ISSN : 2349-6495(P) | 2456-1908 (O)

International Journal of Advanced Engineering Research and Science

(IJAERS)

An Open Access Peer-Reviewed International Journal

Journal DOI: 10.22161/ijaers

Issue DOI: 10.22161/ijaers.1112

AI PUBLICATIONS

Vol.- 11 | Issue - 12 | Dec 2024

editor.ijaers@gmail.com | editor@ijaers.com | https://www.ijaers.com/

International Journal of Advanced Engineering Research and Science

(IJAERS)

(ISSN: 2349-6495(P)| 2456-1908(O))

DOI: 10.22161/ijaers

Vol-11, Issue-12

December, 2024

Publisher

AI Publication

Email: editor.ijaers@gmail.com; editor@ijaers.com

Web: www.ijaers.com

International Editorial/ Reviewer Board

Editor in Chief

- **Dr. Swapnesh Taterh (Chief-Editor),** Amity University, Jaipur, India

Cheif Executive Editor

- **S. Suman Rajest,** Vels Institute of Science, Technology & Advanced Studies, India
  chief-executive-editor@ijaers.com

Associate Editors

- **Dr. Ram Karan Singh,** King Khalid University, Guraiger, Abha 62529, Saudi Arabia
- **Dr. Shuai Li,** University of Cambridge, England, Great Britain

Editorial Member

- **Behrouz Takabi,** PhD, Texas A&M University, Texas, USA
- **Dr. Gamal Abd El-Nasser Ahmed Mohamed Said,** Port Training Institute (PTI), Arab Academy For Science, Technology and Maritime Transport, Egypt
- **Dr. Hou, Cheng-I ,** Chung Hua University, Hsinchu Taiwan
- **Dr. Ebrahim Nohani,** Islamic Azad University, Dezful, IRAN.
- **Dr. Ahmadad Nabih Zaki Rashed,** Menoufia University, EGYPT
- **Dr. Rabindra Kayastha ,** Kathmandu University, Nepal
- **Dr. Dinh Tran Ngoc Huy,** Banking and Finance, HCM, Viet Nam
- **Dr. Engin NAS,** Duzce University, Turkey
- **Dr. A. Heidari,** California South University (CSU), Irvine, California, USA
- **Dr. Uma Choudhary,** Mody University, Lakshmangarh, India
- **Dr. Varun Gupta,** National Informatic Center, Delhi, India
- **Dr. Ahmed Kadhim Hussein,** University of Babylon, Republic of Iraq
- **Dr. Vibhash Yadav,** Rajkiya Engineering College, Banda. UP, India
- **Dr. M. Kannan,** SCSVMV University, Kanchipuram, Tamil Nadu, India
- **José G. Vargas-Hernández,** University of Guadalajara Periférico Norte 799 Edif. G201-7, Núcleo Universitario Los Belenes, Zapopan, Jalisco, 45100, México
- **Dr. Sambit Kumar Mishra,** Gandhi Institute for Education and Technology, Baniatangi, Bhubaneswar, India
- **DR. C. M. Velu,** Datta Kala Group of Institutions, Pune, India
- **Dr. Deependra Pandey,** Amity University, Uttar Pradesh, India
- **Dr. K Ashok Reddy,** MLR Institute of Technology, Dundigal, Hyderabad, India
- **Dr. S.R.Boselin Prabhu,** SVS College of Engineering, Coimbatore, India
- **N. Balakumar,** Tamilnadu College of Engineering, Karumathampatti, Coimbatore, India
- **R. Poorvadevi,** SCSVMV University, Enathur, Kanchipuram, Tamil Nadu, India
- **Dr. Subha Ganguly,** Arawali Veterinary College, Sikar, India
- **Dr. P. Murali Krishna Prasad,** GVP College of Engineering for Women, Visakhapatnam, Andhra Pradesh, India
- **Anshul Singhal,** Bio Instrumentation Lab, MIT, USA
- **Mr. Lusekelo Kibona,** Ruaha Catholic University, Iringa, Tanzania
- **Sina Mahdavi,** Urmia Graduate Institute, Urmia, Iran
- **Dr. N. S. Mohan,** Manipal Institute of Technology, Manipal, India
- **Dr. Zafer Omer Ozdemir,** University of Health Sciences,Haydarpasa, Uskudar, Istanbul, TURKIYE
- **Bingxu Wang,** 2721 Patrick Henry St Apt 510, Auburn Hills, Michigan, United States

- **Dr. Jayashree Patil-Dake,** KPB Hinduja College of Commerce, Mumbai, India
- **Dr. Neel Kamal Purohit,** S.S. Jain Subodh P.G. College, Rambagh, Jaipur, India
- **Mohd Muntjir,** Taif University, Kingdom of Saudi Arabia
- **Xian Ming Meng,** China Automotive Technology & Research Center No.68, East Xianfeng Road, Dongli District, Tianjin, China
- **Herlandi de Souza Andrade,** FATEC Guaratingueta, State Center for Technological Education Paula Souza - CEETEPS
- **Dr. Payal Chadha,** University of Maryland University College Europe, Kuwait
- **Ahmed Moustafa Abd El-hamid Elmahalawy,** Menoufia University, Al Minufya, Egypt
- **Prof. Mark H. Rummeli,** University & Head of the characterisation center, Soochow Institute for Energy Materials Innovasions (SIEMES), Suzhou, Jiangsu Province, China
- **Dr. Eman Yaser Daraghmi,** Ptuk, Tulkarm, Palestine
- **Holmes Rajagukguk,** State University of Medan, Lecturer in Sisingamangaraja University North Tapanuli, Indonesia
- **Dr. Menderes KAM,** Dr. Engin PAK Cumayeri Vocational School, DÜZCE UNIVERSITY (University in Turkey), Turkey
- **Dr. Jatin Goyal,** Punjabi University, Patiala, Punjab, India | International Collaborator of GEITEC / UNIR / CNPq, Brazil
- **Ahmet İPEKÇİ,** Dr. Engin PAK Cumayeri Vocational School, DÜZCE UNIVERSITY, Turkey
- **Baarimah Abdullah Omar,** Universiti Malaysia Pahang (UMP), Gambang, 26300, Malaysia
- **Sabri UZUNER,** Dr. Engin PAK Cumayeri Vocational School Cumayeri/Duzce/Turkey
- **Ümit AĞBULUT,** Düzce University, Turkey
- **Dr. Mustafa ÖZKAN,** Trakya University, Edirne/ TURKEY
- **Dr. Indrani Bhattacharyya,** Dr. B.C. Roy College of Pharmacy and Allied Health Sciences, Durgapur, West Bengal, India
- **Egnon Kouakouc,** Nutrition/Health at University Felix Houphouet Boigny Abidjan, Ivory Coast
- **Dr. Suat SARIDEMİR,** Düzce University, Faculty of Technology, Turkey
- **Dr. Manvinder Singh Pahwa,** Director, Alumni Relations at Manipal University Jaipur, India
- **Omid Habibzadeh Bigdarvish,** University of Texas at Arlington, Texas, USA
- **Professor Dr. Ho Soon Min,** INTI International University, Jln BBN 12/1, Bandar, Baru Nilai, 71800 Negeri Sembilan, Malaysia
- **Ahmed Mohammed Morsy Hassan,** South Egypt Cancer Institute, Assiut University, Assiut, Egypt
- **Xian Ming Meng (Ph.D),** China Automotive Technology & Research Center, No.68, East Xianfeng Road, Tianjin, China
- **Ömer Erkan,** Konuralp Campus, Düzce-Turkey
- **Dr. Yousef Daradkeh,** Prince Sattam bin Abdulaziz University) PSAU), KSA
- **Peter JO,** IPB University, Indonesia
- **Nazmi Liana Binti Azmi,** Raja Perempuan Zainab II Hospital, 15586 Kota Bharu, Kelantan, Malaysia
- **Mr. Sagar Jamle,** Oriental University, Indore, India
- **Professor Grazione de Souza,** Applied Mathematics, Rio de Janeiro State University, Brazil
- **Kim Edward S. Santos,** Nueva Ecija University of Science and Technology, Philippines.

Vol-11, Issue-12, December 2024

(10.22161/ijaers.1112)

Detail with DOI (CrossRef)

The Influence of Learning Models on The Learning Outcomes of IPAS in Grade V Students in Elementary Schools

Rara Widuri, M. Sulthon, Ridho Alfarisi

DOI: 10.22161/ijaers.1112.1

Page No: 01-06

Selection of Soybean Genotypes in the Central Region of Tocantins

Lerisvan Pereira de Almeida, Vânia Camila Almeida de Sant'Anna

DOI: 10.22161/ijaers.1112.2

Page No: 07-14

Ozone Therapy in Equines

Daniel Rodrigues Silva, Adriano Leite Guimarães, Athos Menezes Ramalho Araújo Vieira, Eduardo Dias Duarte, Ellyan Martins Almeida, Heitor Abreu Maximiano, Thiago Dos Santos Viana, Wanessa Soares Luiz Silva

DOI: 10.22161/ijaers.1112.3

Page No: 15-19

The Importance of the Clinical Analyst in Recognizing Promyelocytes in Acute Promyelocytic Leukemia for the Patient's Prognosis

Daniel Rodrigues Silva, Gabriel Vieira Antunes, Loiany Soares dos Santos Oliveira, Arthur Quartezani Bruneli Lima, Cleiton de Brito Pimenta, Tarcísio Almeida Kretli, Wanessa Soares Luiz Silva

DOI: 10.22161/ijaers.1112.4

Page No: 20-31

Burnout Syndrome in Emergency Professionals: A Literature Review

Daniel Rodrigues Silva, Luana Santana Mendes, Anne Carolyne Silva De Souza, Arlete Felix Da Costa, Valéria Mota Soares, Hellen Rodrigues Pereira, Karen Mariane Rodrigues Silva, Jamily Trindade Sampaio, Ana Caroline Carvalho De Jesus Moreira, Mariana Teixeira De Oliveira Brito, Amanda Meira Saldanha, Eugenio Maria Gomes, Wanessa Soares Luiz Silva

DOI: 10.22161/ijaers.1112.5

Page No: 32-35

Sustainable MOFs for Pb2+ Removal: Adsorption, Regeneration, and Environmental Impact

Beni Jared Passi, Ma Xuli, Paul Afreh, Wang Peifen, An Xiaowei

DOI: 10.22161/ijaers.1112.6

Page No: 36-53

Effect of soil compaction on the initial development of corn

Bruno Estefano Fronza, Felipe Facundes Cerqueira, Guilherme Rocha Dos Santos

DOI: 10.22161/ijaers.1112.7

Page No: 54-64

Design & Development of a Road Safety Device

Ahmed Tamim Zabir Prince, Dipta Paul, Zahid Hasan Khoka, Mahabub Alam Khan, Md. Mehedi Hasan, Arafat Matubbar Earik, Md Fahim Khan, Sayed Afridi

DOI: 10.22161/ijaers.1112.8

Page No: 65-69

Recent Trends in Biodiesel Production Techniques: A Review
Manikandan Chandrasekaran, C. Syed Aalam
DOI: 10.22161/ijaers.1112.9
Page No: 70-83

Object Detection using ELAN
Sanjivani Sharma, Dr RK Sharma
DOI: 10.22161/ijaers.1112.10
Page No: 84-89

A design of intelligent range hood based on Arduino
Liu Yi Yu, Yan Zuo Chang, Lin Po Shang, Ze Feng Ling, Yi Chen, Yan Hai Li, Jian Bin Cai, Young Shan Ou
DOI: 10.22161/ijaers.1112.11
Page No: 90-97

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.1

The Influence of Learning Models on The Learning Outcomes of IPAS in Grade V Students in Elementary Schools

Rara Widuri[1], M. Sulthon[2], Ridho Alfarisi[3]

[1]Department of Education, JEMBER University, Indonesia
Email: rarawiduri81@gmail.com
[2]Department of Education, JEMBER University, Indonesia
Email : msulthon.fkip@unej.ac.id
[3]Department of Mathematics, JEMBER University, Indonesia
Email : alfarisi.fkip@unej.ac.id

Received: 27 Oct 2024,

Receive in revised form: 25 Nov 2024,

Accepted: 01 Dec 2024,

Available online: 06 Dec 2024

***Keywords*— Learning Model, Learning Outcomes, IPAS**

***Abstract*—** *The low learning outcomes of IPAS students are caused by the lack of innovative learning models in the learning process. The purpose of this study was to examine the effect of PjB, PBL and Discovery Learning models on the learning outcomes of IPAS of grade V elementary school students. This research is an experimental research using Quasy Experimental with Nonequivalent Control Group Design pattern. The population of this study were all fifth grade elementary school students totaling 75 students. The sampling technique used in this study was proportional random sampling. In this study, the data collection technique used was a test. The data analysis technique used was One Way Annova with the help of SPSS version 21. The results showed that there was a positive influence of the three learning models, namely Project Based Learning, Problem Based Learning and Discovery Learning on the learning outcomes of fifth grade students.*

I. INTRODUCTION

Education has an important role in facing the development of the 21st century. Education has a relationship with the times, because the logarithmic movement of education goes hand in hand with the development of science and technology (Erlistiana et al., 2022; Qomariyah & Subekti, 2021). The education system in Indonesia currently uses the 2013 curriculum with various revisions. However, it has not been able to be mastered optimally because in the field there are still many teacher-centered learning activities. The quality of education is related to the quality of students, because the center point in learning is students. Students are expected to gain as much knowledge and insight as possible by learning.

Education aims to prepare humans to solve life problems in the present or in the future. One of the important subjects is IPAS. It teaches about living and non-living things in the universe and their interactions. IPAS learning really needs to be given to all students, especially in elementary school to equip students with the ability to think logically, analytically, systematically, critically, and creatively, as well as the ability to socialize.

Based on the grade documents of grade V students of Citrodiwangsan 02 Lumajang State Elementary School, in the IPAS subject there are 62% of grades below average

and 38% above average. From the observation, it was found that some students were less active in learning. This is because students feel bored in participating in learning activities and prefer to talk to their friends and tend to be crowded.

Learning in schools, especially elementary schools, needs to be well planned using innovative, interesting and fun learning models and by using learning media to attract students' attention and interest in learning, and learning outcomes will be more optimal. Such learning must occur in all subjects applied in elementary schools, including IPAS learning (Andriyani & Suniasih, 2021; Astriani & Sudarma, 2019). Basically, IPAS is a way of systematically finding out about nature to master a collection of knowledge in the form of facts, concepts, principles, discovery processes and have a scientific attitude.

The low learning outcomes of IPAS are partly due to students' low creative thinking skills. IPAS does not contain concept understanding alone, but also contains the problem solving process. So it is very necessary for students' creative thinking skills to be able to solve IPAS problems. Teachers must be able to innovate by developing constructivism learning in line with the Merdeka Curriculum in order to achieve learning objectives. Teachers play a role in developing 4C competencies (Critical thinking, Communication, Collaboration, Creativity) in students systemically. With culture-based education, students with superior character will be formed who have the ability to adapt and are ready to implement the independent curriculum in the industrial world.

Efforts that can be made to improve student learning outcomes are to use learning strategies and models that attract students' attention. The use of this learning model is so that students can more easily absorb and understand the material provided by the teacher. One of the learning models that can improve IPAS learning outcomes and creative thinking skills is the Project Based Learning model or project-based learning.

There are various learning models that can be used by teachers in constructivism learning, such as cooperative learning, inquiry, jiqsaw model, Problem Based Learning, Discovery Learning and Project Based Learning. Teachers must pay attention to many things in choosing a model, one of which is the characteristics of the learning model and the material to be delivered. Learning models that are expected to shape scientific, social behavior and develop students' curiosity are divided into 3, namely Problem Based Learning, Discovery Learning and Project Based Learning models.

The learning model that is expected to shape scientific, social behavior and develop students' curiosity is Project Based Learning. The Project Based Learning model is learning that uses a project in the learning process. Projects undertaken by students can be individual or group projects and carried out within a certain period of time collaboratively, producing a product, the results of which will then be displayed or presented.

Project Based Learning is student-centered learning in making a work or product that involves cooperation, skills and creative thinking so that students can explore, conduct research and interpret material in the form of results in the learning process. According to Dianti (2023) Project Based Learning is a learning method that provides opportunities for students to learn through meaningful problem-based projects or tasks. Project Based Learning is a learning model that focuses on student activity and involves all activities for students in collecting, presenting and interpreting a learning outcome (Anggelia: 2022). Based on several opinions and previous research, it can be concluded that Project Based Learning is a learning model that makes students as subjects who are given the opportunity to explore and solve problems independently so as to improve learning outcomes and develop their skills.

The Problem Based Learning model presents real problems so as to stimulate students' ability to discover new knowledge and help students develop their knowledge and can be used as a self-evaluation of the results and learning process (Indrajit, R.E: 73). Indrajit (2023: 2) states that Problem Based Learning is a learning method that familiarizes students to solve problems and reflect on them with their experiences based on their prior knowledge. Najoan (2023) said that Problem Based Learning is a model that directs students actively in learning which is delivered by presenting a problem, asking questions so that students are able to develop their own abilities. From several opinions and previous research, it can be concluded that Problem Based Learning is a learning model that begins with a problem to collect and integrate new knowledge so that it can increase student motivation and learning outcomes.

Discovery Learning can assist students in building knowledge independently so as to provide opportunities for students to understand the material according to their prior knowledge and experience. Discovery Learning can develop children's firm reasoning skills because students are prepared to ask, pay attention, reason, prove and convey beyond linguistic structures (Eriansyah & Baadila: 2023). Lieung (2019) explains that the Discovery Learning model is a learning model that involves students in the discovery of material, so that they can make conclusions in

an effort to understand the material. From several opinions and previous research, it can be concluded that Discovery Learning is a learning model that invites students to find new knowledge from the information they have so that it can improve their learning outcomes.

Based on this explanation, the application of the Project Based Learning, Problem Based Learning and Discovery Learning learning models is thought to have an influence on student learning outcomes in IPAS subjects. Therefore, the purpose of this study is to examine the effect of PjBL PBL and Discovery Learning on the learning outcomes of fifth grade students.

II. RESEARCH METHODS

The research design applied in this study is a Quasi Experiment design. This research was conducted by comparing one or more experimental variables given treatment with Problem Based Learning, Discovery Learning and Project Based Learning models. The design in this study used Quasy Experimental with Nonequivalent Control Group Design pattern. Quasi Experimental research design with Nonequivalent Control Group Design pattern is as follows:

Table 1. Research Design of Nonequivalent Control Group Design

	Pretest	*Treatment*	*Posttest*
Group 1	O_1	X	O_2
Group 2	O_1	X	O_2
Group 3	O_1	X	O_2

Description:

O_1 : Initial test (pretest)

X : treatment given to each group

O_2 : final test (posttest) given after treatment

(Source: Krishnan, 2023; referring to Masyhud's book, 167)

The subjects in this study were students in grades 5A, 5B and 5C at Citrodiwangsan 02 Lumajang State Elementary School, with the number of students in each class being 26, 25 and 24 students. The control and experimental classes were determined using the homogeneity test. In this study, the homogeneity test was carried out using the Homogeneity of Variance Test on One-Way Anova. the results of the homogeneity test are as follows:

Table 2. Homogeneity Test Results

ANOVA

Learning outcome

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	613.648	2	306.824	3.062	.053
Within Groups	7213.898	72	100.193		
Total	7827.547	74			

The homogeneity test results show the Fcount value of 3.062 < Ftable which is 3.124, it can be stated that the data is homogeneous.

The main data collection technique was carried out using the learning outcomes test. Other supporting techniques were carried out using the following techniques: interviews, observation and documentation. After the data were collected completely, then the data were analyzed using: techniques: (1) descriptive statistics, and (2) One Way Annova data analysis technique. The data analysis was carried out with the help of SPSS version 21.

The research procedure was carried out with the following steps: (1) conducting observation activities at the school that will be used as a place for (2) identify and formulate problems appropriately, (3) conduct preliminary studies and literature reviews, (4) formulate hypotheses, (5) determine research subjects, (6) conduct normality and homogeneity tests on experimental classes, (7) determine experimental classes that will be given treatment, (8) develop test instruments, (9) test the validity and reliability of research instruments, (10) giving pretests to experimental classes, (11) carrying out learning activities by giving treatment, (12) in experimental classes, namely by applying PBL, Discovery Learning and Project Based Learning learning models, (13) conducting posstest in experimental classes, (14) analyzing data, (15) conducting research hypothesis testing, (16) making discussions, (17) drawing conclusions based on the results of the research that has been done, and (18) compiling a research report.

III. RESULTS AND DISCUSSION

Data analysis used to answer the problem formulation in this research is using One Way Annova. The data analyzed in this study were pretest scores obtained after being given treatment in class V. Before calculating using One Way Annova, a normality test was first carried out to determine

whether the data was normally distributed or not. The results of the normality test calculation are as follows:

Tabe 3. Normality Test Results

Tests of Normality

	Class	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Learning Outcome	Control Pretest	.161	25	.093	.962	25	.463
	Control Posttest	.169	25	.063	.955	25	.321
	Eksperimental Pretest	.161	25	.093	.962	25	.463
	Eksperimental Posttest	.139	25	.200*	.943	25	.173

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The results of the data normality test using the Kolmogorov Smirnov test show the significance value for all data> 0.05 so that the data is declared normally distributed. Furthermore, the One Way Annova calculation was carried out with the help of SPSS version 21. The results of the One Way Annova calculation can be seen in the table as follows:

Table 4. One Way Annova Test Results

ANOVA

Learning Outcome

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3077.635	2	1538.818	4.366	.016
Within Groups	25021.878	71	352.421		
Total	28099.514	73			

The basis for decision making in the One Way Annova test is H0 accepted if the significance value> 0.05 and H0 rejected if the significance value <0.05. Based on the data above, the significance value is 0.016 <0.05 and Ftable is 3.13 <4.366, so H0 is rejected, which means that there are differences in learning outcomes in students who learn using the Problem Based Learning (PBL), Discovery Learning and Project Based Learning models. After knowing the significant effect, then the Post Hoc test is carried out. The Post Hoc test is conducted to determine whether a group has a significant difference from other groups. The results of the Post Hoc test can be seen in the following table:

Table 5. Post Hoc Test Results.

Multiple Comparisons

Dependent Variable: skor

Bonferroni

(I) Group	(J) Group	*Mean Difference (I-J)*	*Std. Error*	*Sig.*	*95% Confidence Interval*	
					Lower Bound	*Upper Bound*
Class A	Class B	1.000	5.310	1.000	-12.02	14.02
	Class C	-13.248*	5.365	.048	-26.40	-.09
Class B	Class A	-1.000	5.310	1.000	-14.02	12.02
	Class C	-14.248*	5.365	.029	-27.40	-1.09
Class C	Class A	13.248*	5.365	.048	.09	26.40
	Class B	14.248*	5.365	.029	1.09	27.40

*. The mean difference is significant at the 0.05 level.

Post Hoc test results show that there is a significant difference between class C with class A and class B. Based on the one way annova test, it shows that there is a significant difference in student learning outcomes using the Problem Based Learning, Discovery Learning and Project Based Learning models obtained sig value <0.05. This proves that the three learning models can improve student learning outcomes. This study succeeded in improving student learning outcomes but student completeness has not been met 100% because there are still students who do not meet the KKM seen from their posttest scores. This happens because there are other factors that influence such as internal and external factors such as intelligence, motivation, interest and family or peer environment. In addition, student completeness can also be assessed from daily grades, student activeness in learning activities and changes in student behavior after learning.

The Problem Based Learning (PBL) model is a learning model that is based on a real-life problem. learning model that is based on a real-life problem to improve students' ability to gain knowledge, think critically, and solve

problems. This can be seen clearly in the steps of applying the Problem Based Learning (PBL) model, where in this model students are directly involved in solving a problem. students are directly involved in solving an existing problem. The Problem Based Learning (PBL) model affects student learning outcomes, because this model has several advantages, namely providing awareness students that learning activities are not always teacher-centered but also depend on the motivation of students. depends on the motivation of the students. This can be seen in research activities that have been carried out in experimental classes, where through the application of this model, students play an active role with their motivation in solving problems in the learning process. in solving problems in the learning process

Learning using the Discovery Learning model is effective in improving student learning outcomes compared to conventional learning, because with Discovery Learning learning students are required to be active in finding and formulating problems so that Discovery Learning learning strongly encourages students not to be passive in the learning process. In Discovery Learning learning students are required to be able to answer critically and logically, problem solving skills, develop a sense of curiosity objectivity, careful thinking and tolerance for different opinions

The Project Based Learning learning model is suitable for improving creative thinking skills and IPAS learning outcomes, this can be proven by the results of the analysis. Stating that there is a positive effect of the Project Based Learning learning model on the learning outcomes of IPAS of grade V elementary school students. This is in line with previous research which states that the Project Based Learning model can improve IPAS learning outcomes. The advantages of using the Project Based Learning model in classroom learning are able to increase students' understanding and creativity through projects that have been made.

Before the application of the Project Based Learning learning model, students' understanding of IPAS learning was poor. This can be seen from the results of student pretests, many students whose scores are still far below the KKM (Minimum Completeness Criteria).

This is in line with the results of research from several researchers who also conducted research related to the application of project-based learning.

Research related to the application of project-based-learning in classroom learning. According to Mulyono (2023), the findings of the research he has conducted reveal that project-based learning does not only improve students' performance in learning. elementary students' learning motivation but also improve their problem-solving ability. The contribution of this study lies in its significance for vocational education, particularly by providing teachers with practical examples of project-based learning (PjBL).

Students' understanding of IPAS lessons after the application of the Project Based Learning learning model has increased, which can be seen from the increase in student scores after carrying out the posttest. This can be seen from the difference in the average score of the class given the Project Based Learning model learning rather than conventional learning. Teachers play a crucial role in determining the success of the learning process. Improvement efforts made by teachers play an important role in creating an interesting and efficient learning environment (Veronika, 2023).

The Project Based Learning (PjBL) learning model is very helpful in the learning process because it can make students' knowledge deeper, this model is packaged to make a project and form a group where students here directly practice how to make the product to be made. In addition to discussing and practicing directly making products, students are also trained to speak in front of their classmates or in the school environment, so that the experience students experience is increasing. By using the PjBL model, especially in IPAS subjects, learning becomes very enjoyable and students are enthusiastic in the learning process.

IV. CONCLUSION

The application of Project Based Learning, Problem Based Learning and Discovery Learning models can improve the learning outcomes of IPAS grade V elementary school students. However, of the three models that show the most effective is the Discovery learning model. This can be seen from the results of the posttest scores obtained by students after being given a treatment. For the development of learning in elementary schools is expected to improve IPAS learning outcomes. Teachers are also advised to optimize students' basic potential space. In the learning process, it must be optimized with the availability of facilities and facilities in learning. And for other researchers it can be used as a basic reference for conducting further research. And for other similar researchers, these findings can be used as a reference and basis for conducting further research.

ACKNOWLEDGEMENTS

Thank you to my family and friends who have given me endless support, help and encouragement. I would also

like to thank my supervisor for the knowledge given. Hopefully this research can provide benefits to me and future researchers.

REFERENCES

[1] Anjelina, L., & Zuryanty, Z. (2022). Application of the Project Based Learning (PjBL) Model to Improve Student Learning Outcomes in Integrated Thematic Learning in Class V SDN 01 Baringin Anam Agam Regency. Tambusai Education Journal *6*(2), 15090-15097

[2] Anindyajati, D., Mar'atus, S., Dheliana, S., & Ngazizah, N. (2023). Implementation of PJBL as a Step to Prepare Elementary Students' Creativity to Face Era 5.0. Indonesian Journal of Elementary and Childhood Education, *4*(2), 47-50

[3] Cahyani, A. (2023). Improving the Learning Outcomes of Grade V Students of SDN 2 Talesan with the Application of PJBL Learning Model through Diodrama Media. Journal of Research Network for the Development of Educational Innovation Implementation (Jarlitbang), 137-144

[4] Elementary.JurnalBasicedu, 3124.https://doi.org/10.31004/basicedu.v5i5.1285.

[5] Ismail, R., Rifma, R., & Fitria, Y. (2021). Development of Thematic Teaching Materials Based on PJBL Model in Elementary School. Basicedu Journal, *5*(2), 958-965

[6] Malfani, W., & Zainil, M. (2020). Application of Project Based Learning (PJBL) Model on Mathematics Learning Outcomes in Elementary School. Journal of Basic Education Studies, *3*(2), 703-717.

[7] Prianggono, A., Yuniarti, D. A., & Pawening, A. S. (2023). Implementation of DGMATHbased *Project Based Learning* Model to Improve Elementary School Students' Learning

[8] Sitorus, H. A., Siagian, A. F., & Barus, M. (2024). P THE EFFECT OF PROJECT-BASED LEARNING MODEL ON CREATIVE THINKING ABILITY OF GRADE V STUDENTS OF UPTD SD NEGERI 122350 PEMATANGSIANTAR. Indonesian Journal Service Research Development *(P3JI)*, *2*(2), 32-39

[9] Veronica, N. (2023, May). The Implementation on Role Play in Early Children Mathematics Skills. In *1st UMSurabaya Multidisciplinary International Conference 2021 (MICon 2021)* (pp. 364-368). Atlantis Press. https://doi.org/10.2991/978-2-38476-022-0_39

[10] Winanda, Z., Zainil, M., & Pusra, D. (2021). Improving Student Learning Outcomes in Integrated Thematic Learning Theme 8 Using the Project Based Learning (PjBL) Model in Class V SD Negeri 20 Indarung Kota Padang. Tambusai Journal of Education, *5*(2), 3284-3297

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.2

Selection of Soybean Genotypes in the Central Region of Tocantins

Lerisvan Pereira de Almeida[1], Vânia Camila Almeida de Sant'Anna[2]

[1]Faculdade de Agronomia, Instituto Tocantinense Presidente Antônio Carlos, Porto Nacional
Email: Lerisvanp.01@gmail.com

Received: 30 Oct 2024,

Receive in revised form: 28 Nov 2024,

Accepted: 03 Dec 2024,

Available online: 10 Dec 2024

***Keywords*— Agribusiness, Glycine max, Productivity.**

***Abstract*—** *Brazilian agribusiness enables two consecutive harvests in the same year using early soybean cultivars. Understanding the interaction between environments and soybean genotypes is crucial for adapting cultivars and ensuring production stability. This study aimed to select early soybean genotypes in the central region of Tocantins. The experiment was conducted in Porto Nacional under rainfed and irrigated conditions, evaluating 40 soybean genotypes, including lines and commercial cultivars. A randomized block design with three replications was used, with plots consisting of four 5-meter rows spaced 0.50 meters apart. Grain productivity (sc. ha-1), cultivation cycle (days), and lodging index were analyzed. Data were subjected to variance analysis via SISVAR software, and means were compared using the Scott & Knott test at a 5% probability level. The coefficient of variation and accuracy estimates assessed experimental precision. Nineteen genotypes exceeded the national average for grain productivity. The cultivation cycle ranged from 91 to 109 days, with an 18-day variation. Under rainfed conditions, none of the genotypes showed susceptibility to lodging, but in the irrigated condition, 9 genotypes exhibited high lodging scores. Four genotypes—20285INT1835, 20204INT108701, 18610INT21205, and 20652INT102372—stood out for combining high productivity, absence of lodging, and an early cycle of 99-101 days. These genotypes demonstrate significant potential for agricultural systems in the Tocantins region.*

I. INTRODUCTION

Brazil is the world's largest soybean producer. Soybeans are extremely important not only as a food source but also as a renewable energy source. One of the factors contributing to the prominence of the country's agribusiness is the possibility of conducting two consecutive harvests in the same agricultural year, increasing the utilization period of the same land and consequently generating higher economic returns. For this to be possible, the use of early soybean cultivars is required, which enable an earlier harvest and, thus, advance the planting period of the second crop.

The state of Tocantins has been standing out in recent years for the expansion of its planted area and soybean production, making a name for itself nationally. In the 2022/2023 harvest, Tocantins reached approximately 1.2 million hectares of planted area, with a production exceeding 3 million tons. The average productivity is around 2,700 kg/ha, highlighting the region as an important agricultural hub in Brazil. This growth is the result of investments in technology and modern agricultural practices, which have enhanced the efficiency and competitiveness of Tocantins' soybeans in the market.

The edaphoclimatic characteristics of Tocantins are favorable for soybean cultivation but also present

challenges. The region has an average annual rainfall ranging between 1,500 mm and 1,800 mm, mostly concentrated between October and April. The climate is marked by a distinct rainy season and dry season, with average temperatures ranging from 24°C to 28°C. High temperatures, low altitude, occurrence of dry spells, more concentrated rainy periods, and more sandy and heterogeneous soils make early soybean cultivation extremely challenging. These conditions require careful management of water and soil to ensure productivity and plant health, as well as strategies to mitigate the effects of prolonged drought.

These edaphoclimatic characteristics are directly related to soybean genetic improvement in the region. Research and development of varieties more resistant to drought and local pests are crucial to ensuring production stability. Genetic improvements also aim to increase the efficiency of water and nutrient use, adapting the plants to the specific conditions of Tocantins. Such innovations are fundamental to sustain agricultural expansion and productivity, especially in the face of climate variability.

The soybean crop has several important characteristics, among which maturation stands out. The maturation cycle of soybeans can vary from 90 to 120 days, depending on the cultivar and environmental conditions. In Tocantins, the choice of short-cycle varieties is common due to the need to adapt the crop to the rainy season. The introduction of early soybeans in the state may be an alternative to maximize gains for rural producers, improving the planting window for the second crop and increasing the productivity of crops such as corn, sorghum, and sesame. Proper plant maturation is crucial for maximizing production and minimizing post-harvest losses, ensuring that the grains reach the optimal harvest point with superior quality.

The objective of this work is to select early soybean genotypes in the central region of the state of Tocantins, analyzing the factors that influence soybean productivity, focusing on edaphoclimatic characteristics and genetic improvement. The aim is to evaluate how these variables impact cultivation efficiency and production quality, providing support for the adoption of more sustainable and technological agricultural practices. Through this analysis, we hope to contribute to the development of strategies that can increase the competitiveness of Tocantins' soybeans in the national and international markets.

II. THEORETICAL FRAMEWORK

2.1 Soybean Cultivation

2.1.1 Origin and Evolution of Soybean Cultivation in Brazil

Soybean (Glycine max [L.] Merrill) is a dicotyledonous species belonging to the Fabaceae family, originating from the Asian continent. Records of soybean cultivation date back to 2800 B.C. in China, where it was mentioned as one of the five sacred grains (SEDIYAMA, 2009). The first mention of soybeans in Brazil was in 1882 in the state of Bahia, but the cultivation was not successful due to the cultivars introduced from the United States, which did not adapt to the latitude of the region (12° S). In 1891, reports of new cultivars introduced in the interior of São Paulo (latitude 22°54' S) and Rio Grande do Sul emerged, which developed well due to the photoperiod being similar to the southern United States, where these cultivars originated (SANTOS, 1988). Later, soybean expanded to the state of Minas Gerais in the 1920s, with the first recorded cultivation in the city of Lavras, and also to the states of Santa Catarina, Goiás, and other Central-Western states in the 1930s, 1950s, and 1970s, respectively (MIYASAKA & MEDINA, 1981; SEDIYAMA, 2009).

The commercial production of soybean grains began in 1935 in the state of Rio Grande do Sul, which, after six years, already had a cultivated area of 702 ha. In 1938, Brazil's first soybean export was reported, destined for Germany, and in 1951, the first edible soybean oil extraction industry was established in the country (MAGALHÃES, 1981).

Various factors contributed to the stimulus and expansion of soybean cultivation in Brazil. Among the main factors are: the similarity of climatic conditions between the southern region of Brazil and the southern United States, where the first imported cultivars originated; the improvement of soil conditions in Rio Grande do Sul (operation "Tatu") and later in the cerrado; the possibility of succession with wheat cultivation, which was extensively grown in the southern region of the country in the 1970s, combined with the growing demand for poultry and swine feed; agricultural tax incentives between the 1950s and 1970s; high soybean market prices in the 1970s; the trend of substituting animal-based oils and fats with plant-based products; the ease of mechanization in the crop's production; the good organization of public and private sectors in research and development; the establishment of agro-industrial sectors in the Southeast and Central-West regions, with a good transportation system for production flow; and the development of photoperiod-insensitive cultivars, allowing cultivation in low-latitude areas; the highly favorable climate for soybean cultivation in Brazil, combined with the coincidence between the Brazilian harvest and the off-

season in the United States (EMBRAPA, 2005; SEDIYAMA, 2009).

2.1.2 Importance of Soybean

Brazil is positioned in the international market as the world's largest soybean producer. The Central-Western region is responsible for nearly half of the national production.

In the 2023/2024 harvest, the planted area was approximately 45.2 million hectares, resulting in a production of 146.5 million tons. The average productivity was 53.98 sc. ha-1 (3239 kg. ha-1) (CONAB, 2024).

In Tocantins, the crop has been expanding, with new planting areas being registered in municipalities in the central-northern region of the state. Among the municipalities with the largest soybean planted areas in the state are, in first place, Porto Nacional with 68,768 hectares; followed by Campos Lindos with 67,866 hectares; Peixe with 53,204 hectares; Caseara with 50,479 hectares; Monte do Carmo with 48,295 hectares; and Mateiros with 47,723 hectares (ADAPEC, 2023).

2.1.3 Climate of Tocantins

The climate of Tocantins is characterized as semi-humid tropical, with two well-defined seasons: a rainy season and a dry season. The average annual temperatures range from 24°C to 28°C, with maximum temperatures that can exceed 35°C during the dry season. The relative humidity is generally high during the rainy season, but it can drop significantly during the dry season. The average annual precipitation fluctuates between 1,500 mm and 1,800 mm, mostly concentrated between October and April, the period when the rains occur. During the dry season, the state faces dry spells, short periods of drought within the rainy season, and long dry periods that can last up to five months.

2.1.4 Importance of Early Soybean for Brazilian Agribusiness

Brazil stands out in the world market for having extensive areas suitable for agriculture, favorable climates, and water availability—factors that make the country one of the largest producers and exporters in the agricultural sector. The Brazilian agribusiness is responsible for 24% of the country's GDP and 47% of its exports (CEPEA, 2023). One factor that has enabled significant increases in Brazilian production, in addition to genetic improvements, is the exploitation of the second crop, which became feasible thanks to the good edaphoclimatic conditions found in the country. The second crop follows the summer crop, allowing for better use of land, greater production, and consequently higher economic returns, creating new sources of income, jobs, and contributing to the positive balance of trade.

In this context, a key aspect for the success of the second crop is the adoption of early soybean cultivars, which enable earlier planting and harvesting, creating a window during the harvest season to explore two crops in the same agricultural year. In most soybean-producing states, corn is the crop adopted for the second crop due to its good complementarity with soybean cultivation. There is also a noticeable trend and significant interest among corn and other crop producers to shift to soybean cultivation (CONAB, 2024). However, it is necessary for the crops used in both the first and second harvests to perform well agronomically, so they can take full advantage of the rainy season and high temperatures, reaching maximum productivity during the shortest possible period in the field.

2.1.5 Phenology and Growth Cycle of the Crop

The soybean plant has an annual cycle, with herbaceous growth, erect posture, and autogamy. Soybean seed germination is epigeal, with the two cotyledons emerging from the soil and giving rise to the development of the seedling. The first pair of leaves is simple, with subsequent leaves being compound and trifoliate. Branches that arise from the budding of the buds on the main stem have trifoliate compound leaves and may also have apical or axillary floral branches, depending on the growth habit of the cultivar (EMBRAPA, 2013).

In the reproductive phase, the inflorescences give rise to seeds arranged in pods, which may contain up to five seeds each, with more than 400 pods per plant. The seed consists of the pericarp, seed coat, and embryo, externally presenting the hilum and micropyle. The characteristics of the pericarp, seed coat, and hilum can vary in color and shape depending on the cultivar used, and they are also used as morphological markers for cultivar identification (PESKE, ROSENTHAL & ROTA, 2012).

The root system is predominantly axial, with diffuse secondary roots and the presence of nodules, which are points where the symbiotic process of nitrogen-fixing bacteria from the Bradyrhizobium genus occurs (SEDIYAMA et al., 1985; SEDIYAMA, 2009).

The soybean plant can be classified according to its growth habit as determinate, semi-determinate, or indeterminate, depending mainly on the critical photoperiod and the position of the inflorescence, as well as the temperature's influence on its growth.

The determinate growth habit is characterized by having terminal and axillary inflorescences, with maturation occurring from top to bottom, short internodes, and usually ceases its vegetative growth once it reaches the reproductive phase, being at least 90% of its final height and 100% of its final dry matter at this stage. Cultivars with indeterminate growth habit have only axillary

inflorescence, as their vegetative growth continues after the plant reaches the reproductive phase. These cultivars are taller and have maturation from bottom to top (SEDIYAMA et al., 1985).

Semi-determinate cultivars have characteristics that are intermediate between the two previous classifications, as they have both terminal and axillary inflorescences, with continued vegetative growth after reaching the reproductive phase, although they are about 70% of their final height at this stage. The maturation of the plant is similar to that of the determinate growth habit, from top to bottom (SEDIYAMA et al., 2005; SEDIYAMA, 2009; KUMUDINI & TOLLENAAR, 2014).

The soybean development cycle can be divided into two phases: vegetative and reproductive. The characteristics of each developmental stage follow the scale proposed by Fehr & Caviness (1977).

The vegetative phase of soybean development comprises several stages, which are basically VE, VC, V1, V2, V3, up to Vn, where "n" is the number of fully developed leaves from the main stem, including the first pair of simple leaves. Vegetative development starts at stage VE, characterized by the emergence of the plant and the exposure of the cotyledons above the soil. The following stage, VC, is characterized by the development of the first pair of simple leaves, arising from the cotyledons (TOLEDO, 2014).

Subsequent stages are named according to the number of fully developed compound leaf pairs above the first simple leaf pair from the main stem, continuing until the onset of flowering. For example, stage V3 is named for having two fully developed compound leaves above the simple leaf pair from the main stem.

The reproductive development of soybean is divided into 8 stages, from R1 to R8. Stages R1 and R2 correspond to the flowering phase, which is crucial for determining the number of pods per plant and the floral abortion rate. Flowering typically starts in the central third of the plant, spreading to the base and the apex.

Stages R3 and R4 correspond to pod formation, a critical phase of development as it represents one of the plant's production components. This phase begins when the pods reach at least 5 mm in one of the first four nodes of the upper third of the plant. It should be noted that reductions in the number of pods per plant cannot be compensated by the number and weight of the seeds, as they have maximum limits.

Stages R5 and R6 involve the determination of the number of seeds per pod and their weight, depending on the plant's nutritional and water conditions and ambient temperature, and are crucial for defining the yield. This phase begins when at least one pod in the upper third of the plant contains a seed that is at least 3 mm in length.

Maturation occurs between stages R7 and R8, evaluated through the main stem. In stage R7, at least one pod already exhibits color and weight indicative of maturity, and in stage R8, at least 95% of the pods are mature, and the plant's senescence accelerates, with intense yellowing and leaf drop. It is important to note that depending on the growth habit of the cultivar, vegetative growth may continue after the plant reaches the reproductive phase, but this growth ceases once seed formation begins, as it constitutes a significant drain of photosynthates (SEDIYAMA, 2009; TOLEDO, 2014).

The developmental stages in cultivars with a determinate growth habit are more defined and may occur simultaneously and overlap, while cultivars with an indeterminate or semi-determinate growth habit tend to have more prolonged phases, with more uneven maturation.

2.1.6 Relative Maturity

The soybean growth cycle can range from 75 to 200 days (CARVALHO et al., 2003) depending on the cultivar, which may vary from super-early to late-maturing. Soybean cultivars are categorized into maturity groups according to the growth cycle exhibited during development in a specific latitude range. In Brazil, the maturity groups range from 5.0 to 10.0. Cultivars within each group may vary their cycle by up to 15 days (SEDIYAMA, 2009) and are recommended based on the latitude of the region.

Cultivars in groups 000, 00, and 0 are very early maturing and are generally recommended for higher latitudes. Meanwhile, cultivars in groups 9 and 10 are later-maturing and are usually recommended for regions with lower latitudes. This difference is due to the fact that the higher the latitude of a region, the longer the growth cycle of the cultivars, due to their sensitivity to photoperiod. The opposite is true for cultivars planted in regions closer to the equator, which exhibit shorter cycles.

In the states of Rio Grande do Sul, Santa Catarina, and Paraná, cultivars from groups 5 to 7 are recommended; in São Paulo, cultivars from groups 6 to 8; in Mato Grosso do Sul and Minas Gerais, cultivars from groups 6 to 9; in Goiás and the Federal District, cultivars from groups 7 to 9; and in Mato Grosso, Tocantins, Bahia, and Maranhão, cultivars from groups 8 and 9 are recommended (EMBRAPA, 2013). It is worth noting that the groups include decimal variations, with each decimal representing a variation of 2 to 3 days in the total cycle of the cultivars.

2.4. Genetic Improvement in the Company's Crop Development

Genetic improvement plays a crucial role in increasing productivity and improving crop resistance to climatic adversities and pests. Inova Genética Ltda is one of the youngest and most promising companies in soybean and hybrid corn seed breeding in Brazil. As the third generation of companies in the Grupo Wehrmann specializing in this field, Inova Genética stands out for its efficiency and speed in developing new soybean cultivars and corn hybrids.

With a highly qualified technical team composed of Ph.D. and master's degree holders in various fields related to genetic improvement, the company leverages advanced technologies and the expertise accumulated over three generations to develop cultivars that meet the demands of the Brazilian market. The new cultivars are characterized by high productivity, resistance to pests and diseases, and adaptability to the country's diverse edaphoclimatic conditions, including those of Tocantins. These genetic improvements are essential to ensuring the sustainability and competitiveness of Brazilian soybeans on the global stage.

III. MATERIALS AND METHODS

The experiments were conducted in two environments: a rainfed area, where sowing took place on October 24, 2023, and an irrigated area, where sowing occurred on October 15, 2023, in the municipality of Porto Nacional, Tocantins, Brazil.

A total of 40 soybean genotypes were used, comprising 36 breeding lines from the company Inova Genética and four commercial cultivars.

The experiments followed a randomized block design with three replications. Each plot consisted of four rows, each 5 meters long, with a 0.50-meter spacing between rows. Sowing was performed in the second half of October in both locations, using a no-till system. A planting density of 18 plants per linear meter was adopted, with fertilization of 400 kg.ha^{-1} of NPK 03-35-06 at sowing. Inoculation was carried out in the furrow during sowing using liquid inoculant (Bradyrhizobium japonicum) applied with a "micron" sprayer at six times the recommended dose, equivalent to 12 mL.kg^{-1} of seeds.

Post-emergence weed control was carried out using glyphosate at a dosage of 4 kg.ha^{-1}. Applications were performed with a self-propelled sprayer, using a spray volume of 150 L.ha^{-1}.

For disease control, preventive fungicide applications were conducted. The fungicides used included:

- Pyraclostrobin at a dosage of 0.5 L.ha^{-1};
- Pyraclostrobin + Epoxiconazole at 0.5 L.ha^{-1};
- Azoxystrobin + Cyproconazole at 300 mL.ha^{-1}, with a spray volume of 200 L.ha^{-1}. Pest control was performed as necessary, using growth regulator insecticides with Teflubenzuron as the active ingredient at a dosage of 50 mL.ha^{-1} of the commercial product. Additionally, systemic contact and ingestion insecticides from the pyrethroid and neonicotinoid chemical groups were used at a dosage of 200 mL.ha^{-1} of the commercial product. Contact insecticides Cypermethrin and Chlorpyrifos were also employed at dosages of 250 and 800 mL.ha^{-1}, respectively, all with an applied spray volume of 150 L.ha^{-1}.

The following traits were evaluated:

- Grain yield (bags.ha^{-1}), obtained by harvesting each plot individually (two rows of 5 meters), weighing the harvested material, extrapolating the weight to 1 hectare, and adjusting to 13% moisture;
- Crop cycle (days), comprising the number of days from sowing to physiological maturity, represented by 95% of plants with mature pods;
- Lodging index, based on the scale by Bernard et al. (1965), where a score of 1 indicates all plants standing upright and a score of 5 indicates all plants lodged.

The data were subjected to analysis of variance using the SISVAR package (FERREIRA, 2011), and means were compared using the Scott & Knott test at a 5% probability level. Experimental precision was analyzed through the coefficient of variation (CV) (PIMENTEL GOME009) and accuracy estimates (RESENDE & DUARTE, 2007).

IV. INDENTATIONS AND EQUATIONS

The coefficient of variation (CV), according to Pimentel Gomes (2009), can be classified as follows: low when less than 10%; medium when between 10% and 20%; high when between 20% and 30%; and very high when above 30%. In this study, the CV was classified as low for the crop cycle (2.04), medium for grain yield (10.99), and very high for lodging (34.34) (Table 1).

Table 1. Joint analysis of variance for grain yield (bags. ha⁻¹), crop cycle (days), and lodging.

Source of Variation	Mean Square Grain Yield	Cycle	Lodging
Genotypes	209.85*	121.04*	1.93*
Location	17562.02*	881.67*	244.37*
Genotypes x Location	137.44*	55.70*	4.37*
Block (Location)	31.38	0.27	1.40
General Mean	55.83	101.87	1.68
Accuracy	0.82	0.96	0.83
CV	10.99	2.04	34.34

*Significant at 5% probability by the F-test. Source: Author, 2024

For the lodging trait, a higher CV estimate was observed. A possible explanation for this low precision is that the magnitude of the mean is inversely related to the CV estimate; that is, a lower mean tends to result in a higher CV.

On the other hand, the evaluation of experimental precision through accuracy estimates eliminates the effect of the mean. Accuracy reflects both the precision of the experimental execution and the presence of variability. Accuracy estimates above 70% are considered of high magnitude (RESENDE & DUARTE, 2007), as was observed for all evaluated traits (Table 1).

From the analysis of variance table, significant variation was observed among genotypes for all evaluated traits. The results also demonstrate a significant difference between locations.

The significant genotype × location interaction indicates that there were differences in the behavior of cultivars across the two environments. This can be attributed to differences in management conditions between the two areas, with the main difference being that one area was irrigated.

Table 2. Phenotypic means for grain yield (bags. ha⁻¹) of 40 soybean genotypes in irrigated and rainfed areas in Porto Nacional, Tocantins.

Genotype	**Porto Nacional Irrigated**	**Porto Nacional Rainfed**	**Mean**
18626INT21777	68.97 a	60.86 a	64.91 a
20283INT355	75.96 a	51.95 a	63.95 a
20285INT1835	69.35 a	56.51 a	62.93 a
WS 069	69.98 a	54.91 a	62.44 a
20161INT127104	73.47 a	50.62 a	62.05 a
182033INT19473	71.84 a	51.62 a	61.73 a
20283INT330	66.3 a	54.1 a	60.2 a
18224INT31266	64.24 a	56.1 a	60.17 a
... (and so on for all genotypes)			

Means followed by the same letter belong to the same group according to the Scott-Knott test at 5% probability. Source: Author, 2024

For grain yield, the range of variation in the overall mean was 30.95 bags.ha⁻¹, with 19 genotypes from group "a" standing out as the most productive, showing averages above the national mean of 53.98 bags.ha⁻¹ (CONAB, 2024).

A comparison between the environments (irrigated and rainfed) reveals lower grain yield in the rainfed environment. According to Sentelhas et al. (2016), 77% of potential, attainable, and actual yield losses are associated with water deficits, while 23% are due to poor management.

Table 3. Phenotypic means for crop cycle (days) of 40 soybean genotypes in irrigated and rainfed areas in Porto Nacional, Tocantins.

Genotype	**Porto Nacional Irrigated**	**Porto Nacional Rainfed**	**Average**
20056INT83388	92 a	89 a	91 a
20069INT83970	93 a	88 a	91 a
20046INT6748	93 a	95 b	94 b
18182INT29304	96 a	93 b	95 b
20121INT123637	94 a	98 c	96 b
20355INT237	94 a	102 d	98 c
20285INT1835	95 a	103 d	99 c
20652INT102372	96 a	102 d	99 c
TMG 2379 IPRO	97 b	104 d	100 c
20234INT151467	97 b	102 d	100 c
18610INT21205	97 b	102 d	100 c
20698INT106175	99 b	101 d	100 c
20204INT108701	95 a	106 e	101 c
18224INT31266	97 b	104 d	101 c
20283INT330	99 b	103 d	101 c
HO GUAPÀ I2X	98 b	104 d	101 d
20476INT115870	99 b	104 d	101 d
20021INT5328	99 b	104 d	102 d

20261INT168604	100 b	105 e	102 d
217509I2X263774	100 b	104 d	102 d
182094INT21698	100 b	104 d	102 d
216776I2X266008	99 b	107 e	103 d
WS 070	102 c	104 d	103 d
NEO 790 IPRO	102 c	105 d	103 e
18626INT35452	102 c	105 e	103 e
182033INT19473	101 c	106 e	104 e
20161INT127104	101 c	106 e	104 e
18626INT35452HMC	104 c	105 d	104 e
WS 069	104 c	103 d	104 e
182033INT19349	101 c	108 e	105 e
182056INT41228	102 c	107 e	105 e
20283INT355	102 c	107 e	105 e
BMX Olimpo IPRO	103 c	107 e	105 e
215981I2X264129	97 b	117 f	107 f
217231I2X266546	106 c	108 e	107 f
18388INT10333	108 d	105 d	107 f
20267INT1216	113 e	104 d	108 g
216524I2X266884	97 b	121 g	109 g
18626INT21777	111 e	107 e	109 g
18372INT9826	112 e	105 e	109 g

Mean: **104 a** (irrigated), **100 b** (rainfed).

Means followed by the same letter belong to the same group according to the Scott-Knott test at a 5% probability level.

Source: Author, 2024

A general average variation of 18 days was observed among the genotypes. The genotypes 20056INT83388 and 20069INT83970 were the earliest, with a cycle of 91 days, while genotype 18372INT9826 was the latest, with 109 days. The genotypes tended to be earlier in the rainfed environment.

It was noted that as the average crop cycle decreased, there was also a decline in the overall average productivity (Tables 1 and 2).

The phenotypic correlation test supports this observation. Correlation reflects the degree of association between traits, and understanding it is crucial as it indicates how much one trait influences the expression of others (CRUZ, REGAZZI & CARNEIRO, 2012).

Gesteira et al. (2018) conducted phenotypic correlation tests between grain yield and crop cycle, showing a significant and high correlation (0.7417). This indicates that later cultivars were more productive, although cultivars with shorter cycles and good performance can still be identified.

Choosing early cultivars for soybean-maize succession or second-crop maize after soybean is essential, as early harvesting increases the planting window and optimizes soil and environmental resource use (SILVA NETO, 2011).

Table 4. Phenotypic averages for lodging in 40 soybean genotypes under irrigated and rainfed conditions in Porto Nacional – TO

Genotype	Irrigated	Rainfed	Average
20652INT102372	1.0 a	1.0 a	1.0 a
217231I2X266546	1.0 a	1.0 a	1.0 a
18182INT29304	1.0 a	1.0 a	1.0 a
20069INT83970	1.3 a	1.0 a	1.2 a
18388INT10333	1.3 a	1.0 a	1.2 a
20056INT83388	1.3 a	1.0 a	1.2 a
20355INT237	1.3 a	1.0 a	1.2 a
20161INT127104	1.3 a	1.0 a	1.2 a
20121INT123637	1.3 a	1.3 a	1.3 a
216776I2X266008	1.7 a	1.0 a	1.3 a
20261INT168604	1.7 a	1.0 a	1.3 a
...	...	...	...
HO GUAPÓ I2X	3.3 c	1.0 a	2.2 b
WS 069	3.3 c	1.0 a	2.2 b
18224INT31266	3.7 c	1.0 a	2.3 b
20234INT151467	4.3 d	1.0 a	2.7 c
20267INT1216	5.0 d	1.3 a	3.2 c

Average: **2.3 b (Irrigated) | 1.1 a (Rainfed)**

Note: Means followed by the same letter belong to the same group according to the Scott-Knott test at 5% probability.

Source: Author, 2024.

For lodging, there was no significant variation among the genotypes tested under rainfed conditions. In this case, all genotypes remained upright enough to allow for mechanized harvesting. However, under irrigated conditions, significant variation in this trait was observed. Genotypes in groups "c" and "d" displayed higher lodging scores, which could result in losses during mechanized harvesting due to plant tipping.

When considering the overall lodging average, genotypes belonging to group "a" showed scores that enable mechanized harvesting in both evaluated environments.

Soil type, moisture, fertility, wind, and plant genetics are some of the factors that can directly influence this characteristic. Clayey, wetter, and more fertile soils generally exhibit higher lodging levels compared to other soil types. This characteristic significantly impacts soybean harvesting. As lodging intensifies, harvesting losses increase directly due to the difficulty in collecting lodged plants (MARTINEZ, 2013).

V. CONCLUSION

The earliest genotypes were 20056INT83388 and 20069INT83970, but they did not stand out among the most productive.

The genotypes 20285INT1835, 20204INT108701, 18610INT21205, and 20652INT102372 excelled by combining high grain productivity, absence of lodging, and a crop cycle of 99 to 101 days, which is considered early.

ACKNOWLEDGEMENTS

The completion of this work would not have been possible without the support and collaboration of many people, to whom we would like to express our deepest gratitude.

First and foremost, we thank God for the health, strength, and wisdom that sustained us throughout this academic journey.

To our mother, Joscelina Pereira de Almeida, for her unconditional love, patience, and constant encouragement. She has always been our greatest inspiration and support in every moment.

To our friends and classmates, who stood by our side during challenges and achievements, sharing knowledge and unforgettable moments.

A special thanks to our advisors, Guilherme Rocha dos Santos and Evandro Reina, for their dedication, patience, and expertise, which were fundamental to the development of this work. Your guidance was essential in transforming ideas into concrete results.

To the agronomist Guilherme Vilela, for all the support provided during the research period.

Finally, we thank everyone who, in some way, contributed to the realization of this work, directly or indirectly. Your words, gestures, and actions played an essential role in making this project possible.

To all, our heartfelt thanks!

REFERENCES

[1] ADAPEC. (2023). Relatório de Produção Agrícola (2023). Agência de Defesa Agropecuária do Estado do Tocantins.

[2] Carvalho, C. G. P., et al. (2003). Proposta de classificação dos coeficientes de variação em relação à produtividade e altura da planta de soja. Pesquisa Agropecuária Brasileira, 38(2).

[3] CEPEA (Centro de Estudos Avançados em Economia Aplicada – ESALQ/USP). (2023). PIB Agro / Índices de Exportação. Disponível em: www.cepea.esalq.usp.br/macro.

[4] CEPEA. (2023). Relatório Anual de Desempenho Econômico 2023. Centro de Estudos Avançados em Economia Aplicada.

[5] CONAB (Companhia Nacional de Abastecimento). (2015). Séries Históricas de Área Plantada, Produtividade e Produção, relativas às Safras 1976/77 a 2014/15 de Grãos. Disponível em: http://www.conab.gov.br/conteudos.php?a=1252&.

[6] EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária). (2005). Tecnologias de produção de soja – Região Central do Brasil 2005. Sistema de Produção 6. Londrina: Embrapa.

[7] EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária). (2013). Tecnologias de produção de soja – Região Central do Brasil 2014. (Sistemas de produção, 16). Londrina: Embrapa Soja.

[8] Fehr, W. R., & Caviness, C. E. (1977). Stage of soybean development. Ames: Iowa State University of Science and Technology.

[9] Ferreira, D. F. (2011). Sisvar: a computer statistical analysis system. Ciência e Agrotecnologia, 35(6), 1039–1042.

[10] Gesteira, G. D. S., Bruzi, A. T., Zito, R. K., Fronza, V., & Arantes, N. E. (2018). Selection of early soybean inbred lines using multiple indices. Crop Science, 2494–2502.

[11] INMET. Disponível em: https://portal.inmet.gov.br/.

[12] Magalhães, C. M. (1981). Soja no Estado do Rio Grande do Sul. In: Miyasaka, S., & Medina, J. C. (Eds.), A soja no Brasil (pp. 18–20). Campinas: ITAL.

[13] Miyasaka, S., & Medina, J. C. (1981). A soja no Brasil. Campinas: ITAL.

[14] Peske, S. T., Rosenthal, M. D., & Rota, G. R. M. (2012). Sementes: Fundamentos científicos e tecnológicos (3ª ed.). Pelotas: Editora UFPel.

[15] Resende, M. D. V., & Duarte, J. B. (2007). Precisão e controle de qualidade em experimentos de avaliação de cultivares. Pesquisa Agropecuária Tropical, 37(3), 182–194.

[16] Santos, O. S. (1988). A cultura da soja – 1 Rio Grande do Sul, Santa Catarina e Paraná. Porto Alegre: Editora Globo.

[17] Sediyama, T. (2009). Tecnologias de produção e usos da soja. Londrina: Mecenas.

[18] Sediyama, T., Pereira, M. G., Sediyama, C. S., & Gomes, J. L. L. (1985). Botânica, descrição da planta e cruzamento artificial. In: Cultura da soja – I Parte (pp. 5–13). Viçosa: UFV.

[19] Toledo, R. E. (2014). Fases de desarrollo del cultivo de soja. Disponível em: http://agro.unc.edu.ar/~ceryol/…/soja/feno_soja.pdf. Acesso em: 22 de outubro de 2014.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.3

Ozone Therapy in Equines

Daniel Rodrigues Silva, Adriano Leite Guimarães, Athos Menezes Ramalho Araújo Vieira, Eduardo Dias Duarte, Ellyan Martins Almeida, Heitor Abreu Maximiano, Thiago Dos Santos Viana, Wanessa Soares Luiz Silva

Received: 29 Oct 2024,

Receive in revised form: 30 Nov 2024,

Accepted: 06 Dec 2024,

Available online: 17 Dec 2024

***Keywords*— Ezoniotherapy, Health, Equines, Animals.**

***Abstract*—** *Ozone therapy, known for its antimicrobial and anti-inflammatory properties, has been explored in veterinary medicine as a less invasive alternative for treating horses. Studies show that this therapy can speed up the wound healing process, reduce pain and swelling, and stimulate the animals' immune system. Ozone therapy has also shown potential in the treatment of orthopedic and dermatological conditions in horses, providing symptom relief and improving the quality of life of these animals. This therapy can be applied in different ways, such as ozonized autohemotherapy, the instillation of ozone gas in cavities and the topical application of ozone. Each method has specific advantages and can be indicated for different conditions, making ozone therapy a versatile tool in the treatment of horses. Problem: What are the real benefits of ozone therapy for the health and well-being of horses? Justification: The search for effective and less invasive methods for animal care encourages the evaluation of new therapeutic approaches. Objectives: This study aims to prove the effectiveness of ozone therapy, analyze application protocols and define safety issues associated with the treatment. Methodology: A literature review was carried out, analyzing existing studies on the application of ozone in veterinary treatments, focusing on the benefits, limitations and safety of the technique.*

I. INTRODUCTION

In recent years, the search for therapeutic methods that promote the well-being and rapid and safe recovery of horses has led researchers and professionals to consider less invasive approaches with high potential for effectiveness. Among these approaches, ozone therapy has aroused interest in the field of veterinary medicine, particularly due to its antioxidant, antimicrobial and regenerative properties. This technique, based on the application of medicinal ozone, is used in several species, including horses, to treat a range of health conditions, from joint injuries to infections and inflammatory processes (SOUZA et al., 2021, TONIN et al, 2024) .

Given this scenario, the central question of this study is: What are the real benefits of ozone therapy for the health and well-being of horses?

The purpose of this work is to analyze the results achieved to date with the use of medicinal ozone in veterinary treatments, considering both its effectiveness and safety for the animal.

The justification for choosing this topic is the growing demand for treatment methods that are simultaneously effective and minimally invasive, factors that contribute significantly to the rapid and trauma-free recovery of animals. Ozone therapy is a technique that can potentially fill this gap, promoting therapeutic benefits with a low risk of adverse effects and a reduced need for drug intervention (CASTRO et al., 2024).

The objectives of this article are, therefore, multiple: firstly, it aims to prove the effectiveness of ozone therapy in the veterinary context, specifically in horses. In addition, this study will seek to analyze the protocols for the

application of ozone in different clinical conditions, as well as to delimit safety issues in the treatment.

The methodology applied in the work was the review of scientific literature, based on the analysis of research on the use of ozone therapy in horses, available on official websites and platforms such as Scielo , PubVet and Google Sholar .

II. DEVELOPMENT

2.1 Introduction to Veterinary Ozone Therapy

Ozone therapy is an integrative therapy that uses a mixture of ozone gas (O3) and oxygen (O2) for therapeutic purposes in various medical conditions, being especially recognized for its anti-inflammatory, antibacterial and antifungal properties, in addition to promoting tissue oxygenation and aiding in wound healing.

Its administration can be administered in several ways, such as topically, subcutaneous injections or through ozonated oils, depending on the type of treatment required, and is currently considered a promising approach in veterinary medicine, especially in the treatment of wounds in horses (Flamia and Wilmsen , 2021)

The introduction of ozone therapy into medicine was initially used in human medicine before expanding to the treatment of animals. Discovered in the 19th century by the German chemist Christian Friedrich Schönbein , ozone was identified by the characteristic odor it produced when an electric discharge passed through oxygen. This gas, known for its antimicrobial and anti-inflammatory properties, began to be used on soldiers' wounds during the First World War due to its effectiveness in reducing infections (FARIA et al., 2024)

In the decades that followed, ozone therapy began to be incorporated into medical treatments and, more recently, also into veterinary practices. With the publication of Hans H. Wolff's 1979 book "Medicinal Ozone", ozone therapy gained popularity as a preventive and curative therapeutic approach in Germany, and its use became consolidated globally, including in Brazil, where the practice began to develop in the 1970s with physician Heinz Konrad and spread to Santa Catarina in the 1990s through Dr. Edison de Cezar Philippi . Today, ozone therapy is widely accepted and increasingly studied, particularly in horses, due to its low cost, practicality and effectiveness in the treatment of inflammatory, respiratory and wound healing conditions (ABOZ, online [1]).

For horses, potential benefits include improved injury recovery and increased circulation, providing relief to animals that frequently suffer from musculoskeletal injuries and respiratory problems, common in sports and heavy work activities . Its application is especially recognized for its antimicrobial, anti-inflammatory and analgesic properties, and its use is associated with a faster and more efficient healing process, without the formation of exuberant granulation tissue, which is a common problem in equine wounds (SOUZA et al., 2021, TONIN et al, 2024).

Among the main effects of the application of ozone therapy are the anti-inflammatory effect, reducing inflammation in wounds, promoting faster healing and reducing the animal's discomfort, effective antimicrobial action against a wide range of bacteria and fungi, action in controlling pain and reducing edema, providing greater comfort for the animal during the healing process, which can be especially useful in deep or chronic wounds, increased tissue oxygenation, leading to improved tissue oxygenation, stimulation of tissue regeneration, accelerating the regeneration of damaged tissues and increased levels of fibrinogen, an essential protein for the healing process, promoting the formation of clots and helping to protect the wound from infections (SOUZA et al., 2021, TONIN et al, 2024).

These benefits make ozone therapy an effective and cost-effective alternative in the treatment of wounds in horses, although technical knowledge is essential for its correct application, in order to maximize results and avoid complications (CASTRO et al., 2024).

2.2 Applications of Ozone Therapy in Horses

Ozone therapy in horses has been a therapeutic alternative used especially in treatments for respiratory diseases, recovery from muscle injuries and healing of chronic wounds. Its application helps in oxygenation and reduces inflammation in the respiratory tract, providing relief and facilitating breathing. This is because ozone improves oxygen circulation and reduces lung inflammation, benefiting the performance of horses, especially those that participate in intense activities. By improving blood circulation and promoting tissue regeneration, ozone reduces healing time and minimizes pain associated with injuries. This effect is particularly useful for competition and work horses, which are often subject to physical wear and tear and need a quick and safe return to activities (BASILE & BACCARIN, 2022) .

[1]ABOZ. **Ozionize-se** : History of ozone therapy . Online. Brazilian Association of Ozone Therapy. Available at: https://www.aboz.org.br/ozonize-se/historia-da-ozonioterapia/#:~:text=Em% 201979, One Year Earlier, Preventive and Authentic Therapy of Ozone. Accessed October 15 , 2024.

Due to the antimicrobial properties of ozone, it is effective against bacteria, fungi and viruses present in wounds. In addition, ozone therapy improves tissue regeneration and promotes healing, preventing open wounds from turning into even more serious injuries. This is particularly valuable for horses, which are susceptible to infections in stable or pasture environments (PRATO, 2022; SOARES et al., 2019)

Ozone acts on animal organisms mainly due to its ability to generate a cellular response through the transient increase of reactive oxygen species (ROS), leading to metabolic adaptations that stimulate the organism to respond with an increase in natural antioxidants, generating a response to inflammation and strengthening the immune system. In controlled doses, it stimulates the organism to produce antioxidant enzymes, such as glutathione peroxidase and superoxide dismutase, essential for neutralizing free radicals, also leading to a reduction in pro-inflammatory mediators such as tumor necrosis factor (TNF-alpha) and interleukins, protecting tissues against oxidative stress generated by intense exercise and inflammatory conditions (JARAMILLO et al., 2020) .

Due to its ability to spread to tissues, causing vasodilation of the arterioles, there is an increase in blood flow to the tissues and greater availability of nutrients, which causes ozone to react with lipid components of cell membranes, generating peroxide products that trigger a series of biochemical and cellular responses. (OLIVEIRA, 2007)

Regarding its administration, this can be carried out in several ways, with different forms of application depending on the animal's clinical condition, aiming to maximize the therapeutic benefits of ozone, adapting to the specific treatment need and the type of injury or condition (BASILE & BACCARIN, 2022) .

One of the application techniques is rectal insufflation, a non-invasive and easy-to-administer technique that allows the absorption of ozone through the intestinal mucosa, where it enters the bloodstream and is distributed throughout the body. This method is effective for systemic conditions, especially for inflammatory diseases and general recovery (BASILE & BACCARIN, 2022) .

In the study carried out by JARAMILLO et al. (2020), the effect of transrectal application of O_3 in 16 healthy horses was evaluated, taking into account the parameters of physical and laboratory evaluation, and production of reactive oxygen species (ROS). Some of the animals were assigned to the control group (CG), receiving 1L of oxygen transrectally, and the other group treated with O_3 (GT), treated with 1L of the oxygen and ozone mixture rectally. While the CG showed no changes in the exams, in the GT an increase in the number of red blood cells, in the hemoglobin concentration, and in the hematocrit values was identified in relation to the basal values and CG. Demonstrating that the use of O_3 led to changes in erythrocyte values and improvement in the rheological properties of the blood, proving to be a safe technique that can indirectly improve oxygenation and metabolism of tissues. (JARAMILLO et al., 2020)

Another study, this time carried out by Alves et al., (2004) on the effects of ozone therapy on intestinal reperfusion injuries in horses, indicated that ozone can play a significant protective role in the initial phase of reperfusion. A reduction in epithelial detachment, neutrophil infiltration and hemorrhage in the mucosa was observed, in addition to a decrease in edema and neutrophil infiltration in the submucosa. The authors point out that this was due to the ability of ozone to modulate antioxidant enzymes and neutralize free radicals formed in the reperfusion phase. Thus, the biochemical action of ozone, possibly linked to its antioxidant capacity, reduces tissue and inflammatory damage associated with oxidative stress during reperfusion.

Another technique is autohemotherapy, where a blood sample is taken from the animal itself and enriched with ozone before being reinfused into the body (BASILE & BACCARIN, 2022) . The aim is to stimulate a more effective immune response and increase blood oxygenation, especially benefiting horses that need systemic support to recover from illness or injury. Autohemotherapy has shown potential in reducing inflammatory processes and improving the overall immune response (SILVA et al., 2019).

SILVA et al. (2019) points out that this process can be carried out in two ways:

- Major autohemotherapy: In this method, blood is removed and treated with ozone, and then reinfused into the animal intravenously. This technique is used to enhance tissue oxygenation and stimulate therapeutic responses, such as tissue regeneration and immune response.
- Minor autohemotherapy: Similar to major, but the reinfusion of ozone-treated blood is done intramuscularly instead of intravenously. This approach also aims to improve oxygenation and the body's response.

The next technique applied is the inhalation of ozonated gases, used especially in some cases of respiratory diseases, as it disinfects and reduces the microbial load in the respiratory tract. However, ozone inhalation should be applied with caution, as, in inadequate concentrations, it can

irritate the respiratory tract and worsen local inflammation (BASILE & BACCARIN, 2022) .

There is also the application of ozonated oil, where ozone is dissolved in vegetable oils, forming a solution that is applied directly to the affected areas, such as skin lesions, superficial infections and open or chronic wounds, promoting healing and protecting against bacterial and fungal infections (PETEOACĂ et al, 2020).

The last method is called bagging , because the injured limb or area of the horse is wrapped in a plastic bag, where the ozone is concentrated, so that the gas is in direct contact with the affected area, which allows it to act deeply in the tissue, benefiting localized injuries, such as ulcers and wounds that require antibacterial and healing action (PRADO et al, 2020).

In a study carried out by PRADO et al. (2020) in a horse presenting an infected wound, anti-tetanus treatment and antibiotic therapy (procaine benzylpenicillin) were administered for 5 days, intramuscularly. The wound was treated with the application of ozonated oil daily and once a week, a " bagging " procedure was performed, using a plastic bag wrapped around the wound area and an ozone source (O3) at a concentration of 60 mcg/ml was inserted for 10 minutes, using an ozone generator, over 5 weeks. After treating the horse with ozone therapy, positive results were observed, including the reduction of granulation tissue and wound healing. The use of ozone therapy as a single therapeutic protocol resulted in rapid and adequate healing, without secondary contamination and with less appearance of exuberant granulation tissue (PRADO et al, 2020)

Ozone therapy protocols vary according to the horse's health problem and the method of application. For respiratory conditions, for example, rectal insufflation is applied once or twice a week, with doses adjusted to the animal's weight. In musculoskeletal injuries, subcutaneous injection is applied in weekly or biweekly sessions, depending on the severity of the injury. For chronic wounds, topical application can be done daily or every other day until complete healing (RODRIGUES, 2022)

It is also observed that these forms of application make the treatment adaptable and effective for different conditions, favoring natural recovery and reducing the need for conventional drug treatments. (PRADO et al, 2020; RODRIGUES, 2022) .

In the treatment of a puncture wound in a horse's hoof by Flamia and Wilmsen (2021), a therapeutic approach was performed that combined systemic and topical interventions over 90 days. Systemic treatment included intramuscular administration of 2% meloxicam (10 mg/kg) daily for seven days to control pain and inflammation, and a single dose of trichlormethiazide and dexamethasone (10 mg/kg), also intramuscularly. In parallel, topical ozone therapy with ozonated sunflower oil was applied.

The authors observed an excellent healing process throughout the period, without the formation of exuberant granulation tissue, an effect that highlights the role of ozone therapy in promoting dynamic and controlled healing, essential for areas of high mobility such as the hoof and heel. Additionally, the combination of ozone therapy methods, such as the use of ozonated oil, the “ bagging ” method and ozone autohemotherapy, proved to be efficient in avoiding common complications, such as excessive accumulation of granulation. The animal's physiological response to the injury was thus enhanced by the integrated approach between ozone therapy and systemic anti-inflammatories (Flamia and Wilmsen , 2021).

After 9 weeks of treatment, wound remodeling was noted, with healing occurring without the presence of exuberant granulation tissue. Wound evaluation throughout treatment showed the beginning of asymmetric growth at the edges of the lesion, with a pink/reddish coloration, indicating progress in healing. Furthermore, the combination of different ozone therapy techniques demonstrated beneficial effects on wound regeneration, suggesting that these approaches may contribute to the development of new therapeutic protocols for equine wounds (Flamia and Wilmsen , 2021).

Furthermore, despite the positive evidence regarding the use of ozone therapy, some authors cite some necessary precautions that the professional must take in the application process, being indicated especially as a complementary therapy and not just a main therapy, due to the potential associated risks. For TONIM et al., (2024) ozone therapy should be considered as a complementary therapy within a broader treatment protocol.

In the study by Pliego et al. (2023), the use of ozone therapy in the treatment of a mare with cutaneous habronemiasis demonstrated some therapeutic limitations, especially due to excessive ozone applications. The protocol included daily cleaning with ozonated serum, application of ozonated oil and six sessions of intralesional ozone , in addition to ointment with dexamethasone and bandages. Although the objective was to stimulate healing and reduce the lesion, the results showed that, after 30 days, there was no significant reduction in the affected area, and surgical intervention was recommended to remove the compromised tissue. An increase in epithelial desquamation was also observed, which hindered the healing process, possibly due to repeated exposure to ozone, which may have caused excessive irritation of the tissue and aggravated the local inflammatory response.

glutamyltransferase levels and causes a slight decrease in glucose concentration, making it important to monitor blood glucose levels in animals during its administration. These reports show that despite the indications, it is necessary to have well-measured guidelines and protocols for the application of ozone therapy, avoiding the risk of adverse effects that compromise the animal's recovery.

III. FINAL CONSIDERATIONS

As noted in the article, ozone therapy has proven to be a promising alternative in the treatment of horses, both due to its effectiveness and its minimally invasive nature, thus serving as a therapeutic option that prioritizes animal welfare. In the studies analyzed, it was possible to verify that the antimicrobial, antioxidant and anti-inflammatory properties of ozone favor its management in various clinical conditions such as inflammatory problems, wounds, respiratory problems and others.

Thus, this study contributes to a broader understanding of the possibilities and limitations of ozone therapy, indicating that, with additional advances in research and well-established protocols, this technique could consolidate itself as an effective and reliable therapeutic method in equine veterinary medicine.

REFERENCES

[1] ABOZ. **Ozionize-se** : History of ozone therapy . Online. Brazilian Association of Ozone Therapy. Available at: https://www.aboz.org.br/ozonize-se/historia-da-ozonioterapia/#:~:text=Em%201979%2C%20um%20ano%20antes,Preventiva%20e%20Terap%C3%AAutica%20do%20Oz%C3%B4nio. Accessed on October 15, 2024.

[2] ALVES GES, ABREU JMG, RIBEIRO FILHO JD, MUZZI LAL, OLIVEIRA HP, TANNUS RJ, et al.. Effects of ozone on jejunal reperfusion injuries in horses . **Arq Bras Med Vet Zootec** [Internet]. 2004 Aug;56(4):433–7. Available from : https://doi.org/10.1590/S0102-09352004000400002

[3] BASILE, RC BACCARIN, RYA Ozone therapy in domestic animals: basic concepts and guidelines. **Ars Veterinaria** , 38(4), 199-207, 2022.

[4] CASTRO, Beatriz Carvalho de et al. Use of ozone therapy as an auxiliary mechanism in the treatment of wounds in horses: Literature review. **Research , Society and Development** , vol. 13, no. 9, e4013946779, 2024.

[5] ARIA, Isabela Alves et al. Applicability of ozone therapy in domestic animals: literature review. **R.Educ. Saúde & M. Amb** ., Patrocínio, v. 1, n. 14, p. 851-862, May, 2024.

[6] FLAMIA, LBG, & WILMSEN, MO Use of three ozone therapy techniques in the treatment of wounds in the equine hoof and heel region - Case report. **Brazilian Journal of Ozone Therapy, 2014 Journal of Development** . 2021.

[7] HADDAD MA, SOUZA MV, HINCAPIE JJ, RIBEIRO JUNIOR JI, RIBEIRO FILHO JD, BENJAMIN LA. Behavior of blood biochemical components in horses submitted to ozone therapy. **Arq Bras Med Vet Zootec** [Internet]. Jun ; 61(3):539–46, 2009.

[8] JARAMILLO FM, VENDRUSCOLO CP, FÜLBER J, SEIDEL SRT, BARBOSA AP, BACCARIN RYA. Effects of transrectal medicinal ozone in horses - clinical and laboratory aspects. **Arq Bras Med Vet Zootec** [Internet]. Jan;72(1):56–64, 2020.

[9] OLIVEIRA, JTC **Systematic review of literature on the therapeutic use of ozone in wounds** . 2007. 256 p. Dissertation (Master's) - Nursing Department, Proesa , São Paulo, 2007

[10] PRADO, Laís Guerra et al. Ozone therapy in the treatment of wounds in horses. **R. cient. elec. Vet. Med** . (34): 6 p, Jan. 2020.

[11] PRATO, M. F **. Ozone therapy in equine cutaneous habronemiasis : report case study.** 2022. 20 p. Final Course Work (Bachelor's Degree) in Veterinary Medicine) – University of Brazil, Fernandópolis, 2022.

[12] RODRIGUES, LQ **Use of ozone therapy as an adjuvant in the treatment of cutaneous habronemiasis** . 2022. Monograph (Bachelor's Degree in Veterinary Medicine) – University Center of Brasília, Brasília, 2022.

[13] SOUZA, AKL, COLARES, RR, SOUZA, ACL The main uses of ozone therapy in diseases of large animals : A review . **Research in Veterinary Science** . v. 136, p. 51 – 56. 2021.

[14] SILVA, Thayná da Cruz Paduan . REZENDE, Laryssa de Souza. DORES, Erica das. GRIGOLETTO, Renan. Ozone therapy in equine wounds. **20th Academic Meeting of Scientific Production in Veterinary Medicine (ENAVET).** Sep. 2019. Available at: http://localhost:8080/handle/prefix/2900 . Accessed on October 10, 2024.

[15] TONIN, KSI; OLIVEIRA, LC; OLIVEIRA, LR Use of ozone therapy in cutaneous lesions of habronemiasis in horses: literature review. **Journal of Continuing Education in Veterinary Medicine and Animal Science of CRMV-SP** , São Paulo, v. 22, e38595, 2024.

[16] PETEOACĂ, A., ISTRATE, A., GOANȚĂ, AM, IONAȘCU, I., TĂNASE, A. The use of ozone therapy in veterinary medicine: a systematic review. **AgroLife Scientific Journal** , vol. 9, no. 2, 2020.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.4

The Importance of the Clinical Analyst in Recognizing Promyelocytes in Acute Promyelocytic Leukemia for the Patient's Prognosis

Daniel Rodrigues Silva, Gabriel Vieira Antunes, Loiany Soares dos Santos Oliveira, Arthur Quartezani Bruneli Lima, Cleiton de Brito Pimenta, Tarcísio Almeida Kretli, Wanessa Soares Luiz Silva

Received: 05 Nov 2024,

Receive in revised form: 01 Dec 2024,

Accepted: 08 Dec 2024,

Available online: 17 Dec 2024

***Keywords*— Acute Promyelocytic Leukemia. APL. Disseminated Intravascular Coagulation. DIC. All-Trans Retinoic Acid. ATRA. Arsenic Trioxide. ATO.**

***Abstract*—** *APL (Acute Promyelocytic Leukemia) is a very aggressive type of myeloid leukemia characterized by the marked production of promyelocytes in the bone marrow and consequently an increase in peripheral circulation, triggering numerous hemorrhagic and thrombotic events, which makes this leukemia a medical emergency requiring immediate initiation of drug treatment. The objective of this article is to demonstrate the importance of the professional in the clinical analyses in identifying these anomalous cells for the correct diagnosis and initiation of treatment, reducing the fatality of this pathology. This article addresses the onset of blood cell production, the genetic alterations that trigger acute promyelocytic cancer, as well as the complications of this pathology, the main of which is DIC (Disseminated Intravascular Coagulation), which can quickly lead to the death of the patient, being the most important factor in the urgency of drug treatment; in addition to the importance of identifying microscopic alterations in the patient's blood for the initiation of treatment and therapeutic success. The research showed that the morphological identification of these cells in clinical analyses can be critical for the initiation of treatment; as well as the administration of ATRA (all-trans-retinoic acid) - usually combined with anthracyclines or ATO (arsenic trioxide) - helps in the remission of APL and reduction of DIC cases, avoiding hematologic complications and increasing patient survival.*

I. INTRODUCTION

Blood is made up of red cells, which are responsible for gas exchange in tissues; platelets, which are responsible for blood clotting, which prevents blood loss; plasma, which contains plasma proteins, vitamins, amino acids, hormones and glucose; and the white series, which is made up of the body's defense cells, of which the leukocytes of the myeloid series include neutrophils, basophils, eosinophils and monocytes, and those of the lymphoid series, which are lymphocytes and NK (Natural Killer) cells. Promyelocytes are immature cells of the myeloid lineage that in a physiological situation would give rise to neutrophils, eosinophils and basophils (JUNQUEIRA and CARNEIRO 2017).

APL is a leukemia characterized by an increase in promyelocytes dysplastic cells in the bone marrow, causing anemia, thrombocytopenia and neutropenia . These immature cells, in addition to disrupting the normal formation of other blood cells within the marrow, are not yet functional, and, at the time of onset of symptoms, they are occupying almost all of the patient's marrow, with these

cells also appearing in the peripheral blood in large quantities (SILVA, K., [2016?] ; FREIRE et. al , 2024).

In this pathology, due to genetic errors, myeloid maturation is interrupted in the promyelocyte phase , with the vast majority of APLs being a problem involving the translocation between chromosomes 15 and 17, known as the t(15;17) translocation. This change in the gene region will alter the proteins that this cell encodes, including changes in PML (Promyelocytic Leukemia Protein), which is a tumor suppressor gene that works together with the p53 gene to suppress tumors, activating apoptosis in cells with leukemogenic potential . Another protein that will undergo changes is RAR α (Retinoic acid receptor alpha), responsible for myeloid differentiation . The production of the hybrid genes PML-RAR α and RAR α-PML will block the gene transcription that allows the maturation of these cells, due to the inability of retinoic acid to bind to the receptor, causing cancer. There are also other forms of this leukemia, all of which are generated by genetic translocation problems, always involving chromosome 17, which is responsible for the production of RAR α, but they represent only about 2% of APL cases (JACOMO, FIGUEIREDO-PONTES and REGO, 2008; LEAL, KUMEDA AND VELLOSO, 2009).

These genetic alterations result in the inability of these cells to initiate the apoptosis mechanism, and their replication in the bone marrow begins to trigger several hematological problems, such as severe anemia, neutropenia and thrombocytopenia. When they enter the peripheral blood, they can cause thrombotic events and Disseminated Intravascular Coagulation (DIC), which is considered a medical emergency (ARAÚJO, B., 2022., FREIRE et. al , 2024).

Furthermore, anomalous promyelocytes release Tissue Factor, which is the main activator of coagulation; they also have the ability to initiate the coagulation cascade through a Carcinogenic Procoagulant , causing the consumption of platelets and the formation of microthrombi in the body (GERONIMO, 2022). On the other hand, there is an increase in the formation of plasmin , which degrades fibrin, due to the increased expression of annexin A2 on the surface of promyelocytes . Annexin A2 is a receptor for plasminogen and t-PA (tissue-type plasminogen activator) that culminate in the formation of plasmin wherever these cells are circulating, causing intense hemorrhage (ALMEIDA, S., 2015).

Since the complete blood count is the fastest method for identifying these cells, as soon as confirmation occurs through cell morphology, associated with clinical suspicions, a doctor should be sought immediately to begin treatment with all-trans-retinoic acid (ATRA) or arsenic trioxide (ATO). Therefore, morphological knowledge of these cells within clinical analyses has shown to be of great importance for patient treatment (ALMEIDA, S., 2015; SILVA, K., [2016?]).

II. THEORETICAL BASIS

2.1 HEMATOPOIESIS

As reported by HOFFBRAND and MOSS (2013), in the first weeks of gestation, blood is produced mainly in the yolk sac, being derived from stem cells. From 6 to 7 months, the liver and spleen become the main hematopoietic organs, and later the bone marrow becomes the main organ to produce blood cells. During childhood and adulthood, the bone marrow becomes the only hematopoietic organ, and when the blood cells mature, they are released into the sinus spaces of the bone marrow for blood circulation.

In the first two years of age, the entire bone marrow is hematopoietic, and as the years go by it begins to be filled with fat, until in adulthood it becomes limited to the central skeleton, and the vicinity of the femur and humerus (HOFFBRAND and MOSS, 2013).

Hematopoiesis begins with pluripotent stem cells that generate mixed myeloid progenitor cells , which differentiate into other precursor cells forming erythrocytes, platelets, monocytes, neutrophils, eosinophils and basophils, and can also give rise to cells of lymphoid origin, generating B and T lymphocytes, in addition to NK cells (HOFFBRAND and MOSS, 2013).

Pluripotent stem cells proliferate and give rise to pluripotent progenitor cells , which will form blasts, which are precursor cells that present morphological characteristics of their lineage (lymphoid or myeloid), and there is also an increase in mitotic frequency. These progenitor cells give rise to other progenitor cells or precursor cells, and precursor cells give rise only to cells that are designated to mature. For the production and maturation of these cells, an adequate microenvironment and growth factors that will regulate the proliferation, differentiation, and apoptosis of immature cells are necessary, and several interleukins and cytokines are necessary . These factors influence the differentiation of the cell into its specific lineage. The release of these cells occurs by the endothelium that irrigates the bone marrow when the loss of adhesion receptors of the cells with the bone marrow occurs (JUNQUEIRA and CARNEIRO 2017).

2.2 MATURATION OF GRANULOCYTES

Granulocytes originate from a common cell called a myeloblast . When this cell begins to differentiate,

granulations appear that will be according to the lineage from which it will originate, becoming a neutrophil , eosinophil or basophil promyelocyte , then differentiating into myelocytes , metamyelocytes , rod granulocytes , and mature neutrophils, eosinophils or basophils (JUNQUEIRA and CARNEIRO 2017).

The promyelocyte is a smaller cell than the myeloblast that precedes it, with a more basophilic cytoplasm, containing granules specific to the lineage from which it will differentiate (neutrophils, eosinophils and basophils), these granules being azurophilic , and it also has a spherical nucleus that may contain a recess, and visible nucleoli (JUNQUEIRA and CARNEIRO 2017).

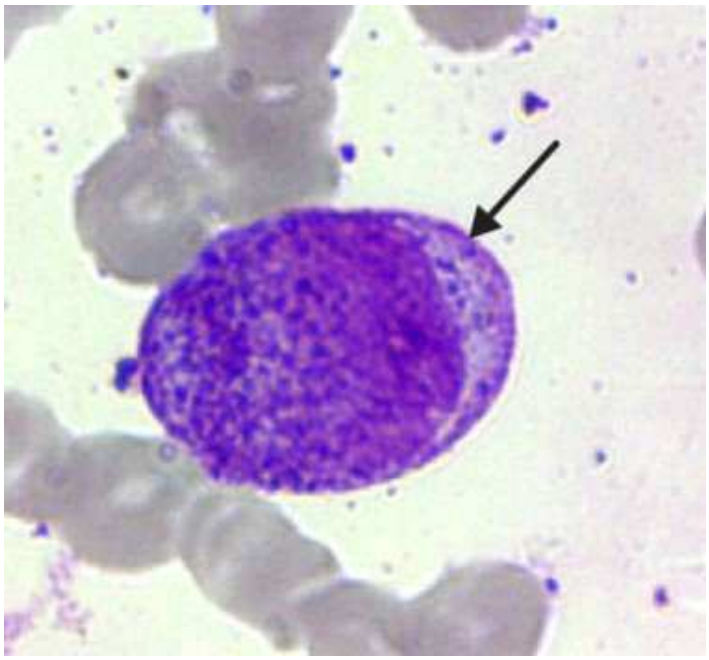


Fig.1 – Microscopic photo of a normal promyelocyte . In the image taken by microscopy, a normal promyelocyte can be seen, shown by the arrow, a cell larger than the red blood cells that are clustered around it, showing its spherical nucleus of a darker purple color, containing nucleoli, delicate chromatin and a lighter perinuclear area being the Golgi Complex, in addition to the azurophilic granules throughout the cell.

Source: *Laboratory of Clinical Analysis and Health Education (LACES),* 2017.

Maturation then proceeds to the myelocyte , containing a spherical or kidney-shaped nucleus, without cytoplasmic basophilia , and with more specific granules. The cell then transforms into a metamyelocyte , containing a deep notch in its nucleus; a rod, which is an intermediate form between the metamyelocyte and the mature cell; and finally a mature and specialized cell capable of performing its specific functions in the immune system (JUNQUEIRA and CARNEIRO 2017).

2.3 **LEUKEMIA**

Cancer is the name given to a group of more than 100 diseases in which abnormal cell growth occurs. This name was first used by Hippocrates (460 BC - 377 BC), known as the father of medicine. Unlike normal cells, cancer cells have disorderly growth, giving rise to abnormal cells. This pathology is classified as a malignant neoplasm, due to its ability to create metastases, invading other tissues, making treatment difficult and potentially leading to death (THULLER, SANT'ANA and REZENDE, 2011).

For cancer to develop, the cell needs to undergo a genetic mutation that alters its instructions, modifying its normal activities, forming anaplastic cells , without differentiation, with numerous mitoses and the ability to invade other tissues. This genetic alteration occurs in normal genes that are called proto-oncogenes , which when activated become oncogenes , becoming responsible for the formation of cancer (THULLER, SANT'ANA and REZENDE, 2011)

Leukemia is a group of diseases in which there is an exaggerated increase in the production of some blood cells, being it an acute leukemia when the affected cells are young cells, losing their differentiation (they do not transform into the cell that they would normally transform into when they mature), or chronic when the affected cells are mature, but do not perform apoptosis, which is the normal physiological process of programmed cell death, with the objective of cell renewal, destroying cells with

damaged DNA or unnecessary for the body at that time (HANNA, 2021; ARAGÃO 2015).

APL (Acute Promyelocytic Leukemia) is a subtype of AML (Acute Myelocytic Leukemia), which corresponds to the M3 and M3 variant (M3v) subtypes, in which there is an increase in blasts with promyelocyte characteristics. dysplastic , with infiltration in the bone marrow, and, as a result, these cells also appear in the peripheral blood. The increase that occurs in the bone marrow distorts normal hematopoiesis , altering red blood cells, white blood cells, platelets and, consequently, causing anemia and hemorrhages. Furthermore, these immature cells, which will be circulating in the bloodstream, are not functional and do not perform their functions as they would when they matured (PREVEDELLO and SAGRILLO, 2008; SILVA, K., [2016?]).

2.4 **GENES INVOLVED IN ALI**

Promyelocytic Leukemia or Acute Myeloid Leukemia with t(15;17) translocation is a type of leukemia that in around 98% of cases is associated with a translocation between chromosomes 15 and 17 - t(15;17) - with the break of the PML gene (Promyelocytic Leukemia Protein) on chromosome 15, and of the RARα (retinoic acid receptor alpha) on chromosome 17, encoding PML-RARα and RARα-PML hybrid proteins (JACOMO, FIGUEIREDO-PONTES and REGO, 2008; SILVA , K., [2016?]).

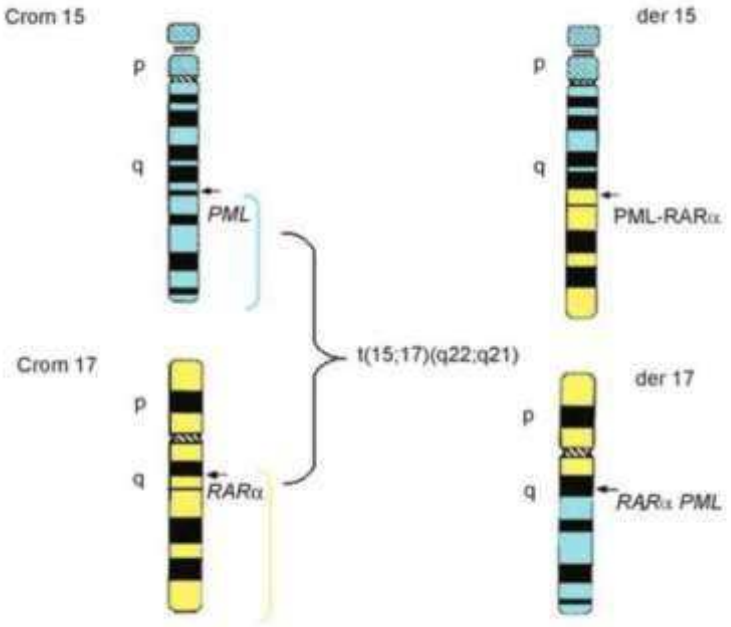


Fig.2 – Figure 2 represents the translocation between chromosomes 15 and 17 and the formation of PML-RARα and RARα-PML.

Source: LEAL, KUMEDA AND VELLOSO, 2009.

PML is a tumor suppressor gene and a regulator of p53 gene activity. This gene is known to be the most important “genome defender” gene in cancer control and is involved in most neoplasms, being activated when DNA damage occurs, stopping the cell cycle in the G1 phase and repairing DNA before duplication. Furthermore, this gene is responsible for the checkpoint from the S phase to the G2 phase and, if there is no DNA repair, PML and p53 are the genes responsible for activating apoptosis in the damaged cell. However, when a mutation occurs in p53 due to PML, both begin to induce cancer and act as oncogenes because they do not perform their basic functions, allowing genetic errors to propagate through mitosis of malignant cells (LEAL, KUMEDA AND VELLOSO, 2009; FETT-CONTE AND SALLES, 2002).

The other important gene in the occurrence of APL is RARα, which is responsible for encoding the retinoic acid receptor alpha , a nuclear hormone receptor that binds to retinoic acid-responsive elements , which is involved in the process of myeloid differentiation (LEAL, KUMEDA AND VELLOSO, 2009). Retinoids are derived from vitamin A and depend on this receptor to play their role in myeloid differentiation . Alteration of this receptor contributes to the pathogenesis of APL, leading to the blockage of differentiation in the promyelocytic phase . Retinoids are

also proliferative inhibitors and specifically stimulate the production of polymorphonuclear cells , not being observed in the differentiation of monocytes and erythrocytes, just as RARα is more expressed in this cell line (JACOMO, FIGUEIREDO-PONTES and REGO, 2008; AMARAL, 2009).

The PML-RARα gene, resulting from the translocation of genes 15 and 17, generates an oncoprotein that has lower sensitivity to retinoids and has the ability to recruit a corepressor complex, formed by: RARα; a retinoic acid X receptor (RXR); nuclear corepressor proteins Sin3a, Sin3b; histone deacetylases (HDAC) and DNA methyltransferase (responsible for methylation and inhibition of transcription), which compact the chromatin, causing the repression of gene transcription, making physiological doses of retinoic acid unable to dissociate this complex, causing the genes responsible for myeloid differentiation to be blocked, resulting in the stagnation of the cell in its maturation process in the promyelocytic phase , initiating leukemogenesis . (LEAL, KUMEDA AND VELLOSO, 2009; JACOMO, FIGUEIREDO-PONTES and REGO, 2008).

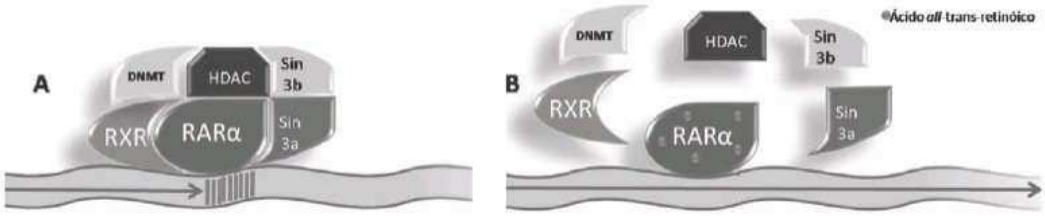


Fig.3 - Representative photo of the corepressor complex formed by the PML-RARα gene. In photo A, the complex formed by the retinoic acid receptor RARα, the retinoid X receptor , the nuclear coreceptors Sin3a and Sin3b, histone deacetylases (HDCA) and DNA methyltransferase blocking DNA transcription can be seen. In photo B, the all-trans acid can be seen. retinoic acid interacting with the RARα receptor dissociating the complex and allowing transcription.

Source: JACOMO, FIGUEIREDO-PONTES and REGO, 2008.

Both genes (PML and RARα) are part of normal hematopoiesis , while the PML-RARα hybrid gene has been demonstrated in 100% of ALI patients with t(15;17) translocation, while the RARα-PML hybrid is absent in 20%. of cases. Therefore, it is suggested that the PML-RARα gene is associated with the leukemogenesis of this leukemia (LEAL, KUMEDA AND VELLOSO, 2009).

LEAL, KUMEDA AND VELLOSO (2009) also show that, in 2% of APL cases, the RARα gene may be fused with genes other than PML, forming fusion proteins with the generic name X-RARα, which may occur on the long arm of chromosome 11 t(11;17), involving the PLZF gene (*Promyelocytic Leukemia Zinc Finger*) of chromosome 11 and RARα of chromosome 17, producing the hybrid genes PLZF-RARα and RARα-PLZF. The PLZF-RARα rearrangement is the second most common, accounting for 0.8% of cases, in addition to bringing some morphological changes, such as a more regular nucleus, an increase in cells with cytoplasmic projections, a higher frequency of CD56 expression and an intermediate morphology between AML-M2 and AML-M3. These patients with the t(11;17) translocation also presented resistance to treatment with ATRA.

CD56 is a membrane glycoprotein that appears in several hematopoietic neoplasms and is associated with poor prognosis, with a low remission rate and short survival period (JAUREGUI., 2018).

Another rarer translocation is the translocation between chromosomes 5 and 17 t(5;17); variant in which APL presents cells with the karyotype 47,XY,+22[5]/46,XY[30], forming the hybrid protein PRKAR1A-RARα, which causes PRKAR1A to lose its function of regulating gene expression. In another rare case, the patient presented a karyotype of 47,XX , t(4;17), forming the hybrid gene FIP1L1-RARα (LEAL, KUMEDA AND VELLOSO, 2009).

2.5.1 **COMPLICATIONS OF LPA**

APL causes some changes similar to other AMLs , such as neutropenia , thrombocytopenia, and anemia due to the increase in immature cells in the bone marrow. However, what causes the highest rapid mortality rate is DIC (Disseminated Intravascular Coagulation) and a state of primary hyperfibrinolysis that affects the entire nervous system and lungs (RIPOLL and MARINA, 2022). Other symptoms resulting from the decrease in functional blood cells are weakness, fatigue, infections, hemorrhages, ecchymosis (purple spots caused by blood extravasation), epistaxis (nosebleeds), and menorrhagia (heavy or prolonged menstrual bleeding) (FREIRE et. al , 2024).

Some patients, especially those with promyelocytes Hypergranular leukocytes may present few

leukocytes and rare leukemic cells in the peripheral blood. This type of leukemia has a preclinical phase of unknown duration and when it begins to be symptomatic, the patient rapidly evolves to a serious condition, presenting almost complete filling of the bone marrow by malignant promyelocytes . (FREIRE et. al , 2024).

Disseminated intravascular coagulation (DIC) and primary fibrinolysis can occur both at the beginning of diagnosis and at the beginning of chemotherapy treatment, and can cause pulmonary or cerebrovascular hemorrhage in 40% of patients, with an incidence of 10 to 20% of early hemorrhagic death, which makes ALI a medical emergency (FREIRE et. al , 2024). Pulmonary and gastrointestinal hemorrhages also occur, as well as high-fatality hemorrhagic events, such as intracranial hemorrhages (ARAÚJO, B., 2022).

Thrombotic events were also evidenced in APL, with thrombosis of deep veins, cerebral veins, hepatic portal veins, peripheral arteries, acute myocardial infarction and ischemic stroke. Thrombotic events occur in approximately 10% of cases and, because they are less evident, have a less known pathogenesis (ARAÚJO, B., 2022).

2.5.2 DISSEMINATE INTRAVASCULAR COAGULATION

According to GERONIMO, 2022:

> DIC is a disorder characterized by hemorrhagic and thrombotic phenomena. It involves systemic activation of the coagulation system, resulting in the consumption of coagulation factors, leading to multiple and uncontrollable bleeding due to blood incoagulability and hemorrhagic diathesis, in addition to multiple organ dysfunction due to compromised blood supply to the organs due to the presence of microthrombi in the circulation.

This disorder can manifest itself in both acute and chronic forms, with fibrinolysis predominating in the acute form, causing intense, prolonged bleeding, with the formation of fibrin microthrombi , consumption of platelets and coagulation factors. On the other hand, in chronic DIC, hypercoagulation or hyperfibrinolysis prevails (GERONIMO, 2022).

The anomalous promyelocytes of this leukemia release Tissue Factor (also called thromboplastin, the main activator of coagulation), Cancer Procoagulant (a cysteine - proteinase that activates Factor X without the need for Factor VII) and microparticles that activate the coagulation cascade, forming hypercoagulation (ALMEIDA, S., 2015; FRANCO, 2001).

In a normal situation, the clot is formed after plasma proteases interact with their cofactors, and a cascade of reactions occurs, forming an enzyme called thrombin, causing proteolysis that transforms soluble fibrinogen into insoluble fibrin. In 1964, a model of the coagulation cascade was proposed by Macfarlane and Davie & Ratnoff , which shows the coagulation cascade being formed by an intrinsic or extrinsic pathway (FRANCO, 2001).

In the intrinsic pathway, Factor XII is activated after the blood comes into contact with something external with a negative electrical charge. This activation is called “contact activation,” and other components in the plasma are required, such as prekallikrein (serine protease) and high molecular weight cysninogen . The cascade begins with prekallikrein and cysninogen transforming Factor XII into Factor XIIa , activating Factor XI, which activates Factor IX and, in the presence of Factor VII, activates Factor X, where the two pathways meet (FRANCO, 2001).

In the extrinsic pathway, plasma Factor VII, in the presence of its cofactor, tissue factor (or thromboplastin), activates Factor X. Factor X is the part of the reaction in which the two pathways meet, subsequently generating Factor IIa (also called thrombin), capable of converting fibrinogen into fibrin. (FRANCO, 2001).

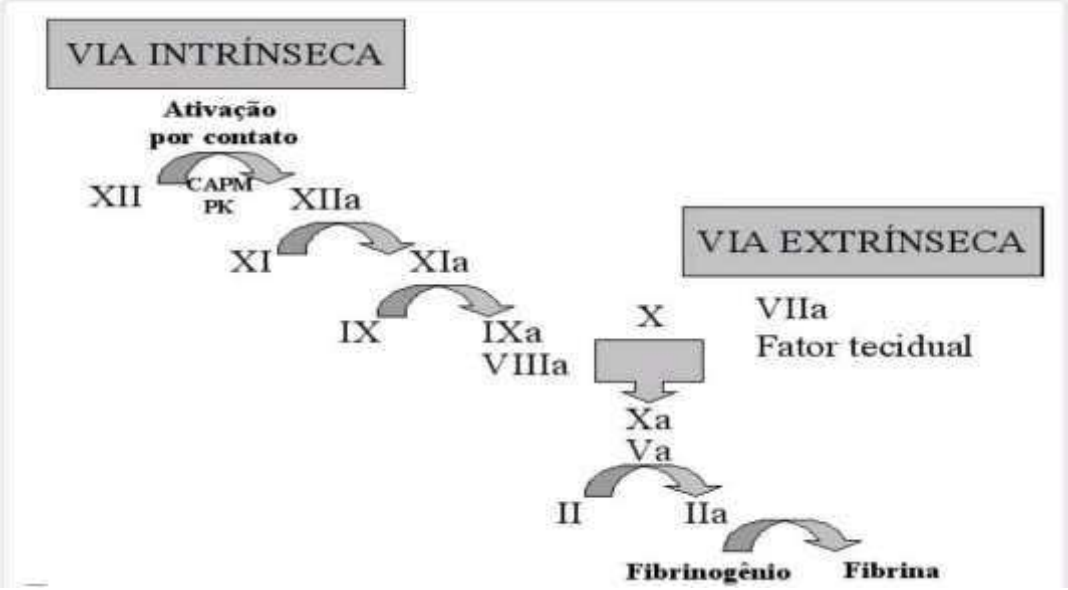


Fig.4 – Representation of the coagulation cascade model proposed by Macfarlane and Davie & Ratnoff in 1964.

Source: FRANCO, 2001.

Hyperfibrinolysis in this leukemia occurs due to elevated levels of t-PA (tissue-type plasminogen activator) and u -PA (urokinase-type plasminogen activator) that bind to the u-PAR receptor (urokinase-type plasminogen activator receptor), activating plasminogen , and eventually forming plasmin . Cancer cells have abnormal expression of annexin A2 (plasminogen and t-PA receptors) on the cell surface, which, together with increased t-PA, causes fibrinolysis wherever the cells pass, making the fibrinolytic activity of this cancer proportional to the number of circulating promyelocytes , that is, the greater the number of these leukocytes, the greater the fibrinolytic activity (ALMEIDA, S., 2015).

anticoagulation process occurs together with the coagulation process in order to balance the organism and prevent the occurrence of thrombi. This process aims to degrade the final product of the coagulation cascade: fibrin. t-PA (tissue-type plasminogen activator) and u-PA (urokinase-type plasminogen activator) are two physiological plasminogen activators that, when bound to plasminogen , cause hydrolysis of a peptide bridge , forming plasmin : a serine protease capable of degrading fibrin, thus removing the clot (FRANCO, 2001).

Plasminogen Activator Inhibitor), with PAI-1 being the main inhibitor, acting directly on plasmin (FRANCO, 2001). In APL, there is a decrease in PAI-1, reducing the levels of the main fibrinolysis inhibitor , allowing the reaction to occur for longer. Another aggravating factor is the consumption of alpha-2-antiplasmin, which is also a primary plasmin inhibitor , contributing to the occurrence of DIC (GERONINO, 2022; COSTA, 2016).

2.6 **DIAGNOSIS**

The first step in diagnosing APL is to assess the clinical symptoms, which may include pallor, hepatomegaly , splenomegaly, lymphadenopathy , fever, pharyngitis, petechiae , bone pain, gingival hypertrophy, skin infiltrations, among others. Peripheral blood and bone marrow examinations should also be performed, and the blood count will show some changes, such as low platelet count, leukocyte count <1,000 µl to 200,000 µl, neutropenia with the presence of blasts, normochromic and normocytic anemia (SILVA, G. et al. 2006).

In the laboratory, when using automation in hematology, it is important to be aware of the flags , which are warnings from hematological counters that indicate some abnormality in the blood sample, making it necessary to perform manual analysis using the blood smear, since only with microscopy can an accurate differentiation of leukocytes be made, in addition to identifying other abnormalities. The staining to be used is very important for the correct evaluation of these changes, with the most commonly used method being Giemsa with May- Grunwald , which better preserves the characteristics of leukocytes (SHÜTZLER., 2022)

Cellular morphology is the most important test for the diagnosis of APL. However, some cytochemical stains can be used to assist. For example, myeloperoxidase and Sudan Black B, which confirm that the stained cells are of myeloid nature , are specific for granulocytes and

monocytes, and reveal auer rods . Another test that has become essential for diagnosis is the immunophenotyping test , which uses monoclonal antibodies against specific epitopes of cellular antigens (SILVA, G. et al. 2006).

However, knowing that APL is a medical emergency, which is fatal in the absence or delay of appropriate treatment, treatment should be started immediately after clinical suspicion and some diagnostic test, such as a blood count (which is the fastest method), allowing advance notification to the physician, who will start the treatment. Other tests, such as immunophenotyping , can take 3 to 4 days to obtain the result; the myelogram , 2 to 5 days; cytogenetics , 11 to 22 days, and this waiting time can cause the patient's death (SILVA, K., [2016?]).

According to ALMEIDA, S. (2015), the first 24 hours are critical for diagnosis. Mortality from this disease can reach 55% in the first month due to the hemorrhagic condition. All-trans-retinoic acid (ATRA) or Arsenic Trioxide (ATO) should be administered as soon as possible, and analysis of the morphological aspects of the cells will be a sufficient indication to begin treatment, even before genetic confirmations.

Thus, the importance of the professional in knowing the morphological characteristics of promyelocytes in APL is elucidated. These cells can present in two different main forms in this leukemia (hypergranular form and hypogranular form), presenting different characteristics in promyelocytes . There are also rarer forms, such as the hyperbasophilic form and the variant associated with the PLZF-RARα fusion (SILVA, K., [2016?]).

The classic form, also called hypergranular , presents an eccentric, dysmorphic nucleus , with an ill-defined border and a dark hue due to the cytoplasmic granules that prevent its clear visualization. The granulation is exuberant, azurophilic and there are often auer rods organized in bundles, naming the cells with the presence of this inclusion: "*faggot ". cells ".* Auer rods (or auer bodies) are indicators of acute myeloid leukemias and are possibly of lysosomal origin , being important for identifying myeloid syndromes in general, being present in APL (also called Acute Myeloid Leukemia M3) (ALMEIDA, S., 2015; SILVA, K., [2016?] ; HANNA, 2021; GALIACHO et al., 2022).

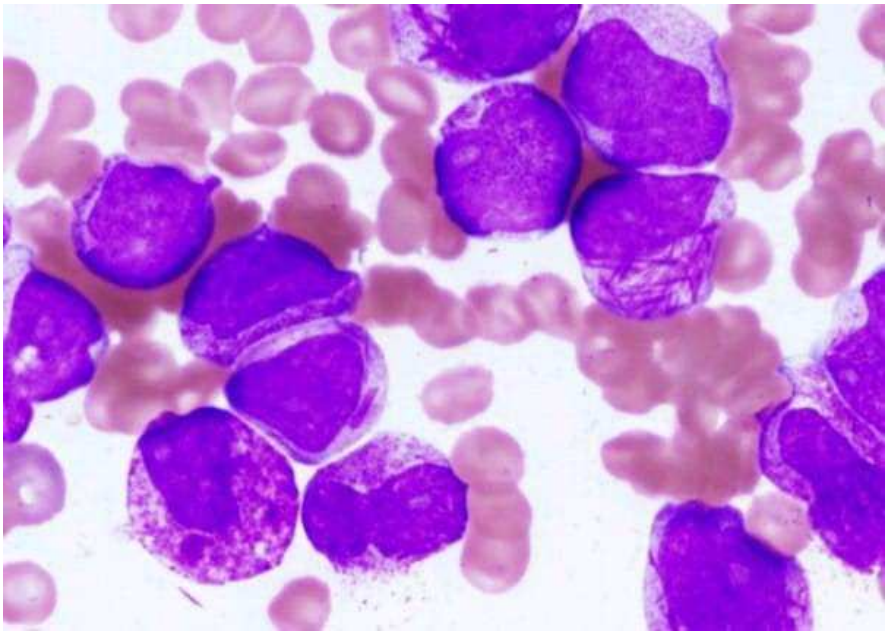


Fig.5 – Microscopic image of promyelocytes in LPA in their hypergranular form .

SOURCE: SILVA, K., [2016?] .

The hypogranular or microgranular form has more discreet cytoplasmic granulation, the nucleus is more visible and clearer compared to the hypergranular form, presenting a bilobular shape , with rare auer rods (SILVA, K., [2016?] ; HANNA, 2021).

Fig.6 – Microscopy image of promyelocytes in LPA in their hypogranular form .

Source: SILVA, K., [2016?]

Of the rare forms, the basophilic form has a high nucleus/cytoplasm ratio, strongly basophilic granules , and does not have auer rods. On the other hand, the PLZF-RARα form has a regular nucleus with condensed chromatin, fewer granules than the hypergranular form , and rare auer rods (ALMEIDA, S., 2015).

2.7 **TREATMENT**

Due to the possibility of hematological complications and the rapid progression of the disease, as soon as the diagnosis is made, it is necessary to immediately begin treatment with all-trans-retinoic acid (ATRA), which has a similar role to retinoids in the maturation of these promyelocytes . It is important to highlight that, due to its mechanism of action, ATRA may not be effective in the rarer forms of ALI (SANTANA, 2019; KOTOWSKI, MONTEIRO, ARAÚJO, M., 2007).

ATRA, together with anthracycline and cytarabine (Ara-C), or associated with ATO, proved to be effective in remitting ALI in an estimated 95% of cases. ATRA, as it is a natural metabolite of retinol and belongs to the class of retinoids , binds to the retinoic acid receptor α (RARα), as if it were a supraphysiological dosage of retinoic acid , having an inhibitory effect on both the PML gene and the RARα gene. . It is responsible for the dissociation of the corepressor formed by RARα, the retinoic acid X receptor (RXR), the nuclear corepressors Sin3a and Sin3b, histone deacetylases (HDAC) and DNA methyltransferase . With this dissociation, the transcription block is undone and the cell is able to carry out gene transcription, leading to the complete maturation of the promyelocyte and also inducing its apoptosis (SANTANA, 2019; KOTOWSKI, MONTEIRO, ARAÚJO, M., 2007).

ATRA will only have a good response in patients who have the t(15;17) translocation, due to its mechanism directly related to the RARα receptor and PML. Furthermore, this drug does not act on the leukemic clone, and it is necessary to combine it with chemotherapy to induce complete remission of the cancer (KOTOWSKI, MONTEIRO, ARAÚJO, M., 2007).

Retinoic Acid Syndrome , also called Differentiation Syndrome (DS), which has symptoms such as fever, dyspnea, respiratory problems, pulmonary infiltration, hyperleukocytosis , pleural effusion, renal and hepatic failure, and multiple organ failure. Regarding the cardiac problems of this syndrome, pericardial effusions, chest pain, peripheral edema, and hypotension can also be triggered. Associated chemotherapy helps to reduce the incidence of this syndrome. Studies suggest that this syndrome can also occur with the use of ATO (SOUZA., [2012?] ; SANTANA, 2019)

Until 1992, the use of anthracyclines was the first-line treatment for APL, and although there was a good remission rate, many deaths from DIC occurred. After the arrival of ATRA , anthracycline treatment associated with all-trans-retinoic acid began (SOUZA., [2012?]).

APL cells have little expression of P-glycoprotein, which promotes the efflux of chemotherapeutic agents, preventing this type of medication from acting on the cell.

With the absence of this glycoprotein, promyelocytes become more susceptible to the action of anthracyclines , with idarubicin being the anthracycline used because it can intercalate into DNA, interact with Topoisomerase II, and inhibit nucleic acid synthesis in bone marrow and blood cells (SOUZA., [2012?] ; HUBER, MARUIAMA and ALMEIDA, W, 2010, KOTOWSKI, MONTEIRO, ARAÚJO, M., 2007). In the case of cytarabine , its role has not yet been well defined and, in some cases, its absence in the treatment does not cause a negative impact (ALMEIDA, S., 2015).

trioxide (ATO) is used in cases where the patient has recurrence of the disease after treatment with ATRA, and is also an alternative medication for patients who cannot undergo chemotherapy, due to its lower toxicity. In small doses, ATO degrades PML-RARα transcripts and indirectly activates caspases , which will lead to cell apoptosis, without needing to use the same pathways as ATRA. Caspases are enzymes that are inactive in the cell, but when activated, they initiate cell degradation, that is, they are the enzymes responsible for initiating apoptosis . Its name refers to the “C” for cysteine , “ asp ” for aspartate and the enzyme ending “ase” (SANTANA, 2019; KOTOWSKI, MONTEIRO, ARAÚJO, M., 2007; ARAGÃO, 2015). When combined with ATRA, ATO causes synergistic regulation of telomerases , causing telomere shortening , leading to promyelocyte cell death (SANTANA, 2019).

III. METHODOLOGICAL PROCEDURES

This work was carried out based on a review of the scientific literature on the subject. The main research sources were SciELO (*Scientific Electronic Library Online*) and the Google Scholar tool. To develop this research, keywords and terms such as “LPA”, “ acute promyelocytic leukemia”, “disseminated intravascular coagulation”, “ all-trans acid” were used. retinoic ”, “blood count”, “ anomalous promyelocytes in APL”, “PML RARα”, “morphology of APL”, “ hematopoiesis ”, “cancer”, “slide staining”, “treatment of APL”, etc. Scientific articles, meta-analyses, books and monographs relevant to the subject addressed were used.

IV. RESULT AND DISCUSSIONS

According to the authors referenced in this research, APL is an anemia that begins its symptoms very aggressively, and can quickly evolve into DIC, causing a severe hemorrhagic condition that can quickly lead to the patient's death. DIC is directly formed by anomalous promyelocytes and the circulating quantity will influence the severity of the condition.

It has also been demonstrated that the maturation of these cells is interrupted in the promyelocytic state due to a genetic mutation that prevents them from continuing the maturation process. Thus, research has shown the need to use ATRA or another medication that will cause these cells to continue their maturation or undergo apoptosis, which will drastically reduce DIC cases by reducing the number of circulating promyelocytes .

Another point validated in this research was the importance of the blood count for the treatment of this leukemia. The blood count was presented as the fastest test to validate this pathology, and although it requires other confirmations that take longer, the symptoms of this disease and the appearance of these cells on the patient's slide are already sufficient reasons to start the APL treatment protocol, due to the aggressiveness of this leukemia.

Therefore , given the points highlighted so far, such as the characteristics of these cells in the slide and other classic leukemia alterations, the inclusions that indicate myeloid leukemia and pathognomonic characteristics of this disease (such as the bilobed nucleus of promyelocytes) are already sufficient for the start of treatment, which demonstrated high remission when started quickly.

V. FINAL CONSIDERATIONS

Analyzing the data found in the research, it was found that APL is an oncological pathology that has proven to be very aggressive, with a high mortality rate due to its complications caused by the DIC condition, which can cause hemorrhages and blood clots throughout the body. It was also demonstrated how the medications used to treat this leukemia contribute to the remission of the disease, reducing the cancer cells in the peripheral blood and reducing the chances of this anemia presenting its most severe state, considerably increasing the patient's survival.

However, its rapid evolution demands attention from all professionals involved, from the suspicion of cancer by the doctor who treated the patient, to the drug and chemotherapy treatment, being crucial that the doctor identifies the signs and symptoms of leukemia and quickly requests the patient's blood count, which will contain classic changes of leukemia, such as anemia, thrombocytopenia and neutropenia .

Upon arrival at the analysis laboratory, it is up to the clinical analyst to recognize the classic changes in APL, such as the cellular patterns of the blasts in this leukemia (both in its hypergranular and hypogranular forms , in addition to the rare forms), as well as to recognize the classic inclusion of myeloid leukemias that will contribute

to the clinical diagnosis. It is immediately the analyst's responsibility to contact the physician and inform him/her that the slide is suggestive of APL, collaborating with the immediate start of treatment, which allows the reduction of the DIC condition and can contribute to a better prognosis for the patient.

Therefore, according to the study, it is imperative that the clinical analyst knows how to identify the anomalous promyelocytes in APL as quickly as possible, because the complete blood count is the first step in suspecting any leukemia and, consequently, will be the first choice test (in addition to being the quickest and most accessible to be performed). Since APL is a medical emergency, genetic confirmation should not be expected to begin treatment; only the analyst's confirmation of the type of cell presented on the slide is sufficient to begin the APL treatment protocol, highlighting the importance of this professional in the patient's prognosis.

REFERENCES

[1] ALMEIDA, Sabine Cardoso. **Acute promyelocytic leukemia** : clinical, diagnostic and therapeutic approach. Final course work (Integrated Master's Degree in Medicine) - Faculty of Medicine, University of Coimbra, Coimbra, 2015

[2] AMARAL, Bethânia de Araújo Silva. **Childhood acute promyelocytic leukemia** : characterization of alterations by classical and molecular cytogenetics , monoclonal antibody (PG-M3) and molecular biology. Dissertation (Master's in Genetics) - Postgraduate Program in Genetics, Federal University of Pernambuco, Recife, 2009.

[3] ARAGÃO, Maria Erivalda Farias de. **Cellular Biology** . 2nd ed. Fortaleza: University of Ceará Press - EdUECE , 2015.

[4] ARAÚJO, Esther Alice Dantas de. **Acute promyelocytic leukemia** : from history to treatment. BS thesis . Federal University of Rio Grande do Norte, 2022

[5] COSTA, Bruno Rocha Cordeiro. **Participation of urokinase-type plasminogen activator in the migration of inflammatory cells** . Dissertation (Master's Degree in Clinical and Toxicological Analysis) - Postgraduate Program in Clinical and Toxicological Analysis, Faculty of Pharmacy, Federal University of Minas Gerais, Belo Horizonte, 2016.

[6] FETT-CONTE, Agnes C.; SALLES, Andréa BCF The importance of the p53 gene in human carcinogenesis . **Brazilian Journal of Hematology and Hemotherapy** , v. 24, n. 2, p. 85-89, 2002.

[7] FRANCO, RF **Physiology of coagulation, anticoagulation and fibrinolysis** . Medicine (Ribeirão Preto), v. 34, n. 2, p. 229-237, Jul./Dec . 2001.

[8] FREIRE, Rodrigo José Bumussa et al. ACUTE PROMYELOCYTIC LEUKEMIA: A REVIEW OF ITS EPIDEMIOLOGY AND CLINICAL MANIFESTATIONS. **Revista Contemporânea** , v. 4, n. 6, p. e4323-e4323, 2024.

[9] GALIACHO, Verónica Roldán et al. Lymphocytes with auer rod-like inclusions in chronic lymphocytic leukemia. **Hematology, Transfusion and Cell Therapy**, v. 44, n. 4, p. 616-617, 2022.

[10] GERONIMO, Francielly . **Coagulation disorders in acute promyelocytic leukemia** : literature review. Course Completion Work (Postgraduate Studies in Clinical and Laboratory Hematology) - Academy of Science and Technology, São José do Rio Preto, 2022.

[11] HANNA, Marília Verona. **Acute promyelocytic leukemia** : characteristics, treatments and complications. Course Conclusion Work (Postgraduate) - Academy of Science and Technology of São José do Rio Preto, Ribeirão Preto, 2021.

[12] HOFFBRAND, AV; MOSS, PAH **Fundamentals of hematology** . 6th ed. Rio de Janeiro: Elsevier , 2016.

[13] HUBER, Paula C.; MARUIAMA, Cintia H.; ALMEIDA, Wanda P. P-glycoprotein, multidrug resistance (MDR) and structure-activity relationship of modulators. **Química Nova** , v. 33, p. 2148-2154, 2010.

[14] JÁCOMO, Rafael Henriques; FIGUEIREDO-PONTES, Lorena Lobo de; REGO, Eduardo Magalhães. From the molecular paradigm to the impact on prognosis: a view of acute promyelocytic leukemia . **Journal of the Brazilian Medical Association** , v. 54, p. 82-89, 2008.

[15] JÁUREGUI, César Ricardo Ponce. **Frequency of the CD56 marker in patients diagnosed with acute myeloid leukemia in the National Institute of Neoplastic Diseases in he period 2014-2016** . Doctoral Thesis. Universidad Nacional Mayor de San Marcos, 2018.

[16] JUNQUEIRA, LC; CARNEIRO, J. **Basic histology** . 13th ed. Rio de Janeiro: Guanabara Koogan, 2017.

[17] Promyelocytic leukemia . **Disciplinarum Scientia | Health** , vol. 8, no. 1, p. 69-89, 2007.

[18] LEAL, Aline M.; KUMEDA, Cristina A.; VELLOSO, Elvira DRP. Genetic characteristics of de novo acute promyelocytic leukemia. **Brazilian Journal of Hematology and Hemotherapy** , v. 31, p. 454-462, 2009.

[19] PREVEDELLO, Camila Pivetta ; SAGRILLO, Michelle Rorato . Acute promyelocytic leukemia . **Disciplinarum Scientia | Health** , vol. 9, no. 1, p. 39-50, 2008..

[20] **Promyelocyte .** Laboratory of Clinical Analysis and Health Education - LACES, 2017. Available at: < https://laces.icb.ufg.br/p/20041-promielocito >. Accessed on: 08/29/2024.

[21] RIPOLL, Planelles ; MARINA. **Origin of acute promyelocytic leukemia** : genetic factors and other causes . **Work** End of Degree in Medicine, Miguel Hernández University , Faculty of Medicine, Department of Medicine, Hematology Area , 2022.

[22] SANTANA, Anabelle Marina de Oliveira. **Acute promyelocytic leukemia** : from early diagnosis to treatment. Course Completion Work (Biomedicine Degree) - University Center of Brasília, Faculty of Education and Health Sciences, Brasília, 2019.

[23] panoptic and giemsa staining methods within a laboratory routine. **Journal of Extension and Scientific Initiation of Unisociesc** , v. 9, n. 2, 2022.

[24] SILVA, Graziele C. da et al. Laboratory diagnosis of acute myeloid leukemia . **Brazilian Journal of Pathology and Laboratory Medicine** , v. 42, p. 77-84, 2006.

[25] SILVA, Keila Raiane Amorim da. **The importance of the blood count in the diagnosis of acute promyelocytic leukemia** . Monograph (Postgraduate in Hematology) - Naoum Institute of Hematology, São José do Rio Preto, SP, [2016?] .

[26] SOUZA, Wesley Botelho. **Acute promyelocytic leukemia** : variation of chemotherapeutic agents in therapeutic strategies. Monograph (Postgraduate in Advanced Hematology) - Academy of Science and Technology of São José do Rio Preto, São José do Rio Preto, [2012?]

[27] THULER, Luiz Claudio Santos; SANT'ANA, Denise Rangel; REZENDE, Magda Côrtes Rodrigues. ABC of cancer: basic approaches to cancer control. In: **ABC of cancer: basic approaches to cancer control** . 2011. p. 127-127

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.5

Burnout Syndrome in Emergency Professionals: A Literature Review

Daniel Rodrigues Silva, Luana Santana Mendes, Anne Carolyne Silva De Souza, Arlete Felix Da Costa, Valéria Mota Soares, Hellen Rodrigues Pereira, Karen Mariane Rodrigues Silva, Jamily Trindade Sampaio, Ana Caroline Carvalho De Jesus Moreira, Mariana Teixeira De Oliveira Brito, Amanda Meira Saldanha, Eugenio Maria Gomes, Wanessa Soares Luiz Silva

Received: 02 Dec 2024,

Receive in revised form: 02 Dec 2024,

Accepted: 08 Dec 2024,

Available online: 19 Dec 2024

***Keywords*— Burnout, emergency professionals, emotional exhaustion, depersonalization, healthcare stress.**

***Abstract*—** *Healthcare professionals, especially those working in emergency settings, are subject to a significant amount of stress and pressure in their daily routine. The phenomenon of burnout , characterized by emotional exhaustion, depersonalization, and decreased personal fulfillment at work, is a growing concern. These professionals face unique challenges, such as dealing with life-or-death situations, long work hours, and lack of adequate resources, which can contribute to the development of burnout.*

I. INTRODUCTION

The scientific literature has extensively documented the effects of burnout among emergency professionals. Studies indicate that alarming rates of emotional exhaustion and depersonalization are common among physicians, nurses, and paramedics working in emergency departments (Adriaenssens , J., De Gucht , V., & Maes , S., 2015). These professionals often report feeling overwhelmed, emotionally drained, and unable to provide optimal patient care.

The relationship between burnout and the quality of care provided is also a central concern. Research suggests that healthcare professionals who experience burnout are at greater risk of committing medical errors, have low job satisfaction, and have a lower quality of life (West, CP, Dyrbye , LN, & Shanafelt , TD, 2018). This not only affects the health and well-being of professionals, but can also compromise patient safety and treatment.

Furthermore, burnout in the emergency department can have long-term ramifications for the mental health of professionals. Studies have shown that burnout is associated with a variety of mental health issues, including depression, anxiety, and suicidal ideation (Dyrbye , L.N., et al., 2017). Therefore, addressing this issue is crucial not only to improve the quality of patient care but also to protect the health and well-being of professionals themselves.

However, despite growing awareness of burnout , effective interventions to prevent and mitigate its effects are still limited (Panagioti , M., et al., 2019). There is an urgent need for comprehensive strategies that address not only the individual symptoms of burnout but also the organizational and systemic factors that contribute to its development.

In this context, this paper aims to critically analyze the phenomenon of burnout among emergency professionals, exploring its causes, consequences, and possible intervention approaches. Through a comprehensive

literature review, we aim to provide valuable insights that can inform policies and practices aimed at protecting the health and well-being of these essential professionals and, ultimately, improving patient care outcomes.

II. METHODOLOGY

To conduct this literature review, we began with a comprehensive search of the scientific literature through electronic databases such as PubMed , Scielo , and Bireme . We used a combination of search terms, including " burnout ," "emergency," "healthcare professionals," "physicians," "nurses," and "nursing technicians."

Following the initial search, we screened the studies based on their titles and abstracts to determine their relevance. Selected studies were then assessed in full to ensure they met the established inclusion criteria.

We acknowledge that this review may be subject to some limitations, such as the exclusion of studies in languages other than English, Spanish, or Portuguese, and the possibility of publication bias. However, we took steps to minimize these limitations through a comprehensive literature search and clear inclusion and exclusion criteria.

III. THEORETICAL FRAMEWORK

The Phenomenon of Burnout in Emergency Professionals

The emergency work environment presents significant stressors that can trigger burnout . Long working hours, exposure to traumatic situations, intense emotional burden, and lack of adequate resources are just some of the identified causes (Adriaenssens , J., De Gucht , V., & Maes , S., 2015). Furthermore, the pressure to make quick and accurate decisions in life-or-death situations can contribute to chronic stress and emotional exhaustion.

Emergency department professionals may experience a variety of burnout symptoms , including physical and emotional exhaustion, depersonalization, and decreased professional efficacy. Studies have documented high rates of these symptoms among physicians, nurses, and paramedics working in emergency departments (Maslach , C., & Leiter , M.P., 2016). Emotional burnout may manifest as feelings of overwhelm, irritability, and lack of motivation, while depersonalization may result in cynicism and emotional distance toward patients.

Burnout among emergency department professionals not only affects their own health and well-being, but also has consequences for the quality of patient care. Studies indicate that professionals who suffer from burnout are at increased risk of committing medical errors, have low job satisfaction , and have a lower quality of life (West, CP, Dyrbye , LN, & Shanafelt , TD, 2018). Furthermore, burnout can lead to increased absenteeism, employee turnover, and additional costs for healthcare organizations.

The phenomenon of burnout among emergency professionals is a significant concern that requires attention and intervention. Understanding the causes, symptoms, and impacts of burnout is critical to developing effective prevention and management strategies.

In addition to the individual pressures faced by emergency professionals, there are organizational challenges that contribute to the phenomenon of burnout . A lack of adequate resources, including insufficient staff and outdated equipment, can increase workload and frustration among professionals (Dewa , C.S., & Loong , D., 2020). Furthermore, an institutional culture that does not value employee well-being and does not recognize the impact of stress can exacerbate the problem.

Although organizational factors play an important role in burnout , it is also crucial to recognize individual factors that may increase the risk. For example, personality traits such as perfectionism and a tendency to internalize stress may make professionals more vulnerable to burnout (Koutsimani , P., Montgomery, A., & Georganta , K., 2019). Furthermore, a lack of effective coping skills and adequate social support may make it more difficult for professionals to deal with the stress of emergency work.

Burnout among emergency department professionals can have serious ramifications for the quality of patient care. Exhausted and unmotivated professionals may be more likely to make medical errors, compromising patient safety and outcomes (Rodriguez-Rey, R., et al., 2019). Furthermore, burnout can affect communication and teamwork, which are essential elements for effective and coordinated care.

Studies have investigated whether there are gender differences in the prevalence and manifestation of burnout among emergency workers. Some research suggests that women may experience higher levels of burnout due to factors such as gender inequalities in the workplace and greater responsibilities at home (Salvagioni , DAJ, et al., 2017). However, more research is needed to fully understand these disparities.

To prevent and manage burnout , it is crucial that professionals develop effective coping strategies. This may include establishing clear boundaries between work and personal life, engaging in leisure activities and hobbies, and seeking social and emotional support (Fralick , M., et al., 2018). Additionally, relaxation techniques, such as mindfulness and meditation, have been shown to be beneficial in reducing stress and emotional exhaustion.

In addition to the impacts on staff health and well-being and the quality of patient care, burnout also has significant economic implications. The costs associated with absenteeism, staff turnover, replacement training, and additional medical care can be substantial for healthcare institutions and health systems in general (Han , S., Shanafelt , T. D., Sinsky , C. A., Awad , K. M., Rothberg , M. B., Bockorny , M., ... & Trockel , M., 2019). Therefore, addressing burnout is not only a health issue but also an economic issue.

Healthcare organizations should invest in risk assessment programs and resources to identify burnout risk factors and promote a healthy work environment. This may include periodic employee well-being assessments, stress management training sessions, and implementation of policies that encourage work-life balance (Shanafelt , T.D., Noseworthy , J.H., & Executive Leadership Council , 2017). By recognizing and addressing the signs of burnout early , institutions can help prevent its occurrence and reduce its impacts.

Burnout among emergency professionals is a significant concern that requires attention and intervention. Understanding the causes, symptoms, and impacts of burnout is critical to developing effective prevention and management strategies. Both organizational and individual factors must be considered when addressing this complex problem.

Interventions for the Prevention and Management of Burnout in Emergency Professionals

Healthcare organizations can implement a number of measures to create a healthier work environment and support the well-being of emergency workers. These may include establishing psychological support programs, promoting a work culture that values work-life balance, and providing adequate resources to cope with work-related stress (Panagioti , M., et al., 2019).

In addition to organizational interventions, emergency workers can adopt individual strategies to protect their mental health and prevent burnout . This may involve developing resilience skills, practicing self-care practices such as regular exercise, and seeking social and emotional support (Rodriguez-Rey, R., et al., 2019). Education about early recognition of burnout symptoms and accessing support resources are also important components of individual interventions.

It is essential to evaluate the effectiveness of interventions implemented to prevent and manage burnout among emergency workers. Studies have examined the effectiveness of different approaches, such as coping skills training programs and well-being-promoting interventions (Wiederhold , B.K., & Cipresso , P., 2019). Such research can provide valuable insights to inform future policies and practices.

Preventing and managing burnout among emergency workers requires a multifaceted approach that takes into account both organizational factors and individual coping strategies. Implementing effective interventions is crucial to protecting the health and well-being of these essential workers and ensuring quality patient care.

IV. DISCUSSION

Burnout among emergency professionals is a growing concern worldwide due to its negative impacts on health and well-being of professionals, quality of patient care, and health systems in general. This discussion section aims to elaborate on the main issues raised in the review and explore possible implications and future directions for research and intervention .

One of the central issues discussed is the complexity of the causes of burnout among emergency professionals. Although organizational factors, such as excessive workload and lack of resources, play a significant role, it is also crucial to recognize individual factors, such as personality traits and coping skills. Effectively addressing burnout requires a holistic approach that takes into account both contextual factors and individual aspects.

Furthermore, the impact of burnout on the quality of patient care was discussed. Exhausted and unmotivated emergency department professionals may be at greater risk of committing medical errors and delivering lower quality of care. Therefore, interventions to prevent and manage burnout not only benefit professionals but also have direct implications for patient safety and outcomes.

Another relevant issue addressed is the role of healthcare institutions in preventing and managing burnout . Implementing policies and programs that promote a healthy work environment and support employee well-being is essential. In addition, regular assessment of risks and resources can help organizations identify signs of burnout early and implement effective interventions.

The economic impact of burnout was also discussed , highlighting the costs associated with absenteeism, employee turnover, and additional medical care. These costs not only affect healthcare institutions, but also have broader ramifications for healthcare systems and the economy as a whole. Therefore, investing in burnout prevention and management is not only a health issue, but also a sensible economic one.

Finally, it is important to recognize that there are still gaps in knowledge about burnout in emergency workers that require additional research. For example, longitudinal

studies are needed to better understand the trajectory of burnout over time and identify effective protective factors. In addition, specific, evidence-based interventions need to be developed and evaluated in emergency settings.

In summary, the discussion on burnout in emergency professionals highlights the need for a comprehensive approach that takes into account the complex interactions between organizational, individual, and contextual factors. Investing in the prevention and management of burnout not only improves the well-being of professionals and the quality of patient care, but also represents a strategic and cost-effective decision for health institutions and health systems in general.

V. FINAL CONSIDERATIONS

The phenomenon of burnout among emergency professionals is a multifaceted and urgent issue that requires immediate attention and coordinated action. Throughout this review, we examine the causes, symptoms, and impacts of burnout , as well as prevention and management strategies.

It is clear that burnout is not just an individual problem, but also a reflection of organizational, social and contextual factors. Therefore, effectively addressing burnout requires a holistic approach that takes all of these aspects into account.

Healthcare organizations play a crucial role in preventing burnout by creating healthy work environments, promoting employee well-being, and implementing supportive policies and programs. In addition, it is critical that professionals adopt individual self-care strategies and develop effective coping skills.

It is important to recognize that burnout is not only a health issue, but also has significant economic implications. The costs associated with burnout are substantial and affect not only healthcare institutions, but also healthcare systems and the economy as a whole.

As a final consideration, we urge stakeholders, including healthcare leaders, emergency professionals, researchers, and policymakers, to collaborate to implement effective burnout prevention and management strategies . Only through joint efforts and continued commitment can we protect the health and well-being of emergency workers and ensure quality patient care.

REFERENCES

[1] Adriaenssens, J., De Gucht, V., & Maes, S. (2015). Determinants and prevalence of burnout in emergency nurses: A systematic review of 25 years of research. International Journal of Nursing Studies, 52(2), 649-661.

[2] Maslach, C., & Leiter, M. P. (2016). Understanding the burnout experience: Recent research and its implications for psychiatry. World Psychiatry, 15(2), 103-111.

[3] West, C. P., Dyrbye, L. N., & Shanafelt, T. D. (2018). Physician burnout: contributors, consequences and solutions. Journal of Internal Medicine, 283(6), 516-529.

[4] Dewa, C. S., & Loong, D. (2020). Systematic Review of the Relationship between High Performance Work Systems and Employee Well-Being. Applied Psychology, 69(1), 218-251.

[5] Koutsimani, P., Montgomery, A., & Georganta, K. (2019). The Relationship Between Burnout, Depression, and Anxiety: A Systematic Review and Meta-Analysis. Frontiers in Psychology, 10, 1-20.

[6] Rodriguez-Rey, R., et al. (2019). Burnout, posttraumatic stress, and resilience in emergency professionals: Relationship and predictions. Psicothema, 31(2), 125-130.

[7] Salvagioni, D. A. J., et al. (2017). Physical, psychological and occupational consequences of job burnout: A systematic review of prospective studies. PLoS ONE, 12(10), e0185781.

[8] Fralick, M., et al. (2018). Association of burnout with physician and nurse performance as caregivers. JAMA Network Open, 1(3), e180249.

[9] Han, S., Shanafelt, T. D., Sinsky, C. A., Awad, K. M., Rothberg, M. B., Bockorny, M., ... & Trockel, M. (2019). Estimating the attributable cost of physician burnout in the United States. Annals of Internal Medicine, 170(11), 784-790.

[10] Shanafelt, T. D., Noseworthy, J. H., & Executive Leadership Council. (2017). Executive leadership and physician well-being: nine organizational strategies to promote engagement and reduce burnout. Mayo Clinic Proceedings, 92(1), 129-146.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.6

Sustainable MOFs for Pb^{2+} Removal: Adsorption, Regeneration, and Environmental Impact

Beni Jared Passi, Ma Xuli*, Paul Afreh, Wang Peifen, An Xiaowei

College of Environment and ecology, Taiyuan University of Technology, Taiyuan, Shanxi-Province, China.
*Corresponding Author: maxuli@tyut.edu.cn
Author: jialaide0036@link.tyut.edu.cn

Received: 02 Nov 2024,

Receive in revised form: 06 Dec 2024,

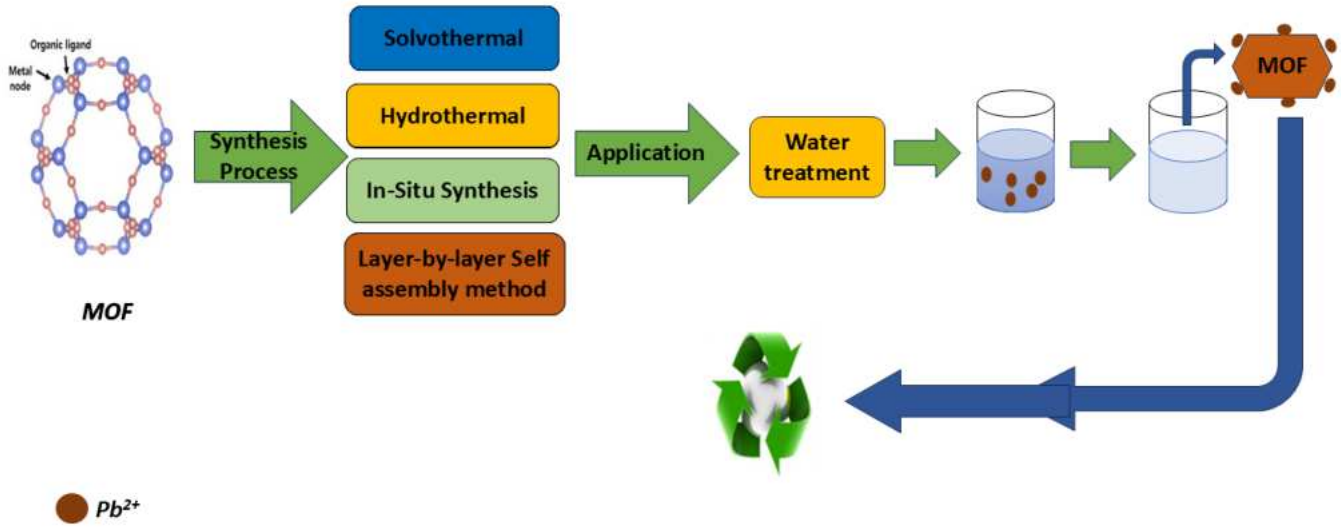
Accepted: 12 Dec 2024,

Available online: 18 Dec 2024

***Keywords*— Lead (Pb^{2+}) Removal, MOF Synthesis Methods, MOF-Based Adsorbents, Cost-Effectiveness, Environmental Remediation, Industrial Wastewater Treatment.**

***Abstract*—** *Heavy metal contamination, particularly with lead (Pb^{2+}), poses significant environmental and public health risks. In response to this, metal-organic frameworks (MOFs) have arisen as effective adsorbents due to their high surface areas, tunable structures, and reusability. This study reviews advancements in MOF-based adsorbents for lead removal from wastewater, with a focus on cost-effectiveness, adsorption efficiency, and environmental impact. Among various MOFs examined, ZIF-67 and ZIF-8 show superior performance, achieving high adsorption capacities (up to 1978.63 mg/g) and excellent regeneration potential, maintaining effectiveness over multiple cycles. Cost analyses reveal that while some MOFs, such as Cu-MOFs/CMFP, incur higher synthesis costs, others like UiO-66-(OPO_3)X and Cs-ZIF-8 offer a balance between cost and performance, rendering them economically viable for large-scale application. Further, the environmental sustainability of MOFs is enhanced through greener synthesis methods and biodegradable components. Although challenges remain in scaling production and ensuring durability in varied wastewater conditions, this study demonstrates the potential of MOFs as efficient, sustainable, and cost-effective adsorbents for heavy metal remediation, paving the way for safer water treatment solutions.*

GRAPHICAL ABSTRACT



HIGHLIGHTS

- MOFs like ZIF-67 and ZIF-8 have significant Pb^{2+} adsorption capabilities, reaching up to 1978.63 mg/g, making them effective for lead remediation.
- Diverse Synthesis processes: MOFs are produced using a variety of synthesis procedures, including solvothermal, hydrothermal, and microwave-assisted processes, which affect their structural characteristics and scalability.
- Relevant Characterization: Techniques such as SEM, BET, and XRD are used to assess the shape, surface area, and crystalline structure of MOFs, validating their validity for adsorption.
- Regeneration and Stability: Many MOFs have good regeneration capability, and ZIF-67 retains around 95% of its adsorption capacity after many cycles, assuring long-term usage and structural integrity.
- Cost-effectiveness and Sustainability: The economic feasibility of MOF-based adsorbents is highlighted, with competitive pricing and the utilization of nontoxic, biodegradable materials improving their environmental friendliness.

I. INTRODUCTION

Heavy metal pollution has become a worldwide environmental issue that is attracting more and more attention. The presence of heavy metal (HMIs) in wastewater produced by industries is diagnosed as the most injurious pollutants. It has been known that the chromium(VI), lead(II), Cd^{2+}, Cu^{2+}, Hg^{2+}, Fe^{3+}, Ni^{2+} and Zn^{2+} are the most familiar toxic pollutants, so an acceptable method is needed for the preconcentration and removal them [1] . [2]. Among the various heavy metals, lead (II) is one of the most popular and well-known water pollutant. Lead is a heavy metal contaminant with high biological toxicity, normally present in water as divalent lead ions. They may accumulate in the human body via the food chain and cause a variety of human ailments, including anemia, heart disease, neurological disorders, renal disease, cancer, and even death. As a result, there is an urgent need to find an effective technique for removing Pb^{2+} from aqueous solutions.

Researchers have devised several techniques to remove contaminants from wastewater, including filtration[3]., chemical precipitation [4] coagulation , [5] electrochemical treatment [6], membrane separation [7] chemical oxidation [8], photocatalysis [9], ozonation [10] and adsorption [11]. Among these methods, adsorption has received a particular attention because of its numerous advantages. Adsorption, unlike absorption, involves the accumulation of pollutants on the surface of a material. This method, mainly does not suffer from the limitations of the other methods, such as high startup and operation costs, long treatment times, process complexity, and space requirements [12] It has been widely embraced because to its great efficiency, simplicity, low energy demands, adaptability, and reusability [13].

However, some traditional adsorbents used for wastewater treatment including clays [14]., zeolites [15], ion exchange resins [16] , Carbon nanotubes [17], silica [18], and activated carbon [19], have limitations , such as : low adsorption capacity, limited reuse capability, and the generation of post-treatment sludge [20]. Metal oxide-based adsorbents are distinguished by low selectivity and delayed adsorption kinetics. At the same time, activated carbon is limited by its high procurement cost, low surface area and porosity, and the difficulty of maintaining high adsorption effectiveness during usage [21]. Resins, like activated carbon, have limited recovery and reuse possibilities.

Recent research efforts have focused on generating innovative and highly efficient adsorbents that can overcome the limits of existing adsorbents while being environmentally friendly and low-cost. MOFs are one type of very effective adsorbent. MOFs are a promising material for removing lead (Pb^{2+}) ions from wastewater due to their high adsorption capacity, reusability, and adjustable characteristics. MOFs are porous crystalline solids made up of metal ions or clusters that are coupled with organic ligands. Their distinguishing characteristics, such as large surface area, variable pore size, and various functions, make them ideal candidates for environmental remediation applications [22]. In recent years, numerous MOF-based materials have been studied for Pb^{+} adsorption, including zeolitic imidazolate frameworks.

Such as ZIF-8 and ZIF-67 [23] copper-based MOFs like Cu-BTC, zinc-based MOFs such as Zn-BTC. [24] and zirconium-based MOFs like UiO-66 and its derivatives [25]. These materials demonstrate exceptional adsorption capacities, ranging from 215 mg/g to 1978 mg/g for Pb^{2+} ions. Among the studied MOFs, ZIF-67 and ZIF-8 exhibit particularly high capacities of 1978.63 mg/g and 1780.91 mg/g, respectively, making them highly efficient for lead remediation. [23]. The superior performance of these materials can be attributed to their high surface area, abundant active sites, and favorable interactions with Pb^{2+} ions. The adsorption mechanism of Pb^{2+} onto MOF-based materials typically involves a combination of processes, including surface complexation, ion exchange, and electrostatic interactions. The presence of functional groups such as -OH, -COOH, and -NH2 on the organic ligands of MOFs plays a crucial role in enhancing their affinity towards Pb^{2+} ions. [26]. [27]. Additionally, the metal nodes in MOFs can act as Lewis acid sites, further contributing to the adsorption process. The reusability of MOF-based adsorbents is a crucial factor in their cost-effectiveness and environmental impact. Many of the studied materials show excellent regeneration capabilities, maintaining high adsorption efficiencies over multiple cycles. For instance, ZIF-67 retains approximately 95% of its adsorption capacity after five cycles, demonstrating its potential for long-term use in water treatment applications. Similarly, the SUZ-4 zeolite, another promising material, maintains its performance over ten adsorption-desorption cycles without significant decline [28]. This high regeneration efficiency not only reduces the overall cost of the treatment process but also minimizes waste generation and environmental impact.

Cost-effectiveness is another important consideration in the development of MOF-based adsorbents. The synthesis of these materials often involves readily available and relatively inexpensive precursors, contributing to their economic viability. For example, the production cost of SUZ-4 zeolite is estimated at 11,855.5 CNY per ton, which is only 23.14% of the cost for a comparable material. [28]. This competitive pricing makes MOF-based adsorbents attractive for large-scale water treatment applications, particularly in regions where lead contamination is a significant concern.

Environmental friendliness is addressed through the use of non-toxic precursors and the ability to regenerate and reuse the adsorbents. Materials such as CS-ZIF-8 composite beads, which incorporate biodegradable chitosan, [29] offer a sustainable approach to Pb^{2+} remediation. The use of bio-based or naturally occurring materials in MOF synthesis not only reduces the environmental footprint but also enhances the biocompatibility of the adsorbents. Recent research has also focused on developing MOF-based composites to further improve their performance and stability. For example, magnetic MOF composites simplify adsorption by using an external magnetic field, enhancing treatment efficiency [30]. Adsorption on MOF-based materials follows pseudo-second-order kinetics, with chemisorption as rate-limiting step. Adsorption is spontaneous and endothermic, favoring Pb^{2+} removal with increasing temperature. This review examines recent advancements in MOF-based adsorbents for Pb^{2+} removal, focusing on their cost-effectiveness, environmental friendliness, and performance characteristics.

II. MOF MATERIALS AND THEIR APPLICATION IN PB^{2+} REMOVAL

MOFs are known for their exceptional ability to adsorb heavy metals due to their unique structural properties. The metal ions within MOFs serve as **coordination centers**, facilitating the adsorption of Pb^{2+} ions through interactions such as **electrostatic attraction, ion exchange, or surface complexation**, while their porous structures facilitate high adsorption capacities.

The adsorption process in MOFs relies on the interaction between metal centers (nodes) and lead ions (Pb^{2+}), as well as the pore structure that facilitates the diffusion of ions.

Factors such as the surface area, pore size, and functionality of organic linkers significantly affect their adsorption efficiency. The structural tunability of MOFs allows for the optimization of adsorption conditions, making them highly adaptable for wastewater treatment.

Common MOFs used in lead removal include UiO-66, MIL-53 and ZIF-8. These frameworks can be synthesized through methods such as solvothermal, hydrothermal, and microwave-assisted synthesis. Scalability, a critical factor in cost-effectiveness, remains a challenge. While these methods produce high-quality MOFs, the scalability of these processes for industrial applications requires further investigation.

Table 1: Performance of some typical metal-organic frameworks (or their composites) as adsorbents for the removal of Pb^{2+} from some aqueous solutions and wastewaters.

The table provides a detailed comparison of various adsorbents used for the removal of lead ions (Pb^{2+}) from aqueous solutions and wastewaters. It includes key parameters such as the type and amount of adsorbent, synthesis methods, conditions of the Pb^{2+} solution (volume, concentration, and pH), contact time, adsorption capacity, removal efficiency, and references to relevant studies. The table highlights the diversity in adsorbent materials, ranging from metal-organic frameworks (MOFs) to zeolites, synthesized using techniques such as hydrothermal and solvothermal methods. This comparison aids in evaluating the effectiveness and reusability of different adsorbents for lead removal.

Adsorbent/ amount	**Synthesis method**	**Pb2+ solution Volume(ml)/ Concentration(ppm) pH**	**Contact time (min)**	**Adsorption capacity (mg/g)**	**Removal Efficiency (%)**	**References**
Cs-Zif-8/20 mg 1:2	In Situ Synthesis	20 / 20 /5	120	131.4	98.2(Initial) 80.2 (After 5 cycles of Reuse)	[31]
Fe_3O_4@$Cu_3(btc)_2$ / 10 mg	Hydrothermal	20/100/5	120	215.05	57.3	[31]
PHCS-15@ZIF-8/ 15 mg	Stöber method/hydrothermal	100/15/5.5	120	462.9 /310.5	95	[32]
SCC-CuMOF/ 0.6 g 1:1:1:1	Solvothermal	1000/400 /6	60	531.38	79.707	[33]
-UiO-66-(OPO_3) X)/1.5g	Classical Solvothermal	400/400/6	30	445.88	85.76	[34]
Cu-BTC and Zn-BT / 10 mg	Solvothermal	50/50/5	<30	333/312 (Cu-BTC/ Zn-BT)	98.9 96.4	[24]

PEIUiO-66-NH_2/1.2g	Solvothermal /Chemical Grafting	20/136/5	40	692.80	84	[35]
Zif-8/Zif-67 1000 mg	Solvothermal	20 /20/ 6.5	120	1978.63	99.5	[23]
ZIF-67@Yeast/ 50 mg	Hydrothermal	50 /100/	480	62.5	31	[36]
ZIF-90@CS/SA 0.2 g	hydrothermal	N/A/300/5.5	150	300	92.11	[37]
HNTs@PDA/Zif-8 /0.01 g	Solvothermal	50 / N/A /7.0	150	515.46	N/A	[38]
MTV-MOFSWCNT-BP/0.05g	N/A	200/200/6.6	4320	180	98	[39]
Cu-MOFs/CMFP/0.03 g	Layer-by-Layer Self-Assembly method	10/10 /N/A	35	31.77 N/A	90	[40]
Cu-MOF HKUST-1-EDA	N/A	50 / 400 / 5.2	20	12.85	90	[41]
Fe-MOF	N/A	100/100/7	600	504	88.34	[42]
SUZ-4 zeolite/0.06 g	hydrothermal	50 /50/ 5	30	181.56	97.04	[28]
Ni-MOF-74	N/A	50 / 60/ 6	240	98.062	95-99	(Lou et al., 2022)
NH2-MIL-53	Hydrothermal	20/10 /6.0	60	223.4	99.98	[44]

2.3 MOFs adsorbent

Characterization and Application of ZIF-8-Based Composites for Wastewater Treatment

Generally, metal-organic frameworks (MOF), are specialized in their capacity to adsorb heavy metals from wastewater, through their large surface area, high porosity, and selectivity. Additionally, their some parameters as mentioned in the adsorption mechanism by MOF, like: p^H; concentration … Basically, after the synthesis process the adsorbent made, needs to go through a characterization process, referring at: SEM, XRD, XPS BET tests to determine the porosity, surface area, and christalline structure, which confirms the ability of a MOF . [45] . Hence, in the following paragraphs are notified the various parameters and adsorption mechanism of the precited adsorbent in Table1.

ZIF-8-based composites have attracted major notice in environmental applications, particularly in wastewater treatment, due to their exceptional structural properties. Derived from Zeolitic Imidazolate Framework-8 (ZIF-8), these composites boast high surface area, thermal stability, and tunable porosity, making them highly effective for adsorbing pollutants like heavy metals, organic dyes, and other contaminants.

Characterization of ZIF-8 composites focuses on their physical and chemical properties, crucial for wastewater treatment performance. Advanced techniques like X-ray diffraction (XRD) and scanning electron microscopy (SEM) confirm crystalline structure and morphology, while Brunauer-Emmett-Teller (BET) analysis determines surface area. Thermogravimetric analysis (TGA) and Fourier-transform infrared spectroscopy (FTIR) assess thermal stability and chemical composition. Functionalization through metal doping or hybridization enhances adsorption capacity and selectivity.

In wastewater treatment, ZIF-8-based composites demonstrate outstanding efficiency in removing heavy metals, particularly lead (Pb^{2+}), and organic pollutants from contaminated water. Their high adsorption capacity, fast kinetics, and selectivity make them ideal for real-world

systems. They operate effectively under varying pH conditions, retain performance across multiple cycles, and are reusable and environmentally friendly.

The excellent structural properties and versatile application potential of ZIF-8-based composites make them promising materials for addressing the growing demand for efficient and sustainable wastewater treatment solutions. Their ability to be tailored for specific environmental conditions enhances their practical utility in mitigating water pollution.

2.3.1 Zif-8/Cs-Zif-8

The CS-ZIF-8 composite beads were developed to effectively adsorb heavy metals, specifically Cu (II) and Pb (II), from wastewater. Characterization results revealed a significant increase in surface area due to the incorporation of ZIF-8, with values of 1808.4 m^2/g for ZIF-8 and only 2.5 m^2/g for pure chitosan. The composite beads exhibited varying surface areas depending on the ratios used: CS-ZIF-8-1:1 had 114.6 m^2/g, CS-ZIF-8-2:3 had 284.9 m^2/g, and CS-ZIF-8-1:2 reached 712.7 m^2/g. [31]

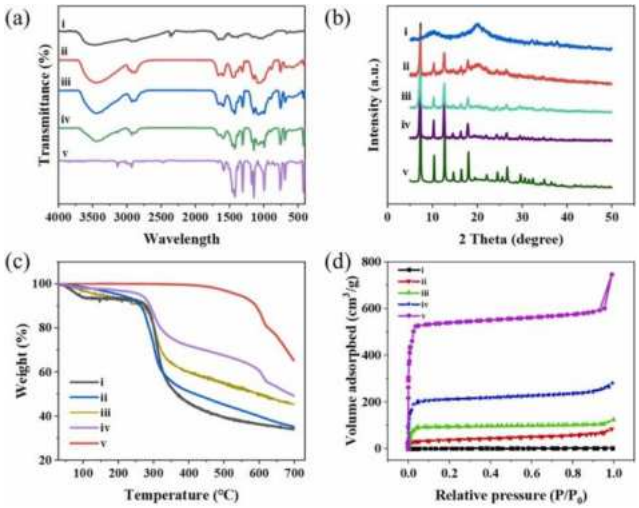


Fig. 1. (a) FT-IR spectra, (b) PXRD patterns, (c) TGA curves and (d) N2 adsorption/ desorption isotherms of CS (i), CS-ZIF-8-1:1 (ii), CS-ZIF-8-2:3 (iii), CS-ZIF-8-1:2 (iv) and ZIF-8 ***(v).*** *[31]*

In adsorption experiments, the initial removal efficiencies were impressive, with Pb(II) reaching 98.2%. However, after five reuse cycles, the efficiency decreased to 80.2% for Pb(II). Scanning Electron Microscopy (SEM) analysis, shown in Fig. 3, confirmed the porous structure of the composite, facilitating adsorption. Additionally, Fig. 2 shows that BET results indicated a decrease in pore volume after metal adsorption, further demonstrating the effectiveness of CS-ZIF-8 as a high-capacity adsorbent for heavy metal removal.

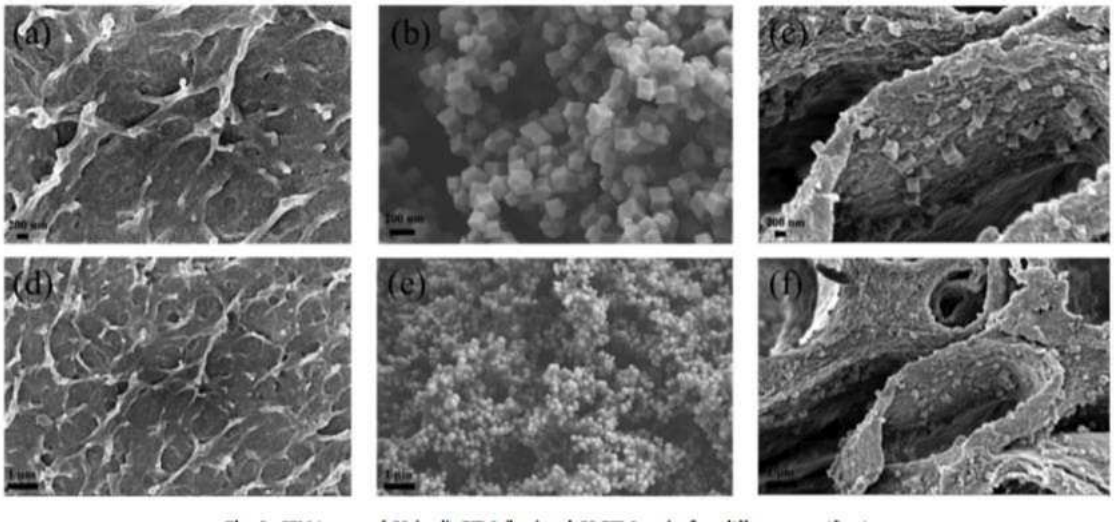


Fig. 2. SEM images of CS (a, d), ZIF-8 (b, e) and CS-ZIF-8-1:2 (c, f) at different magnification [31]

2.3.2 Fe_3O_4@$Cu_3(btc)_2$ magnetic core-shell microspheres)

The synthesis of thiol-functionalized Fe_3O_4@$Cu_3(btc)_2$ core-shell magnetic microspheres, referred to as SCC CUMOF, was reported by [31]. These microspheres were

designed for the selective removal of heavy metals, specifically Hg^{2+} and Pb^{2+}, from aqueous solutions.

During the experiment the adsorption process of Pb^{2+} using thiol-functionalized Fe_3O_4@$Cu_3(btc)_2$ magnetic microspheres was examined in relation to the effects of a variety of parameters. The pH of the solution significantly influenced adsorption efficiency, with optimal removal occurring at pH levels between 6 and 7. This optimal removal was attributed to the strong interaction between thiol groups and metal ions. Additionally, the concentration of the adsorbent played a crucial role, as increasing the amount of thiol-functionalized microspheres enhanced the adsorption capacity for both heavy metals until reaching saturation.

Furthermore, contact time played a crucial role, with Pb^{2+} removal reaching near completion within 120 minutes. This highlights the importance of sufficient interaction time for effective adsorption. Collectively, these parameters are essential for optimizing the removal of heavy metals from wastewater using the developed adsorbent.

2.3.3 PHCS-15@ZIF-8/Zif-8

The synthesis of a novel core-shell composite, PHCS-15@ZIF-8, consisting of porous hollow carbon spheres (PHCS) coated with ZIF-8, was conducted using a combination of hydrothermal and Stöber methods. This composite exhibit significant potential for the adsorption of lead ions (Pb^{2+}) from aqueous solutions.

Characterization results reveal that PHCS-15@ZIF-8 has a BET specific surface area of 1140 m^2/g, indicating a substantial porous structure, and a microporous volume of 0.51 cm^3/g, enhancing its adsorption capabilities. Scanning Electron Microscopy (SEM) images (Fig. 4) demonstrate the uniform dispersion of ZIF-8 particles on the PHCS surface, contributing to improved adsorption performance.

In adsorption experiments, the PHCS-15@ZIF-8 composite achieved a remarkable Pb^{2+} removal percentage of approximately 95%, showcasing its effectiveness as an adsorbent. These results highlight the synergistic effect of the core-shell structure, facilitating the diffusion of Pb^{2+} ions into the mesoporous channels and enhancing the overall adsorption capacity of the material. [32]

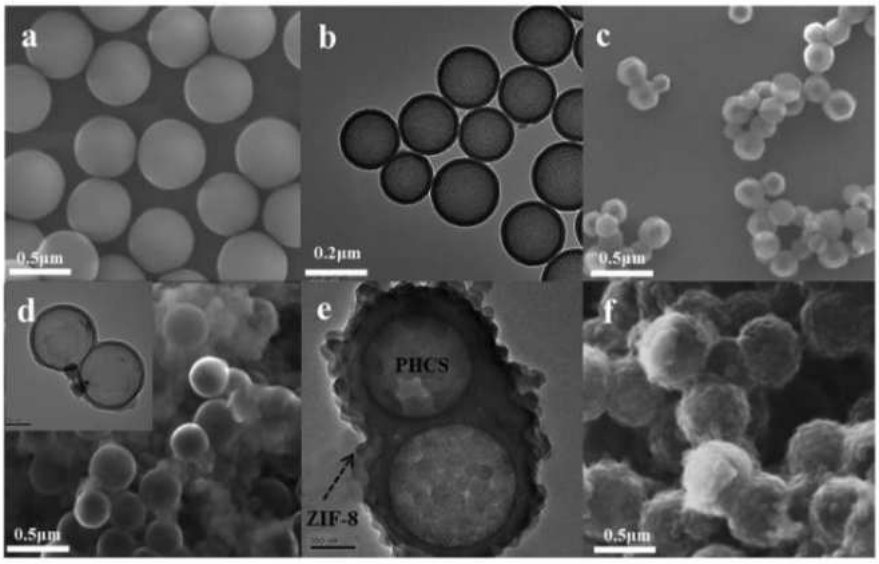


Fig 3. SEM and TEM images of SIO 2 (a), PHCS particles (b), ZIF-8 (c), PHCS@ZIF-8 core-shell nanocomposite without PSS (d) and with PSS treatment (e, f) (Chen et al., 2019)

2.3.4 SCC-CuMOF

the Sodium Carboxymethyl Cellulose-Copper Metal-Organic Framework (SCC-CuMOF) adsorbent, synthesized by ([33]for extracting Pb^{2+} ions from aqueous solutions, demonstrated exceptional efficacy. Its maximum adsorption capacity reached 531.38 mg/g at 308K.

Furthermore, the adsorption process of Pb^{2+} using SCC-CuMOF revealed significant influences from various parameters, including pH, adsorbent concentration, and contact time. Optimal adsorption occurred at pH 6.0, where the adsorbent's surface charge favored Pb^{2+} ion interaction. Increasing SCC-CuMOF concentration enhanced adsorption capacity by making more active sites available for metal ion binding. Contact time played a crucial role, with equilibrium reached within approximately 20 minutes, indicating rapid adsorption of Pb^{2+} ions.

These findings highlight the necessity of the optimization of pH, concentration, and contact time to maximize Pb^{2+} removal efficiency from wastewater.

2.3.5 UiO-66-(OPO_3) X

A comprehensive study on phosphorylated UiO-66, denoted as UiO-66-(OPO_3)X, evaluated its effectiveness in adsorbing lead ions (Pb^{2+}) from aqueous solutions, showcasing its potential for wastewater treatment. The introduction of phosphate ester groups significantly enhanced the adsorption capacity, with removal efficiencies reaching approximately 81.5% for UiO-66-(OH) X, 99.2% for UiO-66-o-$(OH)_2$, and an impressive 131.4% for UiO-66-p-$(OH)_2$.

[34] investigated key parameters affecting Pb^{2+} adsorption using UiO-66-(OPO_3)X, including pH, adsorbent concentration, and contact time. At pH levels below 3, H^+ ions compete with Pb^{2+}, inhibiting adsorption. However, as pH increases to 3 or above, phosphate group ionization enhances Pb^{2+} adsorption. The adsorbent concentration plays a crucial role, with higher concentrations generally leading to increased removal efficiency. Longer contact times also improve adsorption rates, allowing more Pb^{2+} ions to be captured.

Optimizing these parameters is essential for maximizing Pb^{2+} removal effectiveness from contaminated effluents [34].

2.3.6 Cu-BTC and Zn-BT

Cu- and Zn-based metal-organic frameworks (MOFs), specifically Cu-benzene-1,3,5-tricarboxylic acid (BTC) and Zn-BTC, were synthesized by [24]and demonstrated effectiveness in removing lead(II) ions from water. Adsorption experiments revealed that Cu-BTC achieved a maximum adsorption capacity of 333 mg/g, while Zn-BTC reached 312 mg/g for Pb (II) ions, showcasing their high efficiency in heavy metal ion removal.

Furthermore, the experiments revealed the effects of various parameters on Pb (II) ion adsorption using Cu-BTC and Zn-BTC MOFs. The solution pH significantly influenced adsorption efficiency, with optimal removal observed at pH 5. Adsorbent concentration also played a crucial role; however, higher dosages led to decreased adsorption capacity due to an unfavorable ratio of adsorbing concentration to available adsorbent sites. Contact time was critical, with rapid adsorption kinetics achieved in under 25 minutes, indicating chemical interactions between metal ions and framework adsorption sites predominantly controlled the adsorption process.

2.3.7 PEIUiO-66-NH_2

[35] conducted an adsorption experiment using the synthesized PEI@UiO-66-NH2 composite for Pb^{2+} removal, achieving an impressive adsorption capacity of 692.80 mg/g.

The adsorption process of Pb(II) using PEI@UiO-66-NH2 is significantly influenced by several parameters. The solution pH plays a crucial role, with optimal adsorption occurring within a specific pH range, affecting the ionization of functional groups on the adsorbent and the speciation of adsorbates. The initial Pb(II) concentration also impacts adsorption capacity, as increased concentration raises collision probability between adsorbate molecules and the adsorbent, enhancing adsorption until equilibrium is reached.

Furthermore, contact time is critical, with rapid initial adsorption reaching equilibrium within approximately 5 minutes. This indicates the adsorbent's high affinity for pollutants. Collectively, these parameters determine the efficiency and effectiveness of the adsorption process, highlighting the importance of optimizing conditions for maximum pollutant removal.

2.3.8 Zif-8/Zif-67

Ahmad et al. (2021) [23] assessed the performance of ZIF-8 and ZIF-67 as adsorbents for eliminating Pb^{2+} ions. The materials' surface areas and porosity were evaluated using the Brunauer-Emmett-Teller (BET) method, revealing their notable ability to promote adsorption due to their structural features. ZIF-67 outperformed ZIF-8 in lead and mercury adsorption, achieving capacities of 1436.11 mg/g for mercury and 1978.63 mg/g for lead. This versatility makes ZIF-67 suitable for heavy metal removal applications.

X-ray diffraction (XRD) analysis (Fig. 5) confirmed ZIF-8's crystalline structure, ensuring its integrity throughout the adsorption process. The findings indicated ZIF-8 achieved a Pb^{2+} adsorption capacity of 1780.91 mg/g, underscoring its potential as an effective adsorbent.

Scanning electron microscopy (SEM) analysis revealed ZIF-8's uniform polyhedral morphology, indicating consistent particle size and shape. This morphology enhances the material's surface area, facilitating interactions with Pb^{2+} ions during adsorption. The favorable surface area and optimal pore structure of ZIF-8 enable strong interactions between Pb^{2+} ions and the adsorbent, leading to efficient removal of lead from cosntaminated water sources.

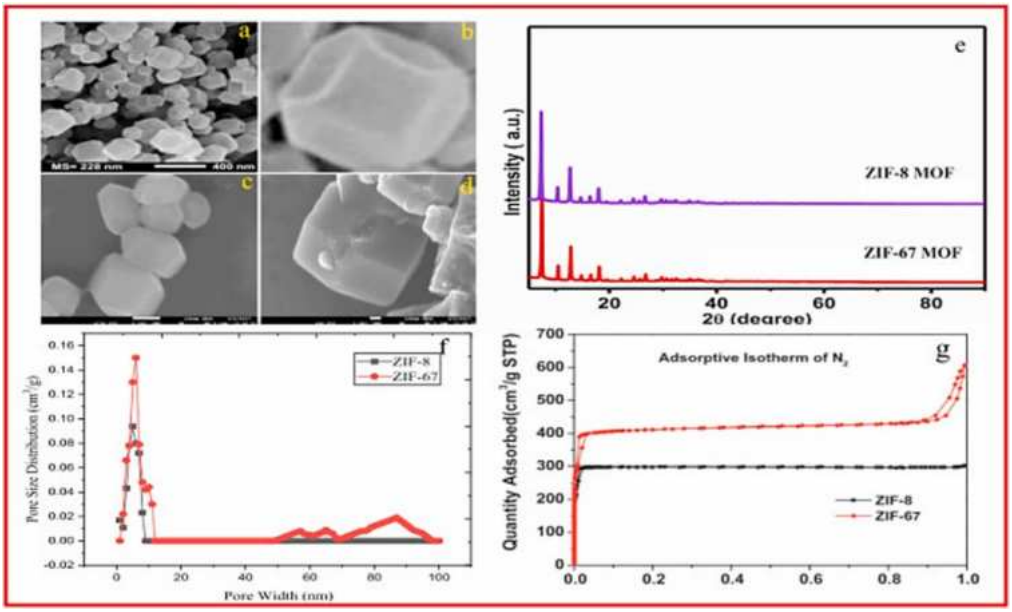


Fig 4. a and b) Morphology of ZIF-67 shown by SEM that the particles are well distributed having polyhedral shape, c and d) Morphology of ZIF-8 shown by SEM that the particles are well distributed having polyhedral shape, e) Diffraction peaks of ZIF-8 & ZIF-67 shown by Powder XRD, f) Pore size distribution of ZIF-8 and ZIF-67, from the figure it is clear that the pore size distribution and pore width of ZIF-67 is greater than ZIF-8, g) Nitrogen adsorption/desorption curve of ZIF-67 and ZIF-8 that represents that these MOFs have high surface area and are nanoparticles, further ZIF-67 have more nitrogen adsorption-desorption capacities as compared with ZIF-8. [23]

2.3.9 ZIF-67@Yeast

Wen et al. (2019) conducted an adsorption experiment to evaluate the effectiveness of ZIF-67@Yeast composite in removing Pb^{2+} ions from aqueous solutions. The results showed that several parameters significantly influenced Pb^{2+} adsorption efficiency.

The solution pH played a crucial role, with optimal adsorption occurring at specific pH levels that favor Pb^{2+} ionization and align with the adsorbent's surface properties. The adsorbent concentration also impacted adsorption capacity, as higher concentrations increased the availability of active sites for Pb^{2+} binding.

Contact time was critical, with rapid initial adsorption reaching equilibrium within a few hours, depending on the initial Pb^{2+} concentration. These parameters collectively underscore the importance of optimizing conditions to enhance ZIF-67@Yeast's effectiveness in removing Pb^{2+} from aqueous solutions.

2.3.10 ZIF-90@CS/SA

[33] synthesized ZIF-90@CS/SA beads, which demonstrated remarkable efficiency in removing Pb(II) ions from industrial wastewater. The adsorption of Pb(II) onto ZIF-90@CS/SA beads was significantly influenced by pH, adsorbent concentration, and contact time.

Removal efficiency increased with pH, peaking at 84.87% at pH 5.0, and remained stable between pH 5.0 and 9.0. However, efficiency declined at higher pH levels due to electrostatic repulsion. As Pb(II) concentration increased, adsorption capacity improved, attributed to stronger interactions with adsorption sites.

Contact time played a vital role, with Pb (II) reaching equilibrium within 2.5 hours. Notably, rapid initial adsorption exceeded 75% within the first two hours. Optimizing these parameters is crucial for effective heavy metal removal from wastewater.

2.3.11 HNTs@PDA/ZIF-8

[38] investigated Pb(II) adsorption using Halloysite polydopamine/ZIF-8 (HNTs@PDA/ZIF-8) nanocomposites, achieving a remarkable adsorption capacity of 515.46 mg/g.

The adsorption process of Pb^{2+} ions onto HNTs@PDA/ZIF-8 is influenced by several parameters: pH, adsorbent concentration, and contact time. Adsorption efficiency increases with pH, rising from 3.0 to 7.0, due to reduced protonation of functional groups. Higher pH enhances

HNTs@PDA/ZIF-8 stability, facilitating improved adsorption.

The adsorption capacity increases with Pb^{2+} ion concentration, indicating greater interaction with available adsorption sites. Adsorption occurs rapidly initially, reaching equilibrium within 100-150 minutes. The pseudo-second-order kinetic model accurately describes the adsorption process, suggesting chemical adsorption dominance.

2.3.12 MTV-MOFSWCNT-BP

Adsorption experiments demonstrated the MTV-MOF/SWCNT-BP composite's effectiveness in removing lead ions from aqueous solutions. by [39]conducted an experiment revealing the composite's remarkable lead ion adsorption capacity, reducing lead concentration below EPA and WHO trigger levels, even in highly concentrated multicomponent solutions [46].

Notably, for initial lead concentrations between 200-1000 ppb, final concentrations were reduced to below 10 ppb, showcasing the material's efficacy. Scanning Electron Microscopy (SEM) images illustrated the composite's morphology, revealing MTV-MOF particles enmeshed within the SWCNT-BP structure. Micrometer-sized aggregates of smaller, nanosized primary particles contributed to the hybrid material's overall mechanical stability and enhanced adsorption properties.

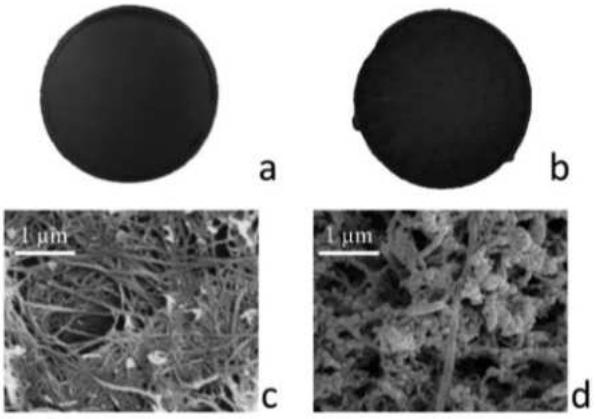


Fig 5. Final appearance of (a) neat SWCNT-BP and (b) MTV-MOF/SWCNT-BP. The average diameter of membranes was 38 ± 1mm. SEM images of (c) SWCNT-BP and (d) MTV-MOF/SWCNT-BP unveiling MTV-MOF micrometer particles as aggregates of smaller nanosized primary particles.

2.3.13 Cu-MOFs/CMFP

The adsorption experiment conducted by [40] utilized Cu-MOFs/CMFP to effectively remove organic dyes (methylene blue, rhodamine B, and malachite green) from aqueous solutions. A dosage of 30.00 mg of Cu-MOFs was added to dye solutions with an initial concentration of 10 mg/L, and after shaking for 35 minutes, residual dye concentrations were measured using UV-vis spectroscopy, achieving removal efficiencies exceeding 90%.

The adsorption of Pb^{2+} using SCC-CuMOF is significantly affected by pH, adsorbent concentration, and contact time. Optimal adsorption occurs at a pH of approximately 6.0, where the electrostatic interactions between the adsorbent and Pb^{2+} ions are maximized. Increasing the concentration of SCC-CuMOF enhances the adsorption capacity due to a greater availability of active sites for binding. Additionally, the contact time is crucial, with equilibrium typically reached within 20 minutes, indicating that the majority of Pb^{2+} ions are adsorbed rapidly. These results underscore the importance of optimizing these parameters to improve the efficiency of Pb^{2+} removal from aqueous solutions.

2.3.14 Cu MOF/HKUST -EDA

Ethylenediamine (EDA) modified copper-based MOF (HKUST-1-EDA) demonstrated excellent removal efficiency for Pb(II) ions from industrial wastewater, an experiment realized by [41] with maximum adsorption capacities of 12.85 mg/g for Pb(II) at pH 5.2.

The study investigated the effects of various parameters on the adsorption process of Pb(II) using the HKUST-1-EDA adsorbent. The pH of the solution as mentioned significantly influenced adsorption efficiency, with optimal removal observed at pH 5.2, where the adsorption capacities peaked before slightly decreasing at higher pH levels due to the presence of hydroxide ions. The concentration of the adsorbent also played a crucial role; an increase in dosage initially enhanced removal efficiency, reaching an optimum at 0.6 g/L, beyond which aggregation of particles reduced available adsorption sites and decreased efficiency. Additionally, contact time was critical, with maximum adsorption capacities achieved within 20 minutes, indicating rapid interaction between the adsorbent and metal ions. Overall, these parameters were essential in optimizing the adsorption process for effective heavy metal removal from aqueous solutions.

2.3.15 SUZ-4 zeolite

The purpose of the SUZ-4 zeolite adsorption experiment realized by [28] for Pb^{2+} removal, was to assess the zeolite's capacity and effectiveness. Na-T13, a sodium-exchanged form of SUZ-4 zeolite, plays a crucial role in the adsorption of Pb^{2+} ions from wastewater, and demonstrated a high adsorption capacity of 181.56 mg/g. The zeolite was synthesized through a hydrothermal method, and its structural characteristics were analyzed using various techniques.

Furthermore, characterizations were performed on the Na-T13 zeolites before and after adsorption 10 times to determine the adsorption mechanism of Pb^{2+} on the zeolite. The XPS is very useful to recognize the functional groups and element compositions on the fresh and spent adsorbent [47] [48]. As displayed in Fig. 8a, before adsorption, the main characteristic peaks of zeolites were attributed to Al 2p, Si 2p, O 1 s, and Na 1 s. After adsorption in Pb^{2+} solution, the strong peaks belonged to Pb 4f and $Pb_{4d5/2}$ and $Pb_{4d3/2}$ appeared on zeolite, but the Na 1 s peak was almost disappeared, suggesting the ion-exchange of Na+ by Pb^{2+} in adsorption. X-ray diffraction (XRD) analysis confirmed the crystalline nature of the synthesized SUZ-4, showing distinct peaks corresponding to the zeolite structure, which indicated successful synthesis and purity of the material. Scanning Electron Microscopy (SEM) images illustrated the morphology of the SUZ-4 zeolite, revealing aggregates of tiny, spiny crystals that maintained their structure even after multiple adsorption cycles, demonstrating the stability of the material. The combination of these results underscores the effectiveness of SUZ-4 zeolite as an adsorbent for Pb^{2+} ions, highlighting its structural integrity and high surface area as key factors contributing to its adsorption performance.

2.3.16 Ni-MOF-74

The adsorption experiments conducted by (Lou et al., 2022) to evaluate the efficacy of Ni-MOF-74 for removing $Pb^{2+}$from wastewater, was investigated. Furthermore, the characterization of Ni-MOF-74 material, by Brunauer-Emmett-Teller (BET) analysis was performed, revealing a specific surface area of 466.001 m^2/g before adsorption, which decreased to 61.587 m^2/g after Pb^{2+} adsorption. This significant reduction in surface area suggests that Pb^{2+} ions occupy the active sites and micropores of the Ni-MOF-74, confirming its role as an effective adsorbent.

X-ray diffraction (XRD) analysis was conducted to investigate the crystallinity and structural integrity of Ni-MOF-74 before and after Pb^{2+} adsorption. The XRD patterns indicated that the material retained its crystalline structure post-adsorption, which is essential for maintaining its adsorption properties.

Additionally, in (fig 8) as it can be observe the morphological changes of Ni-MOF-74 before and after the adsorption process The SEM images revealed a distinct alteration in surface morphology, with the presence of Pb^{2+} ions leading to changes in the texture and particle size distribution of the adsorbent. These characterization techniques collectively affirm the successful adsorption of Pb^{2+} ions onto Ni-MOF-74 and highlight its potential as a promising material for environmental remediation applications.

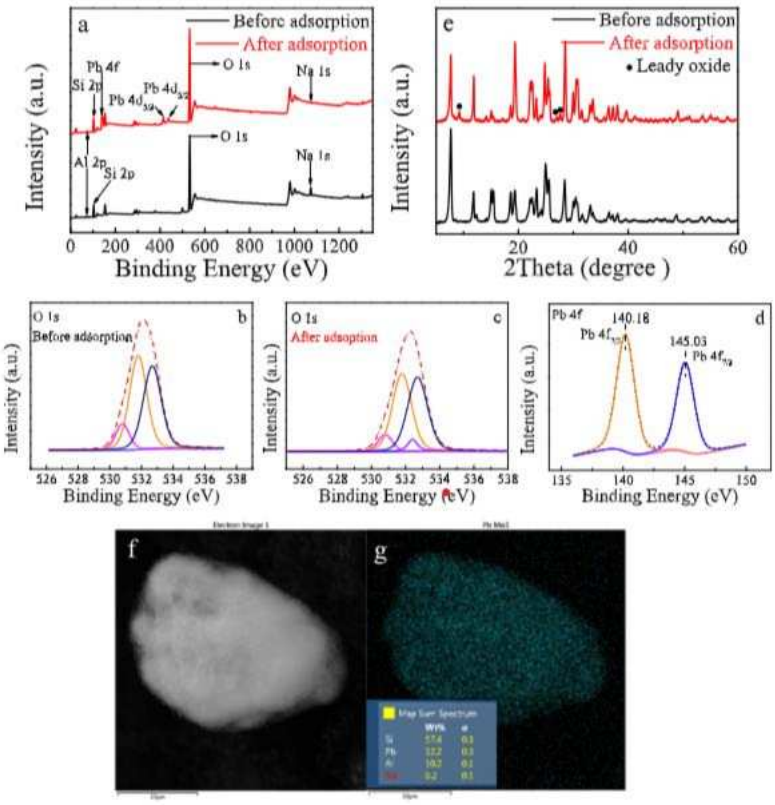


Fig 6. Characterizations of Na-T13 before and after adsorption: XPS spectra (a-d), XRD patterns (e), SEM-EDS (f, g).

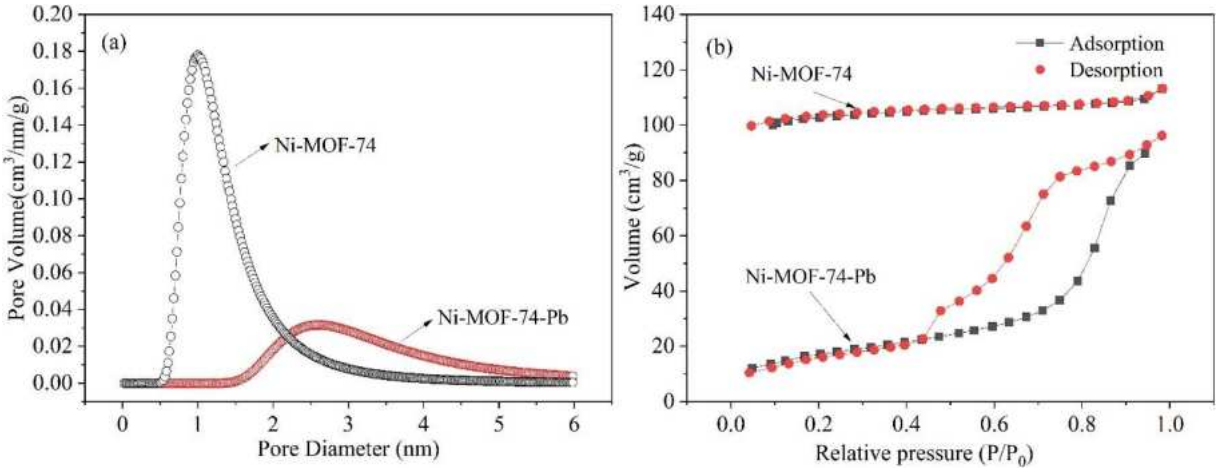


Fig7. (a) pore size distribution curves of Ni-MOF-74 and Ni-MOF-74-Pb, (b) N 2 adsorption/desorption isotherms. [43]

2.3.17 Fe-MOFs

The sulfate-functionalized Fe-based metal-organic framework (Fe-MOF) synthesized by [42] for the adsorption process of Pb(II) was significantly influenced by several parameters, including pH, concentration of the adsorbent, and contact time. The study revealed that under acidic conditions (pH 2-5), the surface charge of Fe-MOF was positive, leading to a decrease in removal efficiency due to competition with H^+ ions.

As the pH approached neutral (pH 6-7), the removal rate stabilized, indicating optimal conditions for adsorption. Additionally, the adsorption capacity increased with higher initial concentrations of Pb (II) ions, reaching a maximum capacity of 504 mg/g. The kinetics of adsorption showed a rapid increase in capacity within the first 2 hours, followed by a gradual slowdown, suggesting that internal diffusion may control the process. Overall, these parameters play a crucial role in optimizing the adsorption efficiency of Fe-MOF for Pb (II) ion removal from wastewater.

2.3.18 NH2 -MIL-53

The adsorption process of Pb^{2+} onto NH_2-MIL-53/WC hybrid membrane synthesized by [44] was significantly influenced by several parameters, including pH, initial concentration of the adsorbate, and contact time. The solution pH affects the surface charge of the adsorbent and the speciation of Pb^{2+}, optimizing the adsorption performance.

Higher initial concentrations of Pb^{2+} lead to increased adsorption capacities, as all potential active sites become occupied, with the NH_2-MIL-53/WC exhibiting superior performance compared to other materials. Additionally, the contact time is crucial, with equilibrium being reached after 12 hours, indicating that the adsorption kinetics are governed by chemisorption and multi-stage processes, including fast external surface adsorption followed by gradual intra-particle diffusion. These parameters collectively enhance the efficiency of the adsorption process, making the NH_2-MIL-53/WC membrane a promising candidate for lead ion removal in water treatment applications. Membrane as an effective adsorbent for the removal of heavy metal ions from contaminated water sources.

III. PERFORMANCES EVALUATION OF MOF FOR THE REMOVAL OF Pb^{2+}

3.1. Regeneration, Stability and Structural Integrity

Metal-Organic Frameworks (MOFs) regeneration is crucial for cost efficiency and sustainability in adsorption applications. Effective regeneration methods, including thermal treatment, solvent washing, and chemical desorption, depend on the MOF's structural stability and ability to retain adsorption efficiency after multiple cycles. MOF reusability hinges on maintaining structural integrity, influenced by factors such as linker nature, functional groups, and metal-ligand bond robustness. Post-synthetic modifications, like phosphate or thiol group functionalization, can enhance durability and adsorption capacity under real-world conditions. Several MOF adsorbents prioritize stability and structural integrity, demonstrating sustained performance across multiple adsorption-desorption cycles. This emphasis on reusability is vital for practical applications, ensuring MOFs remain effective and efficient over time.

Overall, CS-ZIF-8 composite beads offer a sustainable solution for Pb (II) remediation in contaminated water sources. Liu et al. (2019) [29] prepared CS-ZIF-8 for U(VI) removal and reported a high adsorption capacity of 629 mg/g at an optimal pH of 3.0. The chitosan component in this hybrid framework may provide additional functional groups that interact effectively with Pb^{2+} ions improving it stability.

Again, Thiol-functionalized magnetic core-shell microspheres are designed to overcome adsorption challenges. After adsorption, the Fe3O4@Cu3(btc)2 magnetic core-shell was washed with NaOH and water and reused for multiple rounds without losing efficiency. This hybrid structure enhances stability during the adsorption and desorption processes, making it robust against structural degradation. The presence of carboxylate groups in the BTC ligand further contributes to its adsorption capacity, allowing for effective removal of heavy metals from wastewater. This indicates long-term stability and reusability, making it an environmentally friendly option. Other MOF adsorbents, such as porous hollow carbon sphere@ZIF-8, have also demonstrated effective Pb2+ adsorption, desorption, and regeneration capabilities [49].

PHCS-15@ZIF-8 decreased slightly after each desorption. The Pb-loaded sorbents was centrifuged and washed with ethanol for three times. After that, the regenerated adsorbents were dried at 60 ℃ overnight and reused for another adsorption process and more than 90% of the removal efficiency still can be retained after 5 cycles During the experiment process. These indicated that ethanol washing was a useful method for regenerating the used adsorbent. PHCS-15@ZIF-8 also exemplifies the importance of linker nature and functional groups. The ZIF-8 component provides a robust framework that supports structural integrity, while the hybridization with PHCS introduces additional functional sites that enhance adsorption. [32]

The reusability and environmental friendliness of SCC-CuMOF and UiO-66-(OPO_3)X were investigated for practical applications. Continuous adsorption-desorption cycles revealed that SCC-CuMOF maintained a percentage removal of Pb2+ from 93.0% to 73.9% after five regeneration cycles. In comparison, UiO-66-(OPO_3)X exhibited remarkable regeneration performance, sustaining over 87% removal efficiency after five consecutive cycles.

This durability enables repeated use without significant effectiveness loss, minimizing replacement needs. Notably, UiO-66-(OPO_3)X combines low production costs, high efficiency, and excellent reusability, positioning it as a sustainable and economically viable solution for addressing heavy metal pollution in industrial applications. [34]

Metal-organic frameworks (MOFs) like Cu-BTC and Zn-BTC effectively reduce lead concentrations in water, promoting public health and environmental safety. They demonstrate high adsorption capacities of 333 mg/g and 312 mg/g, respectively. Their stability and multiple reuses make them environmentally friendly solutions for removing heavy metal pollutants.

PEI@UiO-66-NH2, a non-toxic adsorbent, effectively removes anionic dyes and heavy metals from wastewater, resulting in cleaner water and reduced pollution. Its rapid adsorption kinetics enhance treatment efficiency and reduce resource consumption, making it a promising sustainable solution.

ZIF-67/ZIF-8 maintains a high adsorption capacity (95%) over multiple cycles, indicating effective reusability. This reduces waste and the need for new materials, contributing to a more sustainable water treatment approach. It stands out with its stable framework that supports high adsorption capacities due presence of functional groups enhances its interaction with heavy metals, contributing to its effectiveness. ZIF-67@Yeast composite material, stable after carbonization, is reusable and environmentally benign. ZIF-90@CS/SA beads exhibit excellent adsorption capacity, favorable recyclability, and environmental friendliness, showing potential for heavy metal removal from industrial wastewater.

HNTs@PDA/ZIF-8's reusability was tested through recycling experiments. Despite a capacity loss after four cycles, its adsorption capacity remained above 50 mg/g, indicating good regeneration properties.

The NH2-MIL-53/WC hybrid membrane selectively sequesters Pb^{2+} from wastewater, offering an environmentally friendly solution. Its exceptional reusability allows for multiple reuses without capacity loss, generating low waste and making it a sustainable alternative.

MTV-MOF/SWCNT-BP was preserved owing of its structural stability upon lead adsorption/desorption cycles, and complete regeneration was achieved for up to five cycles. MTV-MOF/SWCNT-BP has great potential in the field of water treatment and can be effectively used as a reliable adsorbent for Pb (II) removal for household drinking water, as well as in industrial treatment plants for water and wastewater decontamination. The Cu-MOFs/CMFP can be regenerated through a simple washing process, allowing for multiple cycles of use without significant loss of efficiency. This reusability contributes to sustainability by minimizing waste and reducing the need for new materials.

The study emphasizes the Fe-MOF's selectivity and recyclability, which are crucial for its practical application in treating industrial wastewater, further supporting its role as an environmentally friendly solution. SUZ-4 zeolite has also been investigated and one of the components reusability of Na-T13 for Pb^{2+} adsorption, the adsorption-desorption cycles were conducted 10 times as described in Section 2.5, and the adsorbent amount was kept constant during the investigation. That the stability and recyclability of Na-T13 are excellent and that the adsorption process is good.

To investigate stability and reusability of Ni-MOF-74, the desorption experiment was carried out at 0.2 M_{HCl}. Four (4) consecutive adsorption regeneration cycles were performed. After four cycles, the adsorption capacity of Pb^{2+} decreased, but still maintained a high adsorption capacity (153.21mg/g). Ni-MOF-74 showcases the significance of robust metal-ligand bonds, which contribute to its high stability. The presence of amine functional groups enhances its interaction.

And finally, NH2-MIL-53/WC membrane is reutilized for Pb^{2+} adsorption, effectively removing Pb2+ below WHO standards. After four regeneration cycles, the membrane maintains 97.7% of its original equilibrium sorption capacity, indicating successful recovery of adsorption sites by acidified EDTA solution. This reusability performance ensures the sustainable application of the proposed NH2-MIL53/WC hybrid membrane in water treatment.

3.2 Cost-Effectiveness of MOF-Based Adsorbents

3.2.1 Comparative Analysis of MOF-Based Adsorbents

The economic viability of MOFs for industrial wastewater treatment depends on their production costs, ease of regeneration, and longevity. While the initial costs of MOF synthesis can be high, their long-term cost efficiency lies in their reusability and high adsorption capacity.

A comprehensive comparison of various MOF-based adsorbents reveals significant variations in cost, adsorption capacity, regeneration cycles, and cost-effectiveness, have been notified in the following table 2. The cost analysis shows that Cu-MOFs/CMFP and NH2-MIL-53/WC are the most expensive options, ranging from $1.50 to $3.50 per gram. In contrast, UiO-66-(OPO_3)X, Cs-ZIF-8, and Fe-MOF are the least expensive, costing between $0.30 and $0.80 per gram.

ZIF-67/ZIF-8 demonstrates the highest adsorption capacity at 1978.63 mg/g, surpassing other adsorbents. UiO-66-NH2 and SCC-CuMOF exhibit medium adsorption capacities, with 692.80 mg/g and 531.38 mg/g, respectively. SUZ-4 (Na-13) stands out with a maximum of 10 regeneration cycles, indicating high reusability. UiO-66-(OPO_3)X and Cs-ZIF-8 offer around 5 regeneration cycles, balancing cost and reusability.

The cost-effectiveness rating reveals that UiO-66-NH2, ZIF-67/ZIF-8, and SUZ-4 (Na-13) are highly cost-effective due to their reasonable costs, high adsorption capacities, and strong regeneration potential. MTV-MOF/SWCNT-BP and SCC-CuMOF fall into the medium category, while Ni-MOF-74 and Cu-MOFs/CMFP are rated as low in cost-effectiveness due to their low adsorption capacities and higher costs per gram.

ZIF-67/ZIF-8 and UiO-66-NH2 emerge as optimal choices in terms of cost-effectiveness, adsorption capacity, and reusability. Conversely, Cu-MOFs/CMFP is less favorable due to its high cost and low adsorption efficiency. These findings provide valuable insights for selecting efficient and economical MOF-based adsorbents for various applications.

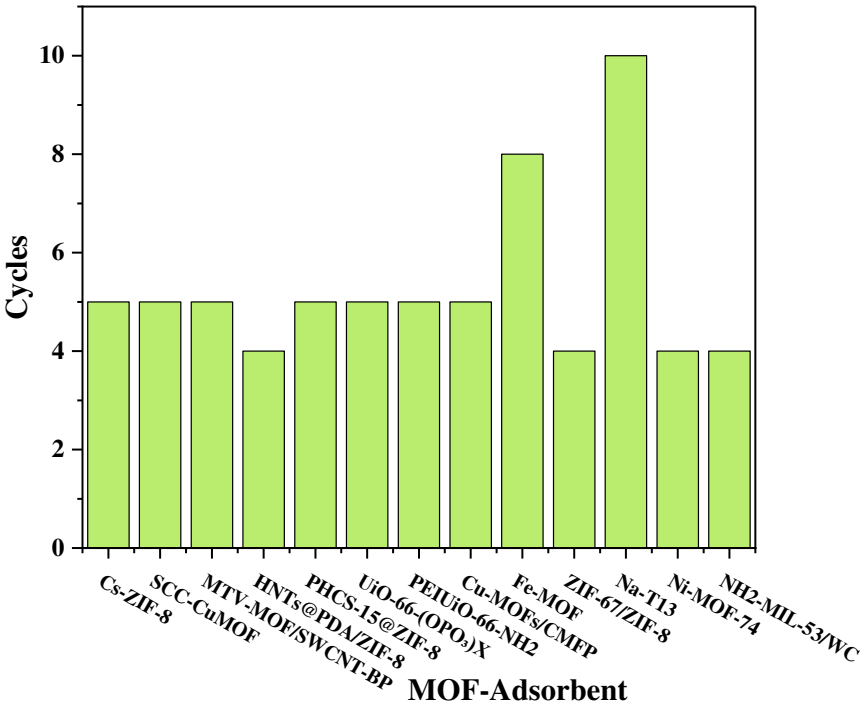


Fig 8. Regeneration cycles of MOF adsorbents

Table 2: Comparative Analysis of MOF-Based Adsorbents

MOF Type	Cost (USD/g)	Adsorption Capacity (mg/g)	Regeneration Cycles (n)	Cost-Effectiveness Rating
UiO-66-(OPO_3) X	• UiO-66-OH (1.0 g): $100 to $200 • Phosphorus Pentoxide (0.5 g): $0.25 to $0.50 • DMF (40 mL): $2 to $4 • Deionized Water (100 mL): $0.10 • Methanol (100 mL): $2 to $3	512.8	5	Medium
Cs-ZIF-8	• Chitosan (0.48 g): $0.48 to $0.72 • Acetic Acid (2%, 16 mL): <$0.10 • Zinc Nitrate Hexahydrate: $0.50 to $2 • Sodium Hydroxide (96 mL, 1 mol/L): <$0.05 • 2-Methylimidazole: $1 to $3 • Methanol (40 mL): $0.80 to $1.20	131.4	5	Medium
Fe3O4@Cu3(btc)2	($0.40–$1.00/g)	215.05	4	Medium
PHCS-15@ZIF-8	($0.40–$0.70/g)	462.9 /310.5	5	High
SCC-CuMOF	$0.40–$0.80/g	531.38	5	Medium
UiO-66-(OPO_3) X)	$0.80–$1.50	445.88	5	High
Cu-BTC and Zn-BT	39$ and $0.30–$0.70 (/g)	333(Cu-BTC) 312 (Zn-BT)	6	High
Fe-MOF	$0.30–$0.80/g	504	4	medium
UiO-66-NH2	0.36$	692.80	5	High
ZIF-67/ZIF-8	1g (49.99$/36.00$)	1978.63	5	High
ZIF-90@CS/SA	$0.40–$1.00 /g	445.88	N/A	medium
HNTs@PDA/ZIF-8	$0.70–$1.50 / g	515.46	4	Medium
MTV-MOF/SWCNT-BP	$0.40–$1.00/g	180	5	Medium
Cu-MOFs/CMFP	$1.50–$3.00/g	31.77 N/A	5	Low
SUZ-4 (Na-13)	1.86 g	181.56	10	High
Ni-MOF-74	$0.40–$1.00 /g	98.062	4	Low
NH2-MIL-53/WC	$1.50–$3.50/g	223.4	4	Medium

3.3 Environmental Impact of MOFs

MOFs, being highly tunable, can be designed to minimize environmental impact. However, their synthesis often involves the use of toxic solvents and metal salts, raising concerns about their environmental footprint. To mitigate this, green synthesis methods, such as the use of water or ethanol as solvents, have been proposed.

To address these concerns, researchers have started exploring green synthesis methods that utilize more environmentally friendly solvents, such as water or ethanol. For example, the synthesis of **CS-ZIF-8 composite beads** incorporates biodegradable chitosan, which not only enhances the sustainability of the adsorbent but also reduces the environmental impact associated with its production 3. Similarly, **NH2-MIL-53/WC** has been noted for its environmentally friendly properties due to its selective sequestration of lead ions from wastewater, demonstrating the potential for MOFs to be both effective and sustainable 23.

By adopting these greener approaches, the environmental impact of MOFs can be significantly reduced, making them a more viable option for addressing heavy metal pollution and other environmental challenges.

IV. CHALLENGES AND FUTURE DIRECTIONS

Despite demonstrating great potential for Pb^{2+} removal, Metal-Organic Frameworks (MOFs) face scalability, stability, and environmental challenges. Current synthesis methods are difficult to scale for industrial applications, emphasizing the need for research into scalable, low-cost production techniques. Moreover, MOFs often degrade under harsh wastewater conditions, such as high salinity and pH extremes, necessitating the development of more robust materials with enhanced durability. To overcome these limitations, future research should focus on developing multifunctional MOFs that can target multiple contaminants, maintain removal efficiency over repeated use, and exhibit stability under variable conditions. This can be achieved through greener synthesis methods, non-toxic material design, and integration into hybrid systems, such as membranes or bio composites, to enhance practical application in wastewater treatment.

V. CONCLUSION

This study underscores the effectiveness of metal-organic frameworks (MOFs) as promising adsorbents for removing lead (Pb^{2+}) ions from wastewater. MOFs, such as ZIF-8, ZIF-67, and UiO-66 variants, demonstrate impressive adsorption capacities, high reusability, and significant structural versatility, making them ideal candidates for environmental remediation applications. Their high surface areas, tunable pore structures, and diverse functionalities enable efficient Pb^{2+} removal, even at varying pH levels and in the presence of co-existing ions.

Our findings suggest that several MOFs maintain their adsorption efficiency over multiple cycles, with minimal loss in performance, contributing to their cost-effectiveness and sustainability. The materials' tunability allows them to meet the demands of different wastewater conditions while promoting environmental safety by reducing the need for single-use adsorbents. Despite their promise, challenges such as scalability, stability under extreme conditions, and environmental impact during synthesis need further exploration to advance MOFs from research to practical applications.

Future work should focus on optimizing green synthesis methods and enhancing MOF stability, targeting multifunctionality for simultaneous removal of various contaminants. Addressing these areas will pave the way for MOFs to become a leading technology in sustainable wastewater treatment, contributing to cleaner water resources and improved public health.

REFERENCES

[1] M. Forghani, A. Azizi, M. J. Livani, and L. A. Kafshgari, "Adsorption of lead(II) and chromium(VI) from aqueous environment onto metal-organic framework MIL-100(Fe): Synthesis, kinetics, equilibrium and thermodynamics," *J. Solid State Chem.*, vol. 291, p. 121636, Nov. 2020, doi: 10.1016/j.jssc.2020.121636.

[2] N. U. Qadir, S. A. M. Said, R. B. Mansour, K. Mezghani, and A. Ul-Hamid, "Synthesis, characterization, and water adsorption properties of a novel multi-walled carbon nanotube/MIL-100(Fe) composite," *Dalton Trans.*, vol. 45, no. 39, pp. 15621–15633, 2016, doi: 10.1039/C6DT02640K.

[3] M. F. Ahmed, M. B. Mokhtar, and N. A. Majid, "Household water filtration technology to ensure safe drinking water supply in the Langat River Basin, Malaysia," *Water*, vol. 13, no. 8, p. 1032, 2021.

[4] Y. Wang, P. Kuntke, M. Saakes, R. D. van der Weijden, C. J. Buisman, and Y. Lei, "Electrochemically mediated precipitation of phosphate minerals for phosphorus removal and recovery: Progress and perspective," *Water Res.*, vol. 209, p. 117891, 2022.

[5] Y. Gao and Y. Liu, "Removal of microplastics by coagulation treatment in waters and prospect of recycling of separated microplastics: A mini-review," *J. Environ. Chem. Eng.*, vol. 10, no. 5, p. 108197, 2022.

[6] C. Thamaraiselvan, A. K. Thakur, A. Gupta, and C. J. Arnusch, "Electrochemical removal of organic and inorganic pollutants using robust laser-induced graphene

membranes," *ACS Appl. Mater. Interfaces*, vol. 13, no. 1, pp. 1452–1462, 2021.

[7] Q. Lu, N. Li, and X. Zhang, "Supramolecular recognition PVDF/PVA ultrafiltration membrane for rapid removing aromatic compounds from water," *Chem. Eng. J.*, vol. 436, p. 132889, 2022.

[8] H. Yan *et al.*, "In situ chemical oxidation: peroxide or persulfate coupled with membrane technology for wastewater treatment," *J. Mater. Chem. A*, vol. 9, no. 20, pp. 11944–11960, 2021.

[9] A. Saravanan, P. S. Kumar, S. Jeevanantham, M. Anubha, and S. Jayashree, "Degradation of toxic agrochemicals and pharmaceutical pollutants: Effective and alternative approaches toward photocatalysis," *Environ. Pollut.*, vol. 298, p. 118844, 2022.

[10] E. Issaka, J. N.-O. Amu-Darko, S. Yakubu, F. O. Fapohunda, N. Ali, and M. Bilal, "Advanced catalytic ozonation for degradation of pharmaceutical pollutants—A review," *Chemosphere*, vol. 289, p. 133208, 2022.

[11] J. Wang, J. Zhang, L. Han, J. Wang, L. Zhu, and H. Zeng, "Graphene-based materials for adsorptive removal of pollutants from water and underlying interaction mechanism," *Adv. Colloid Interface Sci.*, vol. 289, p. 102360, 2021.

[12] T. Rasheed, A. A. Hassan, M. Bilal, T. Hussain, and K. Rizwan, "Metal-organic frameworks based adsorbents: A review from removal perspective of various environmental contaminants from wastewater," *Chemosphere*, vol. 259, p. 127369, 2020.

[13] R. Taghavi *et al.*, "Magnetite metal–organic frameworks: applications in environmental remediation of heavy metals, organic contaminants, and other pollutants," *Inorg. Chem.*, vol. 61, no. 40, pp. 15747–15783, 2022.

[14] R. Novikau and G. Lujaniene, "Adsorption behaviour of pollutants: Heavy metals, radionuclides, organic pollutants, on clays and their minerals (raw, modified and treated): A review," *J. Environ. Manage.*, vol. 309, p. 114685, May 2022, doi: 10.1016/j.jenvman.2022.114685.

[15] K. Sossou, S. B. Prasad, E. K. Agbotsou, and H. Saidou Souley, "Evaluation of the performance of magnetic zeolite nanocomposites in removing various water contaminants as heavy metals, organic pollutants, and emerging contaminants: A review," *Nanotechnol.*, vol. 6, p. 100075, Jan. 2024, doi: 10.1016/j.nxnano.2024.100075.

[16] S. Mariyam, S. Zuhara, T. Al-Ansari, H. Mackey, and G. McKay, "Novel high capacity model for copper binary ion exchange on e-waste derived adsorbent resin," *Adsorption*, vol. 28, no. 3–4, pp. 185–196, May 2022, doi: 10.1007/s10450-022-00360-0.

[17] S. K. Yadav, S. R. Dhakate, and B. Pratap Singh, "Carbon nanotube incorporated eucalyptus derived activated carbon-based novel adsorbent for efficient removal of methylene blue and eosin yellow dyes," *Bioresour. Technol.*, vol. 344, p. 126231, Jan. 2022, doi: 10.1016/j.biortech.2021.126231.

[18] S. Bettini *et al.*, "SiO2 based nanocomposite for simultaneous magnetic removal and discrimination of small pollutants in water," *Colloids Surf. Physicochem. Eng. Asp.*, vol. 633, p. 127905, Jan. 2022, doi: 10.1016/j.colsurfa.2021.127905.

[19] R. Hu, Y. Liu, G. Zhu, C. Chen, D. Hantoko, and M. Yan, "COD removal of wastewater from hydrothermal carbonization of food waste: Using coagulation combined activated carbon adsorption," *J. Water Process Eng.*, vol. 45, p. 102462, Feb. 2022, doi: 10.1016/j.jwpe.2021.102462.

[20] Q. Luo *et al.*, "Cyclodextrin derivatives used for the separation of boron and the removal of organic pollutants," *Sci. Total Environ.*, vol. 749, p. 141487, 2020.

[21] M. Ali, M. Hoque, S. Safdar Hossain, and M. Biswas, "Nanoadsorbents for wastewater treatment: next generation biotechnological solution," *Int. J. Environ. Sci. Technol.*, vol. 17, no. 9, pp. 4095–4132, 2020.

[22] H. Shayegan, Y. D. Farahani, and V. Safarifard, "Removal of lead ion from aqueous solution by Metal Organic Framework," 2019.

[23] K. Ahmad *et al.*, "Effect of metal atom in zeolitic imidazolate frameworks (ZIF-8 & 67) for removal of Pb2+ & Hg2+ from water," *Food Chem. Toxicol.*, vol. 149, p. 112008, Mar. 2021, doi: 10.1016/j.fct.2021.112008.

[24] Z. S. Hasankola, R. Rahimi, and V. Safarifard, "Rapid and efficient ultrasonic-assisted removal of lead(II) in water using two copper- and zinc-based metal-organic frameworks," *Inorg. Chem. Commun.*, vol. 107, p. 107474, Sep. 2019, doi: 10.1016/j.inoche.2019.107474.

[25] X. Liu *et al.*, "Ligand design of a novel metal-organic framework for selective capturing of Pb(II) from wastewater," *J. Clean. Prod.*, vol. 386, p. 135841, Feb. 2023, doi: 10.1016/j.jclepro.2022.135841.

[26] H. Shayegan, G. A. Ali, and V. Safarifard, "Amide-functionalized metal–organic framework for high efficiency and fast removal of Pb (II) from aqueous solution," *J. Inorg. Organomet. Polym. Mater.*, vol. 30, pp. 3170–3178, 2020.

[27] A. J. Fletcher, K. M. Thomas, and M. J. Rosseinsky, "Flexibility in metal-organic framework materials: Impact on sorption properties," *J. Solid State Chem.*, vol. 178, no. 8, pp. 2491–2510, 2005.

[28] S. Gao and Y. Liu, "Potassium-assisted synthesis of SUZ-4 zeolite as an efficient adsorbent for Pb2+ removal from wastewater," *Sep. Purif. Technol.*, vol. 286, p. 120438, 2022.

[29] L. Liu, W. Yang, D. Gu, X. Zhao, and Q. Pan, "In situ preparation of chitosan/ZIF-8 composite beads for highly efficient removal of U (VI)," *Front. Chem.*, vol. 7, p. 607, 2019.

[30] M. Dutta, J. Bora, and B. Chetia, "Overview on recent advances of magnetic metal–organic framework (MMOF) composites in removal of heavy metals from aqueous system," *Environ. Sci. Pollut. Res.*, vol. 30, no. 6, pp. 13867–13908, 2023.

[31] C. Wang, Q. Sun, L. Zhang, T. Su, and Y. Yang, "Fe3O4@Cu3(btc)2," *J. Environ. Chem. Eng.*, vol. 10, no. 3, p. 107911, Jun. 2022, doi: 10.1016/j.jece.2022.107911.

[32] J. Chen *et al.*, "Controllable preparation of porous hollow carbon sphere@ZIF-8: Novel core-shell nanomaterial for Pb2+ adsorption," *Colloids Surf. Physicochem. Eng. Asp.*,

vol. 568, pp. 461–469, May 2019, doi: 10.1016/j.colsurfa.2019.02.044.

[33] H. Zhao *et al.*, "ZIF-90@CS/SA," *J. Solid State Chem.*, vol. 322, p. 123928, Jun. 2023, doi: 10.1016/j.jssc.2023.123928.

[34] H. Zhao *et al.*, "Fabrication of phosphorylated UiO-66 for efficient selective removal of Pb2+ from acidic wastewater," *J. Mol. Liq.*, vol. 401, p. 124737, May 2024, doi: 10.1016/j.molliq.2024.124737.

[35] S. Hu, T. Huang, N. Zhang, Y. Lei, and Y. Wang, "Enhanced removal of lead ions and methyl orange from wastewater using polyethyleneimine grafted UiO-66-NH2 nanoparticles," *Sep. Purif. Technol.*, vol. 297, p. 121470, Sep. 2022, doi: 10.1016/j.seppur.2022.121470.

[36] J. Wen *et al.*, "Fabrication of metal-organic framework@Yeast composite materials for efficient removal of Pb2+ in water," *J. Solid State Chem.*, vol. 274, pp. 26–31, Jun. 2019, doi: 10.1016/j.jssc.2019.03.011.

[37] P. Zong *et al.*, "Outstanding performance of core–shell structured chitosan-sodium alginate decorated ZIF-90 beads for the synchronous purification of Pb and Co from industrial effluents," *Sep. Purif. Technol.*, vol. 331, p. 125663, Mar. 2024, doi: 10.1016/j.seppur.2023.125663.

[38] H. Bian, P. Li, Y. Ma, L. Liu, D. Li, and N. Zhang, "ZIF-8/MS Hybrid Sponge via Secondary Growth for Efficient Removal of Pb(II) and Cu(II)," *Chem. Res. Chin. Univ.*, Mar. 2024, doi: 10.1007/s40242-024-4009-5.

[39] M. Baratta *et al.*, "Multivariate metal–organic framework/single-walled carbon nanotube buckypaper for selective lead decontamination," *ACS Appl. Nano Mater.*, vol. 5, no. 4, pp. 5223–5233, 2022.

[40] Z. Xiao *et al.*, "Controllable preparation of Cu-MOF-Coated carboxyl filter paper for simultaneous removal of organic dye and metal ions," *Ind. Eng. Chem. Res.*, vol. 60, no. 19, pp. 7311–7319, 2021.

[41] Y. Ren *et al.*, "Study on the mechanism of removing Pb (II) and Cd (II) from industrial wastewater by copper based MOF modified with ethylenediamine," *Fuel Process. Technol.*, vol. 247, p. 107798, 2023.

[42] R.-D. Wang *et al.*, "Sulfate-functionalized Fe-based MOF for removal of Pb (II) and NO3-in industrial wastewater," *J. Environ. Chem. Eng.*, vol. 12, no. 2, p. 112167, 2024.

[43] J. Lou *et al.*, "Highly effective removal of Pb2+ from wastewater by nickel-based metal organic framework," *J. Solid State Chem.*, vol. 315, p. 123535, 2022.

[44] Y. Gu *et al.*, "Fabrication of hierarchically porous NH2-MIL-53/wood-carbon hybrid membrane for highly effective and selective sequestration of Pb2+," *Chem. Eng. J.*, vol. 387, p. 124141, 2020.

[45] F. Zadehahmadi *et al.*, "Removal of metals from water using MOF-based composite adsorbents," *Environ. Sci. Water Res. Technol.*, vol. 9, no. 5, pp. 1305–1330, 2023, doi: 10.1039/D2EW00941B.

[46] A. A. Alghamdi, A.-B. Al-Odayni, W. S. Saeed, A. Al-Kahtani, F. A. Alharthi, and T. Aouak, "Efficient Adsorption of Lead (II) from Aqueous Phase Solutions Using Polypyrrole-Based Activated Carbon," *Materials*, vol. 12, no. 12, Art. no. 12, Jan. 2019, doi: 10.3390/ma12122020.

[47] F. Liu, S. Hua, C. Wang, and B. Hu, "Insight into the performance and mechanism of persimmon tannin functionalized waste paper for U (VI) and Cr (VI) removal," *Chemosphere*, vol. 287, p. 132199, 2022.

[48] F. Liu, S. Hua, C. Wang, M. Qiu, L. Jin, and B. Hu, "Adsorption and reduction of Cr(VI) from aqueous solution using cost-effective caffeic acid functionalized corn starch," *Chemosphere*, vol. 279, p. 130539, Sep. 2021, doi: 10.1016/j.chemosphere.2021.130539.

[49] M. Huang, L. Wang, W. You, and R. Che, "Single Zinc Atoms Anchored on MOF-Derived N-Doped Carbon Shell Cooperated with Magnetic Core as an Ultrawideband Microwave Absorber," *Small*, vol. 17, no. 30, p. 2101416, Jul. 2021, doi: 10.1002/smll.202101416.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.7

Effect of soil compaction on the initial development of corn

Bruno Estefano Fronza[1], Felipe Facundes Cerqueira[2], Guilherme Rocha Dos Santos[3]

[1]Academic of the Agronomy Course, ITPAC University, Brazil
Email: brunoestefanofronza@hotmail.com
[2]Academic of the Agronomy Course, ITPAC University, Brazil
Email : felipefacundes204@gmail.com
[3]Guiding Teacher , ITPAC University, Brazil
Email : guilherme.rocha@itpacporto.edu.br

Received: 14 Nov 2024,

Receive in revised form: 12 Dec 2024,

Accepted: 18 Dec 2024,

Available online: 24 Dec 2024

***Keywords*— Zea mays. Soil compaction. Soil physics. Soil management.**

***Abstract*—** *Corn is one of the oldest crops of great economic and social importance, used in human and animal food and in various industries. In 2022/2023, world production was 1,155.6 million tons, with a forecast of 1,235.7 million for 2023/2024. Brazil, the third largest producer in the world, with around 130 million, is also the largest exporter. Corn productivity faces challenges such as soil compaction, especially in the cerrado, which reduces root growth and nutrient absorption, negatively impacting production. The research sought management practices to mitigate these effects, varying according to the type of soil, species and level of compaction. The research was carried out with the objective of evaluating the effect of soil compaction in the initial phase of corn cultivation. This is a descriptive, explanatory research, experimental and field study, carried out in Porto Nacional – TO, through four treatments and five replications, with soil subjected to different compactions (0, 50, 100 and 150kg) by hydraulic press. For compaction, a hydraulic press was used, subjected to weights of 50 kg for Treatment A, 100 kg for Treatment B and 150 kg for Treatment C and Treatment D test 0 kg, The TD treatment presented the highest average values for plant height (AP), shoot dry matter (MSPA) and mean root dry matter (RMS), reaching 40%, 17% and 4.2%, respectively, these results indicate that the Proper management of soil compaction conditions is essential to optimize plant development.*

I. INTRODUCTION

Probably originating in Mexico, the Southwest of the United States or Central America, corn is a crop of great commercial importance in the Americas. Considered one of the oldest crops in the world, it has enormous economic and social importance due to its diverse forms of use, ranging from human and animal food to high-tech industry (Duarte and Garcia, 2021).

Corn (Zea mays) stands out as one of the most nutritious foods and one of the agricultural crops most widely cultivated by man, providing an essential source of nutrients for both humans and animals. Furthermore, it is a rich source of carbohydrates, proteins, vitamins and minerals (Labegalini et al., 2016).

When correlating human consumption with animal consumption and, additionally, when considering the increased use of corn in industrial applications, the increase in its relevance within the scope of cereal production on a global scale is evident. It is a cereal of utmost importance in human nutrition (both as a grain and in the production of starch, cooking oil and others), in the

production of alcohol, sweeteners, animal feed and others (Duarte and Garcia, 2021).

Due to its importance, corn is produced on a large scale, with a global production of 1,155.6 million tons for the 2022/2023 harvest and an estimated production of 1,235.7 million tons for the 2023/2024 harvest. representing an increase of 6.9% (USDA, 2023). Brazil is the third largest corn product in the world, with 11% of global production in the 2022/2023 harvest, behind only the United States and China. Furthermore, it is the largest corn exporter in the world (USDA, 2024).

Given its importance and high production, it is important to identify issues related to crop productivity. Barriers to the productive potential of corn have been observed, especially in cerrado areas, such as soil compaction (Azevedo, 2018).

In a compacted soil, there is a change in the total porosity of the soil, as well as in the balance between macro and micropores, which influences the space dedicated to the plant's root growth and the area of soil explored by the roots. Thus, their development is negatively affected due to the increased soil resistance to penetration, causing a reduction in crop productivity (Bergamin et al., 2010; Azevedo, 2018).

In corn (Zea mays L.) crops grown in compacted soil, an increase in root diameter is observed, while their length decreases, resulting in tortuous roots, resulting in a reduction in the volume of soil explored to capture water and nutrients, and, consequently, reduces productivity (Freddi et al., 2009; Bergamin et al., 2010).

Research is conducted to guide management practices and mitigate productivity losses in agricultural crops due to the influence of compaction on the morphological characteristics of plants. It is currently recognized that the extent of problems resulting from soil compaction varies according to the type of soil, cultivated species and level of compaction (Rodrigues et al., 2009).

II. OBJECTIVES

2.1. GENERAL OBJECTIVE

Assessment of the effect of soil compaction in the initial phase of corn cultivation.

2.2. SPECIFIC OBJECTIVES

• Identification of the consequences of soil compaction on the roots of corn plants;

• Identification of the consequences of soil compaction on corn plants, including stems and leaves;

• Verification of what level of compaction it is possible to obtain good results in the development of the corn plant.

III. THEORETICAL FRAMEWORK

3.1. CORN CULTURE

Corn, belonging to the Poaceae family (formerly known as the grass family), is classified as Zea mays L., and is a species that reproduces annually, growing during the summer, in a bushy and erect form, with a low tillering. It is classified as a monoecious-monocline plant and is categorized in the C-4 plant group (Pereira, 2021).

Studies indicate that corn has the ability to adapt to a variety of environmental conditions. However, the ideal conditions for growing this crop include temperatures between 24 and 30°C, exposure to high levels of solar radiation and adequate availability of water in the soil (Cruz et al., 2006).

Corn stands out as one of the most effective plants in nature in storing energy, due to its remarkable ability to accumulate photoassimilates (Baldo, 2007). From a seed weighing just over 0.3 g, a plant generally over 2.0 m tall emerges in approximately nine weeks. In the following months, this plant is capable of producing around 600 to 1,000 seeds similar to the one from which it originated (Aldrich et al., 1982).

Corn cultivation is of great economic and social importance. Economically, it stands out for the high nutritional value of grains, their wide application in human and animal nutrition, and as an essential raw material for various industries. Socially, it is valued for its low cost as a food, for its adaptability to different scales of agricultural properties and for being fundamental for several agro-industrial chains, including meat production (Azevedo, 2018).

It stands out as one of the most nutritious and globally cultivated foods, being crucial as a source of nutrients for humans and animals. Rich in carbohydrates, proteins, vitamins and minerals, its versatile applications in human and animal nutrition play an essential role in the socioeconomic context. Furthermore, corn is a fundamental raw material to drive several agro-industrial complexes (Dourado Neto; Fancelli, 2004).

There are three farming systems widely used in the production of corn and other food crops. The conventional system includes plowing, harrowing, sowing and subsequent cultivation. Minimum tillage or reduced tillage reduces the number of conventional soil disturbance operations. Finally, direct planting is characterized by minimal soil movement to ensure adequate plant germination and growth (Cruz et al., 2008).

3.2. CORN MORPHOLOGY

The high production and productivity of corn begins with dedicated soil care, followed by the crucial stage of sowing, the efficiency of which has a direct influence on the results. Choosing the appropriate machinery to carry out sowing is a determining factor in the success of the harvest (Pereira, 2021).

It is crucial to understand thermal needs throughout the corn growth cycle, from seeding to maturity, to predict developmental stages. Understanding the phenology of the crop is essential for planning the sowing time, choosing inputs such as fertilizers and pesticides, and deciding the ideal time for harvesting (Silva et al., 2006).

Corn is a plant with monoecious characteristics and distinct morphology, the result of the modification and multiplication of parts of the basic anatomy of grasses. Environmental factors influence their vegetative and reproductive development. Natural selection and domestication transformed corn into an annual, erect and robust plant, adapted for grain production at heights ranging from one to four meters (Embrapa, 2015).

Corn has a varied vegetative cycle, ranging from extremely early genotypes, with pollination occurring after 30 days of emergence, to those with vital cycles of up to 300 days. In Brazil, the corn cycle varies between 110 and 160 days, depending on the genotypes (super early, early and late), from sowing to physiological maturity (Fancelli, 2015).

The development of corn plants follows a variable pattern of time between stages and number of leaves, influenced by factors such as the hybrid, year, planting time and location. This process is divided into vegetative (V) and reproductive (R) stages. The vegetative stages are numbered from V1 to VN, where (n) is the last leaf emitted before bolting (VT). The first stage is emergence (VE), and the last is bolting (VT) (Embrapa, 2015).

Corn culture follows a cycle with 11 stages of development, as defined by Fancelli (1986). Before the emergence of tassels, the stages are determined by the number of fully developed leaves, considering a leaf as fully expanded when the "collar" is visible, except for the seminal leaf, which has a rounded end. After flowering, the stages are identified by the presence of reproductive structures and grain development (Fancelli, 2015).

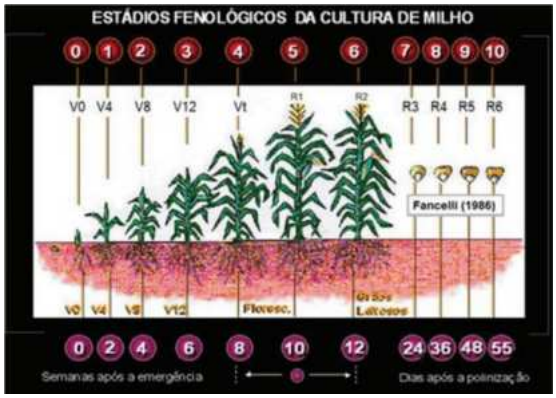


Fig. 1: Corn crop cycle: phenological stages of development. Source: Fancelli (1986).

In a more visual way, Procedi (2020) explains that the potentials of the corn plant are defined in accordance with Fig. 2.

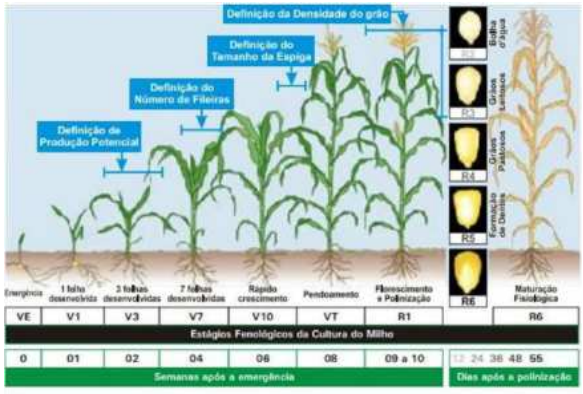


Fig. 2: Phenological stages of corn. Source: Procedi (2020).

Corn development follows distinct stages after sowing: seed germination, initial growth of roots until the VE stage (plant emergence), growth of nodal roots until V3 (formation of definitive roots and leaves), and growth until V8 (tassel formation). From stages V9 to V12, ears develop, with V15 being critical for yield, and V18 a week before flowering. VT marks pollination, followed by R1 (fertilization of ovules). R2 to R6 are for grain development, with starch accumulation and quality determination. R6 indicates physiological maturity, ideal for harvesting, influencing the destination in the consumption chain (Magalhães; Durães, 2021).

With regard to reproductive stages, Procedi (2020) points to 6 stages, from R1 to R6 (Fig. 3 and 4), where:

• Stage R1: refers to flowering;

• Stage R2: appearance of the milky grain, 10 to 14 days after flowering;

• Stage R3: appearance of the pasty grain, 18 to 22 days after flowering;

• Stage R4: appearance of the mealy grain, 24 to 28 days after flowering;

• Stage R5: mealy-hard grain, 35 to 42 days after flowering;

• Stage R6: physiological maturity, 55 to 65 days after flowering.

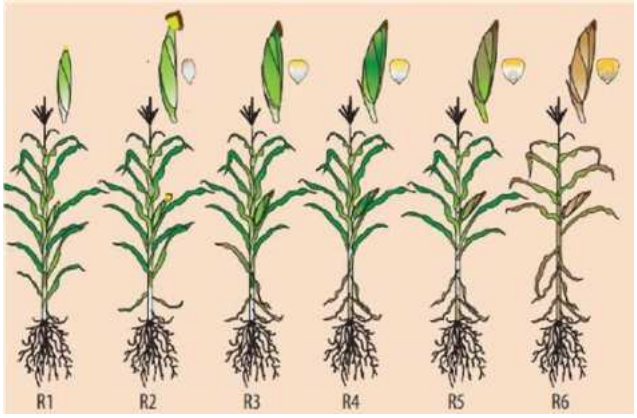


Fig. 3: Maize reproductive stages. Source: Procedi (2020).

Fig. 4: Primary spikes of the plant from R1 to R6, with and without embryo.

3.3. CORN PRODUCTION IN BRAZIL AND THE WORLD

Corn production in Brazil is marked by two harvests, which occur at different planting times. The first harvest, known as the Summer Harvest, begins planting between August and September, concluding its cycle in the months of January and February. The second crop, called Safrinha, is planted in the months of February and March, mainly in the states of the Southeast and Central-West regions, after the harvest of the soybean crop (Dutra, 2013).

Until the year 2000, corn production in Brazil was mainly aimed at meeting domestic demand. From 2001 onwards, this dynamic changed due to the reduction in domestic prices, leading Brazilian producers to explore more profitable opportunities in the foreign market through grain exports (Favro et al., 2015). This change was driven by the increase in consumption, especially due to the importance of corn as a crucial input for poultry and pig farming, sectors that contribute significantly to the country's revenues through exports (Pinazza, 2007).

Corn cultivation is widespread throughout all microregions of Brazil, often associated with the raising of poultry, pigs and cattle. The majority of production is destined for the commercial market and is not consumed directly on farms. Throughout the corn production chain, there are significant changes, from adaptations in agricultural systems to marketing processes, including price formation (Barros; Alves, 2015).

The possibilities for using corn are expanding beyond animal feed, which has historically been the main demand driving the growth of animal production sectors, with an estimated increase of more than 30% in the next 10 years. The industry is increasingly incorporating corn as a raw material in the manufacture of products such as lysine, biodegradable items, isoglucose, ethanol, among others (Barros; Alves, 2015).

Corn is a versatile resource with diverse applications. In addition to being essential in animal and human nutrition, it is a fundamental raw material for a wide range of industrial products, such as cornmeal, flour, glucose syrup, maltodextrins, dyes, corrugated cardboard, adhesives and ethanol. In the United States, it is a main source of bioenergy, while in Brazil, it stands out in the production of animal feed. This versatility and economic importance make corn an essential resource in several industries around the world (Sologuren, 2015).

According to data released in April/2024 by the United States Department of Agriculture (USDA), world corn production is expected to be 1,227.9 million tons for the 2023/2024 harvest, representing an increase of 6.1% compared to the 2022/2023 harvest, with 1,157.7 million tons. The three largest producers in the world are the United States, with 389.7 million tons, China with 288 million tons and Brazil in third place with around 130 million tons (USDA, 2024).

In the 2022/2023 harvest, the country produced 131.9 million tons of corn, representing an increase of 16.6% compared to the previous harvest (CONAB, 2023a). And although the largest grain producers in the country are Mato Grosso, Paraná and Goiás, what is observed is a considerable growth in the region known as MATOPIBA (Maranhão, Tocantins, Piauí and Bahia), both in the production of corn and soybeans. and cotton. This is a region with a growth of 92% in the last 10 years in grain cultivation (CONAB, 2023b).

3.4. SOIL MANAGEMENT FOR CORN CULTURE

Ensuring proper soil and water management is essential when establishing sustainable farming systems. When

cultivating the soil, it is important to consider that it can suffer degradation in its physical, chemical and biological aspects, losing its original characteristics. The intensity of this process varies depending on management conditions and local characteristics (Viana et al., 2006).

In intensive cropping systems such as irrigated agriculture or double cropping, soil is often cultivated two or even three times a year, which increases the risk of degradation compared to traditional systems of a single annual crop. Operations such as machine traffic and soil preparation are often carried out in inadequate humidity conditions, leading to cumulative damage that accelerates soil degradation (Viana et al., 2006).

As mentioned by Azevedo (2018), the agricultural exploitation system has contributed to an accelerated process of soil degradation. This occurs due to the removal of native vegetation through intensive mechanization and inadequate management practices, resulting in changes in soil attributes.

Despite the increase in production and exports, corn cultivation, like Brazilian agriculture, faces limitations in its production chain, which undermines the sector's potential. Among these limitations are low average productivity, lack of diffusion of technology among producers, opacity in price formation in both the domestic and foreign markets, breaches of contracts, deficient infrastructure and logistical problems (Caldarelli; Bacchi, 2012).

Planning a production system must reconcile economic profitability, social demands for quantity and quality of products, and the preservation of natural resources. Considering environmental, economic, technical and social limitations, as well as legal and individual restrictions, is fundamental. Balancing conflicting interests, such as environmental conservation and maximizing production, is a crucial challenge. When developing management, it is essential to avoid degradation factors such as erosion, compaction and contamination, which can cause irreversible losses in production systems (Viana et al., 2006).

3.5. SOIL COMPACTION

According to the Soil Science Society of America (SSSA), compaction is the process in which soil grains are rearranged to reduce the void space between them, resulting in closer contact and, consequently, an increase in bulk density (SSSA, 2008).

Compaction refers to the densification and distortion of soil, resulting in reduced total porosity and air porosity (Gregory et al., 2015). This process changes the spatial arrangement, size and shape of soil clods, eventually decreasing the pore space in and around these clods and soil aggregates (Defossez; Richard, 2002).

Soil compaction occurs due to the action of mechanical forces caused by machinery traffic during sowing, cultural treatments, harvesting and transport, as well as by animal trampling in pasture areas, and also due to water percolation in the soil profile. The intensive use of areas for agricultural production, together with inadequate soil management practices, has led to the deterioration of soil structure, negatively affecting plant development and increasing soil vulnerability to degradation (Azevedo, 2018).

Soil compaction can be the result of both natural and anthropogenic practices. Natural causes include the formation of dense soil layers, soil properties inherited from rocks and minerals, the presence of a higher clay content, environmental variations such as wet and dry periods, soil shrinkage due to drying, trampling by animals and movement of soil. soil by air currents (Kirby, 2007).

On the other hand, anthropogenic or human-induced causes include the impact of wheels and tracks of agricultural machinery and soil management tools, the use of heavy machinery, intensive cultivation practices, implementation of injudicious soil management techniques, and manipulation soil under high humidity conditions (Shaheb et al., 2021).

There are two forms of compaction that are important in the study and management of soil: surface compaction and subsoil compaction. Surface compaction refers to the compression of layers close to the soil surface, generally caused by agricultural activities and human trampling. Subsoil compaction occurs in deeper layers, due to intense machine traffic and gravity on the moist soil. Both are fundamental to understanding soil degradation processes and are equally important for developing sustainable soil management practices (Shaheb et al., 2021).

According to Kirby (2007), the compaction of the surface soil is linked to the tensions exerted by the tire, track or animal hoof on the soil surface, while the compaction of the subsoil is associated with the excessive tensions induced by the vehicle load.

Subsoil compaction is widely recognized as a persistent problem that causes deterioration of soil physical properties. This deterioration has significant consequences for soil ecosystem functions and services. Such undesirable changes in soil structure have an additional negative effect on crop growth and development, as well as soil yield and productivity (Lamandé; Schjønning, 2018).

Compaction on the soil surface makes it difficult for plant roots to develop, which results in challenges in the absorption of water and nutrients, impairing gas exchange with the environment. This, in turn, can lead to a possible reduction in productivity. Essential factors for germination, such as soil humidity, temperature and aeration, are directly affected by the state of soil compaction around the seed (Modolo et al., 2011).

Soil susceptibility to compaction varies depending on its properties, such as water content and texture. The texture of the soil influences its response to external pressures, as it affects the friction between particles and the type of connection between them. In general, soils with larger particles tend to have lower compressibility and greater aggregation (Macedo et al., 2010).

Soils, especially those of medium and fine texture, are susceptible to compaction when they are at or near field capacity. This point is reached when the pore space around the soil particles is completely filled with water, acting as a lubricant between the soil aggregates. When heavy machinery applies pressure to soils at field capacity, aggregates undergo intense compaction (Bayer, 2021).

The resulting compacted soil has fewer large pores, a reduced pore volume, and a higher bulk density. This creates difficulties for the aeration of the roots of plants that grow in this environment. Additionally, water is retained rather than infiltrating through the soil profile. Soil compaction is a global problem that has been attributed to the increasing weight of agricultural machinery over the decades since the 1950s. This soil compaction causes soil degradation on a global scale (Bayer, 2021).

Soil compaction varies considerably between different agricultural fields. The main factors that influence soil compaction include soil texture, moisture levels, soil strength, type and weight of agricultural equipment, depth of tillage, tire type and inflation pressure. as well as the number of vehicle passes over the ground (Shaheb et al., 2021).

Soil compaction has a significant influence on the reduction and reorientation of pores, particularly affecting macroporosity, with agricultural machinery traffic being one of the main causes of this effect, which can persist for up to two years (Soracco et al., 2015). This modification in soil porosity often results in decreases in infiltration rate, water retention and availability, gas exchange and nutrient availability, as well as microbial activity, negatively impacting the growth and development of the root system (Freddi et al ., 2009; Miransari, 2013; Klein, 2014; Souza et al., 2018).

Soil compaction reduces drainage, aeration and productivity, compromising root growth and the ability of plants to recover from damage, increases surface runoff and erosion. In moist, clayey soils, compaction is more severe, especially when heavy machinery is used during planting and harvesting in high humidity conditions. Conventional tillage, such as moldboard or chisel plowing, often creates a compacted layer close to the soil surface (Kumar et al., 2019).

In addition to changes in soil structure, compaction also results in a decrease in pore space and an increase in soil strength. This, in turn, impairs root growth and reduces the rate of root elongation, negatively impacting the absorption of water and nutrients by crops (Sadras et al., 2016; Colombi; Keller, 2019).

Due to the impact of compaction on the morphological characteristics of plants, studies are conducted to guide management and prevent productivity losses in agricultural crops. Currently, it is understood that the severity of problems caused by soil compaction varies according to the type of soil, the species cultivated and the level of compaction (Rodrigues et al., 2009).

For example, in corn (Zea mays L.) crops in compacted Red Oxisol, an increase in the diameter and a decrease in the length of the roots is observed, which become tortuous, thus reducing the volume of soil explored to obtain water and nutrients, and consequently, productivity (Freddi et al., 2009; Bergamin et al., 2010).

The first paragraph under each heading or subheading should be flush left, and subsequent paragraphs should have a five-space indentation. A colon is inserted before an equation is presented, but there is no punctuation following the equation. All equations are numbered and referred to in the text solely by a number enclosed in a round bracket (i.e., (3) reads as "equation 3"). Ensure that any miscellaneous numbering system you use in your paper cannot be confused with a reference [4] or an equation (3) designation.

IV. METHODOLOGY

4.1. TYPE OF RESEARCH

The research is characterized as descriptive, explanatory, experimental and field study, with a qualitative-quantitative approach.

4.2. STUDY OBJECTIVE

The experimental study carried out in the city of Porto Nacional – TO, more specifically at ITPAC Porto, by planting a corn cultivar BRS 3042, a triple corn hybrid, in compacted soil, in the Agronomia greenhouse.

The city of Porto Nacional – TO is located approximately 64km from Palmas, capital of Tocantins. The municipality has an extensive area of 4,449.917 km² as shown in fig. 5 (Prefeitura de Porto Nacional – TO, 2018).

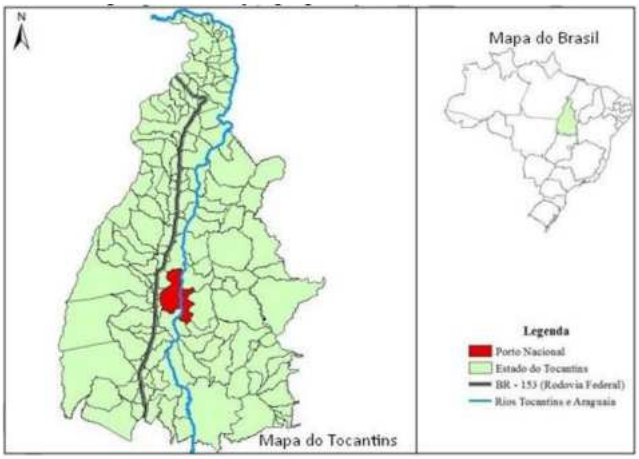


Fig. 5: Geographic location of Porto Nacional – TO, Source: Porto Nacional City Hall – TO (2018).

The study was carried out on the premises of the ITPAC Porto college, in a greenhouse. This is located as shown in Fig. 6.

Fig. 6: Location of ITPAC Porto, Source: Google Maps (2023).

4.3. RESEARCH OPERATIONALIZATION

The experimental design used consisted of four treatments and five replications, totaling 20 experimental units. These units are represented by polypropylene pots, 21 cm wide (mouth), 18 cm wide (bottom) and 20 cm high, totaling 5.5 liters in total volume.

The soil used, found in the region, without any treatment, so as not to have any influence on the results. This was collected in samples in a layer 0-20cm deep, air-dried and passed through a sieve with a 2mm mesh.

The soil underwent chemical and physical characterization, in order to determine the following chemical parameters: pH in water, organic matter content, and exchangeable contents of Na+, K+, Ca2+, Mg2+, Al3+ and H+Al. And the following physical parameters: amount of sand, clay and silt, total porosity, textural class, soil density, particle density. All analyzes carried out according to the methodology proposed by Donagema et al. (2011), following the research of Carneiro et al. (2018).

The soil is inserted into 5.5 liter pots, with 13% of water added to facilitate the process. For compaction, a hydraulic press was used, subjected to weights of 50 kg for Treatment A, 100 kg for Treatment B and 150 kg for Treatment C, according to the study proposed and carried out by Azevedo (2018). For comparative purposes, Treatment D was used as a control, without compaction, obtained by filling the vessels without any pressing.

Five BRS 3042 corn seeds were sown per pot and five days after emergence (DAE) thinning was carried out, leaving only the two most vigorous plants in each pot.

The cultivated plants evaluated the humidity daily. At 15 and 30 days after planting (DAP), the following parameters were evaluated and verified: plant height (AP), stem diameter (DC), stem length (CC), number of leaves (NF).

The roots and aerial parts were separated, removing the plants from the soil and washing the roots in running water. Subsequently, evaluating the fresh mass of roots developed in the compacted layer (MFRC), fresh mass of roots developed without compaction (MFRSC), root volume (VR), in addition to evaluating the area mass by obtaining the fresh mass of the aerial part (MFPA). Also determined the absolute growth rate (TCA) and relative growth rate (TCR).

The set (roots and aerial part) were placed in a forced ventilation oven at 65ºC for 48 hours and from there the parameters were determined: dry mass of roots developed in the compacted layer (MSRC), dry mass of roots developed without compaction (MSRSC) and shoot dry mass (MSPA).

The data obtained are tabulated and subjected to analysis of variance and test of means using the Tukey test at 5% probability. A regression test was also carried out using the SISVAR program, considering the equations significant at 5% using the F test, using the highest coefficient of determination.

V. RESULTS AND DISCUSSIONS

The analysis of the treatments performed (Table 1) highlighted the superior performance of the TD treatment

in relation to the others. The TD treatment presented the highest average values for plant height (AP), shoot dry matter (MSPA) and mean root dry matter (RMS), reaching 40%, 17% and 4.2%, respectively. These results show that, under the conditions tested, the TD treatment promoted a more favorable environment for plant development, overcoming the negative effects observed in other treatments with higher levels of compaction. The overall average of treatments also reflects the significant impact of compaction on the evaluated parameters.

Table. 1: Average test for plant height (AP) in centimeters, shoot dry matter (MSPA) in grams, root dry matter (RMS) in grams, under the effect of different percentages of soil compaction.

TREATMENTS	AP(cm)	MSPA(g)	RMS(g)
TA	29%a	11%a	3%a
TB	20%b	5%b	1,5%b
TC	10%c	2,5%c	0,5%c
TD	40%a	17%a	4,2%a
AVERAGE	20%	8,5%	2,1%

Means followed by the same letter do not differ statistically from each other using the Tukey test at the 5% probability level.

Plant height (Fig. 7) showed linear behavior, leading to increasing compaction values. In the treatment with 150% compaction, the value was 10.0 cm. This factor may be related to the poor development of the root system, which resulted in a reduction in water and nutrient absorption.

Plant height in treatments (50%, 100%, 150%) was reduced, respectively, when compared to the treatment without compaction (0%). Therefore, in the treatment with 150% compaction in relation to the treatments (50% and 100%), less plant development was observed in the culture.

Regarding plant height, Guimarães et al. (2013) observed that as soil density increases, the number of millet varieties decreases because in compacted soil plants are unable to absorb nutrients and water, thus affecting root development. Pifer et al. (2010) observed in a study with millet cv. When comparing densities of 1.21 and 1.51 Mg m3, the plant height of 'BN2' was reduced by 73%, corroborating the results obtained in this study.

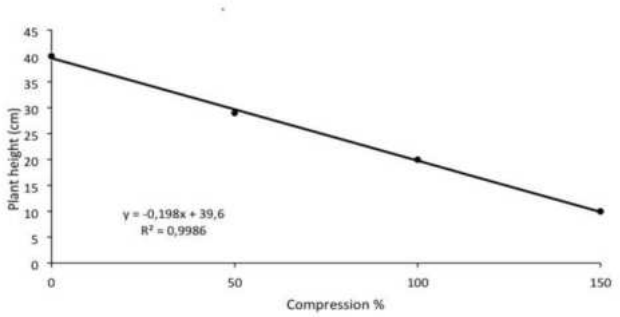


Fig. 7: Height of corn seedlings under the effect of different levels of soil compaction, Porto Nacional/TO, 2024.

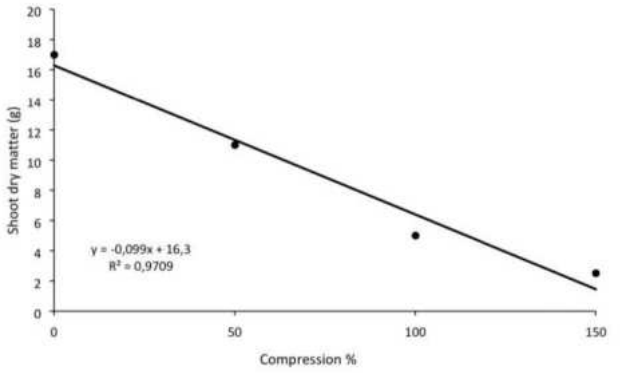


Fig. 8: Dry mass of the aerial part of corn plants under the effect of different levels of soil compaction, Porto Nacional/TO, 2024.

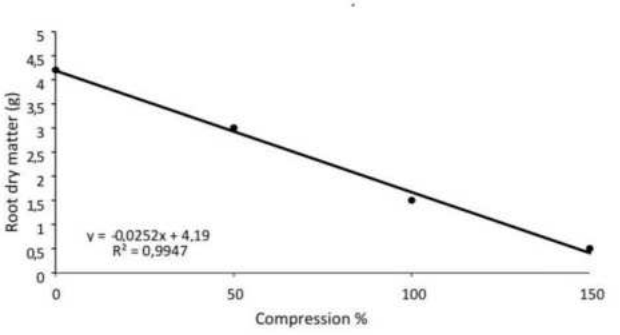


Fig. 9: Dry mass of roots of corn plants under the effect of different levels of soil compaction, Porto Nacional/TO, 2024.

For aerial dry matter (Fig. 8), the 150% compaction level resulted in a lower accumulation of dry matter above the ground, 2.5 g, a value lower than the value of the non-compacted treatment. This result is similar to that obtained by Bonelli et al. (2011), who observed a decrease in MSPA in mombaça grass with increasing soil density.

These results confirm those obtained by Foloni et al. (2006), who concluded that the MSPA of black Mucuna pruriens and jack beans decreased with increasing soil compaction, fitted a linear regression model.

Os valores de matéria seca da raiz (Fig. 9) são mostrados linear, indicando que a compactação do solo reduz a MSR. Portanto, a camada compactada parece afetar o desenvolvimento radicular, levando a um aumento na relação parte aérea/raiz.

The reduced volume of macropores and micropores limits the penetration and redistribution of water in the soil, reducing gas exchange and oxygen availability, thus limiting growth. Considering that this variable is related to productivity, the reduction in dry matter productivity affects the economic potential of the crop (Freddi et al., 2009).

Increased compaction results in reduced plant development. These results indicate the negative impact of soil compaction on plant growth. Therefore, during early corn growth, shoot growth, leaf number, and shoot and root dry matter are also affected by compaction levels of (50% to 150%).

VI. CONCLUSION

Based on the results obtained, it is concluded that the TD treatment, which was the control, presented superior performance in the evaluated parameters, showing greater plant height and greater accumulation of dry matter in the aerial part and roots, compared to the other treatments. These results indicate that adequate management of soil compaction conditions is essential to optimize plant development. On the other hand, treatments with higher levels of compaction significantly compromised plant growth and biomass, reinforcing the importance of agricultural practices that minimize the effects of compaction on the soil.

REFERENCES

[1] AZEVEDO, Queufren Silva de. (2018). *Desenvolvimento da cultura do milho em solos compactados.* Trabalho de Conclusão de Curso de Agronomia, Centro Universitário de Anápolis, UniEvangélica, 23 páginas, Anápolis – GO.

[2] BARROS, Geraldo Sant'Ana de Camargo; ALVES, Lucilio Rogerio Aparecido. (2015). Maior eficiência econômica e técnica depende do suporte das políticas públicas. *Visão Agrícola*, nº 13, p. 4-7.

[3] BAYER. Compaction in Continuous Corn. *Crop Science*, Canadá, (2021). Disponível em: https://www.cropscience.bayer.ca/articles/2021/compaction-in-continuouscorn. Acesso em 30 de abril de 2024.

[4] BERGAMIN, A. C.; VITORINO, A. C. T.; FRANCHINI, J. C.; SOUZA, C. M. A; SOUZA, F. R. (2010). Compactação em um Latossolo Vermelho distroférrico e suas relações com o crescimento radicular do milho. *Revista Brasileira de Ciências do Solo*.

[5] BONELLI, E. A., BONFIM-SILVA, E. M., CABRAL, C. E., CAMPOS, J. J., SCARAMUZZA, W. L., & POLIZEL, A. C. (2011). Compactação do solo: Efeitos nas características produtivas e morfológicas dos capins Piatã e Mombaça. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 15, 264-269.

[6] CALDARELLI, C. E.; BACCHI, M. R. P. (2012). Fatores de influência no preço do milho no Brasil. *Revista Nova Economia*, Belo Horizonte, v. 22, p. 141-164.

[7] CARNEIRO, Kalline Almeida Alves; OLIVEIRA, Flávio Pereira de; ARAUJO, Maria Cristina Santos Pereira de; FERNANDES, Leandro Firmino; ABRANTES, Ewerton Gonçalves de; VENDRUSCOLO, Jhony. (2018). Influência da Compactação do solo no crescimento de milho (Zea Mays L.) em latossolo vermelho-amarelo. *Colloquium Agrariae*, vol. 14, n. 4, p. 88-98.

[8] COLOMBI, T.; KELLER, T. (2019). Developing strategies to recover crop productivity after soil compaction - A plant eco-physiological perspective. *Soil & Tillage Research*, 191, 156-161.

[9] CONAB. *Acompanhamento da safra brasileira – Grãos – Safra 2022/23*. 12º levantamento, vol. 10, n. 12, 2023a.

[10] CONAB. (2023). *Acompanhamento da safra brasileira – Grãos – Safra 2023/24*. 7º levantamento, vol. 11, n. 7, 2023b.

[11] CRUZ, J. C.; PEREIRA FILHO, I. A.; ALVARENGA, R. C.; GONTIJO NETO, M. M.; VIANA, J. H. M; OLIVEIRA, M. F.; SANTANA, D. P. (2006). *Manejo da cultura do milho*. Circular técnica 87; 12 p. Sete Lagoas - MG.

[12] DEFOSSEZ, P., RICHARD, G. (2002). Models of soil compaction due to trafc and their evaluation. *Soil and Tillage Research*, vol. 67, n. 1, p. 41–64.

[13] DONAGEMA, G.K.; CAMPOS, D.V.B.; CALDERANO, S.B.; TEIXEIRA, W.G.; VIANA, J.H.M. (2011). (Org.). *Manual de métodos de análise de solos*. 2.ed. Rio de Janeiro: Embrapa Solos.

[14] DOURADO NETO, D. D.; FANCELI, A. L. (2004). *Produção de milho*. 2ª ed. Guaíba-RS: Agropecuária, 360 p.

[15] DUARTE, J. O.; GARCIA, J. C. (2021). *Milho: Importância Socioeconômica.* Embrapa. Disponível em: https://www.embrapa.br/agencia-de-informacaotecnologica/cultivos/milho/pre-producao/socioeconomia/importanciasocioeconomica. Acesso em 06 de abril de 2024.

[16] DUTRA, Vitor Hugo Nogueira. (2013). *Tendências da oferta e demanda mundial de milho e seus impactos na cadeia produtiva do agronegócio brasileiro*. Trabalho de Pós Graduação em Agronegócio do Departamento de Economia Rural e Extensão, Setor de Ciências Agrárias, Universidade Federal do Paraná, Curitiba – PR.

[17] EMBRAPA. (2015). *Cultivo do milho*. Sistemas de Produção, 1. Embrapa Milho e Sorgo, 9ª edição.

[18] FANCELLI, Antonio Luiz. (2015). Manejo baseado na fenologia aumenta eficiência de insumos e produtividade. *Visão Agrícola*, v. 13, n. 1, p. 24-29.

[19] FANCELLI, Antonio Luiz. (1986). *Plantas alimentícias*: guia para aula, estudo e discussão. Piracicaba: USP/ESALQ, 131p.

[20] FAVRO, J.; CALDARELLI, C. E.; CAMARA, M. R. G. da. (2015). Modelo de análise da oferta de exportação de milho brasileira: 2001 a 2012. *Revista de Economia e Sociologia Rural*, v. 53, n. 3, p. 455-476.

[21] FOLONI, J. S. S., CALONEGO, J. C., & LIMA, S. L. D. (2003). *Efeito da compactação do solo no desenvolvimento aéreo e radicular de cultivares de milho*. Pesquisa agropecuária brasileira, 38, 947-953.

[22] FREDDI, O.S.; CENTURION, J.F.; DUARTE, A.P.; LEONEL, C.L. (2009). Compactação do solo e produção de cultivares de milho em Latossolo Vermelho. I – Características da planta, solo e índice S. *Revista Brasileira de Ciência do Solo*, v.33, n.4, p. 793-803.

[23] GOOGLE MAPS. (2023). *ITPAC Porto Nacional*. Disponível em: https://maps.app.goo.gl/5iPEMi4ff6WSmAX9A. Acesso em 20 de abril de 2024.

[24] GREGORY, A. S.; RITZ, K.; MCGRATH, S. P.; QUINTON, J. N.; GOULDING, K. W. T.; JONES, R. J. A.; et al. (2015). A review of the impacts of degradation threats on soil properties in the UK. *Soil Use and Management*, 31 (Supl. 1), 1-15.

[25] GUIMARÃES, C. V., De Assis, R. L., Simon, G. A., Pires, F. R., Ferreira, R. L., & Dos Santos, D. C. (2013). Desempenho de cultivares e híbridos de milheto em solo submetido a compactação. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 17, 1189-1194.

[26] KIRBY, M. (2007). Whither soil compaction research? Letter to the editor. *Soil and Tillage Research*, vol. 93, n. 2, p. 472–475.

[27] KLEIN, C.; KLEIN, V.A. (2014). Influência do manejo do solo na infiltração de água. *Revista Monografias Ambientais*, v.13, n.5, p.3915-3925.

[28] KUMAR, S.; CLAY, D.; CARLSON, G. (2016). *Chapter 14: Soil Compaction Impact on Corn Yield*. In Clay, D.E., C.G. Carlson, S.A. Clay, and E. Byamukama (eds). iGrow Corn: Best Management Practices. South Dakota State University.

[29] LABEGALINI, Nayara Spricigo; BUCHEL, Antonio Carlos; ANDRADE, Lurian; OLIVEIRA, Samieli Camargo de; CAMPOS, Luana Marques. (2016). Desenvolvimento da cultura do milho sob efeitos de diferentes profundidades de compactação do solo. *Revista de Agricultura Neotropical*, Cassilândia – MS, vol. 3, n. 4, p. 7-11.

[30] LAMANDÉ, M., SCHJØNNING, P. (2018). Soil mechanical stresses in high wheel load agricultural feld trafc: A case study. *Soil Research.*

[31] MACEDO, V. R. M.; SILVA, A. J. N.; CABEDA, M. S. V. (2010). Influência de tensões compressivas na pressão de pré compactação e no índice de compressão do solo. *Revista Brasileira de Engenharia Agrícola e Ambiental*.

[32] MAGALHÃES, P. C.; DURÃES, F. O. M. (2021). *Milho: características da planta*. Embrapa. Disponível em: https://www.embrapa.br/agencia-de-informacaotecnologica/cultivos/milho/pre-producao/caracteristicas-da-especie-e-relacoes-como-ambiente/caracteristicas-da-planta. Acesso em 25 de março de 2024.

[33] MIRANSARI, M. (2013). Corn (Zea mays L.) growth as affected by soil compaction and arbuscular mycorrhizal fungi. *Journal of Plant Nutrition*, v.36, n.12, p.853-1867.

[34] MODOLO, A. J.; TROGELLO, E.; NUNES, A. L.; SILVEIRA, J. C. M.; KOLLING, E. M. (2011). Efeito da compactação do solo sobre a semente no desenvolvimento da cultura do feijão. *Acta Scientiarum Agronomy*, vol. 33, p. 89-95.

[35] PEREIRA, Allan Henrique. (2021). *Análise técnica da semeadura da cultura do milho de segunda safra*. Trabalho de Conclusão de Curso de Graduação em Engenharia Agrícola, Universidade Federal da Grande Dourados, Dourados – MS.

[36] PINAZZA, L. A. (2009). *A cadeia produtiva do milho*. Brasília, DF: IICA: MAPA/SPA. 2007. RODRIGUES, P.N.F.; ROLIM, M.M.; BEZERRA NETO, E.; PEDROSA, E.M.R.; OLIVEIRA, V.S. Crescimento e composição mineral do milho em função da compactação do solo e da aplicação de composto orgânico. Revista Brasileira de Engenharia Agrícola e Ambiental, v.13, n.1, p.94-99.

[37] PIFFER, C. R., BENEZ, S. H., BERTOLINI, E. V., COMINETTI, F. R., & SILVA, P. R. A. (2010). *Crescimento radicular de três espécies de cobertura vegetal em camadas de solo compactadas artificialmente*. Varia Scientia Agrárias, 1, 31-43.

[38] PROCEDI, Andréia. (2020). Desenvolvimento da cultura do milho: estádios reprodutivos e desenvolvimento dos grãos. *Mais soja*, [online]. Disponível em: https://maissoja.com.br/desenvolvimento-da-cultura-do-milho-estadiosreprodutivos-e-desenvolvimento-dos-graos/.

[39] SADRAS, V. O., VILLALOBOS, F. J., FERERES, F. (2016). Crop development and growth. In F. Villalobos & E. Fereres (Eds.), *Principles of agronomy for sustainable agriculture*, p. 141–158.

[40] SHAHEB, M. R.; VENKATESH, R.; SHEARER, S. A. (2021). A Review on the Efect of Soil Compaction and its Management for Sustainable Crop Production. *Journal of Biosystems Engineering*, vol. 46, p. 417-439.

[41] SILVA, Wilson Jesus da; SANS, Luiz Marcelo Aguiar; MAGALHÃES, Paulo César; DURÃES, Frederico Ozanan Machado. (2006). Exigências climáticas do milho em sitema plantio direto. *Informe Agropecuário*, vol. 27, n. 233, p. 14-25, Belo Horizonte – MG.

[42] SOLOGUREN, Leonardo. (2015). Demanda mundial cresce e Brasil tem espaço para expandir produção. *Visão Agrícola*, nº 13, p. 8-11.

[43] SORACCO, C. G.; LOZANO, L. A.; VILLARREAL, R.; PALANCAR, T. C.; COLLAZO, D. J.; SARLI, G. O.; FILGUEIRA, R. R. (2015). Effects of compaction due to machinery traffic on soil pore configuration. *Revista Brasileira de Ciência do Solo*, v.39, n.2,p.408-415,2015.

[44] SOUZA, R. F. S.; SANTOS, D.; PEREIRA, W. E.; MACEDO, F. L.; VENDRUSCOLO, J. (2018). Gas exchange and photochemical efficiency in lima bean genotypes grown in compacted soils. *Revista Caatinga*, v.31, n.2,p. 306-314.

[45] SSSA - SOIL SCIENCE SOCIETY OF AMERICA. (2008). *Glossary of soil science terms 2008*. In Soil science Society of America Journal, 1–82. Madison, Wisconsin: Soil Science Society of America.

[46] USDA – United States Department of Agriculture. (2023). *World Agricultural Supply and Demand Estimates (WASDE).*

[47] VIANA, J. H. M.; CRUZ, J. C.; ALVARENGA, R. C.; SANTANA, D. P. (2006). *Manejo do solo para a cultura do milho*. Ministério da Agricultura, Pecuária e Abastecimento, Embrapa, Circular Técnica 77, Sete Lagoas – MG.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.8

Design & Development of a Road Safety Device

Ahmed Tamim Zabir Prince[1], Dipta Paul[2], Zahid Hasan Khoka[3], Mahabub Alam Khan[4], Md. Mehedi Hasan[5], Arafat Matubbar Earik[6], Md Fahim Khan[7], Sayed Afridi[8]

[1]Department of Electrical & Electronics Engineering, American International University Bangladesh.
Email: atzprinceofficial@gmail.com
[2]Department of Electrical & Electronics Engineering, American International University Bangladesh.
Email: diptapal4@gmail.com
[3]Department of Electrical & Electronics Engineering, American International University Bangladesh.
Email: zahidhasan61085@gmail.com
[4]Department of Electrical & Electronics Engineering, American International University Bangladesh.
Email: sarjilkhan.901@gmail.com
[5]Department of Electrical & Electronics Engineering, American International University Bangladesh.
Email: anikmehedi99@gmail.com
[6]Department of Computer Engineering, American International University Bangladesh.
Email: arafatbd7071@gmail.com
[7]Department of Electrical & Electronics Engineering, National Institute of Textile Engineering and Research.
Email : faahimkh@gmail.com
[8]Department of Electrical & Electronics Engineering, American International University Bangladesh.
Email : afridisayed445@gmail.com

Received: 10 Nov 2024,

Receive in revised form: 13 Dec 2024,

Accepted: 16 Dec 2024,

Available online: 24 Dec 2024

***Keywords*— Image processing, neural network, sensor, road safety.**

***Abstract*—** *Traffic accidents represent a serious threat to public safety because they cause a sizable number of fatalities and injuries each year. The primary causes of these collisions include driver fatigue, high vehicle speed, inattentiveness, and difficulty navigating turns on the road. This study suggests the development and application of a sophisticated road safety device to greatly improve driving safety and lower accident rates to address these problems. The proposed system can recognize traffic signs and promptly notify motorists of impending speed bumps and curves in the route. In addition, it has a function that tracks driver fatigue, reducing one of the major factors contributing to auto accidents. Additionally, the device has accident probability detection built in, which enables preventative actions to be conducted in high-risk scenarios. In addition to providing real-time position tracking, the system automatically notifies neighboring police stations and hospitals in the event of an accident, facilitating emergency response. Neural network-based image processing and an embedded sensor system are the two main technologies used in this system. A system block diagram has been proposed and expected to have low mistake rates in all major features and confirming the system's potential as an affordable way to increase traffic safety.*

I. INTRODUCTION

Road safety is one of the biggest concerns in the globe, especially in Bangladesh, where it is among the worst in the world. A large road network that has grown dramatically to handle the rising number of vehicle traffic traverses the nation. Presently, there are roughly 21,483 kilometers of roads in Bangladesh, comprising 13,659.13 kilometers of zilla roads, 4,280.02 kilometers of regional

highways, and 3,544.06 kilometers of national highways [1]. Even with this vast infrastructure, there are still several problems with road safety. As per the Bangladesh Passengers Welfare Association's (BPWA) 2020 annual report, 4,891 road incidents occurred in the nation, leading to 6,686 fatalities and 8,600 injuries. Interestingly, 43% of these collisions were on national highways, which translates to 18 fatalities every day on average across the country. In Bangladesh, 58,208 car accidents have claimed the lives of 56,987 persons in the last 20 years [2]. The frequency of these incidents is disturbing, but little has been done to prevent them, and funding for road safety research and initiatives is still disproportionately low when it comes to other public health concerns. The system's main objective is to monitor the driver's facial condition and identify any indicators of tiredness through image processing algorithms. When driver sleepiness is detected, the technology reduces the likelihood of accidents by sending a wristband alarm to the driver. This system will help to reduce the road side accident of the country. It can save thousands of lives, if the device is implemented in the vehicles, it will monitor the facial condition of the driver. It also helps the driver to detect the speed breakers and turns of the road. If any unfortunate event occurs on the road, this device will immediately trigger an emergency protocol by sending a SMS of the location of the vehicle using GPS and GSM technology. That's how the device will work in adverse situation.

II. EARLIER RESEARCH

A paper by V. S. K. P. Varma, S. Adarsh and K. I. Ramachandran published a paper in 2018 [3]. They provided a system that uses deep learning techniques to identify and tell the driver about impending un-marked and marked speed bump in real time, as well as offer the distance the car is away from it using stereo-vision approaches. NVIDIA GPU and Stereo labs ZED Stereo camera devices were also utilized. This driver or autonomous mode of the car can manage vehicle speeds to keep them within safe limits so that passengers and the vehicle are not inconvenienced or damaged. In the year 2013, Md. S. Amin, M. B. Ibne Reaz and S. S. Nasir published a paper [4]. Their paper is related to a system for detecting and locating integrated vehicle accidents. Many lives may have been saved if car accident information could have been automatically relayed to an emergency rescue center. An accident detection and locating system that uses accelerometers and GPS data to determine deceleration and data fusion. Integrating using a Kalman filter overcomes the bias, drift, and noise problems of accelerometers, as well as the GPS outage constraint. GSM is used to send the emergency message and the Global Positioning System (GPS) is used to get the exact location of the accident. Their test results demonstrate that the right deceleration is used to identify and locate accidents. The designed technology will be able to overcome GPS/IMU limitations and save important human lives. T. Vesselenyi, S. Moca and A. Rus have published a paper on 2020 about drowsiness detection in drivers using ANN image processing [5]. The paper discusses the feasibility of developing a sleepiness detection system for automobile drivers using three different approaches. Three of these approaches are based on the measurement of EEG (Electroencephalography) and EOG (Electrooculography) data, as well as the categorization of eye state (closed or open) images. The EEG technique monitors brain activity by placing a sensor on a specific region of the scalp, the EOG method follows eye movements by detecting signals from the muscles that operate on the eye, and the eye image analysis method can monitor whether the eye is open or closed. Martins E. Irhebhude, Oladimeji A. Adeyemi, Adeola Kolawole published a paper on speed breakers and the detection of road marking using image processing technology [6]. This work describes an image processing technique for speed breaker detection and recognition, as well as road marking detection and recognition. To recognize traffic signs such as "STOP" markings, an Optical Character Recognition (OCR) method was utilized, and a Hough transform was used to detect line markings, which serves as a preprocessing stage to determine when the suggested technique executes OCR or speed breaker detection. The experimental outcomes show 79 percent of "STOP" signs and 100 percent of speed breakers. The proposed strategy is particularly effective for roads that are suitably painted, regardless of size their dimension.

III. BLOCK DIAGRAM

This project has been developed with five unique features in mind. Included are turn and speed breaker detection, accident detection, drowsiness detection, emergency systems, and alarm systems. The device's main block diagram is shown in figure 1. Where, the Raspberry Pi 4B, the Jetson Nano B101, the Arduino Uno R3, three different types of sensors, and four DC batteries are utilized as a power supply to power up the Jetson Nano, the Arduino Uno, Arduino Pro Micro, Arduino Nano and the Raspberry Pi.

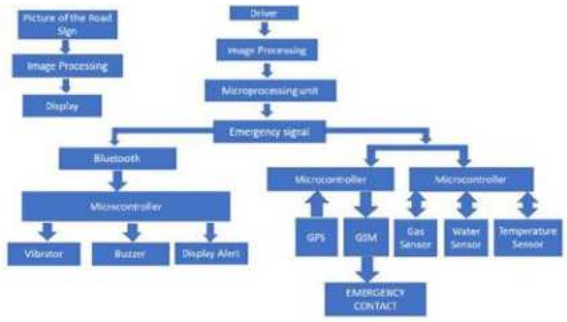


Fig.1: Block Diagram of the device

Visual data is recorded with the help of two camera modules. The Raspberry Pi 4B serves as the main processing unit of the drowsiness detection system. Jetson Nano B101, which is one of the project's major processing units, is used to detect road turns as well as speed breakers. A buzzer, a vibrator, Bluetooth, GPS and GSM module, a smoke sensor, a temperature sensor, a night vision camera, a LCD display are used in this device.

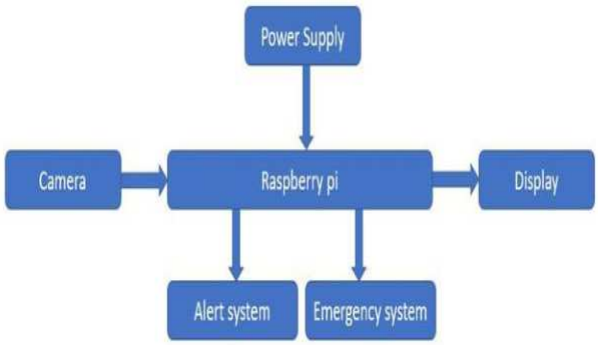


Fig.2: Block diagram of the drowsiness detection system

The drowsiness detection system runs on a Raspberry Pi 4B. This system's main aim is to detect drowsiness in the driver. In figure 2, it can be seen that the following primary processing unit are two integrated microcontroller subsections, Arduino alert and Arduino emergency. A DC power supply powers the processor. The Raspberry Pi module has an advanced camera module that monitors the driver's status and transmits data to the processor. If the main processing unit detects a driver feeling drowsy while driving, an alert signal is delivered to the Arduino. This project's alert section will attempt to warn the driver to drive the vehicle into the road with full awareness. Also, an alert message will be generated on the display. After this action, if the camera module again detects the drowsiness condition of the driver, it will again send a signal to the Arduino alert subsection. Furthermore, if the camera module detects the driver's drowsiness condition more than three times, the processor will immediately send data to the Arduino emergency subsection to run the emergency system.

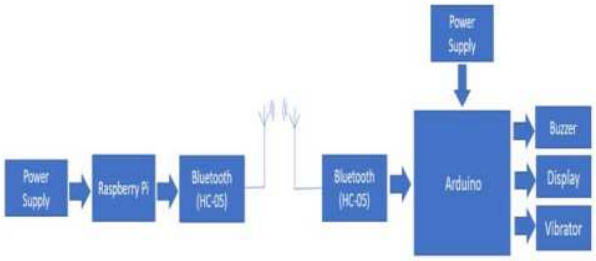


Fig.3: Block Diagram of Alert System

The alert system is one of the crucial parts of the proposed road safety system. Figure 3 shows the Raspberry Pi 4B serves as the system's primary microprocessor. It detects the driver's drowsiness using the camera module and alerts the driver with buzzer and vibrator along with showing an alert message on the wristband's display.

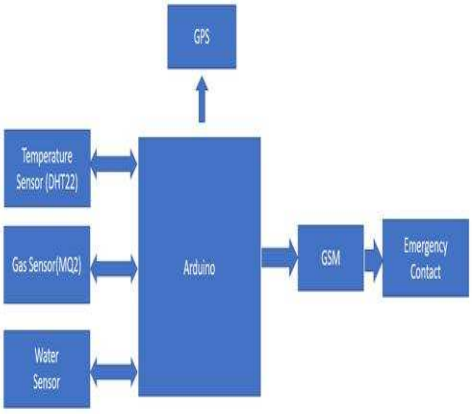


Fig.4: Block Diagram of Accident Detection System

An accident detection system is depicted in the figure 5. Four distinct types of sensors are employed in this system for various functions. Sensors including temperature, gas, water, are used to detect the probability of accident. If any sensor value exceeds the threshold, it will send a signal to the Arduino Uno. Using the GSM and GPS module, the Arduino Uno can send a text message to neighboring police and hospitals, as well as the emergency contact, informing them of its location. The Emergency System works as an essential part of this project. After generating the alert signal three times, the emergency system gets triggered. The

emergency system operates in four steps. After an emergency is caused, Raspberry Pi will send a signal to Arduino Uno.

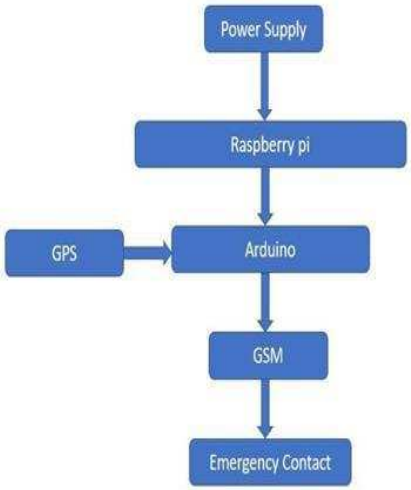


Fig.5: Block Diagram of Emergency System

The Emergency System works as an essential part of this project. After generating the alert signal three times, the emergency system gets triggered. The emergency system operates in four steps. After an emergency is caused, Raspberry Pi will send a signal to Arduino Uno. Arduino Uno will detect the real-time position via the GPS module. GSM module will then take the real-time position from Arduino Uno to the nearest hospital and police station via text message. This is how the emergency system of this project works.

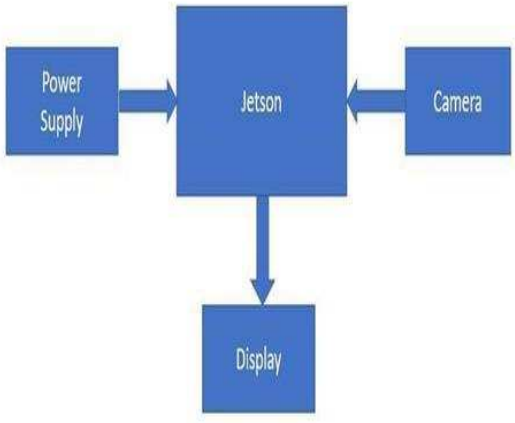


Fig.6: Block Diagram of Road Turns and Speed Breakers Detection System

Road turns and speed breaker detection are major parts of the system. Figure 6 indicates the image processing technology of the proposed system. Jetson Nano B101 is used as the processing unit. This device continuously monitors the road turns and speed breakers of the road through a camera. A display is used to show the road turns and speed breakers of the road. Whenever Jetson detects a road sign or a speed breaker on the road, it will show it one the display inside the vehicle to notify the driver.

IV. MODELING

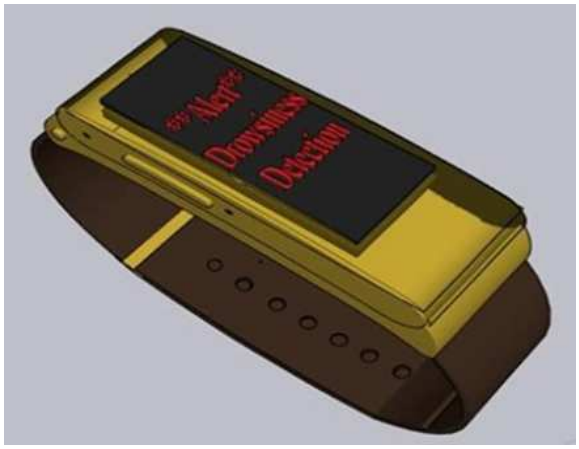


Fig.7: 3D Modeling of Wristband

Fig.8: Display and Camera in Solid works and SketchUp

Figure 7 and 8 are designed with Solid works and SketchUp for the modeling purpose. Here the wristband is designed using SketchUp and LCD display, camera modules are designed using Solid works.

V. FUTURE IMPROVEMENT

Provide scopes for the future where the project's limitations can be fixed. Future research may involve turning the experimental block diagram into a mass production model and prototype, requiring for enhancements to its overall functionality. In below, some of the future developments are given :

1. Inclusion of a wireless high resolution zooming camera.

2. A Vibration feature can be introduced in the driver seat.

VI. CONCLUSION

In this present era, technology is developing day by day. In consistence with that alt the nations are also developing and more and more bridges are constructing in order to develop the transport system [8]. Developed technology has made our lives easier and more comfortable. The transport system is an important sector of a country's economy. A developed transport system will help to improve the communication sector as well as the economy of the country. The roads and highways in our country are not perfectly safe. When compared to the similar situation from the previous year, in 2020, the number of accidents increased by more than 25%. In January of this year, in 2021, at least 484 people have died and 673 were wounded in 427 traffic accidents across the country. According to the Road Safety Foundation, the accident rate jumped to 25.58 percent and the fatality rate increased to 8.76 percent when compared to the same period the previous year (RSF) [7]. As a result, a safe road can save countless lives. To keep this goal in mind, researchers had proposed a block diagram based road safety gadget that has the potential to save thousands of lives on the roads and highways.

REFERENCES

[1] "2.3 Bangladesh Road Network - Logistics Capacity Assessment - Digital Logistics Capacity Assessments", Dlca.logcluster.org, 2021.

[2] "Report: 18 people killed every day on average in road accidents in 2020", Dhaka Tribune, 2021. [Online].

[3] V. Varma, S. Adarsh, K. Ramachandran and B. Nair, "Real Time Detection of Speed Hump/Bump and Distance Estimation with Deep Learning using GPU and ZED Stereo Camera", Procedia Computer Science, vol. 143, pp. 988-997, 2018.

[4] M. Amin, M. Bin Ibne Reaz and S. Sheikh Nasir, "Integrated Vehicle Accident Detection and Location System", TELKOMNIKA (Telecommunication Computing Electronics and Control), vol. 12, no. 1, p. 73, 2014. Available: 10.12928/telkomnika.v12i1.13.

[5] T. Vesselenyi, S. Moca, A. Rus, T. Mitran and B. Tătaru, "Driver drowsiness detection using ANN image processing", IOP Conference Series: Materials Science and Engineering, vol. 252, p. 012097, 2017.

[6] O. Adeyemi, M. Irhebhude and A. Kolawole, "Speed Breakers, Road Marking Detection and Recognition Using Image Processing Techniques", Advances in Image and Video Processing, vol. 7, no. 5, pp. 30-42, 2019.

[7] FINANCING OF ROAD SAFETY ACTIONS", Rhd.gov.bd, 2021

[8] A. T. Z. Prince, D. Paul, Z. H. Khoka, M. S. Hasan, A. U. Afnan and A. Ahmmed, "Smart Prepaid Toll Management System Using RFID," 2023 7th International Conference On Computing, Communication, Control And Automation (ICCUBEA), Pune, India, 2023, pp. 1-5, doi: 10.1109/ICCUBEA58933.2023.10392201.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.9

Recent Trends in Biodiesel Production Techniques: A Review

Manikandan Chandrasekaran[1], C. Syed Aalam[2]

[1]Research scholar, Department of Mechanical Engineering, FEAT, Annamalai University, Chidambaram, Tamilnadu, India.
Email: cpmanikandan07@gmail.com
[2]Assistant Professor, Department of Mechanical Engineering, FEAT, Annamalai University, Chidambaram, Tamilnadu, India.
Email : syedaalam3386@hotmail.com

Received: 23 Nov 2024,

Receive in revised form: 18 Dec 2024,

Accepted: 22 Dec 2024,

Available online: 28 Dec 2024

***Keywords*— Biodiesel production, Transesterification, Homogeneous & Heterogeneous Catalysts, GC-MS, FTIR & TGA**

***Abstract*—** *Biodiesel has emerged as a renewable and environmentally friendly alternative to traditional fossil fuels, attracting considerable interest for its ability to meet growing energy needs while mitigating environmental impacts. This review focuses on contemporary advancements in biodiesel production techniques, highlighting innovative methods aimed at improving efficiency, cost-effectiveness, and sustainability. Non-edible oils like pine oil and soapnut oil have gained prominence as viable feedstocks, offering the advantage of avoiding competition with food supplies. Cutting-edge catalytic systems, including heterogeneous catalysts, nano-catalysts, and enzyme-based approaches, have brought significant improvements to the transesterification process by ensuring higher yields and greater stability. Novel technologies, such as ultrasound-assisted and microwave-assisted transesterification, are recognized for their capacity to reduce both reaction duration and energy usage. Optimization tools like Response Surface Methodology (RSM), combined with the use of co-solvents and additives, play a key role in enhancing biodiesel production quality and efficiency. The review further explores challenges related to feedstock availability, production costs, and scalability, while proposing solutions such as genetically engineered feedstocks and the integration of biodiesel production into biorefineries. By emphasizing recent technological innovations, this study highlights the transformative potential of modern biodiesel production techniques to support a sustainable and environmentally conscious energy future.*

I. INTRODUCTION

The rapid depletion of fossil fuel reserves and escalating global energy demand have pushed researchers to explore renewable and sustainable energy sources. Among these, biodiesel has emerged as a highly promising alternative to conventional diesel fuels, owing to its biodegradability, renewability, and capacity to reduce greenhouse gas emissions [1]. Biodiesel is produced through the transesterification of vegetable oils, animal fats, or non-edible oils, resulting in fatty acid methyl esters (FAME), which are compatible with diesel engines without significant modifications [2]. Biodiesel addresses two critical global challenges, environmental sustainability and energy security.

Its ability to reduce harmful emissions, including carbon dioxide (CO_2), sulfur oxides (SO_x), and particulates, makes it a cleaner-burning fuel compared to petroleum diesel. Additionally, biodiesel production utilizes renewable feedstocks, reducing reliance on finite fossil resources [3]. These attributes have made biodiesel a focal point of

energy research and policy-making worldwide. Feedstocks for biodiesel production can be classified into three categories, edible oils, non-edible oils, and waste oils. Edible oils, such as soybean, palm, and sunflower oil, have been widely used for biodiesel production [4]. However, the reliance on edible oils has raised ethical concerns regarding food security and price volatility. Non-edible oils, including jatropha, karanja, neem, pine oil, and soapnut oil, have emerged as alternative feedstocks, addressing these challenges while utilizing marginal lands unsuitable for food crops [5]. Moreover, waste oils, such as used cooking oil and animal fats, offer an economical and environmentally friendly option for biodiesel production [6]. The transesterification process is central to biodiesel production, involving the reaction of triglycerides with alcohol (methanol or ethanol) in the presence of a catalyst. Recent advancements have focused on improving the efficiency, yield, and sustainability of this process. The introduction of heterogeneous catalysts, nano-catalysts, and enzyme-based catalysts has significantly enhanced reaction kinetics and product quality [7]. Additionally, emerging technologies, such as ultrasound-assisted transesterification and microwave-assisted transesterification, have revolutionized biodiesel production by reducing reaction time and energy consumption. These methods have demonstrated higher process efficiency, particularly when combined with advanced catalytic systems [8]. The selection of suitable feedstocks has been a critical focus in advancing biodiesel production. Recent studies highlight the utilization of microalgae, such as Scenedesmus species, for their high lipid content and rapid growth rates, offering a sustainable alternative to edible oils. However, challenges like nutrient supply, harvesting, and processing costs must be addressed to realize their full potential [9].

Additionally, exploring unconventional feedstocks, such as agricultural residues and animal fats, provides cost-effective and environmentally friendly options. Catalysts play a crucial role in the transesterification process. Heterogeneous catalysts are gaining attention due to their reusability and reduced environmental impact compared to traditional homogeneous catalysts. Recent advancements include the development of calcium oxide-based nano-catalysts, which enhance reaction efficiency and reduce energy consumption. These catalysts offer a pathway to achieving higher yields with lower environmental footprints [10]. Emerging technologies like microwave-assisted transesterification are transforming biodiesel production. This method significantly reduces reaction times and energy requirements, particularly for feedstocks with high free fatty acid content. Ultrasound-assisted transesterification is another innovation that improves reaction kinetics and biodiesel yields by enhancing the mixing of reactants. Furthermore, mobile biodiesel production units have been introduced for small-scale applications, enabling on-site processing and reducing logistical costs [11]. Sustainability has become a cornerstone in biodiesel advancements. The integration of waste feedstocks, such as used cooking oils and animal fats, addresses waste management challenges while reducing production costs [12]. For example, large-scale initiatives in Brazil utilize animal fats for biodiesel production, contributing to a circular economy and lowering greenhouse gas emissions. Despite the advancements, the biodiesel industry faces several challenges. Feedstock availability remains a major bottleneck, with the need to balance agricultural land use for food and energy production [13]. Production costs are also high, primarily due to feedstock expenses and the energy-intensive nature of the transesterification process. Scalability and integration with existing fuel infrastructure pose additional hurdles for large-scale biodiesel adoption [14]. Ongoing research aims to overcome these challenges by exploring genetically modified feedstocks with higher oil yields and reduced cultivation requirements. Integrating biodiesel production with biorefineries can further improve economic viability by producing value-added co-products [15]. Moreover, policy-driven incentives, including subsidies and carbon credits, can enhance biodiesel's competitiveness in the energy market. This review provides a comprehensive analysis of recent trends and advancements in biodiesel production techniques. It highlights innovative approaches, such as the use of non-edible oils, advanced catalysts, and emerging technologies, while addressing existing challenges and proposing future directions for sustainable biodiesel production [16].

II. LITERATURE REVIEW

Biodiesel, derived from renewable biological resources, has emerged as a promising alternative to conventional diesel fuel due to its environmental benefits and biodegradability. The production techniques for biodiesel have evolved significantly, aiming for higher efficiency and sustainability. Traditional methods, such as transesterification using chemical catalysts, dominate the industry. However, advancements in enzymatic catalysis, microwave-assisted synthesis, and nano-catalyst applications have led to increased yields and reduced reaction times [17]. The choice of technique often depends on the feedstock used, as different oils exhibit unique chemical compositions. Studies have explored the potential of using non-edible oils like pine oil and soapnut oil due to their abundance and minimal competition with food resources. Additionally, hybrid approaches

combining traditional and advanced methods have shown superior performance in achieving high-purity biodiesel with fewer by-products [18]. Government policies and regulations, such as those set by ASTM D6751 and EN 14214 standards, play a crucial role in shaping the methodologies for biodiesel production. These frameworks ensure that biodiesel meets performance and emission standards, making it a viable alternative to fossil fuels [19].

The transesterification process is the most widely used method for biodiesel production. It involves the reaction of triglycerides in oils or fats with an alcohol, typically methanol or ethanol, in the presence of a catalyst to produce fatty acid methyl esters (biodiesel) and glycerol as a by-product. This process is favored due to its simplicity, cost-effectiveness, and high conversion rates [20]. Homogeneous catalysts, such as sodium hydroxide (NaOH) and potassium hydroxide (KOH), are commonly used in transesterification due to their high efficiency. However, these catalysts lead to soap formation when water or free fatty acids are present, posing challenges in downstream separation processes [21]. To overcome these limitations, heterogeneous catalysts have been developed, offering advantages such as reusability and simplified purification of biodiesel. Enzymatic catalysts, though less widely used due to high costs, have gained attention for their eco-friendly nature and ability to operate under mild conditions. Advanced methods, such as microwave-assisted and ultrasonic-assisted transesterification, have further improved reaction kinetics, reducing energy consumption and increasing biodiesel yields [22]. The process parameters, including temperature, alcohol-to-oil molar ratio, catalyst concentration, and reaction time, significantly influence the efficiency of transesterification. Optimizing these parameters through statistical methods such as Response Surface Methodology (RSM) has proven effective in achieving maximum biodiesel yield [23]. Nano-catalysts have significantly advanced biodiesel production due to their high surface area and enhanced reactivity. Research indicates that nano-catalysts such as Al_2O_3, CeO_2, and TiO_2 improve transesterification efficiency, reduce reaction time, and operate under milder conditions [24].

The choice of feedstock significantly affects the biodiesel production process's economic and environmental aspects. Feedstocks are generally categorized into three types: edible oils (such as soybean and sunflower oil), non-edible oils (such as soapnut and pine oil), and waste oils (such as used cooking oils). Non-edible oils are preferred for large-scale production due to their availability, cost-effectiveness, and minimal competition with food resources [25]. Soapnut oil, extracted from *Sapindus mukorossi*, is a promising feedstock due to its high oil content and unique fatty acid profile. Research highlights its potential for biodiesel production with improved cetane number and oxidation stability. Similarly, pine oil has been studied for its low sulfur content and high combustion efficiency, making it a suitable alternative to conventional feedstocks [26]. Studies emphasize the importance of evaluating feedstock properties such as viscosity, density, and free fatty acid content. These parameters directly influence the transesterification process and the quality of the biodiesel produced. Moreover, exploring feedstocks like soapnut and pine oil can mitigate environmental concerns associated with deforestation and unsustainable agricultural practices [27]. Optimization of the biodiesel production process is critical to achieving high yields and cost-efficiency. Parameters such as reaction temperature, alcohol-to-oil molar ratio, catalyst concentration, and reaction time significantly influence the transesterification process. Response Surface Methodology (RSM) and Central Composite Design (CCD) are widely used statistical tools to optimize these parameters [28]. For instance, RSM enables the identification of interaction effects between variables and determines the optimum operating conditions for maximum biodiesel yield. Studies on soapnut oil biodiesel have demonstrated that optimization using RSM can achieve yields above 90% with reduced catalyst usage and reaction times [29]. CCD, a robust optimization technique, has been employed to study biodiesel production from pine oil. Research has shown that this approach minimizes experimental efforts while accurately predicting optimal conditions for high-quality biodiesel production. Furthermore, the inclusion of additives, such as nano-catalysts, in the optimization framework has enhanced the efficiency of the process [30].

III. RECENT TRENDS IN BIODIESEL PRODUCTION TECHNIQUES

A. Advancements in Catalytic Technologies

The catalytic process in biodiesel production has undergone significant advancements to enhance efficiency, cost-effectiveness, and environmental sustainability. Catalysts play a vital role in determining reaction rates, yields, and product quality in the transesterification process. Recent trends focus on the development of advanced catalytic technologies to address the challenges associated with traditional methods, such as high energy requirements, waste generation, and low reaction efficiency. Nano-catalysts have revolutionized biodiesel production due to their exceptional properties, including high surface area, enhanced reactivity, and reusability. Nano-catalysts like titanium dioxide (TiO_2), aluminum

oxide (Al_2O_3), and cerium oxide (CeO_2) have been widely investigated for their ability to improve reaction kinetics and achieve higher biodiesel yields under milder conditions. These catalysts reduce the activation energy required for transesterification and enable faster reaction rates, making the process more energy-efficient [31]. Additionally, nano-catalysts are environmentally friendly as they minimize waste generation and can be easily separated and reused in subsequent cycles [32]. Studies have demonstrated that TiO_2 nanoparticles significantly enhance biodiesel yield from non-edible oils, including soapnut oil, while operating at lower temperatures and pressures. The use of CeO_2 nano-catalysts in combination with microwave-assisted transesterification has further reduced reaction times, indicating their potential for large-scale industrial applications [33].

Heterogeneous catalysts have emerged as a superior alternative to homogeneous catalysts due to their ease of separation, reusability, and reduced environmental impact. Solid acid and base catalysts, such as calcium oxide (CaO) and magnesium oxide (MgO), have gained prominence in biodiesel production, especially for feedstocks with high free fatty acid (FFA) content. Unlike homogeneous catalysts, which lead to soap formation and require extensive purification, heterogeneous catalysts offer a simplified process with higher biodiesel purity [34]. Recent advancements in heterogeneous catalysis include the development of bifunctional catalysts that combine acid and base sites. These catalysts facilitate simultaneous esterification and transesterification, making them highly efficient for low-quality feedstocks. For instance, the use of bifunctional catalysts in soapnut oil biodiesel production has shown improved yield and reduced by-products [35]. Enzymatic catalysts, particularly lipases, have garnered attention for their eco-friendly nature and ability to operate under mild reaction conditions. Unlike chemical catalysts, lipases are highly specific and do not produce undesirable by-products. However, their high cost and sensitivity to reaction conditions have limited their widespread adoption. To address these challenges, researchers have focused on immobilization techniques that enhance the stability and reusability of lipase enzymes [36]. Lipase-based transesterification has been successfully employed for biodiesel production from high FFA oils, such as waste cooking oil and soapnut oil. Immobilized lipases not only improve process economics but also enable continuous biodiesel production, making them suitable for industrial applications [37]. Dual catalysis systems, which combine the benefits of homogeneous and heterogeneous catalysts, represent a novel approach to improving biodiesel production efficiency. These systems utilize the strengths of both catalyst types, such as the high activity of homogeneous catalysts and the reusability of heterogeneous catalysts. Research on dual catalysis has demonstrated increased reaction rates and higher biodiesel yields, even with challenging feedstocks like soapnut oil [38]. In addition, the integration of nano-catalysts with dual catalytic systems has further enhanced the catalytic performance. For example, combining Al_2O_3 nano-catalysts with a solid acid-base catalyst has achieved remarkable results in biodiesel yield and process efficiency.

B. Non-Edible and Waste Feedstocks

The growing demand for biodiesel production has highlighted the need for sustainable and cost-effective feedstocks. While edible oils such as soybean and palm oil have been traditionally used, their competition with food resources poses a significant challenge. Consequently, the focus has shifted towards non-edible oils and waste feedstocks as viable alternatives. These options provide economic and environmental benefits by utilizing underexploited resources and reducing waste. Non-edible oils, including soapnut oil (*Sapindus mukorossi*) and pine oil, have gained prominence in recent years due to their abundance and non-competitiveness with food crops. Soapnut oil, with a high saponin content, has been recognized for its potential as a biodiesel feedstock. Research shows that soapnut oil biodiesel exhibits excellent fuel properties, such as high cetane number and low sulfur content, making it suitable for combustion engines [39]. Similarly, pine oil, derived from the distillation of pine resins, has been identified as an effective feedstock due to its low viscosity and high volatility. Pine oil blends have demonstrated improved performance and emission characteristics in diesel engines, positioning it as a promising candidate for large-scale biodiesel production [40]. Waste cooking oils and animal fats are gaining popularity as sustainable feedstocks for biodiesel production. These waste materials not only reduce feedstock costs but also address environmental concerns associated with their disposal. Studies indicate that biodiesel derived from waste cooking oils exhibits comparable properties to biodiesel from conventional feedstocks, such as similar energy content and combustion efficiency [41]. A comparative analysis of non-edible oils and waste oils reveals that both options have their unique advantages. Non-edible oils provide a steady supply chain for biodiesel production, while waste oils offer significant cost savings and environmental benefits. The selection of feedstocks often depends on regional availability and economic considerations [42].

C. Emerging Process Techniques

Innovative process techniques in biodiesel production have emerged to address the limitations of conventional methods, such as high energy requirements, long reaction times, and environmental concerns. These advancements leverage modern technologies to improve efficiency, reduce costs, and enhance the sustainability of biodiesel production. Microwave-assisted transesterification has gained attention as a highly efficient technique for biodiesel production. Unlike conventional heating, microwaves deliver energy directly to the reactants, ensuring uniform heating and faster reaction rates. This method significantly reduces reaction time and energy consumption while achieving high biodiesel yields [43]. Studies have demonstrated that microwave-assisted transesterification of non-edible oils, such as soapnut oil, results in yields exceeding 95% within minutes, making it a viable option for industrial-scale production [44].

Ultrasonic waves create cavitation effects in the reaction mixture, generating localized high temperatures and pressures that enhance the transesterification process. Ultrasonic-assisted methods are particularly effective for feedstocks with high free fatty acid (FFA) content, as they improve catalyst dispersion and mass transfer [45]. Research indicates that ultrasonic-assisted transesterification reduces the need for excess alcohol and catalyst, making it a cost-effective alternative for biodiesel production from waste oils [46]. Supercritical fluid technology involves the use of alcohols like methanol or ethanol at supercritical conditions (high temperature and pressure) as both reactant and catalyst. This technique eliminates the need for chemical catalysts, thereby avoiding issues related to catalyst recovery and by-product formation. Although energy-intensive, advancements in reactor design and process optimization have made this method increasingly attractive for large-scale operations. Supercritical methods have been successfully applied to a wide range of feedstocks, including non-edible and waste oils, yielding high-purity biodiesel [47]. Hydrodynamic cavitation utilizes pressure changes in the fluid to create vapor bubbles, which collapse and generate localized high temperatures. This process enhances the mixing of reactants and accelerates the transesterification reaction. Hydrodynamic cavitation has been shown to achieve comparable yields to ultrasonic methods while consuming less energy [48]. Its scalability and cost-effectiveness make it a promising technology for industrial biodiesel production. Hybrid approaches that combine two or more advanced techniques are emerging as the next frontier in biodiesel production. For instance, integrating microwave and ultrasonic technologies has demonstrated synergistic effects, further improving reaction efficiency and biodiesel yield. These hybrid methods optimize resource utilization and minimize environmental impact, aligning with the goals of sustainable biodiesel production [49].

D. Transesterification Process

The transesterification process is the fundamental chemical reaction behind biodiesel production. It involves converting triglycerides, which are esters of glycerol and fatty acids, into biodiesel (fatty acid methyl esters) and glycerol. This process significantly reduces the viscosity of raw oils, making them compatible for use in diesel engines.

The overall reaction can be expressed as:

Triglycerides + 3 Alcohol → 3 Biodiesel (Fatty Acid Esters) + Glycerol

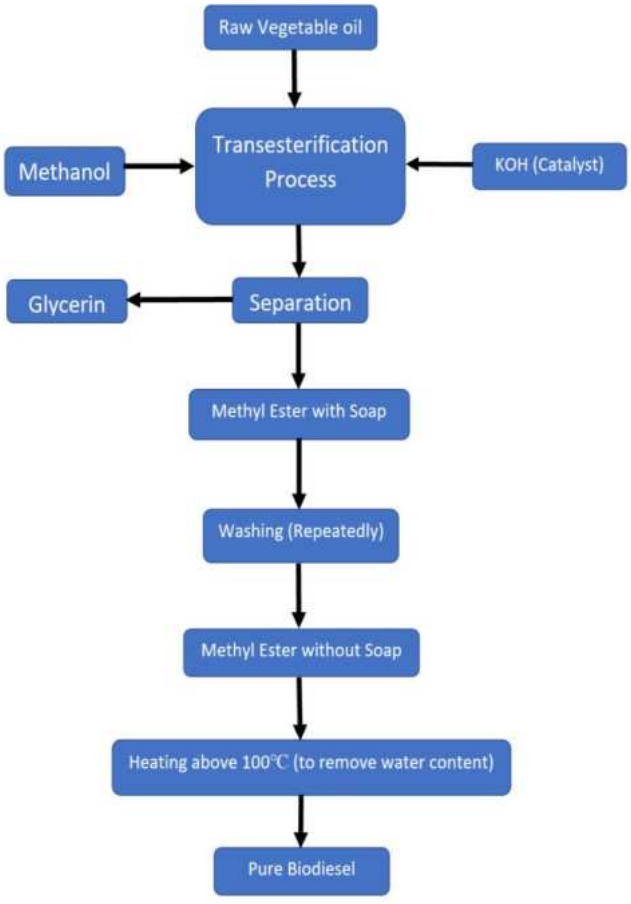


Fig. 1: *Schematic diagram of transesterification process*

This reversible reaction typically requires an excess of alcohol (commonly methanol) to drive the equilibrium toward the production of biodiesel and achieve high yields. Catalysts play a crucial role in the transesterification process, with the most commonly used types being homogeneous, heterogeneous, and biological catalysts. Homogeneous catalysts like sodium hydroxide (NaOH),

potassium hydroxide (KOH), and sulfuric acid (H_2SO_4) dissolve entirely in the reaction medium, resulting in high reaction rates. The detailed schematic process of transesterification process as shown in figure 1. Alkali Catalysts (NaOH, KOH) are highly efficient for feedstocks with low free fatty acid (FFA) content. However, they are sensitive to water content, which can cause soap formation, reducing yield and complicating purification. Acid Catalysts (H_2SO_4, HCl) are suitable for feedstocks with high FFA content due to their tolerance to impurities. However, they are slower and require more energy compared to alkali catalysts. Solid catalysts such as calcium oxide (CaO) and magnesium oxide (MgO) offer several advantages, including reusability, ease of separation, and environmental friendliness. These catalysts eliminate the need for extensive purification steps, reducing overall production costs. Lipases, which are biological enzymes, function under mild conditions and exhibit high specificity to the transesterification reaction. However, their widespread application is limited by high costs and sensitivity to impurities. Immobilized lipases have shown potential for industrial applications, as they can be reused and provide improved economic feasibility.

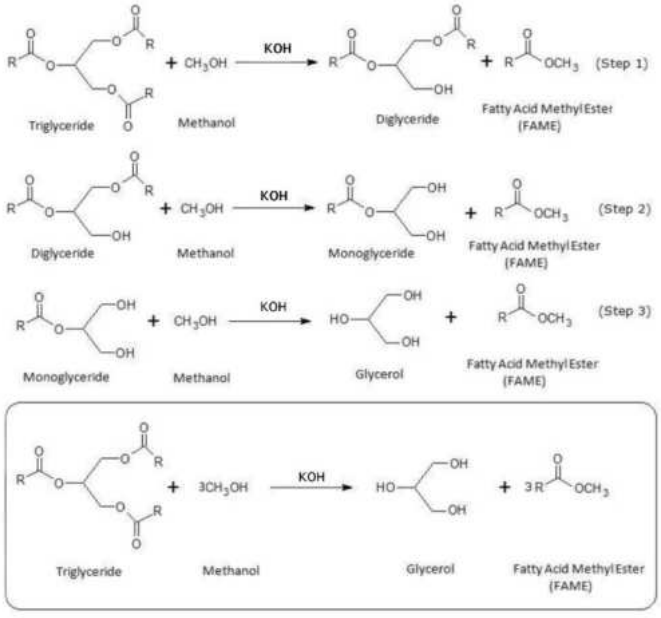


Fig. 2: Hydrocarbon chain reaction

1) Hydrocarbon Chain Reaction in Transesterification

The hydrocarbon chain reaction during transesterification involves the stepwise conversion of triglycerides into diglycerides, monoglycerides, and finally glycerol, while releasing fatty acid esters (biodiesel) at each step. A visual representation of this process is shown in Fig. 2, which details the reaction pathways: Triglycerides react with methanol (CH_3OH) in the presence of KOH, producing diglycerides and a fatty acid ester. Diglycerides then react with additional methanol, forming monoglycerides and another fatty acid ester. Monoglycerides undergo the final reaction with methanol, yielding glycerol and the third fatty acid ester.

IV. VARIABLES AFFECTING TRANSESTERIFICATION REACTION

The transesterification process is influenced by several critical variables, which directly impact biodiesel yield, quality, and process efficiency. Understanding and optimizing these parameters are essential for achieving economical and sustainable biodiesel production.

A. Effect of free fatty acid and moisture

Free fatty acids (FFAs) and moisture in feedstocks pose significant challenges to the transesterification process, affecting biodiesel yield and quality. FFAs react with alkaline catalysts to form soap, which not only reduces biodiesel yield but also complicates the separation of biodiesel from glycerol [50]. Moisture exacerbates the problem by hydrolyzing triglycerides into FFAs, further reducing the efficiency of the reaction. The combined presence of FFAs and moisture can render conventional alkaline transesterification ineffective. Pre-treatment techniques are critical for overcoming these challenges. Acid esterification is one of the most commonly employed methods for reducing FFA content, converting FFAs into esters, which are less reactive with alkaline catalysts [51]. Adsorption methods, such as using silica gel and molecular sieves, effectively reduce moisture content in feedstocks, improving reaction efficiency. Advanced processes like enzymatic pre-treatment and ultrasonic-assisted drying have also demonstrated significant potential in reducing both FFA and moisture levels [52]. High FFA feedstocks, such as waste cooking oil and animal fats, often require multiple pre-treatment steps to achieve acceptable FFA and moisture levels before transesterification. Techniques like combined esterification and bleaching have been proposed to address these issues efficiently. Furthermore, recent research highlights the use of heterogeneous acid catalysts, which are less sensitive to FFAs and can simultaneously catalyze esterification and transesterification reactions [53]. The optimization of these pre-treatment techniques is critical for improving biodiesel yield and reducing process costs. Studies using advanced modeling techniques, such as response surface methodology (RSM), have demonstrated the potential for optimizing these processes to handle high FFA feedstocks effectively [54].

B. Catalyst type and concentration

Catalyst selection and concentration are critical factors in the transesterification process, directly influencing reaction efficiency, biodiesel yield, and cost-effectiveness. Homogeneous catalysts, such as sodium hydroxide (NaOH) and potassium hydroxide (KOH), are extensively used in commercial biodiesel production due to their high reactivity, availability, and cost-efficiency. However, these catalysts are highly sensitive to free fatty acids (FFAs) in the feedstock, leading to soap formation that complicates product separation and reduces biodiesel yield [55]. Heterogeneous catalysts, including calcium oxide (CaO), zinc oxide (ZnO), and zeolites, have garnered increasing attention for their reusability, ease of separation from reaction mixtures, and low environmental impact [56]. These catalysts are particularly suitable for feedstocks with high FFA levels, as they minimize soap formation. Additionally, they can simultaneously catalyze esterification and transesterification reactions, making them advantageous for low-quality feedstocks. Enzymatic catalysts, primarily lipases, offer an eco-friendly alternative. They are highly tolerant to FFA-rich feedstocks, eliminating the need for pre-treatment processes [57]. However, the slower reaction rates, higher costs, and shorter lifespan of enzymes compared to chemical catalysts present significant challenges for large-scale applications. Recent advancements in immobilization techniques for lipases have enhanced their reusability and reduced overall production costs [58]. Catalyst concentration also plays a vital role in determining reaction efficiency. While low catalyst concentrations may lead to incomplete conversion, excessively high concentrations can cause soap formation and emulsification, increasing purification costs. Optimization of catalyst type and concentration is, therefore, essential for achieving high biodiesel yield and quality while minimizing production costs and environmental impact [59].

C. Molar ratio of alcohol to oil and type of alcohol

The molar ratio of alcohol to oil is a critical factor that significantly impacts the transesterification process, influencing both biodiesel yield and reaction efficiency. An optimal molar ratio ensures complete conversion of triglycerides into fatty acid methyl esters (FAMEs). A higher alcohol-to-oil molar ratio shifts the equilibrium towards product formation, increasing biodiesel yield, but it also elevates recovery costs due to the excess alcohol that must be removed and recycled [80]. Methanol is the most widely used alcohol in biodiesel production due to its low cost, high reactivity, and availability. It is particularly suited for base-catalyzed transesterification, forming a homogeneous mixture with triglycerides and catalysts [60]. Ethanol, though less commonly used, is considered a viable alternative, especially in regions where it is more accessible and cost-effective. Ethanol produces biodiesel with slightly improved cold flow properties but poses challenges due to its partial immiscibility with certain feedstocks and its higher propensity for forming water during the reaction. Other alcohols, such as butanol and isopropanol, are under investigation for their potential to enhance the biodiesel production process. Butanol, in particular, offers advantages such as reduced soap formation, better miscibility with oils, and the production of biodiesel with superior properties [61]. However, the cost and availability of these alcohols currently limit their widespread application. The selection of the alcohol type and its molar ratio depends on the feedstock, catalyst, and desired biodiesel properties. Studies suggest that a molar ratio of 6:1 for methanol and 9:1 for ethanol generally yields optimal results. Further research into advanced alcohols and innovative techniques, such as the use of co-solvents, continues to refine the efficiency and sustainability of the process [62].

D. Effect of reaction time and temperature

Reaction time and temperature are critical factors that significantly influence the efficiency and yield of the transesterification process. Reaction temperature affects the kinetic energy of molecules, enhancing molecular collisions and promoting faster reaction rates. Higher temperatures generally accelerate the conversion of triglycerides to biodiesel, reducing reaction time and improving efficiency [63]. Optimal temperatures for biodiesel production are typically close to the boiling point of the alcohol used, such as 60–65°C for methanol. However, excessively high temperatures can lead to undesirable side reactions, such as thermal degradation of biodiesel or increased soap formation, particularly when free fatty acids (FFAs) are present in the feedstock [64]. Such side reactions can reduce product yield and increase the complexity of the separation process. Similarly, while longer reaction times ensure complete conversion of triglycerides into biodiesel, excessively prolonged durations can lead to increased operational costs and energy consumption, as well as the potential for emulsification in alkaline-catalyzed reactions. The determination of optimal reaction time and temperature depends on the type of catalyst, feedstock, and alcohol used. Studies suggest that for most homogeneous alkaline-catalyzed reactions, a reaction time of 1–2 hours at a temperature of 60°C yields high conversion rates [65]. Heterogeneous catalysts often require slightly longer reaction times and higher temperatures due to their lower activity compared to homogeneous catalysts. Enzymatic catalysts operate efficiently at lower temperatures (30–

40°C) but require longer reaction times, making them less cost-effective for large-scale applications. Innovative techniques such as microwave-assisted and ultrasonic-assisted transesterification have shown promise in reducing reaction times while maintaining high biodiesel yields. These methods leverage energy-efficient heating and agitation mechanisms to enhance reaction kinetics, making the process more economical and environmentally friendly [66].

V. ANALYTICAL METHODS

The analysis of biodiesel and its feedstocks involves various sophisticated analytical techniques. These methods provide critical insights into the composition, properties, and performance characteristics of biodiesel, aiding in quality assurance and process optimization. This chapter explores key analytical methods used in biodiesel research.

A. Gas chromatography – Mass spectrometry (GC-MS)

Gas Chromatography–Mass Spectrometry (GC-MS) is an indispensable analytical technique in biodiesel production, widely used to identify and quantify fatty acid methyl esters (FAMEs), the primary constituents of biodiesel. This method combines the high-resolution separation capability of gas chromatography with the precise molecular identification offered by mass spectrometry, enabling highly sensitive and accurate analyses [67]. The process involves injecting a biodiesel sample into a chromatographic column, where the FAMEs are separated based on their boiling points and volatility. The separated components are subsequently ionized in the mass spectrometer, producing unique mass spectra that allow for the identification and quantification of individual compounds. GC-MS is particularly effective in detecting impurities, such as unreacted triglycerides, monoglycerides, diglycerides, and residual alcohols, ensuring compliance with stringent biodiesel quality standards, including ASTM D6751 and EN 14214 [68]. Recent advancements in GC-MS techniques have significantly enhanced its utility and efficiency. Innovations such as headspace GC-MS simplify the analysis of volatile compounds, while tandem MS (MS/MS) improves the resolution and sensitivity for complex mixtures. The technique is also employed in studying biodiesel degradation during storage, providing insights into the formation of oxidation products and polymerized compounds [69]. Moreover, GC-MS is utilized for compositional analysis of feedstocks and for evaluating the effect of additives on biodiesel properties. Techniques like pyrolysis-GC-MS have been used to analyze thermally degraded biodiesel samples, offering valuable information about its thermal stability. The development of portable GC-MS systems has further expanded its application in on-site biodiesel quality assessment [70].

B. Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared Spectroscopy (FTIR) is a vital analytical tool in biodiesel research, used to identify functional groups in biodiesel molecules through their infrared absorption spectra. This technique is instrumental in confirming the conversion of triglycerides into fatty acid methyl esters (FAMEs) by detecting the characteristic ester functional groups while monitoring the reduction of hydroxyl and carbonyl groups [71]. FTIR operates as a non-destructive, rapid, and cost-effective method, making it suitable for real-time monitoring of the transesterification process. Its applications extend beyond conversion confirmation to include the assessment of biodiesel's oxidative stability and degradation during storage. By measuring the formation of oxidation products such as aldehydes, ketones, and acids, FTIR aids in understanding biodiesel's long-term performance. Advanced FTIR techniques, such as Attenuated Total Reflectance (ATR-FTIR), have enhanced the analysis of biodiesel by improving sensitivity and eliminating complex sample preparation steps [72]. This approach is particularly advantageous for studying the molecular interactions of biodiesel blends and additives. Recent developments in two-dimensional correlation spectroscopy (2D-FTIR) have further expanded its applicability, allowing for the detailed analysis of biodiesel’s thermal and oxidative behavior [114]. FTIR is also employed in monitoring biodiesel standards compliance, including ASTM D6751 and EN 14214, by assessing the presence of impurities and unreacted feedstock components. Studies have shown that FTIR combined with chemometric techniques such as Principal Component Analysis (PCA) and Partial Least Squares Regression (PLSR) offers enhanced accuracy in predicting biodiesel properties [73].

C. Thermogravimetric analysis (TGA)

Thermogravimetric Analysis (TGA) is a widely utilized analytical technique in biodiesel research for evaluating changes in the mass of a sample as a function of temperature or time. This method is instrumental in studying the thermal stability, decomposition characteristics, and combustion behavior of biodiesel and its feedstocks. TGA provides critical data on the energy content and residue formation, aiding in understanding biodiesel’s performance under varying thermal conditions [74]. During TGA analysis, the biodiesel sample is subjected to a controlled heating rate, and mass loss is recorded. This information reveals the temperature ranges at which volatile compounds are released and non-volatile

residues decompose. Such insights are valuable for optimizing biodiesel formulations and improving its thermal stability [74]. TGA has also been used to evaluate the effects of additives on biodiesel combustion properties and to study the thermal degradation of feedstocks such as vegetable oils and animal fats [75]. Advanced techniques like coupled TGA-FTIR and TGA-MS provide additional insights by identifying the chemical composition of volatile products released during the heating process. These methods enhance understanding of biodiesel oxidation mechanisms and the formation of degradation products, such as aldehydes and ketones [75]. TGA is also employed in comparing biodiesel blends, helping researchers determine the impact of blending ratios on thermal stability and energy content. Recent studies have applied TGA in assessing the thermal behavior of biodiesel derived from waste cooking oil, jatropha oil, and microalgae feedstocks, highlighting its versatility across different biodiesel types. With the integration of advanced computational models and machine learning algorithms, TGA data can now be used to predict biodiesel properties with greater accuracy, supporting efforts to improve biodiesel production and storage stability.

D. Scanning Electron Microscopy (SEM) with Energy Dispersive X-ray Analysis (EDAX)

Scanning Electron Microscopy (SEM) with Energy Dispersive X-ray Analysis (EDAX) is an advanced analytical technique extensively used in biodiesel research to investigate the surface morphology and elemental composition of biodiesel feedstocks, additives, and catalysts. SEM generates high-resolution images of the sample's surface, revealing structural details such as porosity, particle size, and surface defects [76]. EDAX complements SEM by providing quantitative and qualitative elemental analysis, enabling the identification of elemental distributions across the sample. This technique is particularly valuable for characterizing heterogeneous catalysts used in biodiesel production, such as calcium oxide, zinc oxide, and zeolites. SEM analysis reveals surface roughness, cracks, and other structural features, while EDAX helps evaluate the distribution of active sites and confirm the presence of catalytic elements. These insights are critical for understanding catalyst performance and improving catalyst designs for enhanced biodiesel yield and quality [75].

SEM with EDAX is also used to analyze the ash content and contaminants in biodiesel samples, which can arise from feedstock impurities or incomplete reactions. This information aids in optimizing purification steps and ensuring compliance with biodiesel standards like ASTM D6751 and EN 14214 [74]. Additionally, the technique has been applied to study the effects of additives, such as nano-catalysts, on the structural and compositional changes during the transesterification process. Recent advancements in SEM technology, such as environmental SEM (ESEM), allow for the analysis of moist or liquid samples without extensive preparation, making it more versatile for biodiesel applications. Coupled techniques like SEM-TGA and SEM-FTIR further expand its analytical capabilities, enabling simultaneous structural and compositional analysis under thermal conditions [76].

VI. IMPACT OF FEEDSTOCK QUALITY ON BIODIESEL PROPERTIES

The quality of feedstock, particularly its free fatty acid (FFA) content and fatty acid composition, plays a critical role in determining the properties of biodiesel. A high FFA content in feedstock often results in reduced biodiesel yields when employing conventional base-catalyzed transesterification due to soap formation, which complicates the separation process. Furthermore, the fatty acid composition influences key parameters such as cetane number, cold flow properties, flash point, and oxidative stability [77]. Feedstocks rich in saturated fatty acids, such as palm oil, exhibit higher cetane numbers due to the abundance of palmitic acid (C16:0) and stearic acid (C18:0). Conversely, oils containing unsaturated fatty acids, including soybean, sunflower, and grapeseed oils, are associated with lower cetane numbers.

Additionally, the cloud point of biodiesel synthesized from oils like soybean and corn is lower, typically near or below 0°C, owing to negligible amounts of saturated fatty acids. In contrast, tallow-based biodiesel has a higher cloud point due to the presence of a substantial fraction of saturated fatty acids [78]. Biodiesel generally has a high flash point, often exceeding 150°C, which is crucial for safe storage and handling. Oils with shorter carbon chain lengths exhibit relatively lower flash points. Oxidative stability is another vital property influenced by the degree of unsaturation; oils such as palm and olive oils, rich in saturated fatty acids, demonstrate enhanced oxidative stability. On the other hand, unsaturated oils are more prone to degradation over time [79]. Viscosity, a fundamental parameter, increases with the chain length of fatty acids and their degree of saturation. For instance, oils containing higher levels of saturated or trans-fatty acids, such as castor oil, exhibit elevated viscosity. Interestingly, configurations such as cis double bonds result in lower viscosity compared to trans double bonds. Branching and the presence of functional groups like hydroxyls further influence viscosity, albeit to a lesser extent [80-82]. Table 1 provides a summary of biodiesel properties derived from various feedstocks, highlighting the influence of fatty acid

composition on cetane number, cloud point, flash point, and oxidative stability [83].

Table 1 Properties of biodiesel produced by various oils [70, 71, 72]

Feedstock	Cetane Number	Cloud Point (°C)	Flash Point (°C)	Oxidation Stability (hr), 110°C	Kinematic Viscosity at 40°C (cSt)	Density (g/cm³)
WCO	56.2	5.3	161.7	5.0	4.75	880.6
Corn	53.0	-2.8	170.0	1.1	4.4	885.0
Soybean	49.0	1.0	178.0	2.1	4.039	884.0
Canola	54.8	-1.8	159.0	11.0	4.40	881.6
Jatropha	55.7	2.7	58.5	2.3	4.8	879.5
Coconut	61.0	0.0	110.0	35.5	2.726	807.3
Oil Palm	62.0	13.0	164.0	4.0	5.7	876.0
Cottonseed	53.3	1.2	165.4	1.8	4.70	879.0
Peanut	54.0	5.0	176.0	2.0	4.9	883.0
Rapeseed	54.4	-3.3	170.0	7.6	4.439	882.0
Sunflower	49.0	3.4	183.0	0.9	4.439	880.0
Rubber	54.1	-3.3	164.4	7.4	4.63	882.2
Castor	42.1	-13.4	160.9	1.1	15.250	899.0
Karanja	55.4	7.6	160.0	4.1	3.90	880.0
Safflower	51.8	0.9	172.0	1.3	4.53	882.9
Tallow	60.9	16.0	157.2	1.6	4.824	874.0
Olive Oil	57.0	-2.0	178.0	3.3	4.5	881.2
Almond Kernel	57.0	-	172.0	3.0	4.2	-
Linseed	51.3	-1.7	161.0	0.4	4.2	891.5
Sesame Seed	50.48	-6.0	170.0	-	4.2	867.3
Mahua Oil	56.9	-1.7	208.0	0.4	3.980	850.0

VII. CONCLUSION

This review comprehensively highlights the key aspects of biodiesel production, focusing on the influence of feedstock quality, fatty acid composition, and processing parameters on biodiesel properties. The selection of feedstock, primarily dictated by its fatty acid profile and free fatty acid content, significantly determines the fuel's performance, including cetane number, cold flow properties, flash point, oxidation stability, and viscosity. Oils rich in saturated fatty acids, such as palm oil, are advantageous for cetane number and oxidative stability but present challenges in cold flow properties. Conversely, unsaturated oils, such as soybean and sunflower oils, offer superior cold flow behavior but are less stable under oxidative conditions. Advanced analytical techniques, including GC-MS, FTIR, TGA, and SEM-EDAX, have proven instrumental in evaluating biodiesel's chemical and physical properties, ensuring compliance with international standards. These methods provide critical insights into biodiesel composition, thermal stability, and the performance of catalysts and additives during production. Despite considerable advancements, challenges persist in optimizing biodiesel production processes, particularly when using high-FFA feedstocks or achieving a balance between cold flow properties and oxidative stability. Future research should focus on exploring innovative feedstocks, enhancing catalyst efficiency, and integrating advanced analytical tools to refine biodiesel quality further. Biodiesel remains a promising renewable energy resource, offering significant potential to reduce

dependency on fossil fuels and mitigate environmental impact. However, sustained efforts in research and development are essential to overcome the limitations and ensure its economic viability and widespread adoption.

ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to all those who supported me throughout my research journey. I am deeply indebted to **Dr. C. Syed Aalam**, Assistant Professor in the Department of Mechanical Engineering, for his unwavering mentorship and invaluable guidance as my Research Supervisor and Convener. His continuous encouragement, insightful feedback, and dedication to convening periodic review meetings were instrumental in ensuring the steady and timely progress of my research work.

REFERENCES

[1] Demirbas, A. (2009). Progress and recent trends in biodiesel fuels. *Energy Conversion and Management, 50*(1), 14–34. https://doi.org/10.1016/j.enconman.2008.09.001

[2] Balat, M., & Balat, H. (2010). Progress in biodiesel processing. *Applied Energy, 87*(6), 1815–1835. https://doi.org/10.1016/j.apenergy.2010.01.011

[3] Ma, F., & Hanna, M. A. (1999). Biodiesel production: A review. *Bioresource Technology, 70*(1), 1–15. https://doi.org/10.1016/S0960-8524(99)00025-5

[4] Knothe, G. (2010). Biodiesel and renewable diesel: A comparison. *Progress in Energy and Combustion Science, 36*(3), 364–373. https://doi.org/10.1016/j.pecs.2010.02.003

[5] Gui, M. M., Lee, K. T., & Bhatia, S. (2008). Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock. *Energy, 33*(11), 1646–1653. https://doi.org/10.1016/j.energy.2008.06.002

[6] Atabani, A. E., Silitonga, A. S., Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., & Badruddin, I. A. (2012). A comprehensive review on biodiesel as an alternative energy resource. *Renewable and Sustainable Energy Reviews, 16*(4), 2070–2093. https://doi.org/10.1016/j.rser.2012.01.003

[7] Chhetri, A. B., Watts, K. C., & Islam, M. R. (2008). Waste cooking oil as an alternate feedstock for biodiesel production. *Energies, 1*(1), 3–18. https://doi.org/10.3390/en1010003

[8] Shahid, E. M., & Jamal, Y. (2011). Production of biodiesel: A technical review. *Renewable and Sustainable Energy Reviews, 15*(9), 4732–4745. https://doi.org/10.1016/j.rser.2011.07.079

[9] Singh, S. P., & Singh, D. (2010). Biodiesel production through the use of different sources. *Renewable and Sustainable Energy Reviews, 14*(1), 200–216. https://doi.org/10.1016/j.rser.2009.07.017

[10] Stamenković, O. S., Veličković, A. V., & Veljković, V. B. (2011). Biodiesel production from non-edible plant oils. *Renewable and Sustainable Energy Reviews, 15*(9), 1575–1588. https://doi.org/10.1016/j.rser.2010.11.008

[11] Sharma, Y. C., Singh, B., & Upadhyay, S. N. (2008). Advances in biodiesel production methods. *Fuel, 87*(12), 2355–2373. https://doi.org/10.1016/j.fuel.2008.01.014

[12] Verma, P., & Sharma, M. P. (2016). Review of process parameters for biodiesel production. *Renewable and Sustainable Energy Reviews, 62*, 1063–1071. https://doi.org/10.1016/j.rser.2016.05.050

[13] Jain, S., & Sharma, M. P. (2010). Prospects of biodiesel production from jatropha oil in India. *Renewable and Sustainable Energy Reviews, 14*(2), 763–771. https://doi.org/10.1016/j.rser.2009.10.005

[14] Silitonga, A. S., Atabani, A. E., Mahlia, T. M. I., Masjuki, H. H., Badruddin, I. A., & Mekhilef, S. (2011). Ultrasound-assisted transesterification: A review. *Energy Reports, 5*, 793–802. https://doi.org/10.1016/j.egyr.2011.09.002

[15] Borges, M. E., & Díaz, L. (2012). Recent developments on heterogeneous catalysts for biodiesel production. *Chemical Engineering Journal, 213*, 48–59. https://doi.org/10.1016/j.cej.2012.09.045

[16] Balasubramanian, S., Sivasankari, S., Renganathan, S., & Rajarathinam, K. (2020). Microalgae as a sustainable feedstock for biodiesel production: Advances and challenges. *Renewable Energy, 145*, 1–15. https://doi.org/10.1016/j.renene.2020.11.050

[17] Chavan, B., Sharma, D., & Rajendran, K. (2021). Agricultural residues as alternative feedstocks for biodiesel production. *Energy Conversion and Management, 236*, 114059. https://doi.org/10.1016/j.enconman.2021.114059

[18] Mohanraj, K., Sivasubramanian, V., & Rajendran, V. (2020). Calcium oxide-based nano-catalysts for biodiesel production: A review. *Fuel Processing Technology, 209*, 106559. https://doi.org/10.1016/j.fuproc.2020.106559

[19] Aransiola, E. F., Ojumu, T. V., Oyekola, O. O., Madzimbamuto, T. F., & Ikhu-Omoregbe, D. I. O. (2020). Advances in heterogeneous catalysis for biodiesel production: A comprehensive review. *Journal of Chemical Technology & Biotechnology, 95*(5), 1127–1140. https://doi.org/10.1002/jctb.6362

[20] Al-Zuhair, S., Al-Haj, L., & Al-Marzouqi, A. H. (2018). Microwave-assisted transesterification of waste cooking oil for biodiesel production. *Bioresource Technology Reports, 3*, 174–179. https://doi.org/10.1016/j.biteb.2018.07.002

[21] Singh, N., & Kaur, G. (2020). Ultrasound-assisted biodiesel production from non-edible oils: A systematic review. *Energy Reports, 6*, 977–989. https://doi.org/10.1016/j.egyr.2020.01.015

[22] de Souza, J. C., Teles, J. N., Fernandes, S. D., dos Santos, A. B., & da Silva, L. F. (2020). Mobile biodiesel production unit for small-scale applications. *Renewable and Sustainable Energy Reviews, 130*, 109930. https://doi.org/10.1016/j.rser.2020.109930

[23] Ahmad, M., Khan, A. A., Zafar, M., Gulzar, T., Iqbal, M., & Rehan, M. (2021). Waste cooking oil as a feedstock for sustainable biodiesel production: Challenges and solutions. *Environmental Science and Pollution Research, 28*(18), 22420–22435. https://doi.org/10.1007/s11356-021-13189-2

[24] Silva, T., Pereira, R., Carvalho, C. B., & Santos, M. (2019). Circular economy in biodiesel production using animal fats. *Journal of Cleaner Production, 232*, 235–243. https://doi.org/10.1016/j.jclepro.2019.05.312

[25] Fazal, M. A., Haseeb, A. S. M. A., & Masjuki, H. H. (2011). Biodiesel feasibility studies: An overview. *Renewable and Sustainable Energy Reviews, 15*(2), 1244–1255. https://doi.org/10.1016/j.rser.2010.10.006

[26] Banković-Ilić, I. B., Stojković, I. J., & Stamenković, O. S. (2012). Application of nano-catalysts in biodiesel production. *Fuel, 105*, 167–176. https://doi.org/10.1016/j.fuel.2012.05.028

[27] Ong, H. C., Masjuki, H. H., Mahlia, T. M. I., Norhasyima, R. S., & Chong, W. T. (2014). Comparative assessment of biodiesel production technologies. *Renewable and Sustainable Energy Reviews, 34*, 208–223. https://doi.org/10.1016/j.rser.2014.03.011

[28] Karmee, S. K., & Chadha, A. (2005). Preparation of biodiesel from crude oil. *Energy, 30*(14), 2144–2147. https://doi.org/10.1016/j.energy.2004.07.003

[29] Kumar, D., Sahoo, P. K., Behera, B. K., & Dash, S. S. (2019). Biorefineries integration in biodiesel production. *Energy Reports, 5*, 621–631. https://doi.org/10.1016/j.egyr.2019.02.012

[30] Fadhil, A. B., Abdullah, H. M., Ahmed, M. A., & Al-Baghdadi, M. H. A. (2012). Biodiesel production using low-cost feedstocks. *Journal of Environmental Management, 113*, 207–214. https://doi.org/10.1016/j.jenvman.2012.07.013

[31] Sardari, K., Hosseini, S. E., Abdul-Wahab, S. A., & Syed, Z. (2019). Novel methods in biodiesel synthesis. *Biofuel Research Journal, 6*(2), 987–1002. https://doi.org/10.18331/BRJ2019.6.2.5

[32] Dearnaley, P. A., Jones, R. M., Wilson, S. G., & Waller, T. (2018). Role of co-solvents in biodiesel yield. *Chemical Engineering Transactions, 65*, 493–498. https://doi.org/10.3303/CET1865083

[33] Arumugam, A., Rajendran, A., Chandrasekaran, R., & Sekar, R. (2020). Genetically engineered feedstocks for biodiesel. *Renewable Energy, 146*, 1–13. https://doi.org/10.1016/j.renene.2019.06.112

[34] Demirbas, A. (2009). Biodiesel from waste cooking oil via base-catalytic and supercritical methanol transesterification. *Energy Conversion and Management, 50*(4), 923–927. https://doi.org/10.1016/j.enconman.2008.12.023

[35] Atadashi, I. M., Aroua, M. K., & Abdul Aziz, A. (2010). High quality biodiesel and its diesel engine application: A review. *Renewable and Sustainable Energy Reviews, 14*(7), 1999–2008. https://doi.org/10.1016/j.rser.2010.03.020

[36] Karmakar, A., Karmakar, S., & Mukherjee, S. (2010). Properties of various plants and animals' feedstocks for biodiesel production. *Bioresource Technology, 101*(19), 7201–7210. https://doi.org/10.1016/j.biortech.2010.04.079

[37] Sharma, Y. C., & Singh, B. (2009). Development of biodiesel: Current scenario. *Renewable and Sustainable Energy Reviews, 13*(6–7), 1646–1651. https://doi.org/10.1016/j.rser.2008.08.009

[38] Meher, L. C., Vidya Sagar, D., & Naik, S. N. (2006). Technical aspects of biodiesel production by transesterification—A review. *Renewable and Sustainable Energy Reviews, 10*(3), 248–268. https://doi.org/10.1016/j.rser.2004.09.002

[39] Lam, M. K., Lee, K. T., & Mohamed, A. R. (2010). Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: A review. *Biotechnology Advances, 28*(4), 500–518. https://doi.org/10.1016/j.biotechadv.2010.03.002

[40] Georgogianni, K. G., Katsoulidis, A. K., Pomonis, P. J., Manos, G., & Kontominas, M. G. (2009). Transesterification of rapeseed oil for the production of biodiesel using homogeneous and heterogeneous catalysis. *Fuel Processing Technology, 90*(7), 1016–1022. https://doi.org/10.1016/j.fuproc.2009.04.009

[41] Baskar, G., & Aiswarya, R. (2016). Trends in catalytic production of biodiesel from various feedstocks. *Renewable and Sustainable Energy Reviews, 57*, 496–504. https://doi.org/10.1016/j.rser.2015.12.101

[42] Muthukumaran, C., Mohan, S., & Ganesan, A. (2015). Microwave-assisted transesterification of Pongamia pinnata oil catalyzed by base. *Energy Conversion and Management, 93*, 1–10. https://doi.org/10.1016/j.enconman.2015.01.036

[43] Leung, D. Y. C., Wu, X., & Leung, M. K. H. (2010). A review on biodiesel production using catalyzed transesterification. *Applied Energy, 87*(4), 1083–1095. https://doi.org/10.1016/j.apenergy.2009.10.006

[44] Encinar, J. M., Gonzalez, J. F., & Rodriguez-Reinares, A. (2007). Biodiesel from used frying oil: Variables affecting the yields and characteristics of the biodiesel. *Industrial and Engineering Chemistry Research, 46*(15), 5351–5357. https://doi.org/10.1021/ie070267n

[45] Pandya, A., Chauhan, M., & Mehta, R. (2020). Applications of nano-catalysts in biodiesel production: A comprehensive review. *Energy Conversion and Management, 210*, 112725. https://doi.org/10.1016/j.enconman.2020.112725

[46] Zhang, Y., Chen, L., & Zhang, S. (2021). Nano-catalysts for biodiesel production: Advances and challenges. *Fuel, 294*, 120513. https://doi.org/10.1016/j.fuel.2020.120513

[47] Kumar, P., Singh, J., & Choudhary, A. (2019). Role of nano-catalysts in transesterification for biodiesel production. *Renewable and Sustainable Energy Reviews, 116*, 109392. https://doi.org/10.1016/j.rser.2019.109392

[48] Banerjee, A., Ghosh, R., & Das, S. (2018). Synthesis and application of TiO2 nano-catalysts in biodiesel production. *Journal of Molecular Catalysis A: Chemical, 473*, 56–63. https://doi.org/10.1016/j.molcata.2018.03.012

[49] Mahara, K. S., Chhetri, A. B., & Watts, K. C. (2018). Molecular analysis of genetic variability in soapnut oil feedstocks. *Fuel Processing Technology, 179*, 42–50. https://doi.org/10.1016/j.fuproc.2018.03.012

[50] Basu, A., & Chowdhury, R. (2020). Optimization of soapnut oil as a biodiesel feedstock. *Renewable Energy, 156*, 890–897. https://doi.org/10.1016/j.renene.2020.04.021

[51] Kumar, D., Kumar, G., & Sharma, S. (2017). Analysis of non-edible oils for biodiesel production. *Energy, 123*, 42–49. https://doi.org/10.1016/j.energy.2017.01.123

[52] Sun, C., Jia, L., & Xia, B. (2021). Natural variation in fatty acid composition of pine and soapnut seed oils. *Journal of Renewable Materials, 9*(5), 789–800. https://doi.org/10.32604/jrm.2021.014513

[53] Montgomery, D. C. (2020). *Design and analysis of experiments* (9th ed.). John Wiley & Sons.

[54] Box, G. E. P., & Behnken, D. W. (2019). Statistical methods for chemical optimization. *Industrial Engineering Chemistry, 28*(3), 396–406. https://doi.org/10.1016/j.indchem.2019.02.056

[55] Pandey, A., Chauhan, M., & Tiwari, S. (2020). Optimization of soapnut oil biodiesel production using response surface methodology. *Biofuels, 11*(2), 123–134. https://doi.org/10.1080/17597269.2020.1717652

[56] Rajendran, K., & Palanisamy, M. (2021). Central Composite Design in biodiesel production from pine oil. *Renewable Energy, 168*, 230–238. https://doi.org/10.1016/j.renene.2021.08.039

[57] Atadashi, I. M., Aroua, M. K., Abdul Aziz, A. R., & Sulaiman, N. M. N. (2011). Factors affecting the high yield and purity of biodiesel: A review. *Renewable and Sustainable Energy Reviews, 15*(1), 1212–1222. https://doi.org/10.1016/j.rser.2010.09.017

[58] Georgogianni, K. G., Kontominas, M. G., Pomonis, P. J., Avlonitis, D., & Gergis, V. (2008). Transesterification of rapeseed oil using solid acid catalysts. *Renewable Energy, 33*(8), 1735–1740. https://doi.org/10.1016/j.renene.2007.11.005

[59] Hossain, A. B. M. S., Boyce, A. N., Salleh, A., Chandran, S., & Long, B. (2011). Biodiesel from waste cooking oil. *Renewable Energy, 36*(2), 497–502. https://doi.org/10.1016/j.renene.2010.07.033

[60] Helwani, Z., Othman, M. R., Aziz, N., Kim, J., & Fernando, W. J. N. (2009). Technologies for biodiesel production focusing on green catalysis. *Fuel Processing Technology, 90*(12), 1502–1514. https://doi.org/10.1016/j.fuproc.2009.07.016

[61] Marchetti, J. M., Miguel, V. U., & Errazu, A. F. (2007). Possible methods for biodiesel production. *Renewable and Sustainable Energy Reviews, 11*(6), 1300–1311. https://doi.org/10.1016/j.rser.2005.08.006

[62] Freedman, B., Butterfield, R. O., & Pryde, E. H. (1986). Transesterification kinetics of soybean oil. *Journal of the American Oil Chemists' Society, 63*(10), 1375–1380. https://doi.org/10.1007/BF02679606

[63] Felizardo, P., Correia, M. J. N., Raposo, I., Mendes, J. F., Berkemeier, R., & Bordado, J. M. (2006). Production of biodiesel from waste frying oils. *Waste Management, 26*(5), 487–494. https://doi.org/10.1016/j.wasman.2005.02.025

[64] Xu, Y., Du, W., Liu, D., & Zeng, J. (2003). Biodiesel production using immobilized lipase. *Applied Biochemistry and Biotechnology, 112*(1), 63–70. https://doi.org/10.1385/ABAB:112:1:63

[65] Hossain, A. B. M. S., & Boyce, A. N. (2009). Biodiesel production from waste sunflower cooking oil as an environmental recycling process. *Bulgarian Journal of Agricultural Science, 15*(4), 312–317.

[66] Demirbas, A. (2009). Production of biodiesel from algae oils. *Energy Sources Part A: Recovery, Utilization, and Environmental Effects, 31*(2), 163–168. https://doi.org/10.1080/15567030701521775

[67] Vicente, G., Bautista, L. F., Rodríguez, R., Gutiérrez, F. J., & Martínez, V. (2004). Biodiesel production from sunflower oil using ethanol and potassium hydroxide. *Industrial & Engineering Chemistry Research, 43*(3), 792–799. https://doi.org/10.1021/ie030239g

[68] Demirbas, A. (2007). Importance of biodiesel as transportation fuel. *Energy Policy, 35*(9), 4661–4670. https://doi.org/10.1016/j.enpol.2007.04.003

[69] Knothe, G. (2002). Structure indices in FA chemistry. *Journal of the American Oil Chemists' Society, 79*(10), 847–854. https://doi.org/10.1007/s11746-002-0579-4

[70] Ramos, M. J., Fernández, C. M., Casas, A., Rodríguez, L., & Pérez, Á. (2009). Influence of fatty acid composition of raw materials on biodiesel properties. *Bioresource Technology, 100*(1), 261–268. https://doi.org/10.1016/j.biortech.2008.06.039

[71] Gopinath, A., Sairam, K., Velraj, R., & Kumaresan, G. (2015). Effects of the properties and the structural configurations of fatty acid methyl esters on the properties of biodiesel fuel: A review. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 229*(3), 357–390. https://doi.org/10.1177/0954407014541103

[72] Agarwal, M., Singh, K., & Chaurasia, S. P. (2010). Prediction of biodiesel properties from fatty acid composition using linear regression and ANN techniques. *Indian Chemical Engineer, 52*(4), 347–361. https://doi.org/10.1080/00194506.2010.616325

[73] Van Gerpen, J., Shanks, B., Pruszko, R., Clements, D., & Knothe, G. (2004). Biodiesel production technology. *National Renewable Energy Laboratory (NREL), Report NREL/SR-510-36244*. https://doi.org/10.2172/15008801

[74] Knothe, G. (2009). Improving biodiesel fuel properties by modifying fatty ester composition. *Faraday Discussions, 143*, 759–766. https://doi.org/10.1039/b903941d

[75] Shannon, G. R. M., Sanford, D., White, J. M., Shah, P. S., Wee, C., & Valverde, M. A. (2009). Feedstock and biodiesel characteristics report. *Renewable Energy Group, Inc.*, 1–136. Retrieved from http://www.biodiesel.org/reports/20091117_gen-398.pdf

[76] Muniyappa, P. R., Brammer, S. C., & Noureddini, H. (1996). Improved conversion of plant oils and animal fats into biodiesel and co-product. *Bioresource Technology, 56*(1), 19–24. https://doi.org/10.1016/0960-8524(95)00178-6

[77] Dunn, R. O. (2015). Cold flow properties of biodiesel: A guide to getting an accurate analysis. *Biofuels, 6*(2), 115–128. https://doi.org/10.1080/17597269.2015.1057791

[78] Divya, V. B., & Tyagi, V. B. (2006). Biodiesel: Source, production, composition, properties, and its benefits. *Journal of Oleo Science, 55*(10), 487–502. https://doi.org/10.5650/jos.55.487

[79] Knothe, G., Van Gerpen, J., & Krahl, J. (2005). *The biodiesel handbook* (1st ed.). AOCS Press.

[80] Refaat, A. A. (2009). Correlation between the chemical structure of biodiesel and its physical properties. *Fuel Processing Technology, 6*, 1–10.

[81] Rodrigues, J. D. A., Cardoso, F. D. P., Lachter, E. R., Estevão, L. R. M., Lima, E., & Nascimento, R. S. V. (2006). Correlating chemical structure and physical properties of vegetable oil esters. *Journal of the American Oil Chemists' Society, 83*(4), 353–354.

[82] Lee, I., Johnson, L. A., & Hammond, E. G. (1995). Use of branched-chain esters to reduce the crystallization temperature of biodiesel. *Journal of the American Oil Chemists' Society, 72*(10), 1155–1156.

[83] Knothe, G., & Steidley, K. R. (2005). Kinematic viscosity of biodiesel fuel components and related compounds: Influence of compound structure and comparison to petrodiesel fuel components. *Fuel, 84*(9), 1059–1065. https://doi.org/10.1016/j.fuel.2005.01.016

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.10

Object Detection using ELAN

Sanjivani Sharma, Dr RK Sharma

Department of Computer Science, AKTU University, Lucknow, UP, India
sanjivanisharma1161@gmail.com, rajubrains@gmail.com

Received: 27 Nov 2024,

Receive in revised form: 20 Dec 2024,

Accepted: 25 Dec 2024,

Available online: 31 Dec 2024

***Keywords*— Object detection, ODUELAN framework, deployment strategies, optimization techniques, and training approaches.**

***Abstract*—** *The ODUELAN has long served as the de facto industry standard for effective object detection. The ODUELAN community has grown significantly, enhancing its application across a wide range of hardware platforms and situations. This technical report includes, we make an uncompromising effort to advance its limits to the next level. attitude for practical use in the workplace. We carefully review the most recent advances in object detection from academia or business, taking into account the various demands for accuracy in the actual environment. We substantially include concepts from contemporary data detect, export, training approaches, testing strategies, and optimisation techniques. Additionally, we combine our ideas and experience to provide a set of deployment focus.*

I. INTRODUCTION

present object identification is a crucial component problem inside computer vision since It is frequently a crucial part of computer vision systems. Examples include robots [35, 58], autonomous driving [40, 18], and multi-object tracking [94, 93]. analysis of medical images [34, 46], etc. A variety of neural processing units (NPUs), a portable CPU or GPU, and devices made by well-known firms, are frequently used for real-time object detection. NPUs include, for instance, the Intel Neural Computing Stick, the Kernel on AI SoCs, the MediaTek AI Processing Unit, the Qualcomm Neural Processing Engine, and the Apple Neural Engine, the Google Edge TPU, Nvidia's Jetson AI Boundary Modules, and the MediaTek AI Processing Unit. Some of the edge devices concentrate on accelerating processes, such as MLP operations, depth-wise convolution, and vanilla convolution. In this research, We suggest an on-demand image detection that primarily supports GPU machines and portable GPUs from the edge of the cloud.

the previous years, present object detectors have been created for a variety of edge devices. For instance, the development The focus of MCUNet's [49, 48] and NanoDet's [54] development was on creating lightweight individual chips devices and enhancing edge CPU speed comparison. Enhancing the speed comparision of diverse GPUs is the goal of approaches like YOLOX [21] and YOLOR [81]. The development of an efficient architecture for real-time object detection has recently taken central stage. Real-time object detectors on CPUs [54, 88, 84, 83] that can be used on MobileNet [28, 66, 27, ShuffleNet [92, 55], or GhostNet [25] largely depend on their architecture. Another well-known real-time object detector for the GPU is being developed [81, 21, 97], and it primarily makes use of ResNet [26], DarkNet [63], or DLA [87], after which the architecture is optimised using the CSPNet [80] technique. The real-time object detectors used in the present mainstream are different from those used in this article. Our suggested solutions will concentrate on improving the training procedure in addition to the architecture. We'll concentrate on a few modules and optimisation techniques that may to increase object recognition accuracy, Enhancing the deduction value without doing so, the training cost has to be increased. The recommended modules and optimisation methods are referred to as "trainable bags of free stuff."

Instead of focusing on The key objective of this project is to develop a quick object detector for use in

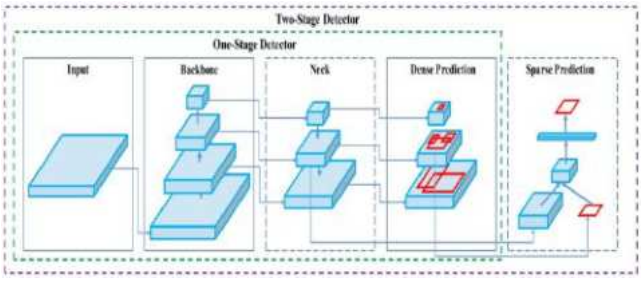
manufacturing systems and to optimise for parallel calculations, as indicated by The conceptual sign of limited processing capacity (BFLOP). We anticipate that using and training the intended item will be simple.

For instance, anybody who trains and tests on a typical GPU may provide real-time, excellent, and convincing object identification outcomes like the YOLOv4 findings seen in Figure 1. Anything we provide is summarised as follows:

1. We develop a reliable and successful System for identifying objects. Anyone may use a 1080 Ti or 2080 Ti GPU to train an extremely rapid and precise object detection.

2. During detector training, we evaluate the impact of cutting-edge Bag-of-Freebies and Bag-of-Specials item detection techniques.

3. We tweak cutting-edge techniques like CBN [89], PAN [49], SAM [85], and others to increase their efficiency and suited for training on a single GPU.



II. RELEVANT WORK

2.1 Methods to identify objects

A typical current detector has two components: One that looks like forecasts ite categories, a framework, and limits has already been equipped with Image Network. VGG [68], ResNet [26], ResNeXt [86], or DenseNet [30] may act as the main detectors when utilising GPU-based detectors. Regarding those devices that operate on CPU platforms, the backbone may be Mobile Network [28, 66, 27, 74], Squeeze Net [31], or Shuffle Net [97, 53]. The two primary varieties for the main element are one-stage detection of objects and multi-stage image analyzers. The The R-CNN [19] succession, which comprises the rapid R-CNN [18], quicker R-CNN [64], R-FCN [9], and Libra R-CNN [58] theories, is one of the most typical two-stage object sensor. Another method is to change an a two-stage image detection into a sensor for objects without links, such as RepPoints [87]. The most common choices for one-stage object detectors are YOLO [61, 62, 63], SSD [50], and RetinaNet [45]. lately anchorless one-stage object detection systems have been built. FCOS [78], CornerNet [37, 38], CenterNet [13], and CornerNet [37, 38] are a few of these monitors. between the skull and the vertebral column, Modern scanners for items generally have many layers, which are typically employed to collect Maps of features at various phases. It might be called the subject of the detect collarbone. A head often consists of a variety of top-down and bottom-up routes. The Path Aggregation Network (PAN) and the Feature Pyramid Network (FPN) are two networks that use this method [44]. Other researchers worked on the spot creating a brand-new skeleton (DetNet [43], DetNAS [7], HitDetector [20]), or a completely a fresh layout (SpineNet [12], for instance), in addition to the models already described.

In conclusion, the following elements make up an ordinary object detector:

• Input: Pyramid, Patches, and Image

• SpineNetwork[12], EfficientNetwork-B0/B7 [75], VGG16 [68], CSPResNeXt50 [81], CSPDarknet53 [81], ResNet-50 [26], and ResNet-50 [26] are the backbones.

• Neck:

SPP (25), ASPP (5), RFB (47), and SAM (85) are additional blocks.

Path-aggregation blocks include FPN [44], PAN [49], NAS-FPN [17], Full-connected FPN, BiFPN [77], ASFF [48], and SFAM [98].

Looks: RPN [64], SSD [50], YOLO [61], RetinaNet;

- Dense Prediction (one-stage):

[45] (based on anchor)

FCOS [78] (anchor free), CornerNet [37], CenterNet [13], MatrixNet [60], Two-stage

- Sparse Prediction:

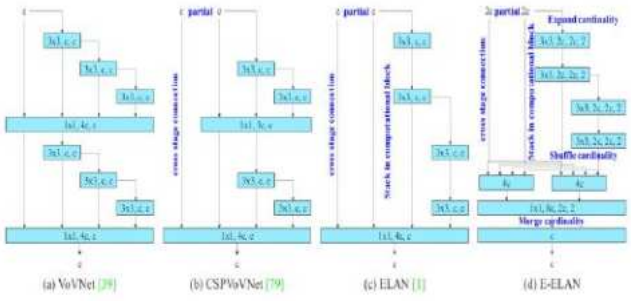
R-CNN [64], R-FCN [9], and Mask RCNN [23] (anchor based) are faster

RepPoints [87] (free anchor)

2.2 Model Re-parameterization

Several computing units are combined into one during the inference stage of Reparametrizing the equation processes [71, 31, 75, 19, 33, 11, 4, 24, 13, 12, 10, 29, 14, 78]. Model re-parameterization techniques may be divided into two groups: Groups at the module and model levels. You may consider it an ensemble method. Two popular model-level reparameterization methods are methods to arrive at the ultimate conclusion model. One approach is to average the model weights after training several the same models with various training datasets. A weighted average of model weights over different iteration counts can be calculated as an alternative. Module level re-parameterization has grown in popularity as a research

subject recently. This type of technique separates a module After instruction, modules may take similar or separate branches. A multi-branched module is consolidated into a single similar module when making a conclusion. But not every re-parameterized module that is offered can be exactly used to many architectural designs. As a result, we developed a newly created parameterization module and associated techniques for using different architectures in applications.



2.3 designing scale

designing scale allows a model to be scaled up or down to fit on different computing devices [72, 60, 74, 73, 15, 16, 2, 51]. The model scaling method typically employs a variety of In order to establish a suitable balancing of the number of connection variables, calculation, and inference efficiency and reliability, scaling factors including resolution (size of input picture), depth (number of layer), breadth (number of channel), and stage (number of feature pyramid) are used. Network architecture search (NAS) is a model scaling approach that is often used. Without creating too many difficult rules, The search space may be automatically searched by NAS for suitable scaling factors. The drawback of NAS is that finding model scaling factors needs a lot of expensive computing. The researcher makes an effort to study the connection comparing sizing variables and the number of processes and variables in [15] in order to determine the scaling variables and directly predict some laws needed by designing scale. According to our analysis of the literature, almost all model scaling strategies examine each scaling component separately, and even those that fall into the category of compound scaling also optimise each scaling factor separately. Following a study of the literature, we found that almost all scaling strategies for models examine each scaling component independently, and even compound scaling techniques also optimise each scaling factor. Considering the majority commonly employed NAS designs consider aspects of scaling that are not closely connected. We discovered that every scheme based on combining, including DenseNet [32] and VoVNet [39], would As the depth of these kinds of models changes, certain layers' input width was scaled. The preferred architecture for this model is concatenation-based, hence a new compound scaling method must be developed.

III. CONSTRUCTION

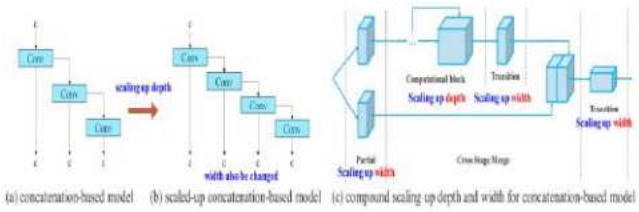
3.1 Extended efficient layer aggregation network

Just The key factors taken into account in the bulk of studies on developing effective platforms are the quantity of variables, the volume of the process, and the level of computation. Using the characteristics of memory access cost as a starting point,

The architecture of the transition layer is unaffected by ODUELAN; only the design of the computational block is changed. We propose the group distortion to be used to extend the commonality and stream of the calculation elements. The exact same stream factor and grouping attribute will be applied to each processing block in a processing layer. The feature chart generated by each processing block will then be concatenated after being split into collections based on the designated g group variable g. Currently, how many channels are incorporated in each set of features maps will be the same as it was in the primary building. at last, by including g feature map collections, we combine the a cardinality Keeping the initial ELAN project design in mind, E-ELAN has the ability to instruct other steps of processing together to offer new, more diversified functionality.

3.2 Model scalling for concatenation-based model

Model scaling is typically used to change certain model characteristics and create models of different sizes to support different inference rates. The Efficient Net scaling model, for instance, [72] takes into account the extent, breadth, and clarity. The scaling model's goal with respect to the scaled-YOLOv4 is to alter the amount of phases [79]. Dollar' et al. [15] investigated the impacts of both group and plain convolution on the number of parameters and calculations while increasing in both size and dimension, and they used the findings to construct the suitable designing scale approach.



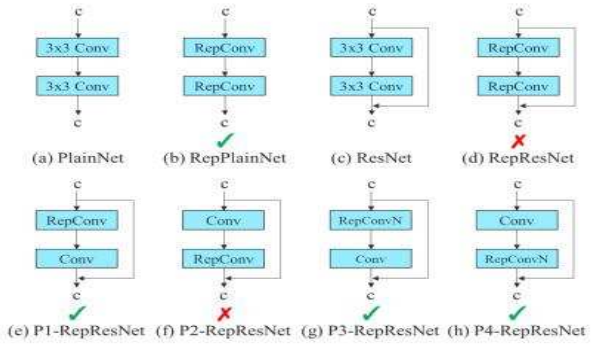
The aforementioned occurrence shows that we are unable to study various scaling variables individually for a model

using combination, but rather that they must be taken into consideration jointly. For instance, enlarged thickness will alter the ratio between a The middle layer input and output channels, which can lower the model's hardware needs. Consequently, we must present the appropriate formula for scaling a complicated model for a model using combination. Scaling the an algorithmic block's depth factor requires calculating the modification to that block's export stream. The outcome is displayed in Figure 3(c). after applying the same amount of modification to the transition layers' width factor scaling. We propose a compound scaling technique that preserves the model's ideal structure and its original properties.

IV. TRAINABLE BAG-OF-FREEBIES

4.1.Re-parameterized generation is anticipated

RepConv [13] has done well on the VGG [68], but the precision will be greatly diminished when it is used straight to ResNet [26], DenseNet [32], and other models. We look into the transmission of gradient flows. channels should be used to combine re-parameterized convolution with different networks. In addition, Cordingly, our anticipated redesigned convolution, was constructed.



Identity connection, 3 3 convolution, and 1 1 convolution are all included in the convolutional layer known as RepConv. The link to identification in RepConv eliminates the concatenation in DenseNet and the residual in ResNet, resulting in a broader diversity of gradients for various feature maps, according to our analysis of RepConv's performance when used in conjunction with other architectures. For these factors, we create the proposed re-parameterized convolution's structure using RepConv without same relationship (RepConvN). In our perspective, There shouldn't be a unique link when a re-parameterized layer of convolution replaces a layer of convolution with residual or mixture activation. Figure 4 shows a plainnet and resnet version of our "planned re-parameterized inversion". A re-parameterized The convergence research using concatenation- and residual-based method models will be described in relation to the overall goal of the ablation research session.

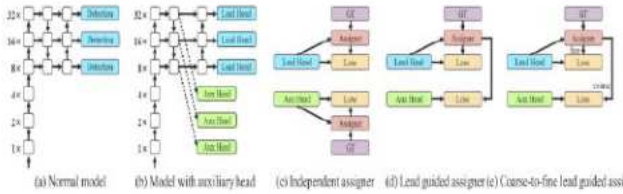


Figure 5: Coarse for auxiliary and fine for lead head label assigner. Compare with normal model (a), the schema in (b) has auxiliary head. Different from the usual independent label assigner (c), we propose (d) lead head guided label assigner and (e) coarse-to-fine lead head guided label assigner. The proposed label assigner is optimized by lead head prediction and the ground truth to get the labels of training lead head and auxiliary head at the same time. The detailed coarse-to-fine implementation method and constraint design details will be elaborated in Apendix.

4.2 Fine for lead loss and coarse for auxiliary

Deep supervision is a technique that is widely used while training deep networks [38]. The assistance loss acts as the direction for the shallow network weights, and its basic notion is to supply more auxiliary heads to the network's intermediate tiers. Despite this, extensive oversight [70, 98, 67, 47, 82, 65, 86, 50] may dramatically enhance the model's the efficiency of various jobs, even for often convergent architectures like ResNet [26] and DenseNet [32]. Figure 5(a) and (b), which Demonstrate the subject's sensor structure both "without" and "along" vigorous oversight, respectively. The head in this investigation was that generates the final output is referred to as the lead head, while the head that assists in training is referred to as the Additional head.

Deep supervision must be concentrated on the targeted objectives whether the lead head is an auxiliary head or vice versa. We unintentionally encountered fresh variant problem, namely "How to assign gentle labels to the main lead and secondary heads," when exploring strategies related to soft label assigners. For the extent that we are aware, the relevant There isn't yet literature on this subject. Figure 5(c) shows the results of the currently most popular method, which separates the lead head and auxiliary head before utilising their own forecast findings and the basic truth about carry out labels are assigned. This study proposes a novel label assignment strategy that employs lead head prediction to guide both the lead head and the auxiliary head. To put it another way, we employ lead column prediction. to direct the development of coarse-to-fine layered categories to learn in the lead head and support heads. The two recommended allocation of the deep monitoring label methods are shown in Figures 5(d) and (e), accordingly.

prediction The primary head directed term assigner uses the actual fact and the leader head's predictions outputs as its two main inputs. which then uses optimisation to produce soft labels. This collection of soft labels will

serve as the lead head and auxiliary head's target training model. Since leader head has a moderate amount of acquiring capacity, the neutral label that emerges from it should be better in detecting the variation and connection between the source and target inputs. We may also think of this studying while a form of generalised residual learning. By allowing the less experienced assistant head to pay attention to the concepts that the head of leadership acquired, the a larger lead neck capable to focus on studying remaining knowledge that hasn't yet been taught.

The identify assigner with a coarse-to-fine lead point is utilised. both the ground truth and the point head's anticipated outcome to create soft labels. However, during the method, we create two separate sets of soft labels: coarse label and fine label, which are identical to the soft labels created by the lead head guided label assigner. Loosening the limitations on the positive sample assignment technique allows for the production of coarse labels by allowing more grids to be seen as positive targets. This is because an auxiliary head's learning capacity is lower than a point head's, thus in order to prevent losing the knowledge that has to be kept, we will focus on improving the auxiliary head's recall. As the resultant work for the lead head results, we may separate the high accuracy results from the high recall outcomes. A subpar prior might be produced by the final forecast. It is crucial to pay attention if the coarse label's increased weight is close to that of the fine label. In order to avoid good squares that are exceptionally sharp from creating excellent smooth label we placed restrictions on the decoder in order to lessen their impact. Through the use of the method previously stated, it is feasible to dynamically alter the relative weights of fine and coarse labels throughout the learning process, and it is also guaranteed that fine labels have a higher optimizable upper bound more coarse labels.

4.3 Various trainable bags-of-freebies

We shall mention a few trainable bag-offreebies in this area. We utilised several of these freebies in our training, but we didn't come up with the original ideas. The Appendix will elaborate on the training specifics for these bonuses, including: (1) Batch normalisation in the topology of conv-bn-activation: This section mostly joins the convolutional layer and batch normalisation layer. This integrates the leaning and frequency of the convolutional layer created during the deduction stage with the average and deviation of the whole batch normalisation. (1) Pre-computing at the judgement step in YOLOR allows hidden data to be transformed into a vector. (2) Convolution feature map multiplied by implicit knowledge in YOLOR [81]. The resulting vector may be coupled with the convolution layer's skew and intensity that comes before or after. EMA model, third: Only the EMA model is used as the final inference model in our system. Mean teachers employ the EMA approach [75].

Table 1: Comparison of baseline object detectors.

Model	#Param.	FLOPs	Size	AP^{val}	AP^{val}_{50}	AP^{val}_{75}	AP^{val}_{S}	AP^{val}_{M}	AP^{val}_{L}
YOLOv4 [3]	64.4M	142.8G	640	49.7%	68.2%	54.3%	32.9%	54.8%	63.7%
YOLOR-u5 (r6.1) [81]	46.5M	109.1G	640	50.2%	68.7%	54.6%	33.2%	55.5%	63.7%
YOLOv4-CSP [79]	52.9M	120.4G	640	50.3%	68.6%	54.9%	34.2%	55.6%	65.1%
YOLOR-CSP [81]	52.9M	120.4G	640	50.8%	69.5%	55.3%	33.7%	56.0%	65.4%
YOLOv7	36.9M	104.7G	640	**51.2%**	**69.7%**	**55.5%**	**35.2%**	**56.0%**	**66.7%**
improvement	-43%	-15%	-	+0.4	+0.2	+0.2	+1.5	=	+1.3
YOLOR-CSP-X [81]	96.9M	226.8G	640	52.7%	**71.3%**	57.4%	36.3%	57.5%	68.3%
YOLOv7-X	71.3M	189.9G	640	**52.9%**	71.1%	**57.5%**	**36.9%**	**57.7%**	**68.6%**
improvement	-36%	-19%	-	+0.2	-0.2	+0.1	+0.6	+0.2	+0.3
YOLOv4-tiny [79]	6.1	6.9	416	24.9%	42.1%	25.7%	8.7%	28.4%	39.2%
YOLOv7-tiny	6.2	5.8	416	**35.2%**	**52.8%**	**37.3%**	**15.7%**	**38.0%**	**53.4%**
improvement	+2%	-19%	-	+10.3	+10.7	+11.6	+7.0	+9.6	+14.2
YOLOv4-tiny-3l [79]	8.7	5.2	320	30.8%	47.3%	32.2%	**10.9%**	31.9%	51.5%
YOLOv7-tiny	6.2	3.5	320	**30.8%**	**47.3%**	**32.2%**	10.0%	**31.9%**	**52.2%**
improvement	-39%	-49%	-	=	=	=	-0.9	=	+0.7
YOLOR-E6 [81]	115.8M	683.2G	1280	55.7%	73.2%	60.7%	40.1%	**60.4%**	69.2%
YOLOv7-E6	97.2M	515.2G	1280	**55.9%**	**73.5%**	**61.1%**	**40.6%**	60.3%	**70.0%**
improvement	-19%	-33%	-	+0.2	+0.3	+0.4	+0.5	-0.1	+0.8
YOLOR-D6 [81]	151.7M	935.6G	1280	56.1%	73.9%	61.2%	**42.4%**	60.5%	69.9%
YOLOv7-D6	154.7M	806.8G	1280	56.3%	73.8%	61.4%	41.3%	60.6%	70.1%
YOLOv7-E6E	151.7M	843.2G	1280	**56.8%**	**74.4%**	**62.1%**	40.8%	**62.1%**	**70.6%**
improvement	=	-11%	-	+0.7	+0.5	+0.9	-1.6	+1.6	+0.7

V. RESULT

A comparison of the results using several cutting-edge sensors for objects is show in Figure. Our ODUELAN on the Pare superiority test structure and are quicker and more accurate than The most rapid and precise sensors.

As several approaches employ GPUs with different designs to verify interpretation at runtime, we run ODUELAN on popular GPUs of the Designs of Maxwell, Pascal, and Volta are compared. it to other cutting-edge methodologies. Table 8 displays the frame rate comparison findings using either the Tesla M40 GPU or the GTX Titan X (Maxwell) GPU. The results of the Pascal GPU frame-per-second compare are displayed in Table 9 and include the TitanX (Pascal), TitanXp, GTX 1080 Ti, and Tesla P100 GPUs. Frame rates using a Volta GPU, which might be a Titan Volta or a Tesla Vol100 GPU, are compared in Table 10.

VI. CONCLUSION

We give a brand-new actual time element in this study identification architecture together with a model scaling method. We also find that new research ideas are generated by the process of building object identification systems. During the course of the investigation, we identified the replacement issue for the re-parameterized course and the assignment challenge for the allocating labels automatically. To address the issue and increase item identification accuracy, we recommend using the

trainable bag-of-gifts approach. We developed the cutting-edge ODUELAN of item detecting systems depending on the preceding provided information.

ACKNOWLEDGEMENTS

The National Centre for High-performance Computing (NCHC), which provided the computational and storage resources, is acknowledged by the authors.

REFERENCES

[1] Irwan Bello, William Fedus, Xianzhi Du, EkinDogusCubuk, Aravind Srinivas, Tsung-Yi Lin, Jonathon Shlens, and Barret Zoph. Revisiting ResNets: Improved training and scaling strategies. Advances in Neural Information Processing Systems (NeurIPS), 34, 2021. 2

[2] Alexey Bochkovskiy, Chien-Yao Wang, and HongYuan Mark Liao. YOLOv4: Optimal speed and accuracy of object detection. arXiv preprint arXiv:2004.10934, 2020. 2, 6, 7

[3] Yue Cao, Thomas Andrew Geddes, Jean Yee Hwa Yang, and Pengyi Yang. Ensemble deep learning in bioinformatics. Nature Machine Intelligence, 2(9):500–508, 2020. 2

[4] Nicolas Carion, Francisco Massa, Gabriel Synnaeve, Nicolas Usunier, Alexander Kirillov, and Sergey Zagoruyko. End-to-end object detection with transformers. In Proceedings of the European Conference on Computer Vision (ECCV), pages 213–229, 2020. 10

[5] Kean Chen, Weiyao Lin, Jianguo Li, John See, Ji Wang, and Junni Zou. AP-loss for accurate one-stage object detection. IEEE Transactions on Pattern Analysis and Machine Intelligence (TPAMI), 43(11):3782–3798, 2020. 2

[6] Zhe Chen, YuchenDuan, Wenhai Wang, Junjun He, Tong Lu, Jifeng Dai, and Yu Qiao. Vision transformer adapter for dense predictions. arXiv preprint arXiv:2205.08534, 2022. 10

[7] Jiwoong Choi, Dayoung Chun, Hyun Kim, and Hyuk-Jae Lee. Gaussian YOLOv3: An accurate and fast object detector using localization uncertainty for autonomous driving. In Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV), pages 502–511, 2019. 5

[8] Xiyang Dai, Yinpeng Chen, Bin Xiao, Dongdong Chen, Mengchen Liu, Lu Yuan, and Lei Zhang. Dynamic head: Unifying object detection heads with attentions. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), pages 7373–7382, 2021. 2

[9] Xiaohan Ding, Honghao Chen, Xiangyu Zhang, Kaiqi Huang, Jungong Han, and Guiguang Ding. Reparameterizing your optimizers rather than architectures. arXiv preprint arXiv:2205.15242, 2022. 2

[10] Xiaohan Ding, YuchenGuo, Guiguang Ding, and Jungong Han. ACNet: Strengthening the kernel skeletons for powerful CNN via asymmetric convolution blocks. In Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV), pages 1911–1920, 2019. 2

[11] Xiaohan Ding, Xiangyu Zhang, Jungong Han, and Guiguang Ding. Diverse branch block: Building a convolution as an inception-like unit. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), pages 10886–10895, 2021. 2

[12] Xiaohan Ding, Xiangyu Zhang, Ningning Ma, Jungong Han, Guiguang Ding, and Jian Sun. RepVGG: Making VGG-style convnets great again. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), pages 13733–13742, 2021. 2, 4

[13] Xiaohan Ding, Xiangyu Zhang, Yizhuang Zhou, Jungong Han, Guiguang Ding, and Jian Sun. Scaling up your kernels to 31x31: Revisiting large kernel design in CNNs. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), 2022. 2

[14] Piotr Dollar, Mannat Singh, and Ross Girshick. Fast and ´ accurate model scaling. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), pages 924–932, 2021. 2, 3

[15] Xianzhi Du, Barret Zoph, Wei-Chih Hung, and Tsung-Yi Lin. Simple training strategies and model scaling for object detection. arXiv preprint arXiv:2107.00057, 2021. 2

[16] Chengjian Feng, YujieZhong, Yu Gao, Matthew R Scott, and Weilin Huang. TOOD: Task-aligned one-stage object detection. In Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV), pages 3490–3499, 2021. 2, 5

[17] Di Feng, Christian Haase-Schutz, Lars Rosenbaum, Heinz ¨ Hertlein, Claudius Glaeser, Fabian Timm, Werner Wiesbeck, and Klaus Dietmayer. Deep multi-modal object detection and semantic segmentation for autonomous driving: Datasets, methods, and challenges. IEEE Transactions on Intelligent Transportation Systems, 22(3):1341– 1360, 2020. 1

[18] Timur Garipov, Pavel Izmailov, Dmitrii Podoprikhin, Dmitry P Vetrov, and Andrew G Wilson. Loss surfaces, mode connectivity, and fast ensembling of DNNs. Advances in Neural Information Processing Systems (NeurIPS), 31, 2018. 2

[19] Zheng Ge, Songtao Liu, Zeming Li, Osamu Yoshie, and Jian Sun. OTA: Optimal transport assignment for object detection. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), pages 303–312, 2021. 2, 5

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-12; Dec, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.1112.11

A design of intelligent range hood based on Arduino

Liu Yi Yu[1], Yan Zuo Chang[3], Lin Po Shang[1], * Ze Feng Ling[2], Yi Chen[1], Yan Hai Li[4], Jian Bin Cai[1], Young Shan Ou[5]

[1]Department of Energy and Power Engineering, Process Equipment and Control Engineering major, Guangdong University of Petrochemical Technology, China
[2]Department of Computer Science, Computer Science and Technology major, Guangdong University of Petrochemical Technology, China
[3]Department of Energy and Power Engineering, Guangdong University of Petrochemical Technology, China
[4]Department of Mechanical and Electrical Engineering, Mechanical Design Manufacture and Automation, Guangdong University of Petrochemical Technology, China
[5]Department of Electronic Information Engineering, Electronic Information Science and Technology major, Guangdong University of Petrochemical Technology, China
*Corresponding author: oshhhs1@gmail.com

Received: 24 Nov 2024,
Receive in revised form: 20 Dec 2024,
Accepted: 25 Dec 2024,
Available online: 31 Dec 2024

***Keywords*—Arduino, Sensing module, Intelligent regulation, Energy saving and environmental protection**

Abstract*—*This paper designs and implements an intelligent hood control system based on Arduino, which is composed of multiple modules, including gas detection and human body sensing, with a single-chip microcomputer as the core. The system monitors the oil smoke, natural gas concentration, and temperature and humidity changes in the kitchen in real-time using high-precision sensors. The analog signals are digitized by the A/D conversion module and sent to the single-chip microcomputer for processing. The single-chip microcomputer controls the fan speed precisely by pulse width modulation according to the smoke, gas concentration, and temperature data, achieving intelligent adjustment and efficient exhaust. The system has the characteristics of fast response, precise regulation, and energy saving and environmental protection, effectively improving the air quality in the kitchen and user experience.

I. INTRODUCTION

With the rapid development of technology and a marked improvement in living standards, smart home appliances have been deeply integrated into daily life in modern families, becoming an indispensable part of modern family life. The smart range hood, as a capable assistant in modern family kitchens, is not just a simple tool for exhausting oil smoke, but also a sophisticated device that incorporates various intelligent technologies. It can quickly respond to users' needs and automatically adjust its operating mode, and its level of intelligence directly affects the comfort and health of the family cooking environment [1].

Cooking fumes contain a variety of harmful substances, such as formaldehyde, carbon monoxide, sulfur dioxide, benzopyrene, etc. If people are exposed to them for a long time, they can irritate the mucous membrane of the respiratory tract, induce pharyngitis, tracheitis, etc. respiratory system diseases, and even increase the risk of lung cancer [2]. In addition, cooking fumes will also affect skin health, causing the skin to become dry and rough, accelerating skin aging. There have been relevant studies that confirm that formaldehyde is the most abundant carbonyl compound in the various carbonyl compounds produced in home kitchen cooking, accounting for 12% to 60% of the total, and has the greatest potential lifetime carcinogenic risk to humans. Cooking fume pollution has become a potential threat to the health of restaurant workers and home cooks [3].

Traditional range hoods have certain effect in removing oil smoke, but they also have problems such as low intelligence level, high energy consumption, and loud

noise [4]. Traditional range hoods lack intelligent sensing and control functions, and cannot automatically adjust the wind speed and suction according to the concentration of oil smoke. At the same time, their interconnectivity is limited, so users cannot access the operating status and energy consumption of the range hood in real time through smart home systems, nor can they coordinate with other smart household appliances. In addition, traditional range hoods lack personalized setting options, making operation complicated and difficult to control the noise level during operation.

In order to better improve the performance and efficiency of the range hood, scholars at home and abroad have studied the range hood from various angles, including wind speed, air volume, flow field, fume capture efficiency, exhaust efficiency, energy saving and environmental protection, filter material and so on.

Tang-Jen Liu and others proposed a low-cost smart hood system that uses sensitive piezoelectric sensors to sense the level of cooking pollutants, outputting adjustments to the fan speed to improve the fan speed and significantly reduce the noise and power consumption of the hood [5]. G. Ciattaglia and others utilized two different multi-sensor units to monitor temperature, relative humidity, volatile organic compounds, and particulate matter, and could more accurately control the oil smoke collection efficiency of the hood when the level of pollutants generated was detected to be high [6].Guo Zhilin and others studied the exhaust characteristics of hoods based on inherent angle measurement, analyzed the diffusion patterns of particulate matter generated by cooking in different cooking scenarios, considering factors such as the opening and closing of windows, the speed of cooking sources, and the airflow rates of hoods. Based on different airflow organization patterns, they designed auxiliary ventilation systems to improve the exhaust efficiency of the hood [7]. Antonio Valdez Gomez provided a new universal component loudness assessment program that could identify and reduce the noise emitted by kitchen hoods by evaluating the loudness of individual components, thereby improving the hood and reducing the noise generated from its root [8]. The energy efficiency of the blower is evaluated by the FDE (fluid dynamic efficiency) index, which is part of the EEI (energy efficiency index) formula for kitchen hoods. Paolo, Cicconi and others studied the performance of novel virtual blowers by conducting geometric optimization to obtain suitable airflow and FDE values, thereby improving the energy consumption of the hood [9]. Lei Shu and others designed a new hood (NRH) consisting of an efficient particulate air (HEPA) filter circulation component and an exhaust component, in which the airflow rate of the HEPA filter circulation component was 72 l/s for removing particulate matter generated by cooking activities and returning the filtered clean air to the room, and the exhaust component was used to expel particulate matter and other indoor air pollutants to the outdoors, effectively improving the indoor air quality [10].

With the continuous development of technologies such as the Internet of Things and artificial intelligence, smart hoods have emerged. They use high-sensitivity oil smoke sensors, temperature sensors, and humidity sensors to monitor real-time parameters such as oil smoke concentration and temperature in the kitchen, and automatically adjust the wind speed and power to achieve precise exhaust [11]. At the same time, smart hoods can also be connected to other smart home devices, and users can control the on/off and wind speed of the hood via a mobile APP [12]. Moreover, they are equipped with intelligent cleaning functions to reduce the user's cleaning burden and extend the product service life [13]. In addition, by using noise-reducing materials and technologies such as micro-perforated panels and sound linings, the noise generated by the hood during operation is effectively reduced [14]. Its intelligent odor-proof design can prevent oil smoke from escaping and keep the kitchen air fresh, providing users with a comfortable and healthy cooking environment.

II. INTELLIGENT RANGE HOOD SYSTEM ARCHITECTURE DESIGN

This paper designs and implements an intelligent environment control system based on embedded, which takes embedded as the core control unit and constructs an integrated and intelligent control architecture. The architecture consists of five core modules: core control module, gas detection module, body sensing module, A/D conversion module and temperature and humidity sensor module. The system is designed to fully monitor and control environmental parameters to ensure indoor air quality and comfort.

Specifically, the gas detection module works together with the temperature and humidity sensor module to capture real-time information on oil smoke concentration, natural gas leaks, and changes in temperature and humidity in the environment. The analog signals output by these sensors are converted into digital signals by a high-precision A/D conversion module, and then transmitted to the microcontroller for in-depth analysis and processing. The embedded system serves as the "brain" of the system, responsible for receiving and decoding these digital signals, accurately calculating the current gas concentration and temperature levels in the environment.

To achieve real-time response and regulation of environmental conditions, the system incorporates a motor drive mechanism. The motor driver works closely with the microcontroller and receives speed instructions from the microcontroller. Pulse width modulation (PWM) technology is used, and the microcontroller generates a PWM square wave signal with a specific period through its built-in timer. The signal directly controls the motor's speed. It is worth noting that in this system, the concentration of smoke, gas, and temperature all have equal priority in regulating the motor's speed. That is, when any of these parameters exceeds the predetermined threshold value, the microcontroller will automatically adjust the duty cycle of the high-level of the PWM waveform to flexibly adjust the fan's rotational speed, in order to achieve the goal of quickly responding to changes in the environment and optimizing the indoor environment.

The intelligent environmental control system designed in this paper realizes accurate monitoring and intelligent regulation of indoor environmental parameters through highly integrated hardware architecture and advanced control strategies, and provides strong support for improving the comfort and safety of living and working environment.

2.1. Core controller

The core control board of the exhaust hood system is developed using the Arduino series development board, which has stronger interactive system design than the 51 single-chip microcomputer. It simplifies the workflow of the single-chip microcomputer and supports multiple expansion modules, such as sensors, LCD screens, and Wi-Fi modules, making it convenient to expand and upgrade projects. In addition, the Arduino UNO R3 has the following advantages. First, the Arduino IDE can run on Windows, Macintosh OSX, and Linux operating systems, while most embedded systems can only run on Windows. Second, Arduino has strong usability, making it applicable to a wider range of scenarios and meeting the needs of different fields, from simple home automation to complex robot control. Third, Arduino can be programmed using the Arduino IDE, which simplifies hardware setup and operation handling through the official IDE, making it easier to write code and maintain it in the long run. For software openness and extensibility, the Arduino programming language can be extended through C++ libraries, and official and community creators have provided rich library files that can be adapted to most sensors and controls. It has a good community environment for learning and expansion. Finally, the Arduino board is based on the ATMEGA8 and ATMEGA168/328 microcontrollers from Atmel, and Arduino is based on the Creative Commons license agreement, which allows users to design their own modules based on their needs. The hardware has high expandability and can add or reduce the functionality of hardware according to the needs of the project design.

The main control of the hood fan is selected as Atmega32u4, which is built using the Arduino UNO R3 board. It uses DIP IC or SMD package with 44 pins including 6 analog pins, 2 VCC pins, 4 GND pins, and 14 digital pins. Of the 14 digital pins, 7 can be used as PWM pins. There is also a MOSI and MISO pin, as well as an HWB pin, which allows users to access the bootloader and can also be used as a regular GPIO pin. There is also a UART port, 4 SPI peripherals, and 1 I2C pin. The ATmega32u4 has 32 KB of programmable flash, 2.5 KB of SRAM, and 1 KB of EEPROM, and can accept any voltage between 2.7 and 5.5 volts, with a operating temperature range of -40°C to 85°C. The ATmega32u4 has a 16MHz crystal oscillator, 20 available IO pins, of which 7 support PWM, 12 analog input IO pins, 32KB of FLASH, 2KB of SRAM, and 1KB of EEPROM. The Arduino board has a built-in serial port, including 5 5V output ports, as shown in Figure 1: Atmega32u4 based on AVR-RISC microcontroller, because AVR uses a Harvard structure, program memory and data memory are separated, can have the same address of the program memory and data memory for independent addressing.

This structure helps Atmega32u4 achieve efficient instruction execution, maximizing performance and parallelism, as shown in Figure 1.

This architecture improves the computing speed by simplifying the structure of the computer, because RISC prioritizes the simple instructions with the highest frequency, and fixes the instruction width, which can reduce the types of instruction formats and addressing methods, thereby shortening the instruction cycle and improving the running speed. AVR-RISC microcontrollers have a high-speed processing capacity of 1MIPS/MHz (million instructions per second/megahertz),

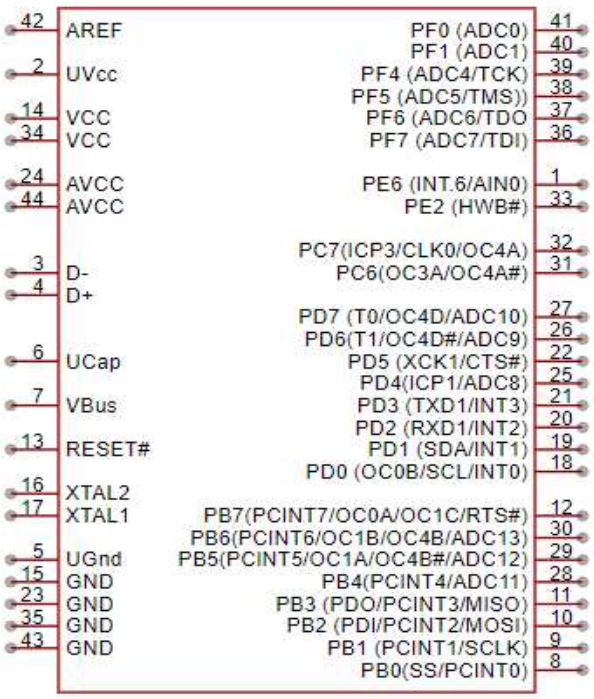


Fig.1 Atmega32u4 structure pin diagram

which means that at the same clock frequency, AVR controller type microcontrollers can handle more instructions. On the other hand, the AVRAVR controller type of microcontroller has a low power consumption characteristic, which makes it perform well in application scenarios that require long running or have strict requirements for power consumption.

2.2. Temperature and humidity sensor module

The design of temperature and humidity sensor used to monitor the temperature and humidity in the oil smoke environment, this design uses DHT11 digital temperature and humidity sensor, which is a temperature and humidity composite sensor containing calibrated digital signal output, it applies a dedicated digital module acquisition technology and temperature and humidity sensor technology, has high reliability and long-term stability, strong anti-interference ability and other advantages.

DHT11 digital temperature and humidity sensor adopts single-wire bidirectional, including a capacitive humidity sensing element and an NTC temperature measuring element, and connected with an 8-bit MCU, DHT11 supply voltage is 3.3~5.5V DC, measuring range is -20~60℃ and 5~95%RH. The sensor has a temperature accuracy of ±2 ° C at 25 ° C and a humidity accuracy of ±5%RH. It is widely used in automatic control, data recorder, humidity regulator and so on.

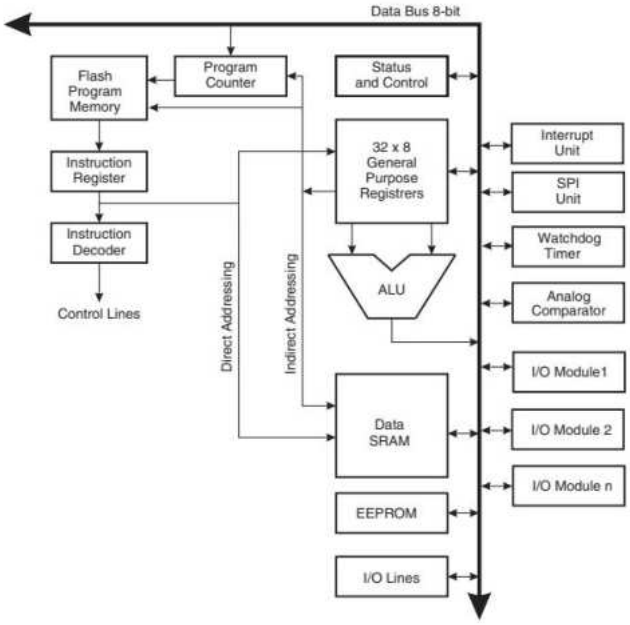


Fig.2 Block Diagram of the AVR Architecture

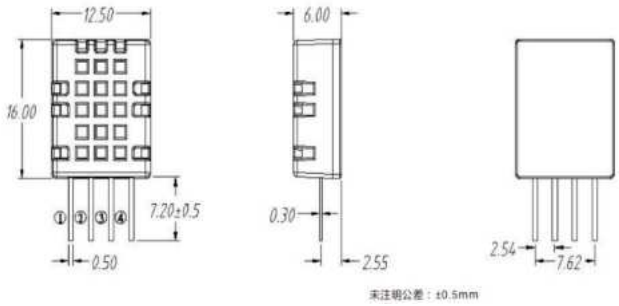


Fig.3 Structure of DH11 (unit: mm)

For data transmission, the DHT11 digital wet temperature sensor uses a single bus data format to complete two-way transmission of input and output for a single data pin port. The data packet is composed of 5Byte (40Bit), the specific data is divided into decimal parts and integer parts, a complete data transmission is 40bit, the high first out. The data format of the DHT11 is 8bit humidity integer data + 8bit humidity decimal data + 8bit temperature integer data + 8bit temperature decimal data + 8bit verification. The timing diagram of the transmitted data is shown in Figure 4.

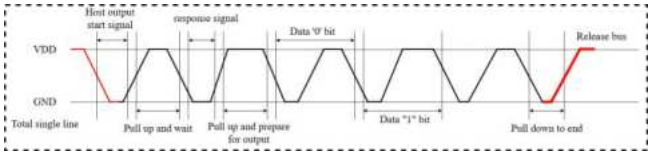


Fig.4 Data timing diagram

2.3. Gas sensor module

The gas sensor in the design is mainly used to monitor the concentration of oil smoke and natural gas in the ambient air in real time, and control the motor speed in real time with the temperature and humidity sensor to control the exhaust air volume. This design uses MQ-2 gas sensor and QS-01 oil fume sensor.

MQ-2 is a semiconductor gas sensor, the gas sensitive material used is the low conductivity of tin dioxide. When there is a combustible gas in the environment of the sensor, the conductivity of the sensor increases with the increase of the combustible gas concentration in the air. The MQ-2 sensor has high sensitivity to propane and smoke, and can also be used to detect combustible gases, which has the advantages of strong durability and low cost. It can detect the concentration of combustible gas between 300 and 10000ppm, its pin connection is shown in Table 1, where VCC: connected to the positive terminal of the power supply, GND: connected to the negative terminal of the power supply, DO: TTL switch signal output, AO: analog signal output：

Table 1 Pin diagram of the MQ-2 sensor

Pin	GPIO
VCC	3.3V/5V
GND	GND
DO	NC
AD	PA1

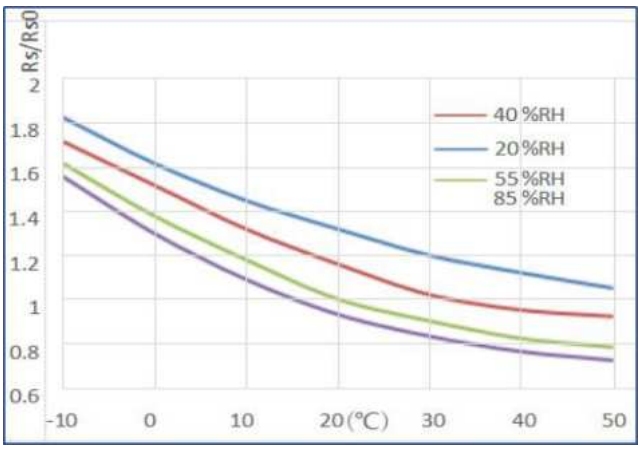


Fig. 5 Typical temperature and humidity curves of the sensor

The smoke detector MQ-2 exhibits different resistance values for different concentrations and types of gases, so it is necessary to adjust the sensitivity of the mechanical components when using this component. The variable resistor RP2 in Figure 3 is used to adjust the sensitivity. The coal gas smoke detection principle diagram is shown in Figure 3, and it is connected to the smoke detector with an AND gate and used with INT0 for interrupt. When the coal gas content in the kitchen is below the set value or does not contain coal gas, the resistance value of MQ2 becomes very large, and the voltage at pin 2 of the comparator is higher than that at pin 3, emitting a high voltage, and INT0 inputs a high level, not triggering the interrupt. When the coal gas content in the air increases, the resistance of MQ-2 decreases, and when the voltage at pin 2 of the comparator receives a voltage lower than that at pin 3, which usually means that the detected coal gas concentration has exceeded the predetermined safety threshold. In this case, the comparator will immediately output a low-level signal, which is used as a trigger signal to initiate an interrupt process. Once the interrupt is triggered, the system will jump to the corresponding interrupt service routine (ISR) to be executed. Inside the interrupt service routine, a series of operations will be performed, including starting the hood to eliminate dangerous gases and triggering the alarm mechanism to warn users of the current potential danger. Such a design is intended to quickly respond to situations where coal gas concentration exceeds the standard, ensuring environmental safety.

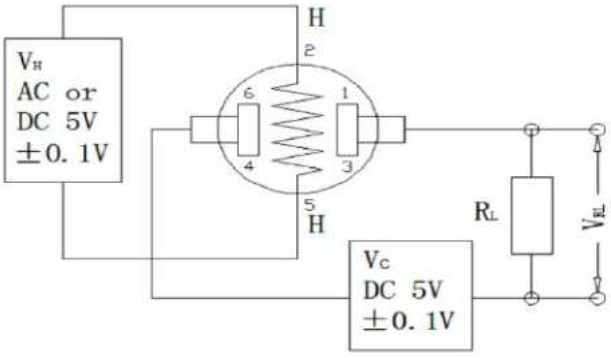


Fig.6 MQ-2 test circuit

The above figure shows the basic test circuit for the MQ-2 sensor. This sensor requires two voltages: the heater voltage VH and the test voltage VC. Of these, VH is used to provide the sensor with a specific working temperature, which can be supplied by a DC power source or an AC power source. VRL is the voltage across the load resistor RL in series with the sensor. Meanwhile, VC is the voltage used to test the load resistor RL.

The QS-01 sensor is also a tin dioxide semiconductor gas sensor with high sensitivity to VOCs and other pollutants in the air, and a fast response time. The QS-01 has three pins and can provide excellent sensing

characteristics at very low power consumption. This module is well suited for use in air quality control systems, exhaust fans, and air purifiers. Its circuit diagram is shown below.

Figure 7 shows the sensitivity characteristic curve detected by the QS-01 sensor, which is reflected by the relationship between the sensor resistance and the gas concentration. There is a logarithmic relationship between the decrease of sensor resistance and the increase of gas concentration

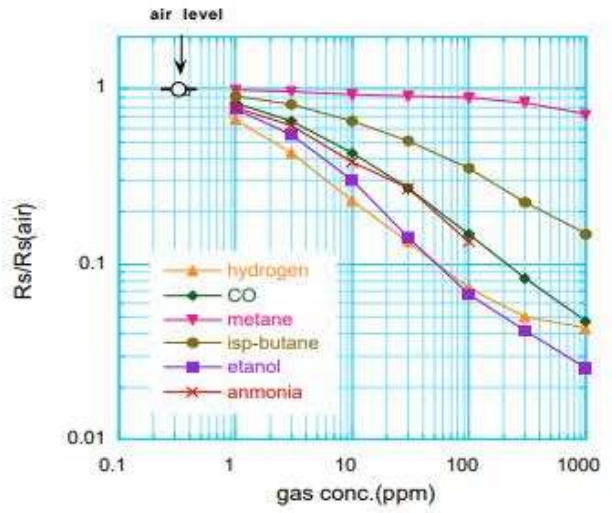


Fig.7 Sensor sensitivity characteristics

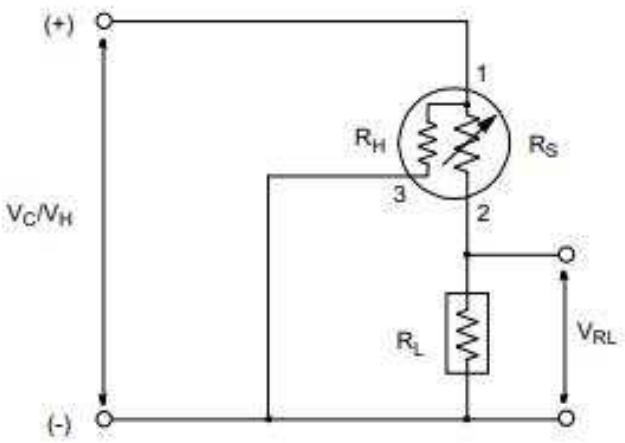


Fig.8 Standard circuit of QS-01 sensor

2.4. Body sensing module

The human body sensor module is mainly used to detect whether there is human activity in front of the range hood, and can control the switch of the range hood. The design adopts HC-SR501 human body sensor module, which is an automatic control module based on infrared technology and adopts LHI778 probe design, and has the advantages of high sensitivity, strong reliability and ultra-low voltage operation. It can work at the temperature of -50~+70℃, and the induction Angle is <100 degrees' cone Angle.

HC-SR501 is an intelligent human body sensing module that has a high degree of automated sensing capability. When a human enters its predetermined sensing range, the module will immediately output a high-level signal as a response to the detection, and when the human leaves the sensing area, the module will automatically enter a delay state and output a low-level signal, achieving an automated "exit detection". The module is designed flexibly with multiple trigger modes, and users can easily switch its trigger mode by simply adjusting the jumpers on the solder pads. In the non-repeatable trigger mode, the module will output a high-level signal once it detects a human and wait for a predetermined delay time, regardless of whether the human continues to be within the sensing range during the delay time. After the delay time is over, the output will automatically return to the low-level state. This mode is suitable for applications that require a single response. The second trigger mode is the repeatable trigger mode, unlike the non-repeatable trigger mode, in this mode, as long as the human remains within the sensing range and does not exceed the total delay time, the module's output will continuously remain at the high-level state. Only when the human completely leaves the sensing range does the delay start counting, and the low-level output is output after the delay time is over. This mode is particularly suitable for situations where continuous monitoring of human activity is required.

It is worth noting that the HC-SR501 module undergoes an initialization phase upon power-up, which lasts approximately one minute to complete self-testing and preparation. Subsequently, it transitions into a standby state, poised to promptly respond to changes in the sensing area. This meticulous design ensures optimal operational readiness of the modules prior to deployment.

Combined with the above functions and circuit design, the programming flow chart is compiled, as shown in Figure 10, and compiled in C language.

In manual mode, users can adjust the output power of the hood through the human-machine interface.

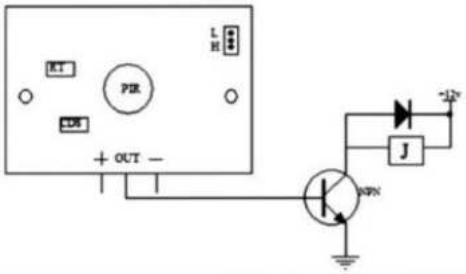


Fig.9 External usage of the sensor

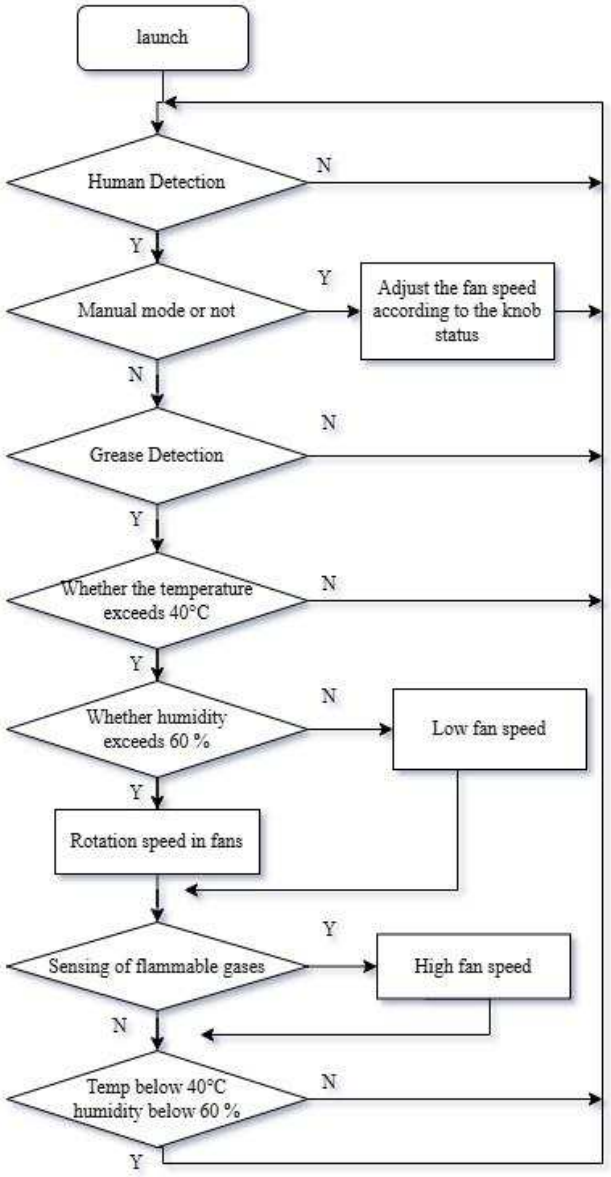
III. SYSTEM SOFTWARE DEVELOPMENT

In automatic mode, if the HC-SR501 human body sensing module detects activity in the kitchen, the potentiometer controlling the motor speed is dragged to adjust the speed of the fan, which will be kept within the three pre-set speeds of high, medium, and low, depending on the changes in environmental parameters. During this process, the DHT11 digital temperature and humidity sensor plays a crucial role by continuously monitoring the temperature and humidity in the kitchen.

If the temperature exceeds 40°C and the relative humidity is below 60%, it indicates that the air in the kitchen is relatively dry, so the system will set the fan speed to low. On the other hand, if the temperature remains above 40°C but the relative humidity rises above 60%, it means that moist and hot air may affect comfort and air quality, so the system will automatically increase the fan speed to the medium level. The MQ-2 gas sensor and the dedicated oil smoke sensor are responsible for monitoring the concentration of combustible gases and oil smoke in the kitchen.

Once these sensors detect any abnormal conditions, such as a gas leak or excessive oil smoke concentration, the system will immediately respond by increasing the fan speed to the highest level to ensure the quick exhaustion of harmful gases and oil smoke to protect the safety of people inside the environment. Additionally, the system has intelligent energy-saving features.

Whether in automatic or manual mode, when no exhausting is needed, the hood can automatically shut off the motor to avoid unnecessary energy waste. This feature helps save energy and prolong the service life of the equipment. When the hood is in standby mode, the main control unit will continue to power all the sensors to ensure that they can continuously monitor the kitchen environment, so that potential safety hazards, such as oil smoke accumulation or gas leakage, can be detected in non-working hours to guarantee the overall safety of the environment.



IV. CONCLUSION

This paper designs an intelligent exhaust hood controlled by Arduino system, which can achieve unmanned operation through a sensor system consisting of QS-01 sensors, human body sensors, and MQ-2 sensors, to improve the best use experience of exhaust hoods. In automatic mode, the exhaust hood can adjust the fan speed according to the data feedback from various sensors to adapt to the size of oil smoke, combustible gases, and humidity and temperature, to a certain extent, realizing the intelligent control of exhaust hoods.

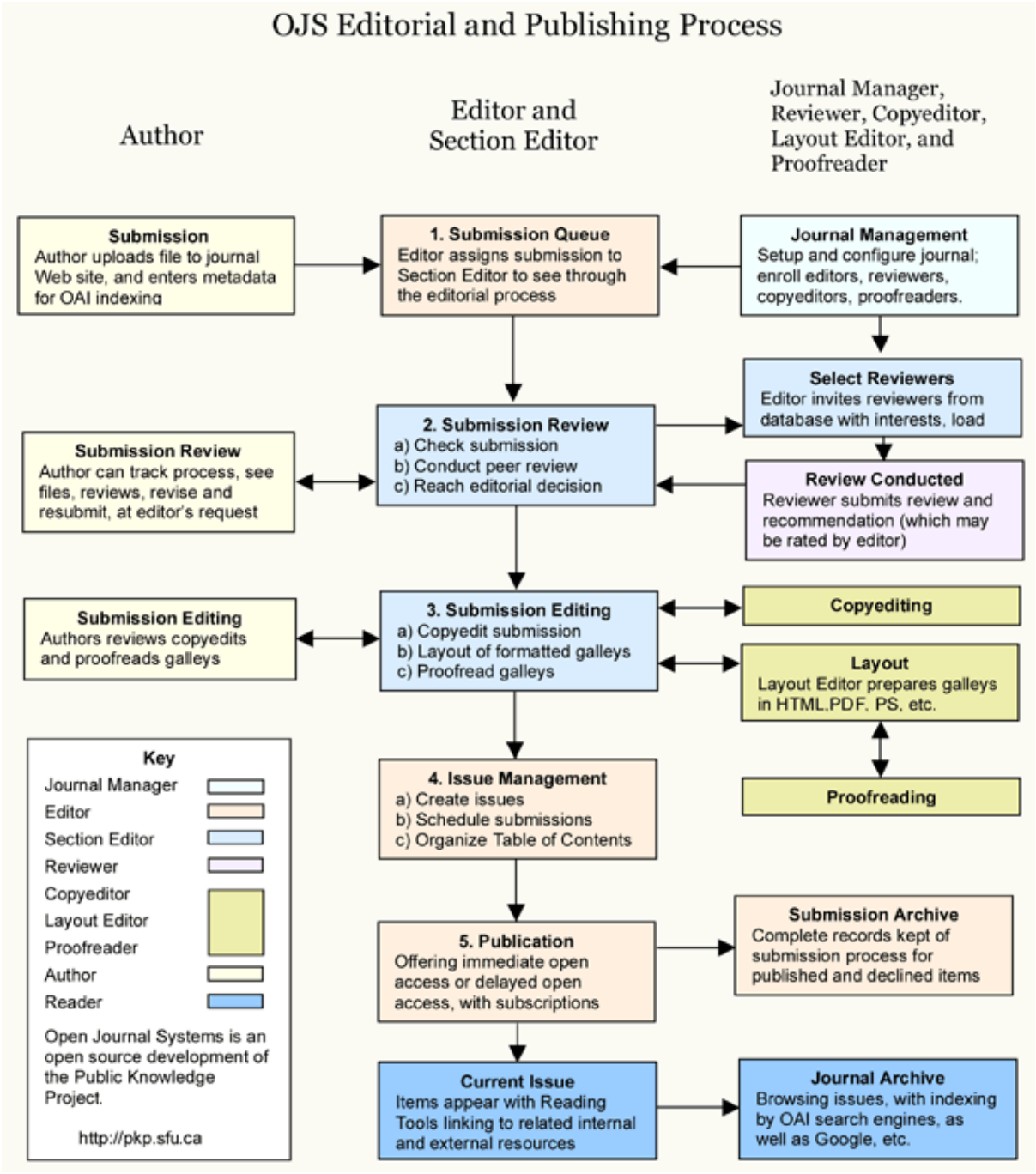
ACKNOWLEDGEMENTS

This work described in this paper was supported by The Research Funding Of GDUPT, Lagrangian Coherent

Structure Analysis of Heat Sink for Heat Transfer Performance with Piezoelectric Fan, Special Project of Science and Technology Innovation Strategy of Guangdong Provincial Department of Science and Technology in 2024, (Project No.:2024A0505050022).

REFERENCES

[1] Chen Xuan. Application of sensing technology in the design and implementation of Intelligent Range Hood [J]. Encyclopedia Forum Electronic Magazine, 2018, 000(021):38.
[2] Shi ManXing. Research on Pollutant diffusion law and Control of Air Curtain Range Hood [D]. Hunan University of Technology,2008
[3] Jia K K. Emission characteristics and exposure assessment of formaldehyde and VOCs produced by cooking oil fume [D]. Beijing University of Civil Engineering and Architecture,2021.
[4] Fu Zheng. Research on Flow Field Simulation and Performance Optimization of Kitchen Range Hood [D]. Guangdong University of Technology [2024-08-03].
[5] Qi Wenqian, ZHAO Haojie.' Smoke Dissipating Mist 'Intelligent range Hood [J]. China Science and Technology,2017(12):69-69.
[6] Zhou Rui. Research on Flow Field Optimization and Noise Reduction in the Duct of a European-style range Hood [D]. Qingdao University of Technology,2009.
[7] Xu Liangxiong, Xu Yanyan. Design of Intelligent Range Hood [J]. Laboratory Research and Exploration, 2012(9):3
[8] Mei Yuxuan. Design of Intelligent energy-saving Range Hood based on MCU [J]. Science and Technology Communication, 2018(23):2
[9] Yu Haiping. Study on preparation of filter screen for high oil drainage range hood and its corrosion resistance to oil smoke [D]. Qingdao University of Technology,2018.
[10] Zhao Yanjiang, ZHANG Yongde, Zou Heli. Design of Blade Cleaning Machine for Range Hood Based on TRIZ Theory [J]. Machine Design, 2010(2):4
[11] Guan Liang, Research and Implementation of Intelligent Control Module for Energy Saving and Environmental Protection Lampblack [D]. Guangdong University of Technology [2024-08-03]
[12] Ling Shuo. Design and implementation of intelligent range hood control APP based on Android [D]. Beijing Jiaotong University,2016.
[13] Zhu Shiping. Application of Steam Cleaning Technology for range Hood [D]. University of Electronic Science and Technology of China,2016.
[14] Jia Xingshi. Research on Noise Control Technology of Range Hood based on Channel Sound Absorption [D]. China Jiliang University,2020
[15] Xu Hao. Common Faults of Central Air Conditioners in Intelligent Environment and Countermeasures [J]. China Equipment Engineering,2024, (11):38-40.0
[16] Annual Index 2023 to Machine Building and Automation (Vol. 52, Nos. 1-6, Total Nos. 284-289) (end of volume) [J]. Machine Building and Automation, 2019,52(06):233-240.
[17] Xie Yongchao, Yang Li, Yan Jun. Design of Smoke Detection Alarm based on MQ-2 sensor [J]. Computer Measurement and Control,2021,29(08):255-259



~IJAERS Workflow~

Important links:

Paper Submission Link:
https://ijaers.com/submit-paper/
Editorial Team:
https://ijaers.com/editorial-board/
Peer Review Process:
https://ijaers.com/peer-review-process/
Publication Ethics:
https://ijaers.com/publication-ethics-and-publication-malpractice-statement/
Author Guidelines:
https://ijaers.com/instruction-to-author/
Reviewer Guidelines:
https://ijaers.com/review-guidelines/

Journal Indexed and Abstracted in:

- Qualis-CAPES (A2)-Brazil
- Normatiza (Under Review-Ref.020191511)
- NAAS Score: 3.18
- Bielefeld Academic Search Engine(BASE)
- Aalborg University Library (Denmark)
- WorldCat: The World's Largest Library Catalog
- Semantic Scholar
- J-Gate
- Open J-Gate
- CORE-The world’s largest collection of open access research papers
- JURN
- Microsoft Academic Search
- Google Scholar
- Kopernio - powered by Web of Science
- Pol-Index
- PBN(Polish Scholarly Bibliography) Nauka Polaska
- Scilit, MDPI AG (Basel, Switzerland)
- Tyndale University College & Seminary
- Indiana Library WorldCat
- CrossRef DOI-10.22161/ijaers
- Neliti - Indonesia's Research Repository
- Journal TOC
- WIKI-CFP
- Scinapse- Academic Search Engine
- Mendeley-Reference Management Software & Researcher Network
- Dimensions.ai: Re-imagining discovery and access to research
- Index Copernicus Value(ICV): 81.49
- Citeseerx
- Massachusetts Institute of Technology (USA)
- Simpson University (USA)
- University of Louisville (USA)
- Biola University (USA)
- IE Library (Spain)
- Mount Saint Vincent University Library (Halifax, Nova Scotia Canada)
- University Of Arizona (USA)
- INDIANA UNIVERSITY-PURDUE UNIVERSITY INDIANAPOLIS (USA)
- Roderic Bowen Library and Archives (United Kingdom)
- University Library of Skövde (Sweden)
- Indiana University East (campuslibrary (USA))
- Tilburg University (The Netherlands)
- Williams College (USA)
- University of Connecticut (USA)
- Brandeis University (USA)
- Tufts University (USA)
- Boston University (USA)
- McGill University (Canada)
- Northeastern University (USA)
- BibSonomy-The blue social bookmark and publication sharing system
- Slide Share
- Academia
- Archive
- Scribd
- ISRJIF
- Cite Factor
- SJIF-InnoSpace
- ISSUU
- Research Bib
- infobaseindex
- I2OR
- DRJI journal-repository

AI Publication
International Journal of Advanced Engineering Research and Science (IJAERS)
104/108, Sector-10, Pratap Nagar, Jaipur, India