances* **7**: 26839-26848.

[32] Akyüz, D. (2021) rGO-TiO_2-CdO-ZnO-Ag photocatalyst for enhancing photocatalytic degradation of methylene blue, *Optical Materials* **116**: 111090.

[33] Shinde, R.S., Khairnar, S.D., Patil, M.R., Adole, V.A., Koli, P.B., Deshmane, V.V., Halwar, D.K., Shinde, R.A., Pawar, T.B., Jagdale, B.S., Patil, A.V. (2022) Synthesis and Characterization of ZnO/CuO Nanocomposites as an Effective Photocatalyst and Gas Sensor for Environmental Remediation, *Journal of Inorganic and Organometallic Polymers and Materials* **32**: 1045-1066.

[34] Hassanpour, M., Safardoust-Hojaghan, H., Salavati-Niasari, M. (2017) Degradation of methylene blue and Rhodamine B as water pollutants via green synthesized Co_3O_4/ZnO nanocomposite, *Journal of Molecular Liquids* **229**: 293-299.

[35] Kalaycıoğlu, Z., Özuğur Uysal, B., Pekcan, Ö., Erim, F.B. (2023) Efficient Photocatalytic Degradation of Methylene Blue Dye from Aqueous Solution with Cerium Oxide Nanoparticles and Graphene Oxide-Doped Polyacrylamide, *ACS Omega* **8**: 13004-13015.

[36] Rajendran, S., Khan, M.M., Gracia, F., Qin, J., Gupta, V.K., Arumainathan, S. (2016) Ce^{3+}-ion-induced visible-light photocatalytic degradation and electrochemical activity of ZnO/CeO_2 nanocomposite, *Scientific Reports* **6**: 31641.

[37] Linda, T., Muthupoongodi, S., Shajan, X.S., Balakumar, S. (2016) Fabrication and characterization of chitosan templated CdO/NiO nano composite for dye degradation, *Optik* **127**: 8287-8293.

Thamar University Journal of
Natural & Applied Sciences

ISSN-Print: 203-0764
ISSN-Online: 2959-4340

TUJNAS

Volume 10, Issue 1, 2025

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