SCIENCE AND TECHNOLOGY RESEARCH CENTRE
UNIVERSITAS PGRI SEMARANG - INDONESIA

ISSN: 2715-4211

Journal ASSET

Advance Sustainable Science, Engineering and Technology

Volume 4 Number 2 October 2022

URL LINK: http://journal.upgris.ac.id/index.php/asset

Advance Sustainable Science, Engineering and Technology

e-ISSN: 2715-4211

Volume 4 Number 2 October 2022

Science and Technology Research Centre, Universitas PGRI Semarang, Indonesia

Advance Sustainable Science, Engineering and Technology (ASSET) is a peer-reviewed open-access international scientific journal dedicated to the latest advancements in sciences, applied sciences and engineering, as well as relating sustainable technology. This journal aims to provide a platform for scientists and academicians all over the world to promote, share, and discuss various new issues and developments in different areas of sciences, engineering, and technology.

ASSET papers will be published twice a year by Universitas PGRI Semarang, Central Java, Indonesia.

Advance Sustainable Science, Engineering and Technology
e-ISSN: 2715-4211
Volume 4 Number 2 October 2022
Science and Technology Research Centre, Universitas PGRI Semarang, Indonesia

Editorial Preface

Advance Sustainable Science, Engineering and Technology (ASSET)
Volume 4 Number 2 October 2022

It is our great pleasure to present the Volume 4 Number 2 Advance Sustainable Science, Environmental Engineering and Technology (ASSET). This issue includes eleven manuscripts. The first article, written by Dwiningsih *et al.*, discusses the complex traits in maize detects genomic regions and genes. The following four articles from Bataan Peninsula State University, Philippines discuss the 3D printing in various applications such as the dimensional accuracy, the viability assessment, the ergonomically – designed violin chinrest, and the ergonomic tool handles. Next, there are five bibliometric mapping studies using VOSviewer performed by authors from Universitas Pendidikan Indonesia. Several themes such as nanocrystalline starch in food packaging application, aluminium oxide nanoparticle and platinum nanoparticles in biomedical applications, graphene-based surfaced – enhanced Raman scattering (SERS) and the nano propolis. Last but not least, Ibrahim *et al* studied the feasibility solar power generation system for public street lighting.

We thank all of the 34 authors affiliated from University of Arkansas, USA, King Saud University, Saudi Arabia, Bataan Peninsula State University, Philippines, Universitas Pendidikan Indonesia and Universitas PGRI Semarang, Indonesia who have contributed to this issue. We believe that all the papers published in this issue will have great influence on the science, environmental engineering and technology.

October 2022
Asst. Prof. Mega Novita
Asst. Prof. Rizky Muliani Dwi Ujianti

Advance Sustainable Science, Engineering and Technology
e-ISSN: 2715-4211
Volume 4 Number 2 October 2022
Science and Technology Research Centre, Universitas PGRI Semarang, Indonesia

Table of Content

Advance Sustainable Science, Environmental Engineering and Technology (ASSET)
Volume 4 Number 2 October 2022

Advance Sustainable Science, Engineering and Technology
e-ISSN: 2715-4211
Volume 4 Number 2 October 2022
Science and Technology Research Centre, Universitas PGRI Semarang, Indonesia

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220201-01 ~ 0220201-12
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.13004

Assessment of the Viability of using 3D printing for the Design and Prototyping of Historical Artifacts as Replicas

Ruevan Evangelista Alboro[1*], Leslie R. Jorge Acain[2], Cristina G. Rivera[3], Aaron Paul C. Rivera[4], Shiela Marie Roxas-Buce[5], Robert O. Aguilar[5], Ray Noel M. Delda[6], John Ryan C. Dizon[6]

[1]Department of Industrial Engineering, College of Engineering and Architecture, Bataan Peninsula State University, City of Balanga, Bataan, 2100, Philippines

[2]Department of Tourism, College of Business and Accountancy, Bataan Peninsula State University, City of Balanga, Bataan, 2100, Philippines

[3]Department of Computer Science, College of Information and Communications Technology, Bataan Peninsula State University, City of Balanga, Bataan, 2100, Philippines

[4]Department of Entertainment and Multimedia Computing, College of Information and Communications Technology, Bataan Peninsula State University, City of Balanga, Bataan, 2100, Philippines

[5] Department of Architecture, College of Engineering and Architecture, Bataan Peninsula State University, City of Balanga, Bataan, 2100, Philippines

[6]Design, Extension, Research and Entrepreneurship in Additive Manufacturing, Advanced Materials and Advanced Manufacturing (DR3AM) Center, Bataan Peninsula State University, City of Balanga, Bataan, 2100, Philippines

*realboro@bpsu.edu.ph

Abstract. 3D printing is now being used in many different applications. Souvenir items and replicas of artifacts, which usually do not need to have high durability/strength, may be one of the possible applications of 3d printing. In this study, the researchers tried to manufacture keychains, refrigerator magnets, and display items from historical artifacts in the province of Bataan. Three experts (1 from the tourism industry, 1 BS Tourism Faculty, and 1 expert in 3d printing) were tapped to assess the viability of using 3d printing in the production of souvenir items. The items were particularly evaluated based on their quality, color, surface finish, cost, durability, authenticity, material, etc. Important considerations were obtained from 3d printing as well as from the insights/evaluation provided by the experts. Experts suggested modifying the thickness, color, and materials for added appeal. Reducing the price might also increase the market for souvenir items. Adding labels and descriptions has also been recommended. All these

improvements will inspire different emotions, create impact and make the design more memorable.

Keywords: Additive Manufacturing in Architecture, 3D Printing, Historical Artifacts, 3D Design and prototyping, Replicas

(Received 2022-08-28, Accepted 2022-10-30, Available Online by 2022-10-31)

1. Introduction

3D printing, more formally known as Additive Manufacturing, has gained considerable attention in the academic and research communities and is now being adopted by the industry. This is because cheaper and faster 3D printing technologies which can produce high print qualities are now available. Polymer materials for 3D printing also are now being produced with a wider range of properties. These advancements continuously change how the products are designed and manufactured and how they are used by consumers. Innovators and makers can now easily produce prototypes of their ideas as 3D printing greatly simplifies prototype production. The design and fabrication processes have been reduced from weeks to a few hours essentially allowing for innovation on the fly. AM could minimize production costs and improve the overall efficiency in the design and manufacturing sector. Moreover, AM provides solutions where complex designs are required, with short lead time and small lot sizes. AM is now being seriously considered to produce materials for several applications, namely: construction, apparel, agriculture, desalination, education, medicine, electronics, automotive, robots, military, oceanography, aerospace, satellites, oil & gas, architectural design, and many more [1-10].

3D printing can be used in producing souvenir items. 3D printing is ideal because it can do customization of souvenir items. Production of these replicas will help preserve the memory of historical artifacts. Additionally, it will inspire different emotions and create a lasting impact. However, important parameters have to be considered including the following: cost, quality, durability, authenticity, surface finish, color, the material used, overall quality and acceptability, and others.

Objectives of the Study

General Objectives

The main objective of the project is to assess the viability of using 3D printing for historical artifacts as replicas.

Specific Objectives

1) To generate designs of historical artifacts for the production of replicas
2) To 3d print replicas of historical artifacts
3) To assess the 3d-printed replicas

Literature Review

Souvenirs are considered to be a fundamental component of each human being's travel experience, as these objects tend to bring back special moments and experiences. It is solid proof that easily recognizes that special moment in their lives [11][12]. It can be a shirt, keychain, jewelry, sand, and scale models of a specific landmark. Souvenirs are often noticed due to their symbolic meaning and significance in a specific tourist location [13][14]. These small or big pieces of remembrance are psychologically important to many women tourists according to a study conducted in the North American regions [15].

Items such as souvenirs are deemed a major component in a tourism-based retail system as they can generate a lot of jobs for people who are involved in manufacturing, distribution, and sales [16][17].

Small to large-scale industries, and mass manufacturing firms that can distribute their products on a global scale are the leaders in the production of souvenir items [14]. Small to medium types of businesses have a team of artisans or craftsmen who specialize in locally produced items that are produced by traditional methods. Through such old methods of production, handcrafted souvenirs are believed to be able to retell the cultural stories of their origin. Meanwhile, mass manufacturing firms are known to embrace globalization more; settling for low-quality souvenirs that are products overseas thus lacking authenticity [18].

The use of any manufacturing or technological method in the interpretation of culture or creation has changed the perception of tourists toward how their experience is remembered [19]. A greater price or value is assigned to items that are compelling yet personalized, as these factors enable the consumers to be involved in the co-production of their souvenirs; a part of a very creative experience [20].

As technological advances move beyond functional tooling to creative production activities, 3D printing technologies can be facilitated to develop co-creative activities focused on tourism products. These technologies had rapidly progressed in the last decade, and these advances made 3D printers capable of producing functional parts that are fully customizable [21]. It also allows the objects or landmarks to be scanned, converted, or manipulated to a 3D printing file such as .stl, and then shared to be printed anywhere [22].

Through sites such as Thingiverse, people gained access to a huge array of open-source designs. It also offered multiple opportunities for people with zero knowledge of 3D printing and design principles to design and print their objects which can be produced using a 3D printer [23]. Another website that is worth mentioning is MyMiniFactory.com, it features Scan The World – a community-built museum that aims to archive the world's famous sculptures, statues, artifacts, and even landmarks using 3D scanners and 3D printers. The section uses photogrammetry, the scanned objects are free to download for the sole purpose of giving access to people to cultural heritage, education, and cultural preservation. Landmarks such as the Parthenon in Greece, and Arc de Triomphe in France, and sculptures such as the La Pieta, Venus de Milo, and Moses can now be downloaded and printed for free [24].

3D printers were created for rapid prototyping purposes in engineering and manufacturing aspects. However, 3D scanners and printers are also used in cultural heritage and museums to remake digital copies of artifacts, landmarks, and other objects for educational and preservation purposes [25]. 3D printing has advantages over traditional manufacturing methods, and its foremost edge is its ability to produce customized products. Its method of production also lessens material waste, alongside the avoidance of the need for a large storage space to store products for future use and distribution [26]. AM can explore and focus on the co-creation of souvenirs through the adaption, modification, and transformation of existing designs to improve the tourism experience [23][27].

Hector Serrano wished to explore the potential of 3D printing as a manufacturing method for the production of souvenir products. He produced a collection for an exhibition about sustainable design. The project tackled how objects are produced using modern manufacturing methods and how alternative ways or methods can reduce their impact on the environment. It concluded with less carbon footprint due to the designs being sent through email and produced using 3D printers, thus gaining no carbon footprint from transportation or shipping [28].

As AM technologies are more accessible to the masses, the possibility that 3D printing can be a viable production method for souvenir items as it can promote co-creation activities; bringing an immersive experience to tourists, must be evaluated [29] [30].

2. Methods

The study has three phases namely the Design Phase, 3D Printing Phase, and Assessment Phase. The first phase will include the design of the models. The second phase will focus on the 3d printing of models based on the design. The third and last phase will be the assessment of the models by experts, the architects, through interviews. Please see the interview guide questions. Figure 1 shows the design process followed in the study showing all three (3) phases.

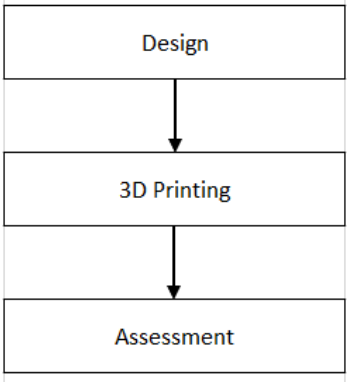


Figure 1. Research Methodology

The three phases will lead to Specific Objectives as enumerated here. The first specific objective is to generate designs of historical artifacts for the production of replicas. 3d modeling software such as Autodesk Inventor and Google Sketchup has been used to generate the models of the replicas. The second specific objective is to 3d print replicas of historical artifacts with the different 3d printers such as Zortrax M200 and Ultimaker 3 Extended have been used to produce the replicas of historical artifacts, also 3d printing materials such as acrylonitrile butadiene styrene (ABS) and Polylactic Acid (PLA) have been used for the replicas, and the post-processing such as sanding and cutting have been employed. The third specific objective is to assess the 3d-printed replicas. There were three (3) experts who have been interviewed/surveyed to assess the 3d-printed replicas in terms of their quality, color, surface finish, cost, durability, authenticity, material, etc.

Here are the short profiles of three (3) experts as respondents to this study. They are Ms. Lucille Marcelo, Engr. Brian Tuazon, and Ms. Danica Lolita Tigas. The several organizations, educational attainment, skills, eligibilities, working experience, published papers, oral and poster research presentations, seminars, and training attended considered our respondents knowledgeable in tourism trends, 3D printing, and tourism industries, respectively.

Ms. Lucille Marcelo is a Tourism faculty instructor at the Bataan Peninsula State University since August 2016, taking up a Master of Science in Hospitality Management major in Tourism Management from Centro Escolar University in Manila Campus in 2017 up to the present. Ms. Marcelo is a regional tour guide of the Bataan Peninsula Tour Guide of Bataan Tourism Center, a member of the Philippine Association for Tourism and Hospitality, and a member of the Association of Tourism Officers of Central Luzon of the Department of Tourism in Region III. The first expert started attending related seminars and training in 2012 and among these were Tour Guide Seminar Techniques, Actual practice and Workshop in Laoag City, Ilocos Norte; InfiniTHI Eco-Tourism, Tourism Planning as a Profession and Career opportunities in the Local and national Government, Global Trends and Tour Products in Balanga City, Bataan; Expose – Seminar on Global Tourism in Balanga City also; Bataan Tourism marketing and Strategies Seminar; Seminar on Career Opportunities in the Tourism Industry; Tourism Entrepreneurship: Training Workshop on Simplified Accounting and Agripreneurship; Cultural Guiding Seminar in Balanga City, Bataan; 3rd International Creative Tourism Design Conference 2016 in SM North Edsa, Quezon City and more.

The second respondent is Engr. Brian Tuazon, a 3D printing expert, a permanent instructor at the Bataan Peninsula State University since 2014, a licensed Mechanical Engineer, a registered master plumber, and graduated Master of Science in Mechanical Design and System Engineering with a full

scholarship from Andong National University, Republic of Korea. This second expert became a Research Assistant in the Materials Behavior Measurement and Evaluation Laboratory during his stay at Andong National University from October 2012 to August 2014 in Andong, Kyungbuk, Republic of Korea. This respondent is a Board of Directors Member of the Philippine Society of Mechanical Engineers Bataan Chapter since 2018 up to the present, and a regular member of the Mechatronics and Robotics Society of the Philippines, Inc since 2018 also. Among his related training and seminars attended from 2009 to 2019 were the 24-Hour Training Workshop on 3D Studio Max 2019 at the Bataan Peninsula State University; the Design Thinking Workshop in Central Luzon State University, Nueva Ecija; Computer Aided Sprinkler System Design from CADVision Engineering Technologies in Sampaloc, Manila; the Operation, Programming and Functionality of Intelitek SCORBOT ER 4u from State Alliance Enterprises Inc. in Balanga City, Bataan; and 2009 3rd Quarter Technocon and Innovention Contest of the Philippine Society of Mechanical Engineers Bataan Chapter, Balanga City Bataan.

The third expert is Ms. Danica Lolita Tigas, MSHM-TM, a Tourism industry practitioner. Ms. Tigas is a Tourism Operations Officer 1 at the Bataan Provincial Tourism Office since November 5, 2015, up to the present and a graduate of Master of Science in Hospitality Management major in Tourism Management from Centro Escolar University, Mendiola, Manila in March 2018. Among the training and seminars attended by the third respondent from 2013 to 2018 were the 19th Association of Tourism Officers of the Philippines national Convention in Cagayan de Oro City, Advanced Tourism Statistics Training, Tourism Marketing Seminar on Regional Branding in South Cotabato, 1st North Philippines Tourism Forum and Career Fair in Baguio City, 18th Association of Tourism Officers of the Philippines National Convention in Ilo-ilo City, International Conference on Cultural Statistics in Ermita, Manila, 6th UNWTO International Conference on Tourism Statistics: Measuring Sustainable Tourism in Pasay City, 3rd Leg of Pamana: World Heritage and Biosphere Reserve Nomination Series in Albay, Tourism Product Development Workshop and Tour package Development and Delivery Seminar in Balanga City.

3. Results and Discussion

The researchers surveyed for the assessment of the viability of using 3d printing for the design and prototyping of souvenir items. The respondents are namely: a tourism faculty member, a 3d printing expert, and a tourism officer. Here are the results of the survey.

3.1. Bataan Map Keychain

Souvenir item number one (Fig. 2a) is the Bataan Map Keychain wherein we value the historical path. We can view also the shape of the province, the distance, and natural resources such as mountains and lands can be figured-out. The researchers design the map in a keychain to make it handy and can be used anytime. Table S1 shows the ratings for the Bataan Map Keychain made by the experts.

Experts Assessment: Respondent #1 pointed out that another design of the Bataan map can be better for Municipalities to easily identify that the keychain is from Bataan. Respondent #2 also said that it is better to enlarge, thicken, have additional color, and use other materials like plastic for the keychain to see the details of the Bataan map.

3.2. Bataan Map Ref Magnet

Souvenir item number two (Fig. 2b) is the Bataan Map Ref Magnet wherein aside from the historical path value of the design we can also keep important notes by sticking to our fridge door with this product. Table S2 shows the ratings for the Bataan Map Ref Magnet made by the experts.

Experts Assessment: Respondent #1 suggested the following, white color will be more attractive for the Bataan map ref magnet, Bataan map with towns will suit in memento and lower the price below

Php240 or if possible ranging from Php150 to Php180 for tourists. Respondent #2 advised using vibrant colors of filament to highlight the details of the Bataan Map.

3.3. Bataan Map with Town Names Ref Magnet

Souvenir item number three (Fig. 2c) is the Bataan Map with Town Names Ref Magnet where we can view easily the different municipalities and boundaries. Table S3 shows the ratings for the Bataan Map with Town Names Ref Magnet made by the experts.

Experts Assessment: Respondent #1 requested that the price may range from Php150 to Php200.

(a) (b) (c)

Figure 2. Photos of 3D-printed miniature maps (key chains and ref magnets)

3.4. Death March Marker Display

Souvenir item number five (Fig. 3a): is the Death March Marker Display where we can recall the historical event of the Bataan Death March has come to dominate the role that our country, the Philippines played in World War II.

Experts Assessment: Respondent #1 commented that for uniqueness and authenticity, put km00 and have an additional size on the base to look like more of a km marker. Price may range from Php150 to Php200. Respondent #3 and Respondent #2 urged to include some details in the marker like if it's 00 in Bagac or 0 in Mariveles for the Death March Marker display just to depict that this is from Bataan and not from Pampanga or Tarlac. Additional color will highlight important parts of the Death March Marker display as pointed out by 3d experts.

3.5. Philippine-Japanese Friendship Tower Display

Souvenir item number five (Fig. 3b) is the Philippine-Japanese Friendship Tower Display.

The site of the Philippine-Japanese Friendship Tower in Bagac, Bataan is ~200 meters from where the Bataan Death March of April 1942 started. The death march caused the deaths of ~10,000 war prisoners.

Experts Assessment: Respondent #1 suggested enlarging the size and having the additional weight of the Philippine-Japanese Friendship Tower display to sell at a range from Php300 to 350. Respondent #2 also advised having a label that will give information about the design and additional color to highlight important points and takeaways. Respondent #3 proposed changing the display to white color and including the important bell and the highlight of the tower.

3.6. Dambana ng Kagitingan Display

Souvenir item number five (Fig. 3c): is the Shrine of Valor (Dambana ng Kagitingan). This shrine is located in Mt. Samat, Pilar, Bataan. This shrine was built to remember and honor the gallantry of American and Filipino soldiers who fought against the Japanese Imperial Army during WWII.

Experts Assessment: Respondent #1 recommended a thicker size of the display to look the same as the Shrine of Valor in terms of authenticity and additional thickness below the part to look heavy. Respondent #2 proposed to include the landscape of Mount Samat in Pilar to recognize easily the Mount Samat National Shrine. Respondent #3 was encouraged to include the Nabiag Na Bato in the lower part of the cross and include or replicate the glass on the arms of the cross

(a) (b)

(c)

Figure 3. Photos of 3D-printed replicas of historical markers

3.7. Morong Church Display

Souvenir item number four (4a) is the Morong Church Display where we can view easily the place of worship and church members or religious communities will love this product.

Experts Assessment: Respondent #1 as well as Respondent #2 asked to put the label with the name of the church to identify easily. Respondent #2 also recommended having additional colors in the design to highlight the beauty of the church. Respondent #3 emphasized that this Morong church display was her favorite among the souvenir items because it shows the uniqueness of Morong Church. However, she was also encouraged to include the St. Dominic Cathedral of Abucay which is the oldest church in Bataan, and also to coordinate the use of the churches as souvenir items with the Diocese of Balanga. She also advised to lessen the price and include a short description about the destination, or even the name and the location to use the item as a promotional platform, as well.

3.8. Bataan Provincial Capitol Display

Souvenir item number four (4b) is the Bataan Provincial Capitol Display.

Experts Assessment: Respondent #1 proposed additional stairs around the façade of the Bataan Provincial Capitol display. Respondent #3 praised the display as 99.9% or close to perfect. However, she and Respondent #2 preferred to include a label for future customers who don't know what the place is and lessen the price. Respondent #2 also advised having additional colors to highlight the design.

3.9. Bataan Map Display

Souvenir item number five (5) is the Bataan Map Display

Experts Assessment: Respondent #1 advised thickening and having additional weight to the Bataan map display while Respondent #2 recommended having additional color to inspire different emotions, create impact, and make the design more memorable.

(a)

(b)

Figure 4. Photos of 3D-printed replicas of historical sites

(i)

Figure 5. Photo of a 3D-printed replica of the Bataan map for display

4. Conclusion

3d printing is now being used in many different applications. Therefore, souvenir items and replicas of artifacts, which usually do not need to have high durability/strength, may be one of the possible applications of 3d printing. In this study, the researchers tried to manufacture keychains, refrigerator magnets, and display items from historical artifacts in the province of Bataan. 3 experts (1 from the tourism industry, 1 expert in 3d printing, and 1 BS Tourism Faculty) were tapped to assess the viability of using 3d printing in the production of souvenir items. The items were particularly evaluated based on their quality, color, surface finish, cost, durability, authenticity, material, etc. Important considerations were obtained from 3d printing as well as from the insights/evaluation provided by the experts.

The experts suggested modifying the thickness, color, and materials for added appeal. Reducing the price might also increase the market for souvenir items. Adding labels and descriptions has also been recommended. All these improvements will inspire different emotions, create impact and make the design more memorable. Below are further detailed suggestions from the experts.

First, a keychain design was suggested to contain the names of the municipalities to easily identify that the product is from Bataan. As for other designs, labels were also suggested. Second, the thickness and colors of the souvenirs should be altered and improved to create a greater impact, making them more memorable and aesthetically pleasing. Third, the selling price of the items is also suggested to increase. Forth, the experts suggested the coordination between the manufacturer and the Diocese of

Balanga; the inclusion of the St. Dominic Church as a souvenir as it is the oldest church in Bataan. Lessen the price, according to Respondent #3, and include a short description of the destination. Fifth, enlarge some of the designs and increase the weight. Sixth, the inclusion of Nabiag Na Bato in the lower part of the Dambana ng Kagitingan or Shrine of Valor, the landscape of Mt. Samat, and replicating the class on the arms of the cross. Seventh, additional stairs for the façade of the Bataan Provincial Capitol display. Eighth, add more colors to the design, and always label the souvenirs; labels should contain the place's or landmark's history.

The experts agreed that 3d printing is a viable manufacturing process for the production of replicas of historical artifacts.

Supplemental Information

Supplemental information for this material is provided in a separate word file.

Acknowledgments

This study is supported by the Bataan Peninsula State University through its Main Campus Research and Development Office.

References

[1] A. Espera Jr, J. R. C. Dizon, A. Valino, and R. C. Advincula, "Advancing flexible electronics and additive manufacturing," Japanese Journal of Applied Physics, "Special Issue: Flexible and Printed Electronics (ICFPE2021)," 2022. https://doi.org/10.35848/1347-4065/ac621a.

[2] J-R. R. Diego, D. W. C. Martinez, G. S. Robles, and J. R. C. Dizon, "Development of Smartphone-controlled Hand and Arm Exoskeleton for Persons with One-Arm Disability (SCHAX)," Open Engineering, 2021; 11:161–170.

[3] B. J. Tuazon, N. A. V. Custodio, R. B. Basuel, L. A. Delos Reyes, and J. R. C. Dizon, "3D Printing Technology and Materials for Automotive Application: A Mini-Review, Key Engineering Materials, 2022, vol. 913, https://doi.org/10.4028/p-26o076

[4] M. B. De Leon, U. B. Ante, M. S. Velasco, A. O. S. Ng, J. A. V. Garcia, F. P. Liza, R. C. Advincula, and J. R. C. Dizon, "3D-Printing for Cube Satellites (CubeSats): Philippines Perspectives, Engineering Innovations, 2022, vol. 1, https://doi.org/10.4028/p-35niy3.

[5] E. C. Macaraeg, C. R. Rivera, R. D. Dela Rosa, and J. R. C. Dizon, "Establishment of An Academic Makerspace at the Bataan Peninsula State University: Prospects and Challenges," Advance Sustainable Science, Engineering and Technology (ASSET), 2022, vol. 3, no. 2, pp. 0210202-01 ~ 0210202-09, DOI: https://doi.org/10.26877/asset.v3i2.9655.

[6] E. B. Caldona, J. R. C. Dizon, R. A. Viers, V. J. Garcia, Z. J. Smith, and R. C. Advincula, "Additively manufactured high performance polymeric materials and their potential use in the oil and gas industry, MRS Communications," 2021, vol. 11, 701–715, https://doi.org/10.1557/s43579-021-00134-9.

[7] D. W. Martinez, M. T. Espino, H. M. Cascolan, J. L. Crisostomo, and J. R. C. Dizon, "A Comprehensive Review on the Application of 3D Printing in the Aerospace Industry," Key Engineering Materials, 2022, vol. 913, https://doi.org/10.4028/p-94a9zb.

[8] J. L. B. Crisostomo, and J. R. C. Dizon, "3D Printing Applications in Agriculture," "Food Processing, and Environmental Protection and Monitoring," Advance Sustainable Science, Engineering and Technology (ASSET), 2021, vol. 3, No. 2, pp. 0210201-01 ~ 0210201-12, DOI: https://doi.org/10.26877/asset.v3i2.9627

[9] L. Tijing, J. R. C. Dizon, and G. Cruz Jr., "3D-Printed Absorbers for Solar-Driven Interfacial Water Evaporation: A Mini-Review, Advance Sustainable Science, Engineering and Technology, 3, 1, 0210103, 2021. http://journal.upgris.ac.id/index.php/asset/article/view/8367.

[10] R. N. M. Delda, R. B. Basuel, R. P. Hacla, D. W. C. Martinez, J. -J. Cabibihan, and J. R. C.

Dizon, “3D Printing Polymeric Materials for Robots with Embedded Systems and Technologies” 2021, 9, 82. https://doi.org/10.3390/technologies9040082.
[11] H. Wilkins, “Souvenirs: What and Why We Buy,” J. Travel Res., 2011, vol. 50, no. 3, pp. 239–247, doi: 10.1177/0047287510362782.
[12] L. Héroux and N. J. Church, “Marketing Strategies of Gift and Souvenir Shops in Canada and the United States,” Téoros, 2018, vol. 33, no. 2, pp. 1–19, doi: 10.7202/1042438ar.
[13] M. Meitiana, M. Setiawan, F. Rohman, and D. W. Irawanto, “Factors affecting souvenir purchase behavior: valuable insight for tourism marketers and industry,” J. Bus. Retail Manag. Res., 2019, vol. 13, no. 03, pp. 248–255, doi: 10.24052/jbrmr/v13is03/art-22.
[14] K. K. Swanson and D. J. Timothy, “Souvenirs: Icons of meaning, commercialization, and commoditization,” Tour. Manag., 2012, vol. 33, no. 3, pp. 489–499, doi: 10.1016/j.tourman.2011.10.007.
[15] L. F. Anderson and M. A. Littrell, “Souvenir-Purchase Behavior of Women Tourists,” 1995, vol. 22, no. 2, pp. 328–348.
[16] S J. Cave, and D. Buda, Souvenirs as transactions in place and identity: Perspectives from Aotearoa New Zealand. In J. Cave, L. Jolliffe, and T. Baum (Editors) 2013, Tourism Souvenirs: Glocal Perspectives on the Margins. Clevedon, UK: Channel View. Tourism and Cultural Exchange Series, pp. 98-118, DOI: 10.21832/9781845414078-008.
[17] P. Paraskevaidis and K. Andriotis, “Values of souvenirs as commodities,” Tour. Manag., 2015, vol. 48, pp. 1–10, doi: 10.1016/j.tourman.2014.10.014.
[18] F. Thompson, K. Hannam, and K. Petrie, “Producing Ceramic Artworks through Tourism Research,” Ann. Tour. Res., 2012, vol. 39, no. 1, pp. 336–360, doi: 10.1016/j.annals.2011.06.006.
[19] E. Dussel, “No Title이것은 임시도서,” la “conquista” a la “colonización” del mundo la vida, 1994, vol. 1982, p. 323.
[20] B. Neuhofer, D. Buhalis, and A. Ladkin, “Journal of Destination Marketing & Management Conceptualising technology enhanced destination experiences,” J. Destin. Mark. Manag., 2012, vol. 1, no. 1–2, pp. 36–46, doi: 10.1016/j.jdmm.2012.08.001.
[21] A. Alafaghani, A. Qattawi, and M. A. Ablat, “Design Consideration for Additive Manufacturing: Fused Deposition Modelling,” Open J. Appl. Sci., 2017, vol. 07, no. 06, pp. 291–318, doi: 10.4236/ojapps.2017.76024.
[22] S. J. Berman, “Digital transformation: Opportunities to create new business models,” Strateg. Leadersh., vol. 40, no. 2, pp. 16–24, 2012, doi: 10.1108/10878571211209314.
[23] C. Anastasiadou and S. Vettese, “‘ From souvenirs to 3D printed souvenirs ’. Exploring the capabilities of additive manufacturing technologies in (re) -framing tourist souvenirs,” Tour. Manag., vol. 71, no. June 2018, pp. 428–442, 2019, doi: 10.1016/j.tourman.2018.10.032.
[24] E. Further, “Scan the World We are a community-built museum of the future archiving the world’s sculptures, statues, and artifacts using 3D scanning and printing technology .”
[25] M. Groenendyk and R. Gallant, “3D printing and scanning at the Dalhousie University Libraries: A pilot project,” Libr. Hi-Tech, vol. 31, no. 1, pp. 34–41, 2013, doi: 10.1108/07378831311303912.
[26] J. Kietzmann, L. Pitt, and P. Berthon, “Disruptions, decisions, and destinations: Enter the age of 3-D printing and additive manufacturing,” Bus. Horiz., vol. 58, no. 2, pp. 209–215, 2015, doi: 10.1016/j.bushor.2014.11.005.
[27] T. Rayna and L. Striukova, “Open innovation 2.0: Is co-creation the ultimate challenge?” Int. J. Technol. Manag., vol. 69, no. 1, pp. 38–53, 2015, doi: 10.1504/IJTM.2015.071030.
[28] M. Fairs, “Reduced Carbon Footprint Souvenirs by Héctor Serrano,” Dezeen, 2008.
[29] R. Naty, “Statistics and Tourism Growth,” 1Bataan, 2019.
[30] Bataan.gov.ph, “ Special Events and Festivals in Bataan”, Travel to the Philippines, 2012.

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220202-01 ~ 0220202-12
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.13332

Bibliometric Mapping Analysis of Nanocrystalline Starch in Food Packaging Application using VOSviewer

Asep Bayu Dani Nandiyanto[1*], Alifa Listina Dewi[1]

[1]Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alama, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudhi No. 229 Bandung 40154, West Java, Indonesia

*nandiyanto@upi.edu

Abstract. Biodegradable materials needed to reduce packaging waste and extend food shelf life. Starch nanomaterials are one of the promising alternatives as environmentally friendly sustainable food packaging for single-use products. This study was to conduct a bibliometric analysis of starch nanocrystal research in food packaging applications using mapping analysis on VOSviewer software. Data was obtained from Google Scholar search which is integrated with Publish or Perish as a reference application. The data search was based on the keywords "nanocrystalline, starch, food, packaging, chemistry". The results showed that there were 1000 articles that met the research keyword criteria with visualization showing 269 items and 10706 links divided into 8 clusters. The results of the analysis show that the number of research publications from 2012 to 2022 has increased every year until 2021. However, in 2022 the number of articles published decreased quite dramatically. This research is expected to help further researchers and be a consideration in deciding the research topic.
Keywords: bibliometric, nanocrystalline starch, food packaging, VOSviewer

(Received 2022-09-25, Accepted 2022-10-29, Available Online by 2022-10-31)

1. Introduction

Application of nanotechnology in food packaging aims to improve the characteristics of food packaging materials, such as strength, antimicrobial properties, and stability to temperature **[1]**. Most of the materials used for food packaging are non-biodegradable resulting in waste that has the potential to become serious global problem. In reducing packaging waste and extending food shelf life, biomaterials are needed to develop edible and biodegradable films/coatings. Biopolymers such as starch-based materials are a promising alternative for a good environmental health as sustainable food packaging for single-use products **[2]**.

Over the years, starch nanomaterials is a concern due to their heteropolymer structure that can be used in various applications **[3]**. Starch as nanoparticles has a high binding strength so that it can be applied as a reinforcement or filler for synthetic or plastic polymers **[4] [5]**. Many researches have been

studied about application of starch nanomaterials in the food sector as food packaging materials. Starch nanocrystals used as food packaging that can decompose naturally **[6]**. Furthermore, reported that green sago starch nanocrystals can be used as reinforcement, barrier capacity, and good hydrophobicity for food packaging **[7]**. In addition, rice starch layers containing nanocrystalline were reported as good candidates for food packaging **[8]**. The use of starch nanoparticles as nanofiller for the synthesis of nanocomposite films has been extensively studied recently **[9] [10] [11] [12] [13]**. The scientific study of starch nanoparticles to improve packaging quality is a very promising field. Application of starch nanocrystals as industrial packaging continues to look for innovative solutions to create an efficient and sustainable system. Starch nanoparticles have become the focus of an increasing number of scientific papers with the aim of developing bio composite by combining starch nanoparticles with different biopolymer matric.

Before conducting further studies, it is necessary to analyze interesting and relevant topics to be discussed in developing starch nanocrystals as industrial packaging. The future food industry plays an important role in finding new starch sources, modifying processes, mechanical properties, functional properties, improving the performance of starch-based materials by mixing with other biopolymers, as well as the use of micro and nano-sized reinforcement. One way to do this is through bibliometric analysis.

Therefore, this study aims to mapping bibliometric analysis of nanocrystalline starch in food packaging in the VOSviewer application with the Google Scholar database integrated into the Publish or Perish application. The results of this study are expected to help further researchers in deciding research topics, especially those related to the development of food packaging with starch nanocrystals.

2. Methods

Data in this study were obtained from articles that published in journals indexed by Google Scholar. Google Scholar is a publication search engine that can be accessed freely and some of its features support the search for published research results. Google Scholar is integrated with Publish or Perish to calculate citations and some related information as well as a reference manager application to get research data by searching *Google Scholar Search*. Publish or Perish software used by entering keywords, publication type, and year of publication. Search article data with the keywords "*nanocrystalline, starch, food, packaging, chemistry*" in the 2012-2022 range. The data obtained is saved as a result in *.ris and *csv formats. Furthermore, the visualization and analysis of the trend of the mapping bibliometric was carried out using the VOSviewer software. The data obtained are mapped into three forms of visualization including, network visualization, density visualization, and overlay visualization.

3. Results and Discussion

3.1. Publication data search results

Based on the results of collected by publication data based on the Google Scholar through the Publish or Perish reference manager application, 1000 articles were obtained that met the research keyword criteria. Search results in *csv file format display metadata including number of citations, author, title, year, journal name, publisher, rating, article links, and related URLs. Based on the data displayed by Publish or Perish (see Figure 1), the total number of citations for all articles is 34483 with the number of citations per year 3448.30, citations per article 34.48, and authors per article 4.01. The impact and productivity of published articles is measured by the h-index value of 94 with hI,annual (per year) 4.3; g-index 141; hI, norm 43; and hA-index 39. Table 1 shows the 50 relevant articles with the highest number of citations

Results	Help
Publication years:	2012-2022
Citation years:	10 (2012-2022)
Papers:	1000
Citations:	34483
Cites/year:	3448.30
Cites/paper:	34.48
Authors/paper:	4.01
h-index:	94
g-index:	141
hI,norm:	43
hI,annual:	4.30
hA-index:	39

Figure 1. Results of article search data obtained from the Publish or Perish reference manager

Table 1. Relevant published data regarding starch nanocrystals in food packaging applications

No	Authors	Title	Year	Cites
1	B Hassan, SAS Chatha, AI Hussain, KM Zia…	Recent advances on polysaccharides, lipids and protein based edible films and coatings: A review	2018	573
2	D Trache, MH Hussin, CTH Chuin, S Sabar…	Microcrystalline cellulose: Isolation, characterization and bio-composites application—A review	2016	435
3	H Wang, J Qian, F Ding	Emerging chitosan-based films for food packaging applications	2018	424
4	X He, HM Hwang	Nanotechnology in food science: Functionality, applicability, and safety assessment	2016	384
5	F Garavand, M Rouhi, SH Razavi, I Cacciotti…	Improving the integrity of natural biopolymer films used in food packaging by crosslinking approach: A review	2017	322
6	MP Arrieta, J López, A Hernández, E Rayón	Ternary PLA–PHB–Limonene blends intended for biodegradable food packaging applications	2014	319
7	S Ranjan, N Dasgupta, AR Chakraborty…	Nanoscience and nanotechnologies in food industries: opportunities and research trends	2014	261
8	I Majid, GA Nayik, SM Dar, V Nanda	Novel food packaging technologies: Innovations and future prospective	2018	222

9	N Duran, PD Marcato	Nanobiotechnology perspectives. Role of nanotechnology in the food industry: a review	2015	217
10	YI Cornejo-Ramírez, O Martínez-Cruz…	The structural characteristics of starches and their functional properties	2018	205
11	J Wróblewska-Krepsztul, T Rydzkowski…	Recent progress in biodegradable polymers and nanocomposite-based packaging materials for sustainable environment	2018	185
12	B Khan, M Bilal Khan Niazi, G Samin…	Thermoplastic starch: A possible biodegradable food packaging material—A review	2017	177
13	M Atef, M Rezaei, R Behrooz	Preparation and characterization agar-based nanocomposite film reinforced by nanocrystalline cellulose	2014	149
14	H Tian, J Yan, AV Rajulu, A Xiang, X Luo	Fabrication and properties of polyvinyl alcohol/starch blend films: Effect of composition and humidity	2017	142
15	A Ali, Y Chen, H Liu, L Yu, Z Baloch, S Khalid…	Starch-based antimicrobial films functionalized by pomegranate peel	2019	138
16	AM Salaberria, J Labidi, SCM Fernandes	Chitin nanocrystals and nanofibers as nano-sized fillers into thermoplastic starch-based biocomposites processed by melt-mixing	2014	130
17	AI Cano, M Cháfer, A Chiralt…	Physical and microstructural properties of biodegradable films based on pea starch and PVA	2015	123
18	K Ramachandraiah, SG Han…	Nanotechnology in meat processing and packaging: potential applications—a review	2015	120
19	E Ogunsona, E Ojogbo, T Mekonnen	Advanced material applications of starch and its derivatives	2018	113

20	J Muller, C González-Martínez, A Chiralt	Poly (lactic) acid (PLA) and starch bilayer films, containing cinnamaldehyde, obtained by compression moulding	2017	110
21	KK Dash, NA Ali, D Das, D Mohanta	Thorough evaluation of sweet potato starch and lemon-waste pectin based-edible films with nano-titania inclusions for food packaging applications	2019	106
22	N Bumbudsanpharoke, J Choi…	Applications of nanomaterials in food packaging	2015	106
23	K Piyada, S Waranyou, W Thawien	Mechanical, thermal and structural properties of rice starch films reinforced with rice starch nanocrystals	2013	105
24	M Fazeli, M Keley, E Biazar	Preparation and characterization of starch-based composite films reinforced by cellulose nanofibers	2018	104
25	S Tabasum, M Younas, MA Zaeem, I Majeed…	A review on blending of corn starch with natural and synthetic polymers, and inorganic nanoparticles with mathematical modeling	2019	104
26	R Jumaidin, SM Sapuan, M Jawaid, MR Ishak…	Characteristics of thermoplastic sugar palm Starch/Agar blend: Thermal, tensile, and physical properties	2016	103
27	JBA Da Silva, FV Pereira, JI Druzian	Cassava starch-based films plasticized with sucrose and inverted sugar and reinforced with cellulose nanocrystals	2012	97
28	L Dai, J Zhang, F Cheng	Effects of starches from different botanical sources and modification methods on physicochemical properties of starch-based edible films	2019	97
29	A Bratovčić, A Odobašić, S Ćatić…	Application of polymer nanocomposite materials in food packaging	2015	94

30	S Ali Akbari Ghavimi, MH Ebrahimzadeh…	Polycaprolactone/starch composite: Fabrication, structure, properties, and applications	2015	90
31	E Šárka, V Dvořáček	New processing and applications of waxy starch (a review)	2017	85
32	A Chávez-Salazar, LA Bello-Pérez…	Isolation and partial characterization of starch from banana cultivars grown in Colombia	2017	82
33	J Jeevahan, M Chandrasekaran	Nanoedible films for food packaging: A review	2019	81
34	SJ Wesley, P Raja, AAS Raj…	Review on-nanotechnology applications in food packaging and safety	2014	79
35	LM Fonseca, CE dos Santos Cruxen, GP Bruni…	Development of antimicrobial and antioxidant electrospun soluble potato starch nanofibers loaded with carvacrol	2019	73
36	P Shao, H Zhang, B Niu, W Jin	Physical stabilities of taro starch nanoparticles stabilized Pickering emulsions and the potential application of encapsulated tea polyphenols	2018	68
37	P Chaudhary, F Fatima, A Kumar	Relevance of nanomaterials in food packaging and its advanced future prospects	2020	67
38	JHR Llanos, CC Tadini	Preparation and characterization of bio-nanocomposite films based on cassava starch or chitosan, reinforced with montmorillonite or bamboo nanofibers	2018	65
39	E Fortunati, A Mazzaglia…	Sustainable control strategies for plant protection and food packaging sectors by natural substances and novel nanotechnological approaches	2019	65
40	M Cheng, J Wang, R Zhang, R Kong, W Lu…	Characterization and application of the microencapsulated carvacrol/sodium alginate films as food packaging materials	2019	59

41	V Goudarzi, I Shahabi-Ghahfarrokhi	Photo-producible and photo-degradable starch/TiO2 bionanocomposite as a food packaging material: Development and characterization	2018	57
42	A Mukurumbira, M Mariano, A Dufresne…	Microstructure, thermal properties and crystallinity of amadumbe starch nanocrystals	2017	55
43	H Molavi, S Behfar, MA Shariati, M Kaviani…	A review on biodegradable starch based film	2021	55
44	P Jariyasakoolroj, P Leelaphiwat…	Advances in research and development of bioplastic for food packaging	2020	54
45	N Devi, J Dutta	Development and in vitro characterization of chitosan/starch/halloysite nanotubes ternary nanocomposite films	2019	48
46	ML Sanyang, SM Sapuan, M Jawaid…	Effect of plasticizer type and concentration on dynamic mechanical properties of sugar palm starch–based films	2015	46
47	M Guimarães, VR Botaro, KM Novack…	High moisture strength of cassava starch/polyvinyl alcohol-compatible blends for the packaging and agricultural sectors	2015	42
48	A Azfaralariff, FF Fazial, RS Sontanosamy…	Food-grade particle stabilized pickering emulsion using modified sago (Metroxylon sagu) starch nanocrystal	2020	41
49	K Gonzalez, L Iturriaga, A Gonzalez, A Eceiza…	Improving mechanical and barrier properties of thermoplastic starch and polysaccharide nanocrystals nanocomposites	2020	37
50	A Plucinski, Z Lyu, BVKJ Schmidt	Polysaccharide nanoparticles: from fabrication to applications	2021	33

3.2. Research development of nanocrystalline starch in food packaging application

Based on research data from Publish or Perish, an analysis of the development of starch nanocrystal research in food packaging applications from 2012 to 2022 is summarized in **Table 2**.

Table 2. Research developments of starch nanocrystals in food packaging

Year	Number of Publication
2012	13
2013	26
2014	32
2015	38
2016	43
2017	60
2018	108
2019	129
2020	172
2021	219
2022	156
Average	**90.55**

The relationship between the number of articles published in each year is depicted by a curve (see Figure 2). The data shows the development of research from year to year, it can be seen that the number of related research publications has increased every year until 2021. From 2012 to 2017, the increase in the number of publications that occurred did not differ significantly, as shown by a gentle curve. Then, the curve rose sharply from 2017 to 2018 showing a significant increase from 60 to 108 published articles. The same thing happened in 2019-2021 with an increase of 90 articles from the previous total. However, in 2022 the number of articles published decreased quite dramatically from 219 to 156 articles.

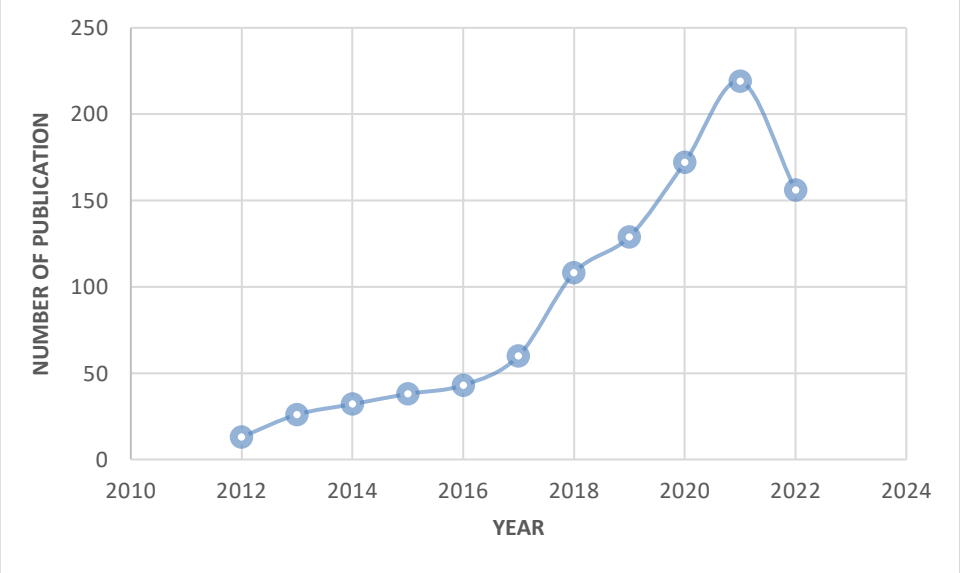


Figure 2 Development of publication of articles on starch nanocrystal research in food packaging application

3.3. Visualization nanocrystalline starch topic area using VOSviewer

VOSviewer displays a bibliometric map that interprets a relationship. VOSviewer software has several characteristics including, it can map various types of bibliometric analysis, supports several bibliographic databases, limits the analysis of small to medium amounts of data in a certain time. This mapping is a function of text processing using layout and cluster techniques with visualization features [11]. The results of the visualization of research mapping related to starch nanocrystals in food packaging applications show 269 items with a total of 10706 links which are divided into 8 clusters, namely:

a. Cluster 1 consists of 48 items including, antimicrobial agent, antimicrobial film, antimicrobial property, bio, biodegradable packaging, biodegradable polymer, biomedical application, bio nanocomposite film, bioplastic, cellulose nanofiber, chemistry, chitin, chitin nanocrystal, chitosan, cnc, cnf, cross, derivative, environment, form, investigation, matrix, mechanical property, nanocellulose, nanocomposite, nanocrystal, nanofiber, nanomaterial, ncc, opportunity, optical property, overview, paper, pbat, polylactic acid, process, prospect, recent advance, recent progress, review, state, thermoplastic starch, treatment, type, wvp, zinc oxide, zinc oxide nanoparticle
b. Cluster 2 consists of 46 items including, acid hydrolysis, advance, approach, bacterial cellulose nanocrystal, banana starch, biodegradable packaging material, chemical characteristic, chemical method, chemical modification, citric acid, comparison, emulsion, esterification, filler, functional property, gelatin, granule, green chemistry, hydrolysis, hydroxyl group, microcrystalline cellulose, microstructure, modification, native starch, packaging, physical, physicochemical property, plastic, plasticizer, product, properties, reagent, rice starch, size, snc, solution, starch, starch granule, starch nanocrystal, starch nanoparticle, structure, surface, surface modification, synthesis, utilization, water.
c. Cluster 3 consists of 44 items including, ability, acid, active film, agent, antioxidant property, behavior, biodegradable material, bio nanocomposite, case, cassava, cellulose nanocrystal, cellulose nanocrystals, characterization, chemical change, chemical structure, chemical treatment, chitosan film, cncs, corn, corn starch, crystallinity, drug delivery, effect, enhancement, fabrication, fermentation, fiber, field, ftir, isolation, lactic acid, morphology, oil, polyvinyl alcohol, potato, potato starch, potential, processing, raw material, rice, study, sugar, sugarcane bagasse, tensile
d. Cluster 4 consists of 39 items including active food packaging, active packaging, anthocyanin, biodegradable film, cationic starch, chemical bound, chemical crosslinking, chemical interaction, component, curcumin, development, edible film, essential oil, evaluation, ectuction, film, food additive, food packaging, food packaging film, impact, improvement, morphological property, nanocomposite film, natural polymer, packaging application, pea starch, pectin, polysaccharide, potential application, potential use, preparation, property, protein, pva, quality, researcher, safety, stability, vinyl alcohol.
e. Cluster 5 consists of 32 items including, antimicrobial activity, arenga pinata, bio nanocomposite, biodegradability, biodegradation, cellulose, characteristics, chemical reaction, chemical similarity, compatibility, composite, comprehensive review, degradation, fibre, food packaging application, food packaging material, food product, nanocrystalline, nanocrystalline cellulose, packaging film, physical property, physicochemical property, polymer, reinforcement, shelf life, starch film, sugar palm, sugar palm starch, synthetic polymer, tio, water barrier property
f. Cluster 6 consists of 29 items including addition, advantage, analytical grade, antibacterial activity, application, barrier property, biopolymer, cassava starch, cellulose nanofibril, chemical, chemical reagent, coating, fact, food, food packaging industry, low cost, mechanical, mechanical treatment, nanofiller, nanoparticle, optimization, packaging industry, performance, production, source, starch matrix, storage, textile, vaue
g. Cluster 7 consists of 23 items including, alternative, bacterial cellulose, bio composite, chemical resistance, combination, composite film, content, food chemistry, food industry, glycerol, hemicellulose, hydrophobicity, interaction, lignin, nanotechnology, packaging material, rice starch

nanocrystal, silver nanoparticle, soy protein, strength, structural property, surface chemistry, thermal stability.

h. Cluster 8 consists of 9 items including agriculture, chemical composition, chemical property, extraction, formation, influence, medicine, morphological, thermal property.

Each visualized cluster shows the relationship between one term and another. The size of the letters and circles correlated positively with the occurrence of keywords and abstracts of related articles. That is, the size of the circle is determined by the frequency of its occurrence, the more it appears, the larger the size and letters visualized [12]. Bibliometric mapping in VOSviewer is displayed in three different visualizations, network visualization (**Figure 3**) shows the relationship between terms in the topic of nanocrystalline starch in food packaging which is connected by various lines to form a network. This visualization depicts clusters from each research area studied, such as starch nanocrystals in cluster 2 with 120 occurrences, 193 links and a total link strength of 819. Starch nanocrystals are associated with food packaging terms, nanocomposite films, and biodegradable films in cluster 4. Density visualization (**Figure 4**) shows that the brighter the yellow color, the larger the size of the term circle. That is, a lot of research involving the term has been done. On the other hand, when the color fades and resembles a background color, it shows that there is little research on the term [13]. The results of density visualization show that studies on starch, food packaging, and films have a high number of studies

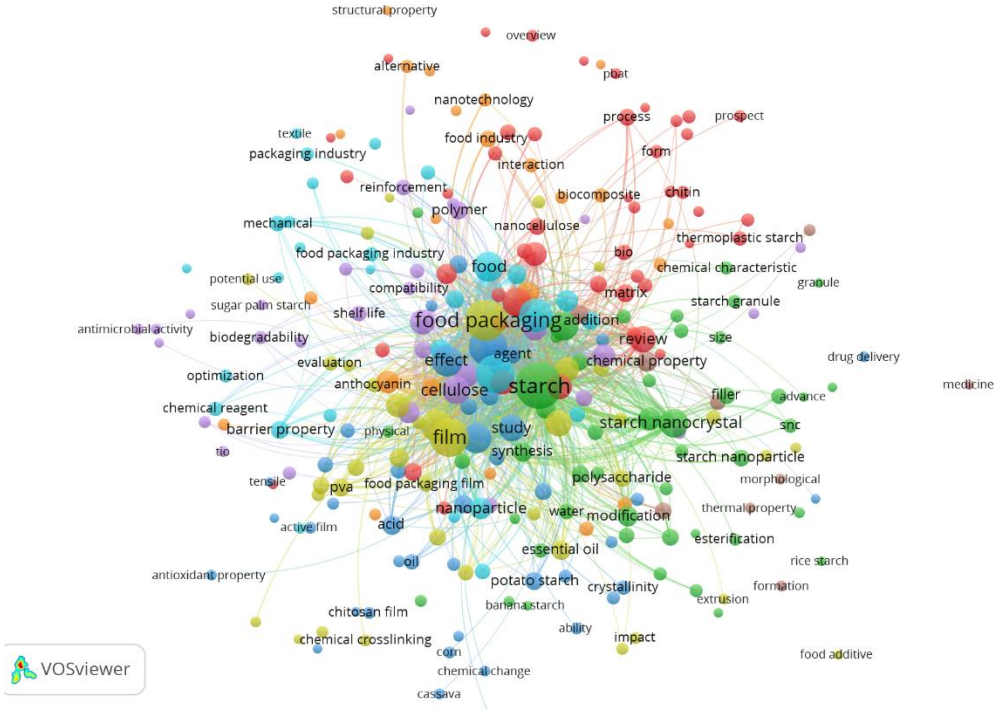


Figure 3 Network visualization with keywords nanocrystal, starch, food, packaging, chemistry in VOSviewer

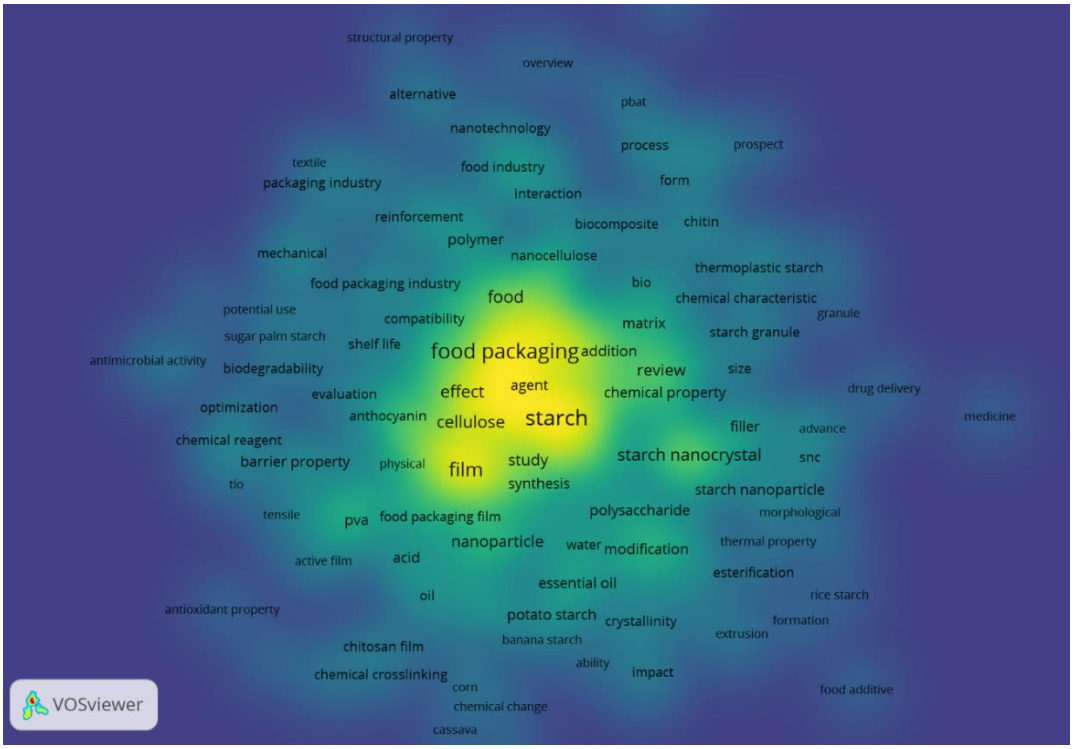


Figure 4 Network visualization with keywords nanocrystal, starch, food, packaging, chemistry in VOSviewer

4. Conclusion

This study aims to analyze bibliometric mapping related to starch nanocrystal research in food packaging applications using VOSviewer. The article data to be analyzed is obtained from the Publish or Perish reference manager application with the Google Scholar database. The data obtained relates to the keywords "nanocrystalline, starch, food, packaging, chemistry" in the year 2012-2022 with a total of 1000 articles relevant to 269 items and 10706 links divided into 8 clusters. The results showed that the number of related research publications increased every year until 2021. From 2012 to 2017, the increase in the number of publications did not differ significantly. A significant increase occurred in 2017 to 2018. Recently, in 2019 to 2021 there was a significant increase. However, in 2022 the number of articles published decreased quite dramatically. The results of the analysis show that research on starch nanocrystals in food packaging applications still has the potential to increase publications this year and the following year.

Acknowledgements
This study acknowledgement Universitas Pendidikan Indonesia and Advanced Sustainable Science, Engineering, and Technology.

References

[1] A. Sudibyo, "Penerapan Nanoteknologi dalam Industri Pangan dan Pengembangan Regulasinya," *Journal of Industrial Research,* vol. 3, no. 2, 2008.

[2] G. Cabrera-Barjas, L. Garcia-Guzman, C. G. Soria-Hernandez, J. Castano, A. Y. Guadarrama-Lezama and S. Rodriguez Lamazares, "Progress in Starch-Based Materials for Food Packaging Applications," *Polysaccharides,* vol. 1, no. 3, pp. 136-177, 2022.

[3] Hakke et al, "Ultrasound assisted synthesis of starch nanocrystals and its application with polyurethane for packaging film," *Journal of Renewable Materials,* vol. 3, no. 8, 2020.

[4] Angellier et al, "Optimization of the preparation of aqueous suspensions of waxy maize starch nanocrystals using a response surface methodology," *Biomacromolecules,* vol. 4, no. 5, pp. 1545-1551, 2004.

[5] Kristo et al, "Physical properties of starch nanocrystal reinforced pullulan films," *Carbohydrate Polymers,* no. 68, pp. 146-158, 2007.

[6] Escobar-Puentes, "Effect of amylose/amylopectin content and succinylation on properties of corn starch nanoparticles as encapsulants of anthocyanins," *Carbohydrate polymers,* no. 250, 2020.

[7] Ahmad et al, "Green sago starch nanoparticles as reinforcing material for green composites," *Polymer,* no. 202, 2020.

[8] Piyada et al, "Mechanical, thermal, and structural properties of rice starch films reinforced with rice starch nanocrystals," *International Food Research Journal,* vol. 1, no. 20, 2013.

[9] Slavutsky et al, "Water barrier properties of starch-clay nanocomposite films," *Brazilian Journal of Food Technology,* vol. 3, no. 15, pp. 208-218, 2012.

[10] Babu et al, "Current progress on bio-based polymers and their future trends," *Progress in Biomaterials,* vol. 1, no. 2, 2013.

[11] Zia et al, "Starch based polyurethanes: a critical review updating recent literature," *Carbohydrate polymers,* no. 134, 2015.

[12] Al Husaeni et al, "Bibliometric computational mapping analysis of publications on mechanical engineering education using vosviewer.," *Journal of Engineering Science and Technology,* vol. 2, no. 17, pp. 1135-1149, 2022.

[13] Al Husaeni et al, "Bibliometric using Vosviewer with Publish or Perish (using google scholar data): From step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post Covid-19 pandemic.," *ASEAN Journal of Science and Engineering,* vol. 1, no. 2, pp. 19-46, 2022.

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220203-01 ~ 0220203-11
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.13336

Bibliometric Analysis of Aluminium Oxide Nanoparticle in Biomedical Applications

Zahrah Rufaida[1], Asep Bayu Dani Nandiyanto[1*]

Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Jl. Setiabudi No. 229 Bandung 40154, West Java, Indonesia

*nandiyanto@upi.edu

Abstract. Aluminium oxide nanoparticles are materials that can be used in various applications, for example in biomedicine. The purpose of this study was to determine research trends on Al_2O_3 nanoparticles in biomedical applications using bibliometric analysis. The data used in this study was obtained from Google Scholar using the Publish or Perish reference manager and data visualization using VOSviewer. The data obtained were based on the keywords Al_2O_3 nanoparticle, aluminium oxide nanoparticle, and biomedical application. Based on the analysis, we found 987 articles relevant to the keywords from 2012–2022. The results show that research on Al_2O_3 nanoparticles in biomedical applications from 2012–2022 tends to increase with the most articles in 2012, as many as 196 articles. This bibliometric analysis is expected to help other researchers who will conduct research on the same theme as discussed in this article.

Keywords: bibliometric, Al_2O_3 nanoparticle, biomedical application

(Received 2022-09-25, Accepted 2022-10-29, Available Online by 2022-10-31)

1. Introduction

Nanotechnology can be interpreted as the design, characterization, production, and application by controlling shape and size at the nanoscale (<100 nm). Modern nanotechnology can produce various metal or non-metallic particles in nano size which also called nanomaterials or nanoparticles with unique mechanical, optical, electrical, and magnetic properties [1], [2]. Alumina is an aluminium oxide compound with the formula Al_2O_3. Al_2O_3 nanoparticles are metal oxide materials and are included in nanomaterials with pores that are thermodynamically stable at various temperatures [3], [4]. Al_2O_3 is one of the most produced nano-sized chemicals, it is even estimated to reach 20% of all nanoparticle materials in 2005. There are various methods of synthesizing Al_2O_3 nanoparticles, there are precipitation, combustion, sol-gel, wet chemical, synthesis under supercritical water conditions, with microwaves, mechano-chemically, and hydrolysis [5].

Al_2O_3 nanoparticles are widely used in catalysts, ceramics, materials that can increase cement strength, polymer modification, textile functionalization, heat transfer fluids, and wastewater treatment [6], [7]. In addition, Al_2O_3 nanoparticles have also been investigated for various biomedical applications,

such as in drug delivery systems, biosensing, cancer therapy, anti-microbial effects, immunotherapy, and anti-bacteria [2], [3]. Beside that, high purity-Al_2O_3 nanoparticles can be used in bio-ceramic applications [8].

From this explanation, it can be seen that Al_2O_3 nanoparticles have various benefits in life. So, knowledge of research trends is needed for the development of applications of Al_2O_3 nanoparticles. Bibliometric analysis is a form of meta-analysis of research data that researchers can use to study bibliographic content and citation analysis from articles published in journals or other scientific works [9]. Bibliometrics can be used to evaluate research that has been conducted annually, both qualitatively and quantitatively. Visualization of bibliometric analysis is carried out using software, one of which is VOSviewer which is included in open source and free [10].

Bibliometric analysis has been carried out on various types of research, for example bibliometric analysis on research trends in drug delivery and magnetic nanoparticles [11]; cancer therapy using nanoparticles [12]; research progress on transition metals in biomedicine [13]; chitosan and PVC polymers in biomedical applications [14]; and silver nanoparticles in biomedical applications [15]. In addition, bibliometric analysis of nanoparticles has been carried out on the nanoparticles toxicity on algae [16]. However, until now, there has been no bibliometric analysis of Al_2O_3 nanoparticles in biomedical applications.

This study aims to determine research trends on aluminium oxide nanoparticles in biomedical applications during the period 2012–2022 using bibliometric analysis. In this analysis, the data obtained from Publish or Perish and visualized using VOSviewer software. This analysis is expected to be a reference for researchers to start appropriate research, especially those related to aluminium oxide nanoparticles.

2. Methods

In the Publish or Perish application, keywords are used in the form of "Al_2O_3 nanoparticle, aluminium oxide nanoparticle, biomedical application". After obtaining various articles that containing these keywords, the article data that was publish in 2012–2022 is stored into *.ris format and *.csv format. The next step is visualization and analysis of research trends through mapping using VOSviewer [9]. VOSviewer is a software that can be used to create bibliometric maps by visualizing networks or relationships in citing an article [17]. There are three types of mapping performed during visualization using VOSviewer, namely network visualization, overlay visualization, and density visualization. Before the visualization is done, there are terms that can be selected according to the keywords used.

3. Results and Discussion

3.1. Publication data search result

Based on the search results using the Publish or Perish application from the data obtained in Google Scholar, there were 987 articles that matched with the criteria. The data includes the title, author, year, number of citations, journal name, publisher, article links, and other data. The number of citations from all articles obtained was 26636. All articles obtained have an average h-index of 73 and a g-index of 135. **Table 1.** shows examples of article search results using Publish or Perish.

Table 1. Al_2O_3 nanoparticle in biomedical application publication data from Publish or Perish

No.	Author	Title	Year	Number of citation
1	W Yu, H Xie	A review on nanofluids: preparation, stability mechanisms, and applications	2012	1598
2	SR Saptarshi, A Duschl, AL Lopata	Interaction of nanoparticles with proteins: relation to bio-reactivity of the nanoparticle	2013	931

3	B Tanhaei, A Ayati, M Lahtinen, M Sillanpää	Preparation and characterization of a novel chitosan/Al_2O_3/magnetite nanoparticles composite adsorbent for kinetic, thermodynamic and isotherm studies of Methyl Orange adsorption	2015	404
4	GEJ Poinern, S Brundavanam, D Fawcett	Biomedical magnesium alloys: a review of material properties, surface modifications and potential as a biodegradable orthopaedic implant	2012	328
5	IM Hamouda	Current perspectives of nanoparticles in medical and dental biomaterials	2012	249
6	E Bajraktarova-Valjakova, V Korunoska-Stevkovska, B Kapusevska, N Gigovski, C Bajraktarova-Misevska, A Grozdanov	Contemporary dental ceramic materials, a review: chemical composition, physical and mechanical properties, indications for use	2018	143
7	MA Ansari, HM Khan, AA Khan, SS Cameotra, Q Sauib, J Musarrat	Interaction of Al_2O_3 nanoparticles with Escherichia coli and their cell envelope biomolecules	2014	126
8	DK Koli, G Agnihotri, R Purohit	Properties and characterization of Al-Al_2O_3 composites processed by casting and powder metallurgy routes	2013	125
9	P Samal, PR Vundavilli, A Meher, MM Mahapatra	Recent progress in aluminum metal matrix composites: A review on processing, mechanical and wear properties	2020	120
10	PA Prashanth, RS Raveendra, RH Krishna, S Ananda, NP Baghya, BM Nagabhushana, K Lingaraju, HR Naika	Synthesis, characterizations, antibacterial and photoluminescence studies of solution combustion-derived α-Al_2O_3 nanoparticles	2015	115
11	M Jama, T Singh, SM Gamleldin, M Koc, A Samara, RJ Isaifan, MA Atieh	Critical review on nanofluids: preparation, characterization, and application	2016	115
12	SZ Heris, TH Nassan, SH Noie, H Sardarabadi, M Sardarabasi	Laminar convective heat transfer of Al_2O_3/water nanofluid through square cross-sectional duct	2013	111
13	MA Ansari, HM khan, MA Alzohairy, M Jalal, SG Ali, R Pal, J Musarrat	Green synthesis of Al_2O_3 nanoparticles and their bactericidal potential against clinical isolates of multi-drug resistant *Pseudomonas aeruginosa*	2015	109
14	D Yohan, BD Chithrani	Applications of nanoparticles in nanomedicine	2014	101
15	S Parham, DHB Wicaksono, S Bagherbaigi, SL Lee, H Nur	Antimicrobial treatment of different metal oxide nanoparticles: a critical review	2016	97
16	J Sengupta, S Ghosh, P Datta, A Gomes, A Gomes	Physiologically important metal nanoparticles and their toxicity	2014	93

17	ZU Abideen, JH Kim, JH Lee, JY Kim, A Mirzaei, HW Kim, SS Kim	Electrospun metal oxide composite nanofibers gas sensors: A review	2017	91
18	SV Rao, GK Podagatlapalli, S Hamad	Ultrafast laser ablation in liquids for nanomaterials and applications	2014	88
19	CJ DeSantis, RG Weiner, A Radmilovic, MM Bower, SE Skrabalak	Seeding bimetallic nanostructures as a new class of plasmonic colloids	2013	88
20	D Bruggermann	Nanoporous aluminium oxide membranes as cell interfaces	2013	86
21	F Kundie, CH Azhari, A Muchtar, ZA Ahmad	Effects of filler size on the mechanical properties of polymer-filled dental composites: A review of recent developments	2018	86
22	C Bai, M Tang	Toxicological study of metal and metal oxide nanoparticles in zebrafish	2020	82
23	F Parnia, J Yazdani, V Javaherzadeh, SM Dizaj	Overview of nanoparticle coating of dental implants for enhanced osseointegration and antimicrobial purposes	2017	78
24	R Liu, R Lal	Nanoenhanced materials for reclamation of mine lands and other degraded soils: a review	2012	78
25	E Demir, D Burgucu, F Turna, S Aksakal, B Kaya	Determination of TiO_2, ZrO_2, and Al_2O_3 nanoparticles on genotoxic responses in human peripheral blood lymphocytes and cultured embyronic kidney cells	2013	71
26	W Najahi-Missaoui, RD Arnold, BS Cummings	Safe nanoparticles: Are we there yet?	2020	71
27	S Neethirajan, MA Clond, A Vogt	Medical biofilms—nanotechnology approaches	2014	68
28	K Zhou, X Zhou, J Liu, Z Huang	Application of magnetic nanoparticles in petroleum industry: A review	2020	67
29	SD Almeida-Didry, MM Nomel, C Autret, C Honstettre, A Lucas, F Pacreau, F Gervais	Control of grain boundary in alumina doped CCTO showing colossal permittivity by core-shell approach	2018	66
30	JC Wang, H Dommati, SJ Hsieh	Review of additive manufacturing methods for high-performance ceramic materials	2019	65
31	AK Hussein, A Walunj, L Kolsi	Applications of nanotechnology to enhance the performance of the direct absorption solar collectors	2016	64
32	KC Wickramasinghe, H Sasahara, EA Rahim, GIP Perera	Green Metalworking Fluids for sustainable machining applications: A review	2020	64

33	N Biswas, UK Sarkar, AJ Chamkha, NK Manna	Magneto-hydrodynamic thermal convection of Cu–Al_2O_3/water hybrid nanofluid saturated with porous media subjected to half-sinusoidal nonuniform heating	2021	63
34	H Zhang, Z Li, BN Kim, K Morita, H Yoshida, K Hiraga, Y Sakka	Effect of alumina dopant on transparency of tetragonal zirconia	2012	63
35	M Sheikholeslasi, H Sajjadi, AA Delouei, M Atashafrooz, Z Li	Magnetic force and radiation influences on nanofluid transportation through a permeable media considering Al_2O_3 nanoparticles	2019	62
36	M Daroonparvar, MAM Yajid, NM Yusof, HR Bakhsheshi-Rad	Preparation and corrosion resistance of a nanocomposite plasma electrolyte oxidation coating on Mg-1%Va alloy formed in akuminate electrolyte containing titania nano-adictives	2016	59
37	MK Meybodi, A daryasafar, MM Koochi, J Moghadasi, RB Meybodu, AK Ghahfarokhi	A novel correlation approach for viscosity prediction of water based nanofluids of Al_2O_3, TiO_2, SiO_2, and Cu	2016	58
38	HA Derazkola, A Simchi	Effects of alumina nanoparticles on the microstructure, strength and wear resistance of poly (methyl methacrylate)-based nanocomposites prepared by friction stir processing	2018	58
39	AK Mishra, BB Lahiri, J Philip	Thermal conductivity enhancement in organic phase change material (phenol-water system) upon addition of Al_2O_3, SiO_2, and TiO_2 nano-inclusions	2018	52
40	B Mukherjee, OA Rahman, A Islam, M Sribalaji, AK Keshri	Plasma sprayed carbon nanotube and graphene nanoplatelets reinforced alumina hybrid composite coating with outstanding toughness	2017	50
41	JA Ali, AM Kalhury, AN Sabir, RN Ahmed, NH Ali, AD Abdullah	A state-of-the-art review of the application of nanotechnology in the oil and gas industry with a focus on drilling engineering	2020	50
42	KH Huynh, XH Pham, J Kim, SH Lee, H Chang, WY Rho, BH Jun	Synthesis, properties, and biological applications of metallic alloy nanoparticles	2020	49
43	S Nagappan, SS Park, CS Ha	Recent advances in superhydrophobic nanomaterials and nanoscale systems	2014	49
44	EJ Park, GH Lee, C Yoon, U Jeong, Y Kim, MH Cho, DW Kim	Biodistribution and toxicity of spherical aluminum oxide nanoparticles	2016	48
45	M Hasan, J Zhao, Z Jiang	Micromanufacturing of composite materials: a review	2019	48

46	I Nowrouzi, AK Manshad, AH Mohammadi	Effects of TiO_2, MgO, and γ-Al_2O_3 nanoparticles in carbonated water on water-oil interfacial tension (IFT) reduction in chemical enhanced oil recovery (CEOR) process	2019	46
47	V Karagkiozaki, S Logothetidis, AM Pappa	Nanomedicine for atherosclerosis: molecular imaging and treatment	2015	45
48	VK Sharma, V Kumar, RS Joshi	Investigation of rare earth particulate on tribological and mechanical properties of Al-6061 alloy composites for aerospace application	2019	45
49	M Arshadi, F Mousavinia, A Khalafi-Nezhad, H Firouzabadi, A Abbaspourrad	Adsorption of mercury ions from wastewater by a hyperbranched and multi-functionalized dendrimer modified mixed-oxides nanoparticles	2017	43
50	R Chakravarty, A Dash	Role of nanoporous materials in radiochemical separations for biomedical applications	2013	41

3.2. Research developments in the fiels of Al_2O_3 nanoparticle in biomedical application

From the data that we obtained using Publish or Perish, it is known that there are 987 articles published and indexed by Google Scholar with the keywords "Al_2O_3 nanoparticle, aluminium oxide nanoparticle, biomedical application" from 2012–2022. The trend of research developments on aluminium oxide nanoparticles in biomedical applications is shown in **Figure 1.**

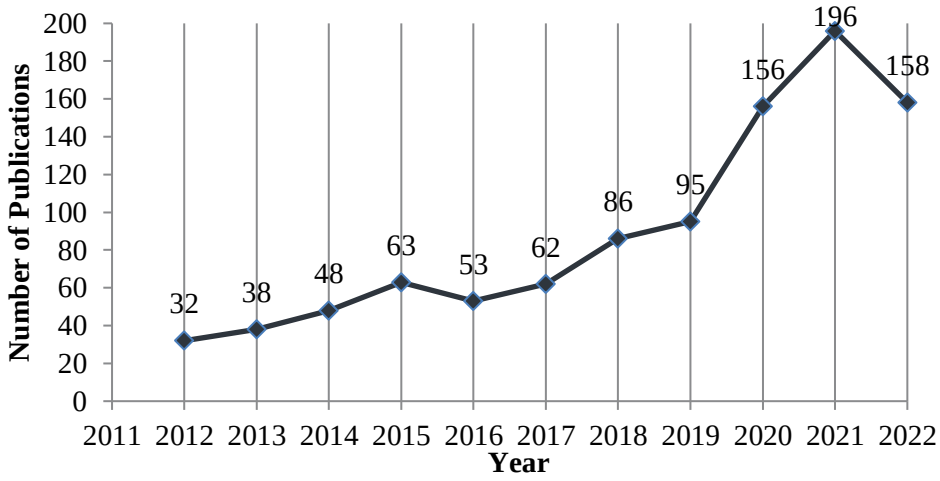


Figure 1. Research trend in aluminium oxide in biomedical application

Figure 1. shows that research related to biomedical applications on Al_2O_3 nanoparticles is increased in 2012 by 32 articles to 63 articles in 2015. However, in 2016 the articles were decreased to 53 articles and increased again in 2017 to 2021. The research on this topic decreased again in 2022, from 196 publications in 2021 to 158 in 2022. The highest number of articles was in 2021 with 196 articles and the lowest was in 2012, which was 32 articles.

3.3. Visualization Al_2O_3 nanoparticle in biomedical application topic area using VOSviewer

Based on the mapping of various research results through the search for Al_2O_3 nanoparticles in biomedical applications, they are divided into 8 clusters, namely:

i. Cluster 1 has 70 items, there are agglomeration, Al_2O_3 nanoparticle, amount, analysis, base fluid, bio medical application, biomedical engineering, biomedical study, biomedical science, characteristic, comparative study, conductivity, convective heat transfer coolant, copper, copper oxide, Cu nanoparticle, CuO, diameter, dispersion, drug, effect, electronic, engineering, enhancement, ethylene glycol, field, flow, fluid, heat transfer, heat transfer application, heat transfer enhancement, hybrid nanofluid, hybrid nanofluid flow, hybrid nanoparticle, impact, increase, magnetic field, magnetic nanoparticle, mechanical, metallic nanoparticle, mixed convection, mixture, nano fluid, nano particle, numerical simulation, performance, porous medium, presence, radiation, sheet, silver, stability, suspension, system, temperature, thermal conductivity, thermal radiation, titanium dioxide, type, variation, viscosity, volume fraction, water, water nanofluid, and wide range.
ii. Cluster 2 has 51 items, there are adsorbent, adsorption, alloy, aluminium, antibacterial activity, atomic layer deposition, attention, biomedical application, ceramic, characterization, coating, comparison, corrosion behavior, decomposition, deposition, development, energy, evaluation, fabrication, formation, graphene, green synthesis, growth, iron oxide nanoparticle, metal, metal nanoparticle, metal oxide nanoparticle, nano Al, nanopowder, nanostructure, optimization, oxidation, phase, plasma, potential biomedical application, powder, preparation, process, removal, sample, sensor, solution, state, structure, study, surface, surface modification, synthesis, technique, thin film, and ZnO nanoparticle.
iii. Cluster 3 has 45 items, there are adverse effect, Al_2O_3, Al_2O_3 np, alumina, aluminium oxide, aluminium oxide nanoparticle, aluminium, aluminium oxide, biomedical field, CaO, catalysis, catalyst, CeO_2, cerium oxide, drug delivery, figure, improvement, iron, magnesium oxide, medical application, metal oxide, MgO, nanofluids, oxide, oxide nanoparticle, oxygen, potential application, SiC, silica, silicon, silicon carbide, SiO, SiO_2, TiO_2, titanium oxide, treatment, utilization, variety, zinc oxide, zinc oxide nanoparticle, zirconium oxide, ZnO, ZrO, and ZrO_2.
iv. Cluster 4 has 39 items, there are addition, aerospace, aluminum nanoparticle, behavior, biocompatibility, composite, corrosion resistance, density, environment, experimental investigation, flexural strength, form, friction, hardness, incorporation, industrial application, industry, influence, investigation, layer, matrix, mechanical property, microstructure, particle, present study, property, reinforcement, role, shape, size, strength, superior property, TiO, TiO_2 nanoparticle, titanium, wear resistance, zirconia, and zirconium.
v. Cluster 5 has 36 items, there are adhesion, alumina nanoparticle, aluminum alloy, aluminum oxide np, application, carbon, carbon nanotube, cell, challenge, chemical, combination, comprehensive review, cytotoxicity, drug delivery system, example, food, gold nanoparticle, hydrogel, interest, membrane, nano, nanocomposite, nanomaterial, novel, overview, poly, polymer, production, recent advance, recent progress, research, review, silicon dioxide, toxicity, use, and wastewater treatment.
vi. Cluster 6 has 17 items, there are Ag nanoparticle, AgNP, biomedical use, composition, Fe_2O_3, Fe_3O_4, gene, interaction, iron oxide, magnesium, modification, nanoparticles, pva, recent development, silver nanoparticle, titanium alloy, and way.
vii. Cluster 7 has 11 items, there are additive, aluminum oxide nanoparticle, basis, bulk, concentration, efficiency, minimum quantity lubricant, nanomedicine, oil, steel, and vegetable oil.
viii. Cluster 8 has 3 item, there are area, nanotechnology, and science.

The eigth clusters are marked with different colors, red for cluster 1, green for cluster 2, dark blue for cluster 3, yellow for cluster 4, purple for cluster 5, light blue for cluster 6, orange for cluster 7, and brown for cluster 8. The relationship between one topic and another is shown in Figure 2. for network visualization, Figure 3. for overlay visualization, and Figure 4. for density visualization.

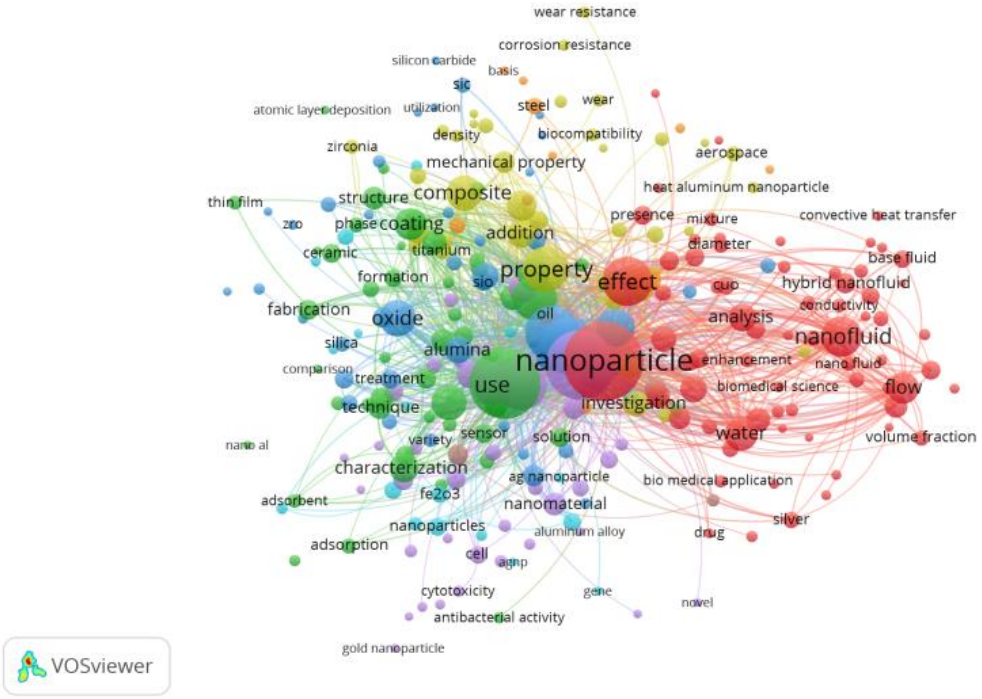


Figure 2. Network visualization for Al_2O_3 nanoparticle, aluminium oxide nanoparticle, and biomedical keywords

Figure 2. shows the relationship between the topics found in the cluster is illustrated with a line connecting each topic to another [9]. In the network visualization found in Figure 2., different colors indicate which cluster the topic belongs to [18]. From Figure 2. for Al_2O_3 nanoparticle items, found in cluster 1 with 101 links and 22 occurrences, for aluminum oxide nanoparticles, found in cluster 3 with 60 links and 16 occurrences, and for biomedical application items found in cluster 2 with 252 links and 313 occurrences.

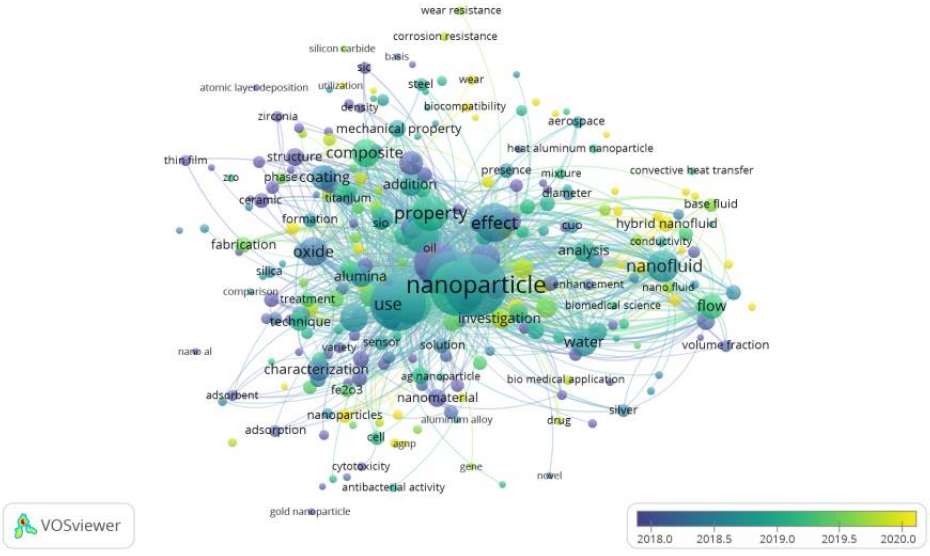


Figure 3. Overlay visualization for Al_2O_3 nanoparticle, aluminium oxide nanoparticle, and biomedical application keywords

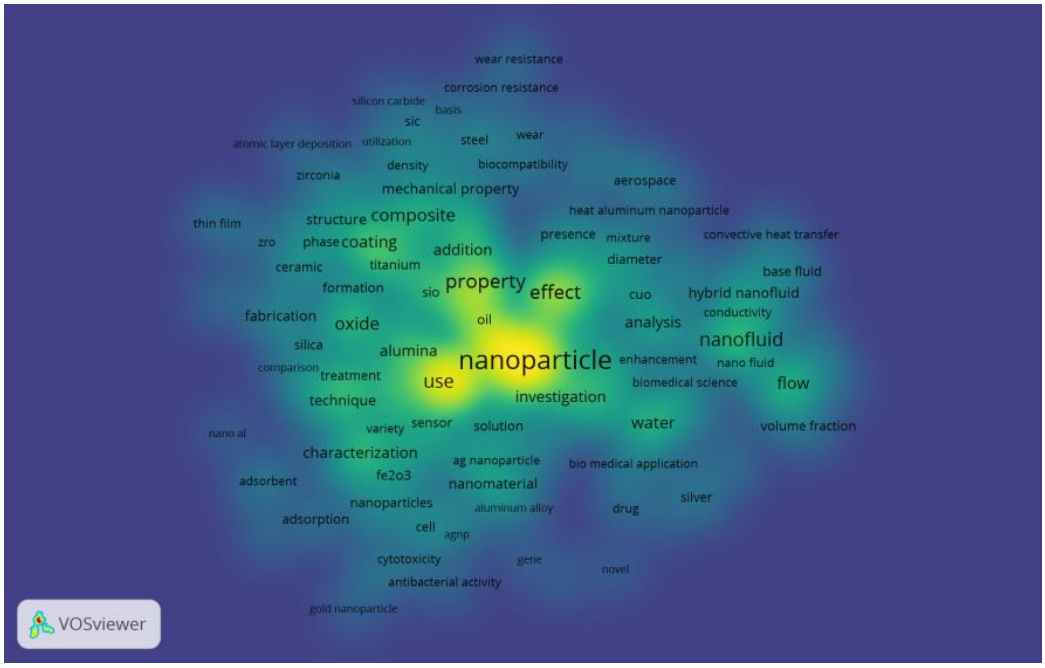


Figure 4. Density visualization for Al_2O_3 nanoparticle, aluminium oxide nanoparticle, and biomedical application keywords

Furthermore, overlay visualization in Figure 3. shows that research on Al_2O_3 nanoparticles in biomedical applications is mostly carried out in 2018 to 2020. Density visualization is depicted in Figure 4. In density visualization, there are points that depends on item density. Thus, this picture shows that the larger the circle, the denser or more frequent the keywords in question appear [17].

4. Conclusion

In this analysis, bibliometrics is used to determine research trends regarding Al_2O_3 nanoparticles in biomedical applications from 2012 to 2022. This research data was obtained through the Publish or Perish application and visualized using VOSviewer software. The keywords used in this bibliometric analysis are Al_2O_3 nanoparticle, aluminium oxide nanoparticle, and biomedical application. From this analysis, there were 987 articles that matched with the keywords and the research trends that tended to increase even though there was a slight decline in 2016. From these articles, 8 clusters with various topics were found and the year with the most articles was in 2021, which was 196 articles.

References

[1] A. Albanese, P. S. Tang, and W. C. W. Chan, "The effect of nanoparticle size, shape, and surface chemistry on biological systems," *Annu. Rev. Biomed. Eng.*, vol. 14, pp. 1–16, 2012.

[2] A. Prakash, S. Satsangi, S. Mittal, B. Nigam, P. K. Mahto, and B. P. Swain, "Investigation on Al2O3 nanoparticles for nanofluid applications-a review," *IOP Conf. Ser. Materails Sci. Eng.*, vol. 377, pp. 1–7, 2018.

[3] P. Hassanpour *et al.*, "Biomedical applications of aluminium oxide nanoparticles," *Micro Nano Lett.*, vol. 13, no. 9, pp. 1227–1231, 2018.

[4] A. Mukherjee, M. Sadiq, T. C. Prathna, and N. Chandrasekaran, "Antimicrobial activity of aluminium oxide nanoparticles for potential clinical applications Antimicrobial activity of aluminium oxide nanoparticles for potential clinical applications," *FORMATEX*, pp. 245–251, 2011.

[5] A. Z. Ziva, Y. K. Suryana, Y. S. Kurniadianti, A. Bayu, D. Nandiyanto, and T. Kurniawan, "Mechanical engineering for society and industry recent progress on the production of aluminum oxide (Al2O3) nanoparticles : A review," *Mech. Eng. Soc. Ind.*, vol. 1, no. 2, pp. 54–77, 2021.

[6] A. Nazari, S. Riahi, S. Riahi, S. F. Shamekhi, and A. Khademno, "Influence of Al2O3 nanoparticles on the compressive strength and workability of blended concrete Influence of Al2O3 nanoparticles on the compressive strength and workability of blended concrete," *J. Am. Sci.*, vol. 6, no. 5, pp. 2–6, 2014.
[7] A. F. Prakash, G. J. D. Babu, M. Lavanya, K. S. Vidhya, and T. Devasena, "Toxicity studies of aluminium oxide nanoparticles in cell lines," *Int. J. Nanotechnol. Appl.*, vol. 5, no. 2, pp. 99–107, 2011.
[8] S. Ghotekar, "Plant extract mediated biosynthesis of Al2O3 nanoparticles- a review on plant parts involved, characterization and applications," *Nanochem Res*, vol. 4, no. 2, pp. 163–169, 2019.
[9] D. F. Al Husaeni and A. B. D. Nandiyanto, "Bibliometric computational mapping analysis of publications on mechanical engineering education using vosviewer," *J. Eng. Sci. Technol.*, vol. 17, no. 2, pp. 1135–1149, 2022.
[10] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. Marc, "How to conduct a bibliometric analysis : An overview and guidelines," *J. Bus. Res.*, vol. 133, pp. 285–296, 2021.
[11] S. A. Ebrahim, A. Ashtari, M. Z. Pedram, and N. A. Ebrahim, "Publication trends in drug delivery and magnetic nanoparticles," *Nanoscale Res. Lett.*, vol. 14, no. 164, pp. 1–14, 2019.
[12] M. Darroudi, M. Gholami, M. Rezayi, and M. Khazaei, "An overview and bibliometric analysis on the colorectal cancer therapy by magnetic functionalized nanoparticles for the responsive and targeted drug delivery," *J. Nanobiotechnology*, vol. 19, no. 1, pp. 1–20, 2021.
[13] Y. Liu, S. Zhu, Z. Gu, and Y. Zhao, "A bibliometric analysis: Research progress and prospects on transition metal dichalcogenides in the biomedical field," *Chinese Chem. Lett.*, vol. 32, no. 12, pp. 3762–3770, 2021.
[14] N. Ranjan, "Chitosan with PVC polymer for biomedical applications: A bibliometric analysis," in *Materials Today: Proceedings*, 2022.
[15] A. Naganthran *et al.*, "Synthesis, characterization and biomedical applications of silver nanoparticles," *Materials (Basel).*, vol. 15, no. 427, pp. 1–43, 2021.
[16] Y. Tang, H. Xin, F. Yang, and X. Long, "A historical review and bibliometric analysis of nanoparticles toxicity on algae," *J. Nanoparticle Res.*, vol. 20, no. 4, 2018.
[17] Tupan, "Perkembangan bibliometrik dengan VOSviewer terhadap perkembangan hasil penelitian bidang pertanian di Indonesia," *VISI PUSTAKA*, vol. 18, no. 3, pp. 217–230, 2016.
[18] N. J. Eck and L. Waltman, "Citation-based clustering of publications using CitNetExplorer and VOSviewer," *Scientometrics*, vol. 111, no. 2, pp. 1053–1070, 2017.

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220204-01 ~ 0220204-10
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.13340

Bibliometric Analysis of the Application of Platinum Nanoparticles in the Field of Biomedical Research During 2012-2022 Using VOSviewer

Kinanti Aulia Putri[1], Asep Bayu Dani Nandiyanto[1]

Universitas Pendidikan Indonesia, Jl. Setiabudhi No.229, Bandung Indonesia

* nandiyanto@upi.edu

Abstract. Platinum nanoparticles are materials with excellent biocompatibility, high surface mass ratio, small size, and high reactivity in their biomedical applications. The purpose of this research is to perform bibliometric analysis on the application of platinum nanoparticles in the biomedical field using VOSviewer. The data used in this study were obtained and collected using the Publish or Perish software. The data obtained are based on the keywords "nanoparticles, platinum, biomedical". Based on the analysis conducted, obtained 985 articles relevant to the keywords used in the 2012-2022 range. The results show that the application of platinum nanoparticles in the biomedical field is unstable every year. Research fluctuations occurred from 2012-2018 (57, 53, 72, 63, 75, 70, 93 publications per year respectively). In 2019-2020 there was an increase in research, namely from 118 studies (2019) to 149 studies (2020) and in 2021-2022 there was a decrease in research, from 147 studies (2020) to 88 studies (2022). This research is expected to help and become a reference for other research as consideration for determining the research theme to be taken.

Keywords: bibliometric, biomedic, nanoparticles, platinum

(Received 2022-09-25, Accepted 2022-10-30, Available Online by 2022-10-31)

1. Introduction

Platinum nanoparticles (PtNPs) have received a lot of attention for their various applications which include the chemical industry, the automotive sector, the biomedical field, and the therapeutic field [1] . In particular, PtNPs have attracted researchers' interest in their biomedical uses which can be attributed to their excellent biocompatibility, high surface/mass ratio, small size, high reactivity, and electrocatalytic [2], which is why they have been used as nanoenzymes due to their excellent behavior. similar to superoxide dismutase and catalase [2]. In addition, the optical characteristics of PtPNs associated with surface plasmon resonance (SPR) allow them to be candidates as radiotherapy agents. With respect to other metal nanoparticles, PtPNs have been reported to have higher catalytic activity compared to palladium nanoparticles. PtPNs have a greater cytotoxic effect, which can be used in cancer therapy because platinum ions can interact with DNA inhibiting its replication [3] . PtPNs also exhibit antibacterial activity against Gram-positive and Gram-negative pathogens, which are similar to silver nanoparticles (AgPNs), although these exhibit greater toxicity than PtPNs, which limits their clinical use [4].

Nanomedicine is an aspect of nanotechnology that continues to develop because of its various applications in the biomedical field. It has been reported that nanoparticles used as nanotherapy have

higher desired effects compared to conventional drugs, this can be attributed to the surface functionalization, which improves solubility, biocompatibility and specific targeting capacity. Metal nanoparticles can be functionalized by conjugating antibodies, nucleic acids, peptide ligands, and drugs on their surfaces [5]. Recently, researchers have reported the selectivity of functionalized platinum nanoparticles on cancer cells via specific pathways. They can also potentiate radiotherapy because they accumulate specifically at the tumor site. Platinum nanoparticles have also been used in disease diagnosis. Therefore, this review focuses on recent reports on the functionalization of platinum nanoparticles with bioactive molecules such as antibodies, biocompatible polymers, peptides, and biomolecules, among others, and their biomedical applications.

Analysis of bibliometric data that is displayed visually through a mapping tool will be very helpful to map the trends of the research being carried out. Based on Al Husaeni and Nandiyanto (2022) [6] Bibliometrics can be a tool used to evaluate research trends qualitatively and quantitatively in a study from time to time. This method uses a literature database and the metrological characteristics of the literature. This method is quite popularly used to broaden the horizons of a particular research field. Free software available for bibliometric analysis is VOSviewer [7] [8] . This software is quite popular to use because besides being free it is also easy to use [9].

In this study, we analyze the trend of research conducted on the application of platinum nanoparticles in biomedicine in the period 2012 to 2022. This study aims to conduct a bibliometric analysis of the application of platinum nanoparticles in biomedicine with bibliographic data on article titles, keywords, and abstracts. Bibliometric analysis was performed using VOSviewer software on data that had been collected with Publish or Perish. This research is expected to help and become a reference for other researchers as a consideration for determining the research theme to be taken.

2. Method

The research data used in this study is research data obtained from articles published in journals indexed by Google Scholar. Google Scholar is used because the site can be accessed for free, in contrast to Scopus which is not freely accessible. In this study, Publish or Perish as the reference manager was used to obtain research data. Every article data obtained must be from articles indexed by Google Scholar and have relevance to the themes needed in this research and will then be backed up in a file that will be used for analysis with VOSviewer.

The research was conducted through several stages:

(i) Collection of publication data using the publish or perish application.
(ii) Processing of bibliometric data for articles that have been obtained using Microsoft Excel application.
(iii) Computational mapping analysis of bibliometric publication data using the VOSviewer application.
(iv) Analysis of computational mapping results.

In this study, each article was screened only articles related to the biomedical application of platinum nanoparticles. This data was obtained through a search on the Publish or Perish application with the keywords "platinum, nanoparticle, biomedic" which matched the title, keyword, and abstract criteria. From the search results, obtained 985 articles that match the selected topics published in the 2012-2022 range. The data obtained were then collected and stored in RIS format. Furthermore, analysis using VOSviewer to visualize and analyze trends using bibliometric maps. The data obtained are divided into three types, namely, network visualization, density, and overlay. In addition, the search for terms that will be included in the visualization of the VOSviewer network mapping.

3. Result and Discussion

3.1 Publication data search results

Based on data searching through the publish or perish application from the Google Scholar database, 985 article data were obtained that met the research criteria. The data obtained in the form of article metadata consisting of the author's name, title, year, journal name, publisher, number of citations, article links, and related URLs. Table 1 shows some examples of published data used in the VOSviewer analysis of this study. Data samples were taken from the 20 best articles that had the highest number of citations.

Table 1. Publication data of platinum nanoparticles in biomedicine

No	Authors	Title	Year	Cites
1	I Khan, K Saeed, I Khan	Nanoparticles: Properties, applications and toxicities	2019	2908
2	XF Zhang, ZG Liu, W Shen, S Gurunathan	Silver nanoparticles: synthesis, characterization, properties, applications, and therapeutic approaches	2016	1856
3	W Yu, H Xie	A review on nanofluids: preparation, stability mechanisms, and applications	2012	1597
4	S Jain, DG Hirst, JM O'Sullivan	Gold nanoparticles as novel agents for cancer therapy	2012	1085
5	J Singh, T Dutta, KH Kim, M Rawat, P Samddar	'Green'synthesis of metals and their oxide nanoparticles: applications for environmental remediation	2018	912
6	SH Lee, BH Jun	Silver nanoparticles: synthesis and application for nanomedicine	2019	748
7	P Kuppusamy, MM Yusoff, GP Mania.	Biosynthesis of metallic nanoparticles using plant derivatives and their new avenues in pharmacological applications–An updated report	2016	742
8	K Jyoti, M Baunthiyal, A Singh	Characterization of silver nanoparticles synthesized using Urtica dioica Linn. leaves and their synergistic effects with antibiotics	2016	683
9	A Abdal Dayem, MK Hossain, SB Lee, K Kim	The role of reactive oxygen species (ROS) in the biological activities of metallic nanoparticles	2017	646
10	J Estelrich, MJ Sánchez-Martín	Nanoparticles in magnetic resonance imaging: from simple to dual contrast agents	2015	575
11	BY Xia, HB Wu, X Wang, XW Lou	One-Pot Synthesis of Cubic PtCu3 Nanocages with Enhanced Electrocatalytic Activity for the Methanol Oxidation Reaction	2012	563
12	M Moritz, M Geszke-Moritz	The newest achievements in synthesis, immobilization and	2013	557

		practical applications of antibacterial nanoparticles		
13	V Sanna, N Pala, M Sechi	Targeted therapy using nanotechnology: focus on cancer	2014	556
14	D Lombardo, MA Kiselev, MT Caccamo	Smart nanoparticles for drug delivery application: development of versatile nanocarrier platforms in biotechnology and nanomedicine	2019	530
15	J Conde, G Doria, P Baptista	Noble metal nanoparticles applications in cancer	2012	515
16	Y Dai, H Xiao, J Liu, Q Yuan, P Ma	In Vivo Multimodality Imaging and Cancer Therapy by Near-Infrared Light-Triggered trans-Platinum Pro-Drug-Conjugated Upconverison Nanoparticles	2013	499
17	S Vardharajula, SZ Ali, PM Tiwari, E Eroğlu	Functionalized carbon nanotubes: biomedical applications	2012	475
18	S Ponarulselvam, C Panneerselvam, K Murugan	Synthesis of silver nanoparticles using leaves of Catharanthus roseus Linn. G. Don and their antiplasmodial activities	2012	457
19	D Sharma, S Kanchi, K Bisetty	Biogenic synthesis of nanoparticles: a review	2019	445
20	SE Lohse, CJ Murphy	Applications of colloidal inorganic nanoparticles: from medicine to energy	2012	441
21	N Pantidos, LE Horsfall	Biological synthesis of metallic nanoparticles by bacteria, fungi and plants	2014	421
22	AP Blum, JK Kammeyer, AM Rush	Stimuli-responsive nanomaterials for biomedical applications	2015	417
23	BY Xia, HB Wu, Y Yan, XW Lou…	Ultrathin and ultralong single-crystal platinum nanowire assemblies with highly stable electrocatalytic activity	2013	405
24	PG Jamkhande, NW Ghule, AH Bamer	Metal nanoparticles synthesis: An overview on methods of preparation, advantages and disadvantages, and applications	2019	399
25	S Sarkar, E Guibal, F Quignard	Polymer-supported metals and metal oxide nanoparticles: synthesis, characterization, and applications	2012	390
26	AC Anselmo, S Mitragotri	A review of clinical translation of inorganic nanoparticles	2015	386
27	SC Baetke, T Lammers	Applications of nanoparticles for diagnosis and therapy of cancer	2015	367

28	G Sharma, A Kumar, S Sharma, M Naushad	Novel development of nanoparticles to bimetallic nanoparticles and their composites: A review	2019	367
29	IL Bergin, FA Witzmann	Nanoparticle toxicity by the gastrointestinal route: evidence and knowledge gaps	2013	361
30	S Rajeshkumar, S Menon, SV Kumar	Antibacterial and antioxidant potential of biosynthesized copper nanoparticles mediated through Cissus arnotiana plant extract	2019	357
31	KS Soni, SS Desale, TK Bronich	Nanogels: An overview of properties, biomedical applications and obstacles to clinical translation	2016	346
32	JK Patra, KH Baek	Green nanobiotechnology: factors affecting synthesis and characterization techniques	2014	346
33	P Elia, R Zach, S Hazan, S Kolusheva	Green synthesis of gold nanoparticles using plant extracts as reducing agents	2014	328
34	B Ramezanzadeh, Z Haeri	A facile route of making silica nanoparticles-covered graphene oxide nanohybrids (SiO2-GO)	2014	325
35	M Xuan, Z Wu, J Shao, L Dai, T Si	Near infrared light-powered Janus mesoporous silica nanoparticle motors	2016	325
36	H Padalia, P Moteriya, S Chanda	Green synthesis of silver nanoparticles from marigold flower and its synergistic antimicrobial potential	2015	316
37	CH Wu, IJ Liu, RM Lu, HC Wu	Advancement and applications of peptide phage display technology in biomedical science	2016	295
38	S Ahmed, S Ikram	Biosynthesis of gold nanoparticles: a green approach	2016	290
39	G Unsoy, S Yalcin, R Khodadust, G Gunduz	Synthesis optimization and characterization of chitosan-coated iron oxide nanoparticles produced for biomedical applications	2012	288
40	S Mukherjee, S Paria	Preparation and stability of nanofluids-a review	2013	267
41	P Malik, R Shankar, V Malik, N Sharma	Green chemistry based benign routes for nanoparticle synthesis	2014	266
42	SZH Naqvi, U Kiran, MI Ali, A Jamal	Combined efficacy of biologically synthesized silver nanoparticles and different antibiotics against multidrug-resistant bacteria	2013	265
43	D Ramimoghadam, S Bagheri	Progress in electrochemical synthesis of magnetic iron oxide nanoparticles	2014	259

44	R Kaur, I Badea	Nanodiamonds as novel nanomaterials for biomedical applications: drug delivery and imaging systems	2013	250
45	T Maiyalagan, X Dong, P Chen, X Wang	Electrodeposited Pt on three-dimensional interconnected graphene as a free-standing electrode for fuel cell application	2012	244
46	M Khan, M Khan, SF Adil, MN Tahir	Green synthesis of silver nanoparticles mediated by Pulicaria glutinosa extract	2013	239
47	F Jia, X Liu, L Li, S Mallapragada, B Narasimhan	Multifunctional nanoparticles for targeted delivery of immune activating and cancer therapeutic agents	2013	235
48	LKEA Abdelmohsen, F Peng, Y Tu	Micro-and nano-motors for biomedical applications	2014	226
49	K Vijayaraghavan, T Ashokkumar	Plant-mediated biosynthesis of metallic nanoparticles: a review of literature, factors affecting synthesis, characterization techniques and applications	2017	226
50	MS Wason, J Zhao	Cerium oxide nanoparticles: potential applications for cancer and other diseases	2013	226

3.2 Research Developments in the Field of Applications of Platinum Nanoparticles in Biomedical

This study analyzes the development of research on the application of platinum nanoparticles in biomedicine which was carried out in the period 2012 to 2022. **Figure 1** shows the curve of the application of platinum nanoparticles in biomedicine for 10 years. Based on **Figure 1**, it can be seen that the research related to the application of platinum nanoparticles in biomedicine is quite a lot but the research shows that the application of platinum nanoparticles in the biomedical field is unstable every year. Research fluctuations occurred from 2012-2018 (57, 53, 72, 63, 75, 70, 93 publications per year respectively). In 2019-2020 there was an increase in research, namely from 118 studies (2019) to 149 studies (2020) and in 2021-2022 there was a decrease in research, from 147 studies (2020) to 88 studies (2022).

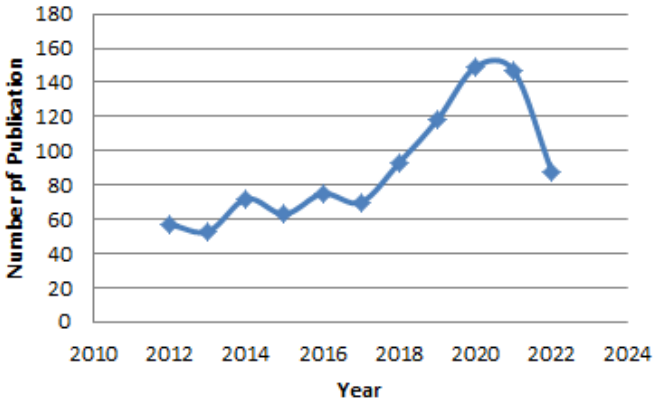


Figure 1. Progress of application of platinum nanoparticles in biomedicine

3.3 Visualization of Applications of Platinum Nanoparticles in Biomedical using VOSviwer

Research related to the application of platinum nanoparticles in biomedical analysis based on mapping visualization is divided into 8 clusters, namely:

(i) Cluster 1 has 44 items, 44 items are advancement, anticancer agent, biomedical application, biomedical imaging, biomedical purpose, cancer, cancer therapy, chemical, chemotherapy, cisplatin, co delivery, delivery, drug, drug delivery, drug delivery system, effect, efficacy, example, facile synthesis, Fe_3O_4, inorganic nanoparticle, iron oxide nanoparticle, light, magnetic nanoparticle, mesoporous silica nanoparticle, msn, nanomaterial, nanoparticle, nanotechnology, platinum drug, poly, preparation, recent progress, researcher, self assembly, silica, silica nanoparticle, superparamagnetic iron, system, therapy, toxicity, tumor, use, vitro.

(ii) Cluster 2 has 37 items, 37 items are ability, advantage, analysis, biomedical research, biosensor, carbon, carbon nanotube, carbon paste electrode, composite, counter electrode, detection, determination, development, distribution, dopamine, efficiency, electrode, environmental application, glassy carbon electrode, glucose, graphene, graphene oxide, hyperthermia, magnetite nanoparticle, metal oxide, nanomedicine, palldium nanoparticle, platinum nanoparticle, platinum wire, possibility, role, sensitive detection, sensor, structure, surface.

(iii) Cluster 3 has 31 items, 31 items has addition, antibacterial application, antioxidant activity, biogenic synthesis, biological application, biological property, biomedical science, biomedicine, catalysis, catalytic application, cathode, cytotoxicity, fept, fept nanoparticle, field, hyfrogel, iron platinum nanoparticle, mechanism, modification, nanoparticle synthesis, oxide nanoparticle, physicochemical properties, plant extract, protein, recent advance, solution, state, step, synthesis. Zinc oxide nanoparticle.

(iv) Cluster 4 has 28 items, 28 items are AgNP, agriculture, antibacterial activity, anticancer, anticancer activity, attention, Au NP, bimetallic nanoparticle, biosynthesis, cancel cell, characterization, copper, cytotoxic activity, eco friendly synthesis, engineering, iron nanoparticle, medicine, metal, metal nanoparticle, metallic nanoparticle, noble metal, palladium, platinum, silver, silver nanoparticle, titanium , utilization, zinc.

(v) Cluster 5 has 25 items, 25 items are antimicrobial activity, bacterium, biological synthesis, biomedical use, cell, cytotoxic effect, dose, form, great

potential, green synthesis, influence, interaction, microorganism, oxidative stress, particle size, platinum electrode, potential biomedical application, present study, product, production, property, shape, stability, synthesized nanoparticle, zno nanoparticle.

(vi) Cluster 6 has 21 items, 21 items are catalyst, cobalt, core, diagnosis, hydrogen peroxide, imaging, ionic liquid, iron oxide, layer, ligand, metal oxide nanoparticle, morphology, particle, polymer, presence, pt nanoparticle, pt np, reaction, sample, sensing, water.

(vii) Cluster 7 has 15 items, 15 items are activity, amount, au nanoparticle, biomedical field, biomedical study, breast cancer, catalytic activity, challenge, coating, nanostructure, nanozyme, platinum np, progress, tio, treatment.

(viii) Cluster 9 has 8 items, 8 items are agent, biocompability, comprehensive review, mouse, potential, potential application, selenium, selenium nanoparticle.

3.4 Research developments in the field of Application of Nanoparticles in Biomedical

The visualization network displays the relationship between the terms found and visualized through the displayed image. Based on Al Husaeni and Nandiyanto (2022) **Figure 2** shows the relationship between the terms found described by a network or line connecting one term to another. From **Figure 2** it can be seen that each term found is divided into several clusters. The term platinum nanoparticles are combined in cluster 2 and connected to cluster 3 and cluster 4. In clusters 1 and 4 the biomedical terms and platinum are found. While in cluster 1 found the term nanoparticle. The term nanoparticle has 207 links with a total link strength of 2913, the term platinum has 184 links with a total link strength of 1391, and the term biomedical has 34 links with a total link strength of 48.

In this visualization, the cluster size indicates the number of publications. The bigger the cluster, the more publications. The distance between clusters shows the relationship between clusters in the quote. The closer the distance between the clusters, the stronger the attachment. Curved lines connecting groups represent the interrelationships between items [31] . The mapping visualization analyzed in this study consists of 3 parts: network visualization (see **Figure 2**), density visualization (see **Figure 3**), and overlay visualization (see **Figure 4**).

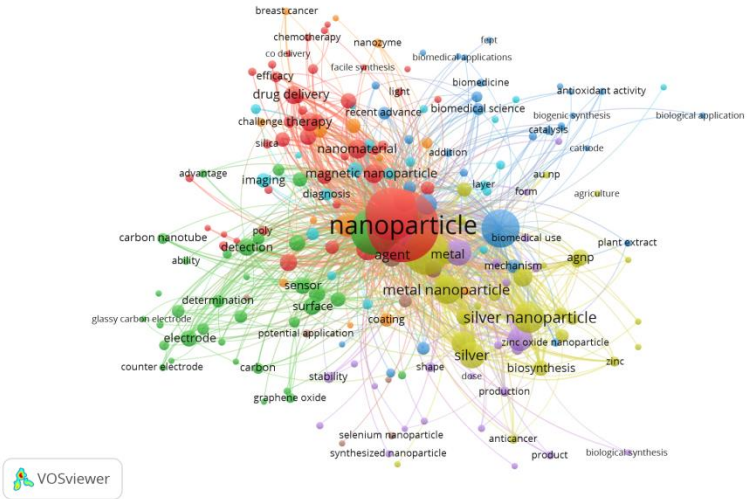


Figure 2. Visualization of the platinum, nanoparticle, biomedic keyword network.

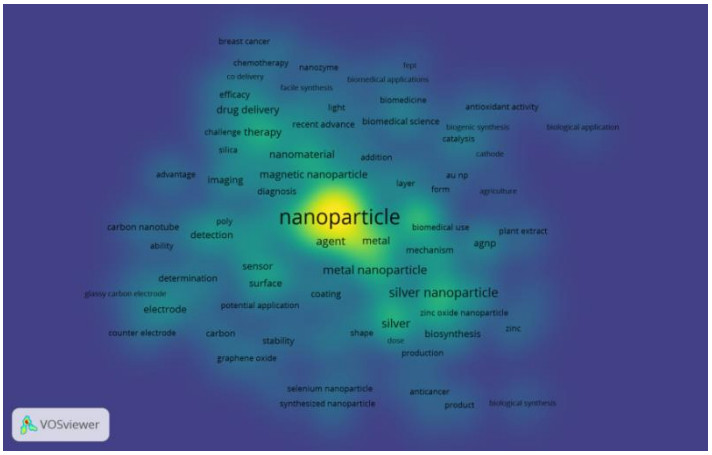


Figure 3. Density Visualization application of platinum nanoparticles in biomedicine

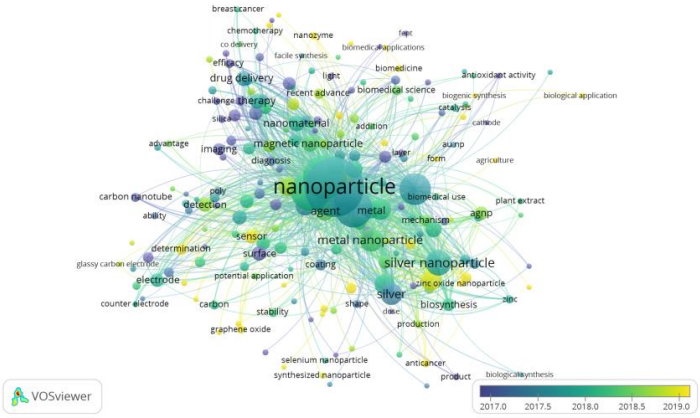


Figure 4. Overlay Visualization of platinum nanoparticles in biomedicine

4. Conclusion

In this study, bibliometric analysis was carried out related to the application of platinum nanoparticles in biomedicine using VOSviewer. The data analyzed was obtained from the reference manager application, namely Publish or Perish. The data collected are articles published from 2012 to 2022 which are filtered based on the keywords “nanoparticle, platinum, biomedic” with the term nanparticle having 207 links with a total link strength of 2913, the term platinum having 184 links with a total link strength of 1391, and the term biomedical. has 34 links with a total link strength of 48. The bibliographic data used in this study are topics, titles, keywords, abstracts. Based on the research results obtained 985 articles relevant to these keywords. By searching the data using the keywords “nanoparticle, platinum, biomedic”, you get 8 clusters with various number of terms.

5. Reference

[1] M. Jeyara, S. Gurunathan, M. Qasim, M. Kang and J. Kim, "A Comprehensive Review on the Synthesis, Characterization, and Biomedical Application of Platinum Nanoparticles," *nanomaterials,* vol. 9, p. 1719, 2019.

[2] E. Boanini, P. Torricelli, P. Cassani, M. Rubini, K. Fini and M. Pagani, "Platinum nanoparticles supported on functionalized hydroxyapatite: Anti-oxidant properties and bone cells response," *Ceram. Int,* vol. 46, p. 19574–19582, 2020.

[3] H. Mohammadi, A. Abedi, A. Akbarzadeh, A. Mokhtari, H. Shahmabadi and H. Mehrabi, "Evaluation of synthesized platinum nanoparticles on the MCF-7 and HepG-2 cancer cell lines," *Int. Nano Lett,* vol. 3, p. 28, 2013.

[4] R. Nisanthi, S. Malathi, S. P. John and P. Palami, "Green synthesis and characterization of bioinspired silver, gold and platinum nanoparticles and evaluation of their synergistic antibacterial activity after combining with different classes of antibiotics," *MaterSci. Eng. C,* vol. 96, pp. 693-707, 2019.

[5] A. Abed, M. Derakhshan, M. Karimi, M. Shiramizinia, M. T. Mahjoubin and M. Homayonfal, "Platinum Nanoparticles in Bio medicine: Preparation, Anti-Cancer Activity, and Drug Delivery Vechicles," *Front.Pharmacol,* vol. 13, p. 797804, 2022.

[6] F. D. Al Husaeni, " Bibliometric using vosviewer with publish or perish (using google scholar data): from step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post covid," *ASEAN Journal of Science and Engineering*, vol. 2(1), pp. 19-46, 2022.

[7] E. Garfield, "Citation analysis as a tool in journal evaluation," *Essays of an Information* , vol. 1(178), pp. 527-544, 1972.

[8] A. T. Malik, "The top 50 most-cited articles on cervical spondylotic myelopathy," *World Neurosurgery*, vol. 116, pp. 168-180, 2018.

[9] E. a. Orduña-Malea, " Link-based approach to study scientific software usage The case of VOSviewer," *Scientometrics,* vol. 126(9), pp. 8153-8186, 2021.

[10] N. J. Eck, " Citation-based clustering of publications using CitNetExplorer and VOSviewer," *Scientometrics*, vol. 111(2), pp. 1053-1070, 2017.

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220205-01 ~ 0220205-13
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.13343

Bibliometric Computational Mapping Analysis of Graphene-Based Surfaced – Enhanced Raman Scattering Spectroscopy (SERS) During 2012 – 2022

Afviva Nissa[1], Asep Bayu Dani Nandiayanto[2*]

[1]Faculty of Mathematic and Natural Science Education, Universitas Pendidikan Indonesia, Jl Setiabudhi No. 229, Bandung Indonesia 40154, West Java, Indonesia

[2] Faculty of Mathematic and Natural Science Education, Universitas Pendidikan Indonesia, Jl Setiabudhi No. 229, Bandung Indonesia 40154, West Java, Indonesia

*nandiyanto@upi.edu

Abstract This study aims to examine the development of research related to Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) through a bibliometric approach to computational mapping analysis using VOSviewer. The acquisition of article data was obtained from the Google Scholar database using the publish or perish reference manager application. The keywords used to guide the process of searching for the title and abstract of the article were "Graphene, SER, surface enhanced Raman scattering, nanoparticle". A total of 920 articles were obtained which were considered related to the topic of this research. The study period used as study material is Google Scholar indexed articles for the last 10 years (2012 to 2022). The results showed that the Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) research can be separated into 4 terms:Raman Spectroscopy, Graphene, Nanoparticle and Surface. The term "Raman Spectroscopy" is associated with 189 links with total link strength 1539 The term "Graphene" has 198 links with total link strength 2036 the term "Nanoparticle" has 199 links with total link strength in 2739 and the term "Surface" has 189 links with total link strength 1651. The results of the analysis of the development of Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) in the last 10 years show an increase. However, in 2020-2021, there was a slight decrease from 136 in 2020 to 135 in 2021. The increase in research occurred from 2014 - 2020 (49, 63, 80, 99, 105,116 and 136 publications per year respectively). While the popular Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) research was carried out in 2020, there were 136 studies. From the results of research on article data using VOS viewer on Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) and its relationship to the problem area, the results show that there has been an increase over the last 10 years. This study can be an initial consideration for future researchers who will conduct research related to this research topic.

Keywords: Bibliometric Analysis, Graphene-Based Surface-Enhanced Raman Scattering (SERS), Publish of Perish, VOS viewer

(Received 2022-09-25, Accepted 2022-10-31, Available Online by 2022-10-31)

1. Introduction

Since its inception, Surfaced-Enhanced Raman Scattering Spectroscopy (SERS) has been used for a variety of purposes, including structural analysis of materials, bimolecular analysis, and detection of chemicals and hazardous substances. A single component Graphene is one of the nanoparticle substrates that can be used to develop Surface-enhanced Raman Spectroscopy (SERS). Noble metals such as Au and Ag, which can produce strong electromagnetic enhancement and generate strong SERS signals from molecules adsorbed on the surface, are common SERS substrates. However, this substrate has the disadvantage of being less stable, and it is difficult to use in the long term. The modification of noble metal and graphene with the goal of achieving a composite structure is an effective solution to the problem of instability and poor sensitivity of SERS substrates. As a result, graphene-based SERS has become a popular research topic in recent decades.

After decades of continuous efforts and exploration by researchers, SERS has been developed as a new technique which has the advantages of non-destructive, fast, and highly sensitive detection of structural information of chemical and biological molecules with increasing factors up to 1014~1017 [1-5]. Therefore, SERS can be applied in ultra-trace detection of harmful substances, quantitative detection of molecular concentrations, and flow cytometry, which are beyond the reach of conventional Raman spectroscopy. The most common metallic materials used in SERS substrates are Au, Ag, and Cu, with Ag being the most effective enhancement. However, Ag substrates are susceptible to oxidation by oxygen in the air during preparation and storage. Therefore, most researchers currently use Au nanoparticles to prepare various SERS substrates. In addition, many transition metals can be used to make SERS substrates, such as cobalt, iron, nickel, platinum, and lead [6,7], but their enhancing effects are weak and have not been widely studied.

Graphene as a monolayer carbon film of sp^2 hybridized carbon atoms has been considered in scientific studies since the 1940s [8], but the available preparations are unstable. Novoselov et al. [9,10] have obtained the first stable graphene preparation on film support using mechanical exfoliation of high-oriented pyrolytic graphite bands. Since then, graphene has attracted the attention of researchers and industrial manufacturers in fundamental physics research and advanced functional composites and devices for applications such as biological and chemical sensors, flexible displays, new energy batteries, and seawater desalination. It was found that the Raman signal of the molecule can be significantly enhanced when certain molecules are adsorbed on the graphene surface using graphene as a substrate [11]. By comparing the Raman signal intensity of phthalocyanine molecules on graphene and SiO2/Si substrates, it was found that the Raman signal intensities of phthalocyanine molecules adsorbed on the monolayer graphene surface were much stronger than on SiO_2/Si substrates, indicating that monolayer graphene has a significant Raman enhancing effect. Despite the many advantages of graphene in SERS applications, its CM effect is weak, with increasing factors (EFs) usually only in the range of 0.3-100 [12-15], much lower than that of metal SERS substrates.

In recent years, several scholars have reviewed work on graphene-based SERS. For example, Cao et al. [16] and Kang et al. [17] have summarized the sensing and catalytic applications of graphene-based SERS. The analytical applications of graphene-based SERS are summarized by Zhang et al. [18]. SERS properties of graphene/silver nanocomposite are summarized by Sharma et al. [19]. A series of reviews summarize important work on this topic in recent years, ranging from the material properties of graphene and conventional SERS. In this review, we try to analyze and summarize this topic using bibliometric analysis. Bibliometric analysis is a form of meta-analysis of research data that can assist researchers in studying bibliographic content and analysis of citations from articles published in journals and other scientific works.

However, research on computational mapping of bibliometric analysis of published data in the field of surface-based Graphene-Enhanced Raman Scattering (SERS) that has been carried out specifically to determine research development has not been carried out. Especially bibliometric analysis for research in the last 10 years in the period 2012 to 2022 through Publish of Perish and the VOSviewer application.

Therefore, this study was conducted to conduct computational research on mapping bibliometric analysis of articles indexed by Google Scholar using Public of Perish and VOSviewer software. This research was conducted with the hope that it can be a reference for researchers to conduct and determine the research themes to be taken, especially those related to the Graphene-based Surface-Enhanced Raman Scattering (SERS) field.

2. Methods

The article data used in this study is based on research from publications that have been published in Google Scholar indexed journals. We chose Google Scholar in this study because the Google Scholar database is open source. To obtain research data, a reference manager application, namely Publish or Perish, is used. Publish or Perish software was used to conduct a literature review on our chosen topic. Detailed information for using and installing the software and a step-by-step process for obtaining data are described in the study [20] and detailed information on library search in searching for data in Google Scholar is described in a previous study conducted by Azizah et al. [21]

The research was conducted through several stages:
(i) Collection of publication data using the publish or perish application,
(ii) Processing of bibliometric data for articles that have been obtained using Microsoft Excel applications,
(iii) Computational mapping analysis of bibliometric published data using the VOSviewer application, and
(iv) Analysis of computational mapping analysis results

An article data search in Publish or Perish is used to filter publications using the keywords "Nanoparticle, SERS, Graphene, Graphene Surface-Enhanced Raman Scattering" based on the title requirements of the publication. The papers used were published between 2012 and 2022. All data were obtained in September 2022. The collected articles that met the research analysis criteria were then exported into two types of files: research information system (.ris) and comma separated values format (. *.csv). VOSviewer is also used to visualize and evaluate trends using bibliometric maps. The article data from the source database is then mapped. VOSviewer is used to create 3 variations of mapping publications, namely network visualization, density visualization, and network-based overlay visualization (co-citation) between existing items. When creating a bibliometric map, the keyword frequency is set to be found at least 3 times. Therefore, 271 terms and keywords that were less relevant were omitted.

3. Results and Discussion

This chapter lays out specific instructions for writing the full text, including the article section, the systematic chapter and its contents. These specific instructions will guide the entire editorial process of the article as shown in Figure 2.

3.1. Publication Data Search Results

Based on the data search through application reference manager publish or perish from the Google Scholar database, 920 data articles were obtained that met the research criteria. The data was obtained in the form of article metadata consisting of the author's name, title, year, journal name, publisher, number of citations, article links, and related URLs. Table 1 shows some examples of published data used in the VOSviewer analysis of this study. The data samples taken were the 50 best articles that had the highest number of citations. The number of citations from all articles used in this study is 25568, the number of citations per year is 2556.80, the number of citations per paper is 25.59, the average author in the articles used is 4.62, all articles have an average h-index is 71, and the g-index is 129.

Table.1 Articles about Graphene with H – Index Obtain from Bibiliometric Analysis with Poblish or Peries

No	Authors	Title	Year	Number of Citation
1.	X Ling et al	Charge-Transfer Mechanism in Graphene-Enhanced Raman Scattering	2012	161
2.	Z Fan et al	Hybrid Graphene Oxide Based Ultrasensitive SERS Probe for Label-Free Biosensing	2013	137
3.	Y Liu et al	Few-Layer Graphene-Encapsulated Metal Nanoparticles for Surface-Enhanced Raman Spectroscopy	2014	117
4.	Q Hao et al	Surface-Enhanced Raman Scattering Study on Graphene-Coated Metallic Nanostructure Substrates	2012	112
5.	M Iiut et al	A new green, ascorbic acid-assisted method for versatile synthesis of Au–graphene hybrids as efficient surface-enhanced Raman scattering platforms	2013	109
6.	X Ling et al	Graphene-Thickness-Dependent Graphene-Enhanced Raman Scattering	2012	97
7.	H Lai et al	Recent progress on graphene-based substrates for surface-enhanced Raman scattering applications	2018	88
8.	H Kang et al	Recent progress in the applications of graphene in surface-enhanced Raman scattering and plasmon-induced catalytic reactions	2018	88
9.	Y Li et al	A facile fabrication of large-scale reduced graphene oxide–silver nanoparticle hybrid film as a highly active surface-enhanced Raman scattering substrate	2015	85
10.	J Liu et al	Fabrication of Graphene Nanomesh and Improved Chemical Enhancement for Raman Spectroscopy	2012	82
11.	Y Du et al	Enhanced light–matter interaction of graphene–gold nanoparticle hybrid films for high-performance SERS detection	2014	77
12.	F Yin et al	Self-assembly of mildly reduced graphene oxide monolayer for enhanced Raman scattering	2016	75
13.	Y Zhao et al	Enhanced SERS Stability of R6G Molecules with Monolayer Graphene	2014	69
14.	Y Guo et al	A dual colorimetric and SERS detection of Hg^{2+} based on the stimulus of intrinsic oxidase-like catalytic activity of Ag-$CoFe_2O_4$/reduced graphene oxide nanocomposites	2018	67

15.	M Paillet et al	One-pot synthesis of multifunctional magnetic N-doped graphene composite for SERS detection, adsorption separation and photocatalytic degradation of Rhodamine 6G	2018	59
16.	Balcioglu et al	Doxorubicin loading on graphene oxide, iron oxide and gold nanoparticle hybrid	2013	58
17.	H Luo et al	Mechanical enhancement of copper matrix composites with homogeneously dispersed graphene modified by silver nanoparticles	2017	58
18.	A Shiotari et al	Tip-enhanced Raman spectroscopy of graphene nanoribbons on Au (111)	2014	58
19.	S Jiang et al	A novel U-bent plastic optical fibre local surface plasmon resonance sensor based on a graphene and silver nanoparticle hybrid structure	2017	57
20.	H Lai et al	A review of the preparation and application of magnetic nanoparticles for surface-enhanced Raman scattering	2018	57
21.	Y Lin et al	An electrochemical sensor for the determination of bisphenol A using glassy carbon electrode modified with reduced graphene oxide-silver/poly-L-lysine	2017	57
22.	Divyapriya G et al	An innate quinone functionalized electrochemically exfoliated graphene/Fe3O4	2017	57
23.	SF Zhou et al	Enhanced electrochemical performance for sensing Pb (II) based on graphene oxide incorporated mesoporous MnFe2O4 nanocomposites	2018	57
24.	IV Lightcap et al	Electron hopping through single-to-few-layer graphene oxide films. Side-selective photocatalytic deposition of metal nanoparticles	2012	56
25.	YJ Mai et al	Preparation and tribological behavior of copper matrix composites reinforced with nickel nanoparticles anchored graphene nanosheets	2018	56
26.	TB Limbu et al	Green synthesis of reduced Ti 3 C 2 T x MXene nanosheets with enhanced conductivity, oxidation stability, and SERS activity	2018	55
27.	PT Do et al	A highly sensitive electrode modified with graphene, gold nanoparticles, and molecularly imprinted over-oxidized polypyrrole for electrochemical determination of electrochemical determination of dopamine	2014	54

28.	RK Biroju et al	Defect enhanced efficient physical functionalization of graphene with gold nanoparticles probed by resonance raman spectroscopy	2014	54
29.	K Deng et al	Simultaneous detection of sunset yellow and tartrazine using the nanohybrid of gold nanorods decorated graphene oxide	2016	53
30.	RT Thomas et al	Synthesis of nanotitania decorated few-layer graphene for enhanced visible light	2014	52
31.	XF Zhang et al	Simultaneous detection of sunset yellow and tartrazine using the nanohybrid of gold nanorods decorated graphene oxide	2016	51
32.	Dhara et al	Au nanoparticles decorated reduced graphene oxide for the fabrication of disposable nonenzymatic hydrogen peroxide sensor	2016	50
33.	P Nagaraju et al	Facile in-situ microwave irradiation synthesis of TiO2/graphene nanocomposite for high-performance supercapacitor applications	2018	50
34.	M Aamir et al	Graphene oxide nanocomposite with Co and Fe doped LaCrO3 perovskite active under solar light irradiation for the enhanced degradation of crystal violet dye	2021	50
35.	Zhong et al	Copper phthalocyanine functionalization of graphene nanosheets as support for platinum nanoparticles and their enhanced performance toward methanol oxidation	2013	49
36.	M Gautam et al	Detection of organic vapors by graphene films functionalized with metallic nanoparticles	2012	49
37.	RK Matharu et al	Microstructure and antibacterial efficacy of graphene oxide nanocomposite fibres	2020	49
38.	HY Yu et al	Nanoparticles of magnetite anchored onto few-layer graphene: A highly efficient Fenton-like nanocomposite catalyst	2018	49
39.	Govinda et al	Decoration of few-layer graphene-like MoS2 and MoSe2 by noble metal nanoparticles	2012	48
40.	Z Ji et al	Enhanced electrocatalytic performance of Pt-based nanoparticles on reduced	2012	48
41.	Sen et al	Trimetallic PdRuNi nanocomposites decorated on graphene oxide: a superior catalyst for the hydrogen evolution reaction	2018	48

42.	Ahmad et al	Fabrication of sensitive non-enzymatic nitrite sensor using silver-reduced graphene oxide nanocomposite	2018	47
43.	Lan et al	Photochemical decoration of silver nanoparticles on graphene oxide nanosheets and their optical characterization	2014	47
44.	Khan et al	A comprehensive review on carbon dots and graphene quantum dots based fluorescent sensor for bio thiols	2020	45
45.	T Fujigaya et al	A highly durable fuel cell electrocatalyst based on polybenzimidazole-coated stacked graphene	2014	44
46.	S Benitez et al	Multilayer graphene–gold nanoparticle hybrid substrate for the SERS determination of metronidazole	2015	44
47.	C Li et al	Surface-amorphized TiO2 nanoparticles anchored on graphene as anode materials for lithium-ion batteries	2018	44
48.	N Song et al	A novel electrochemical biosensor for the determination of dopamine and ascorbic acid based on graphene oxide/poly (aniline-co-thionine) nanocomposite	2020	42
49.	J Liu et al	Environmentally friendly synthesis of graphene–silver composites with surface-enhanced Raman scattering and antibacterial activity via reduction with l-ascorbic acid	2015	42
50.	Z Qian et al	Fabrication of graphene oxide/Ag hybrids and their surface-enhanced Raman scattering characteristics	2013	40

3.2. *Research Development in The Field of Graphene – Based Surfaced-Enhanced Raman Scattering*

Table 2 shows the development of research in the field of Graphene-Based Surfaced-Enhanced Raman Scattering studies published in the Google Scholar indexed journal. Based on the data shown in Table 2, it can be seen that the number of researches in Graphene-Based Surfaced-Enhanced Raman Scattering is 920 articles from 2012-2022. In 2012 there were 38 articles. In 2013 there were 49 articles. In 2014 there were 49 articles. In 2015 there were 63 articles, in 2016 there were 80 articles, in 2017 there were 99 articles, in 2018 there were 105 articles, in 2019 there were 116 articles, in 2020 there were 136 articles, in 2021 there were 135 articles and in 2022 there were 107. From the number of publications, it can be seen that research on Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) is still relatively rarely studied every year, especially in the last 10 years (2012-2021). Its development is also quite volatile as can be seen clearly in Figure 1. Figure 1 shows the development of Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) research for the last 10 years in the range of 2012 to 2022. Based on Figure 1, it is known that the development of research related to Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) has decreased from 2020-2021. This decline can be seen from the number of publications in 2012 as many as 136 to 2014 only 135 publications. The development of research on Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) has so far increased from 2012 to 2022. But it has decreased slightly in 2021 compared to 2022. The data shows that the popularity of research on Graphene-Based Surfaced-

Enhanced Raman Scattering (SERS) tends to be stable and research interest on this subject continues to increase every year.

Table 2. Development of Graphene-Based Surfaced-Enhanced Raman Scattering (SERS)

Year of Publications	Number of Publications
2012	38
2013	49
2014	49
2015	63
2016	80
2017	99
2018	105
2019	116
2020	136
2021	135
2022	107
Average	**88,8**

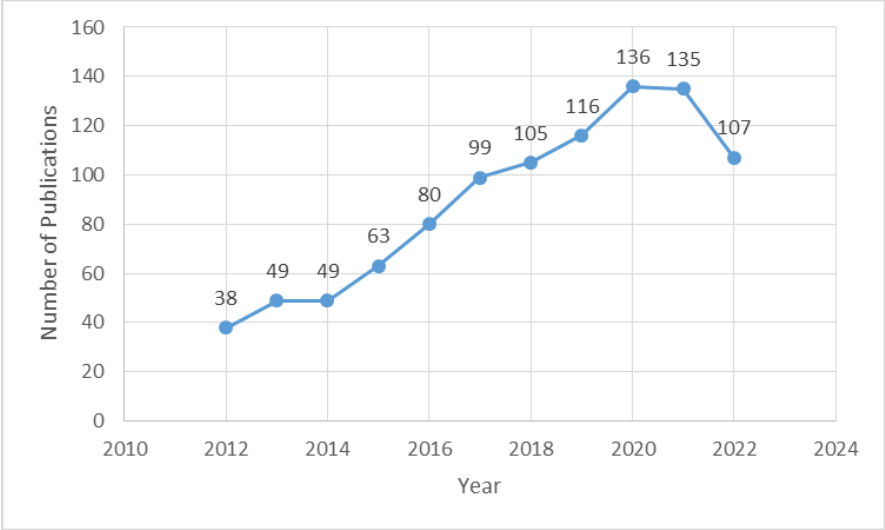


Figure 1. Level of development in Graphene-Based Surfaced-Enhanced Raman Scattering (SERS)

3.3. Visualization Graphene – Based Surfaced – Enhanced Raman Scattering

Computational mapping was performed on the article data. VOSviewer is used in computational mapping. From the results of computational mapping found 195 items. Each item found related to Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) in data mapping is divided into 9 clusters, namely:

(i) Cluster 1 has 34 items and marked in red, the 34 items are ability, aggregation, array,assembly, based surfaced, biomolecule, challenge, chemical, degradation, detection, efficiency, gold nanorod, light, metal, noble metal nanoparticle, novel surface, organic pollutant, performance, plasmonic nanoparticle, rapid, rhodamine, self, sensitive detection, sensitive ser, sensitive SERS detection, sensitive SERS detection, sensitive surface, ser, SERS detection, SERS experiment, SERS signal, shape, signal, technology, and ultrasensitive detection.

(ii) Cluster 2 has 31 items and marked in green, the 31 items are active surface, activity, advantage, biosensor, capability, case, catalytic activity, excellent surface, facile synthesis, fluorescence, glucose, high surface, layer, metallic nanoparticle, mos, photothermal therapy, plasmonic, plasmonic property, Raman scattering, Raman scattering activity, research, role, sensitivity, SERS intensity, SERS performance, shell, silver nanoparticle, stability, structure, ultrasensitive surface and weak Raman signal.

(iii) Cluster 3 has 28 items and marked in blue, the 28 items are addition, characterization, discovery, efficient surface, enhancement, graphene oxide, influence, metal nanoparticle, molecule, optical property, organic dye, paper, powerful tool, preparation, property, Raman enhancement, Raman scattering platform, Raman signal, reduction, sensing, ser application, SERS effect, SERS platform, surface plasmon resonace, surfaceenchanced Raman scattering synthesis and trace.

(iv) Cluster 4 has 27 items and marked in yellow, the 27 items are adsorption, analysis, analyte, compound, copper, determination, effect, enhanced Raman scattering, gold, gold nanoparticle, gold nanoparticles, intensity, interaction, ion, nanoparticle surface, phenomenon, Raman spectra, Raman spevtroscopy, resonace, SERS, SERS study, silver, study, surface enhanced Raman spectroscopy, time and variety.

(v) Cluster 5 has 27 items and marked in purple, the 27 items are active substrate, application, attention, bimetallic nanoparticle, concentration, field, graphene, high performance surfaced, high sensitivity, laser, nanostructure, photochemical synthesis, plasmon, presence, Raman scattering application, Raman scattering spectroscopy, Raman scattering suvstrate, Raman spectrum, rapid detection, recent progress, recent year, SERS active substrate, SERS activity, SERS probe, surface and tool.

(vi) Cluster 6 has 17 items and marked in sky blue, the 17 items are area enhancement factor, fabrication, food, hotspot, magnetic nanoparticle, oxide, pesticide residue, powerful analysis technique, Raman scattering detection, Raman spectroscopy substrate, technique and use.

(vii) Cluster 7 has 17 items and marked in orange, the 17 items are combination, development, importance, investigation, mechanism, new surface, Raman, recent advance, reproducibility, sensor, SERS active nanoparticle, SERS measurement, single molecule, single nanoparticle spectra and spectroscopy.

(viii) Cluster 8 has 9 items and marked in brown colour, the 9 items are deposition, film, gap, identification, morphology, nanoparticle, reproducible surface, SERS sensor and substrate.

(ix) Cluster 9 has 5items and marked in pink, the 5 items are charge transfer, probe, surface enhanced Raman scattering and tio.

Labels are given to each term with coloured circles. The size of the circle for each term varies depending on the frequency of occurrence of the term. The size of the label circle shows a positive correlation with the occurrence of the term in the title and abstract]. The more often the term is found, the larger the label size. The mapping visualization analysed in this study consists of 3 parts: network visualization (see Figure 2), density visualization (see Figure 3), and overlay visualization (see Figure 4)[49].

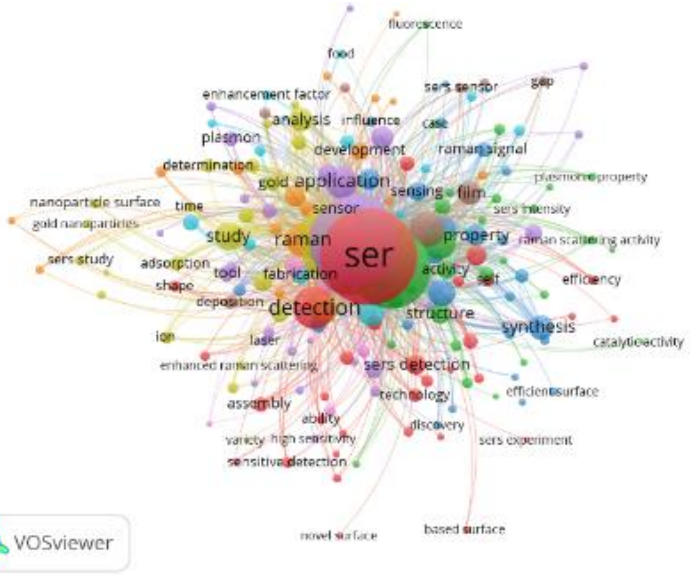


Figure 2. Network visualization of Nanoparticle, SERS, Graphene, Graphene Surface-Enhanced Raman

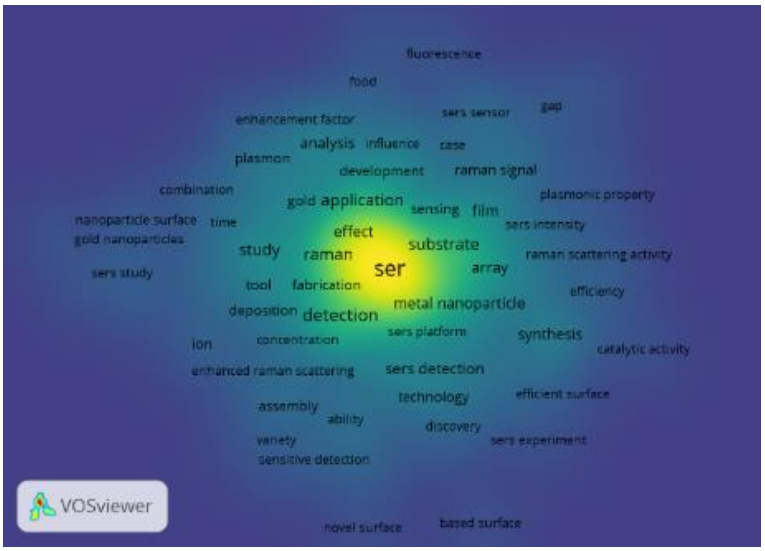


Figure 3. Density visualization of Nanoparticle, SERS, Graphene, Graphene Surface-Enhanced Raman Scattering keyword

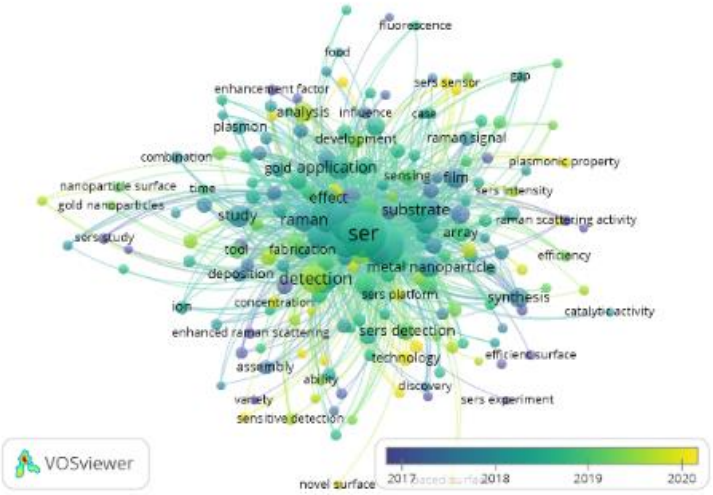


Figure 4. Overlay visualization of Nanoparticle, SERS, Graphene, Graphene Surface-Enhanced Raman Scattering keyword.

Figure 2 shows the relationship between terms. The relationship between terms is depicted in an interconnected network. Figure 2 shows the cluster of each term that is often researched and related to the research topic of Graphene-Based Surfaced-Enhanced Raman Scattering (SERS). From the clusters contained in the network visualization, it can be seen that the research Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) can be separated into 4 fields, namely the education term which is included in cluster 4 with 195 links total, 1201 total link strength, and 179 occurrences (see Figure 5). The second term is Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) to cluster 7 with a total of 213 links, a total link strength of 1036, and occurrences of 159 (see Figure 6), and a mechanical engineering education term which belongs to cluster 4 with a total of 157 links, a total link strength of 564, and 77 occurrences (see Figure 7).

Figure 3 shows the density visualization. Density visualization means that the brighter the yellow colour and the larger the diameter of the circle of term labels, the more often the term appears. This means that a lot of research on related terms has been carried out. Vice versa, if the colour of the term fades closes to the background colour, then the number of studies on the term is small. Based on Figure 3, it can be seen that research related to surface, nanoparticle, ser, Raman scattering, Raman spectroscopy has a high number of studies. Figure 4 shows the overlay visualization in mechanical engineering education research. This visualization overlay shows the novelty of research on related terms.. Figure 4, which is clarified in Figure 8, shows that research on Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) was mostly carried out from 2017 to 2018. The time for the popularity of the term Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) in research has been quite long. Thus, we can easily create new research on Graphene-Based Surfaced-Enhanced Raman Scattering (SERS). Figure 5 shows a network of ser relations with other terms, namely

Figure 3 shows the density visualization. Density visualization means that the brighter the yellow color and the larger the circle diameter of the term label, the more often the term appears. This means that a lot of research on related terms has been done. On the other hand, if the color of the term fades close to the background color, then the number of studies on the term is small. Based on Figure 3, it can be seen that research related to surface, nanoparticles, ser, Raman scattering, Raman spectroscopy has a high number of studies. Figure 4 shows the overlay visualization in mechanical engineering education research. This visualization overlay demonstrates the novelty of research on related terms.

Figure 4 which is clarified in Figure 8 shows that research on Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) was mostly carried out from 2017 to 2018. It's time for the popularity of the term Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) in research for a

long time. . Thus, we can easily make new research on Graphene-Based Surfaced-Enhanced Raman Scattering (SERS).

4. Conclusion

The purpose of this study is to examine the development of research related to Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) through a bibliometric approach to computational mapping analysis using VOSviewer. The article data was obtained from the Google Scholar database using the publish or perish reference manager application. The keywords used to guide the process of searching for the title and abstract of the article were "Nanoparticles, SERS, Graphene, Graphene Surface-Enhanced Raman Scattering". A total of 920 articles were found that were considered related to the topic of this research. The research period used was the last 10 years, which was published in the range of 2012 to 2022. The results showed that the Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) research significantly increased from 2012 to 2020 and decreased in 2021. The results of this study indicate that there is a high possibility of Graphene-Based Surfaced-Enhanced Raman Scattering (SERS) research for future researchers who will conduct research related to this topic.

References

[1] Li, Z.-Y.; Xia, Y. Metal Nanoparticles with Gain toward Single-Molecule Detection by Surface-Enhanced Raman Scattering. Nano Lett. 2010, 10, 243–249.

[2] Han, Y.; Liu, S.; Liu, B.; Jiang, C.; Zhang, Z. In Situ Loading of Ag Nanocontacts onto Silica Nanospheres: A SERS Platform for Ultrasensitive Detection. RSC Adv. 2014, 4, 2776-2782.

[3] Jiang, S.-M.; Wu, D.-J.; Wu, X.-W.; Liu, X.-J. Enormous Enhancement of Electric Field in Active Gold Nanoshells. Chin. Phys. B 2014,23,047807.

[4] Zhou, Q.; Zhu, J.; Yuan, J.; Fang, X. Numerical Simulation of Surface-Enhanced Coherent Anti-Stokes Raman Scattering on Gold Nanoparticle Substrate. J. Nanosci. Nanotechnol. 2017,17,1667

[5] Kneipp, K.; Wang, Y.; Kneipp, H.; Perelman, L.T.; Itzkan, I.; Dasari, R.R.; Feld, M.S. Single Molecule Detection Using Surface-Enhanced Raman Scattering (SERS). Phys. Rev. Lett. 1997, 78, 1667.

[6] Tian, Z.-Q.; Ren, B.; Wu, D.-Y. Surface-Enhanced Raman Scattering: From Noble to Transition Metals and from Rough Surfaces to Ordered Nanostructures. J. Phys. Chem. B 2002, 106, 9463–9483.

[7] . Ren, B.; Huang, Q.; Cai, W.; Mao, B.; Liu, F.; Tian, Z. Surface Raman Spectra of Pyridine and Hydrogen on Bare Platinum and Nickel Electrodes. J. Electroanal. Chem. 1996, 415, 175–178.

[8] Wallace, P.R. The Band Theory of Graphite. Phys. Rev. 1947, 71, 622.

[9] Novoselov, K.S.; Geim, A.K.; Morozov, S.V.; Jiang, D.; Zhang, Y.; Dubonos, S.V.; Grigorieva, I.V.; Firsov, A.A. Electric Field Effect in Atomically Thin Carbon Films. Science 2004, 306, 666–669.

[10] Zhang, Y.; Tan, Y.-W.; Stormer, H.L.; Kim, P. Experimental Observation of the Quantum Hall Effect and Berry's Phase in Graphene. Nature 2005, 438, 201–204

[11] Ling, X.; Xie, L.; Fang, Y.; Xu, H.; Zhang, H.; Kong, J.; Dresselhaus, M.S.; Zhang, J.; Liu, Z. Can Graphene Be Used as a Substrate for Raman Enhancement? Nano Lett. 2010, 10, 553–561.

[12] Huh, S.; Park, J.; Kim, Y.S.; Kim, K.S.; Hong, B.H.; Nam, J.-M. UV/Ozone-Oxidized Large Scale Graphene Platform with Large Chemical Enhancement in Surface-Enhanced Raman Scattering. ACS Nano 2011, 5, 9799–9806. Enhancement of a Dipolar Molecule on Graphene. J. Phys. Chem. C 2014, 118, 2077–2084.

[13] Yu, X.; Cai, H.; Zhang, W.; Li, X.; Pan, N.; Luo, Y.; Wang, X.; Hou, J. Tuning Chemical Enhancement of SERS by Controlling the Chemical Reduction of Graphene Oxide Nanosheets. ACS Nano 2011, 5, 952–958. [CrossRef] [PubMed]

[14] Colomban, P.; March, G.; Mazerolles, L.; Karmous, T.; Ayed, N.; Ennabli, A.; Slim, H. Raman

Identification of Materials Used for Jewellery and Mosaics in Ifriqiya. J. Raman Spectrosc. 2003, 34, 205–213.
[15] Huang, C.; Kim, M.; Wong, B.M.; Safron, N.S.; Arnold, M.S.; Gopalan, P. Raman Enhancement of a Dipolar Molecule on Graphene. J. Phys. Chem. C 2014, 118, 2077–2084.
[16] Cao, Y.; Cheng, Y.; Sun, M. Graphene-Based SERS for Sensor and Catalysis. Appl. Spectrosc. Rev. 2021, in press.
[17] Kang, L.; Chu, J.; Zhao, H.; Xu, P.; Sun, M. Recent Progress in the Applications of Graphene in Surface-Enhanced Raman Scattering and Plasmon-Induced Catalytic Reactions. J. Mater. Chem. C 2015, 3, 9024–9037
[18] Zhang, N.; Tong, L.; Zhang, J. Graphene-Based Enhanced Raman Scattering toward Analytical Applications. Chem. Mater. 2016, 28, 6426–6435. [CrossRef]
[19] Sharma, S.; Prakash, V.; Mehta, S. Graphene/Silver Nanocomposites-Potential Electron Mediators for Proliferation in Electrochemical Sensing and SERS Activity. TrAC Trends Anal. Chem. 2017, 86, 155–171.
[20] AL HUSAENI, Dwi Fitria; NANDIYANTO, Asep Bayu Dani. Bibliometric using Vosviewer with Publish or Perish (using google scholar data): From step-by-step processing for uSERS to the practical examples in the analysis of digital learning articles in pre and post Covid-19 pandemic. *ASEAN Journal of Science and Engineering*, 2022, 2.1: 19-46.
[21] AZIZAH, Nissa Nur; MARYANTI, Rina; NANDIYANTO, Asep Bayu Dani. How to search and manage references with a specific referencing style using google scholar: From step-by-step processing for uSERS to the practical examples in the referencing education. *Indonesian Journal of Multidiciplinary Research*, 2021, 1.2: 267-294.

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220206-01 ~ 0220206-15
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.13377

Bibliometric Analysis of Computational Mapping in The Publication of Nano Propolis using VOSviewer

Alifia Vidiashtari Nabilla[1], Asep Bayu Dani Nandiyanto[2*]

[1,2]Faculty of Mathematics and Natural Sciences Education, Universitas Pendidikan Indonesia, Jl. Setiabudhi No 229 Bandung 40154, West Java, Indonesia

*nandiyanto@upi.edu

Abstract. Previous research has shown that propolis contains natural ingredients such as antibacterial, antifungal and anti-inflammatory activities. With a lot of content and benefits for health, further research is needed on nanoparticles in propolis. This research was conducted to determine the development of studies on nano propolis in the last 10 years. The data used in this study comes from indexed articles that have been published on Google Scholar. The software used for data processing is Publish or Perish for data filtering and VOSviewer for visualization of bibliometric computational. The results showed that there were 1000 articles that matched the criteria, and it was found that nano propolis is divided into 3 main fields, namely nanoparticles, propoli, and propolis. Based on data mapping, it can be seen that there is an increase in research on nanopropolis around 2019-2020. This review can be a starting point for further research related to nanopropolis.

Keywords: Bibliometric, Nano Propolis, VOSviewer

(Received 2022-09-27, Accepted 2022-10-30, Available Online by 2022-10-31)

1. Introduction

In this era, many people are starting to become health conscious and look for natural alternative ingredients to help maintain a healthy body. One of the natural ingredients that are widely used for health is propolis. Propolis is a resin mixture produced by honey bees from plant exudates, has a complex chemical composition that has actually been used by previous generations as medicine[1]. Propolis is a material that is rich in flavonoids, phenolic acids and is a terpene derivative. With the content of compounds like this propolis can work as an ingredient with antibacterial, antifungal and anti-inflammatory properties. Chemical analysis has shown interesting molecules in propolis that also present interesting anti-oxidant and anti-proliferative properties in the field of anti-cancer therapy[2]. Unfortunately, it is still not certain whether the field of research on propolis is in great demand or not, especially in the field of nanopropolis research.

To determine the development of research in the field of nano propolis, blibiometric analysis can be used. Bibliometric analysis is a form of meta-analysis of research data that can assist researchers in

studying bibliographic content and citation analysis from articles published in journals and other scientific works[3]. The collected bibliometric data can be processed using a simple data processing application.

Previously, there were many studies that used bibliometric analysis, including bibliometric analysis in the field of education[3], bibliometric analysis in the field of economics[4], bibliometric analysis in the field of health[5]. However, research on computational mapping of bibliometric analysis of published data in the field of nano propolis to determine the development of research has not been carried out. Therefore, this study aims to carry out computational research and mapping bibliometric analysis of articles that have been indexed on google scholars using VOSviewer software. It is hoped that this research can be a reference for researchers to conduct and determine the research themes to be taken, especially those related to nano propolis.

2. Methods

2.1. Data Collection

The data used in this study comes from articles that have been indexed and have been published on Google Scholar. Article data will be collected using the Publish or Perish reference manager application. Information on how to use the Publish or Perish application is obtained from articles published by Azizah et al. [6] Keywords used to filter publications were "nano propolis" and "nanoparticle". The article data used in this study came from journals published in 2012 to 2022.

2.2. Blibiometric data processing using Microsoft Excel

The data obtained from the Publish or Perish application is exported into two types of files: reasearch information system format (.ris) and comma separated value format (*.csv). The data collected from the metadata will contain the author's name, title, year, journal name, publisher, number of citations, article links, and related URLs.

2.3. Computational mapping analysis of bibliometric published data using the VOSviewer software

Article data from the source database was mapped using VOSviewer to create 3 variations of mapping publications, namely network visualization, density visualization, and overlay visualization based on the network (co-citation) between existing items. When creating a bibliometric map, the keyword frequency is set to be found at least 3 times. Therefore, 281 less relevant terms and keywords were removed.

3. Result and Discussion

3.1. Data collection results

Based on the search data on the Publish or Perish reference application from the Google Scholar database, 1000 article data met the research criteria. **Table 1** shows some examples of published data used in the VOSviewer analysis in this study. The data samples taken were 50 articles most related to the topic of nano propolis. The number of citations from all articles used in this study is 21350, the number of citations per year is 2135.00, the number of citations per article used is 21.35, the average author in the articles used is 3.78, all articles have an average h-index of 71, and a g-index of 111.

Table 1. The most cited nano propolis publication data

No	Authors	Title	Year	Cites	Refs
1	H Wang, J Qian, F Ding	Emerging chitosan-based films for food packaging applications	2018	429	[7]

2	CJM Rivas, M Tarhini, W Badri, K Miladi…	Nanoprecipitation process: From encapsulation to drug delivery	2017	337	[8]
3	A Alexander, RJ Patel, S Saraf, S Saraf	Recent expansion of pharmaceutical nanotechnologies and targeting strategies in the field of phytopharmaceuticals for the delivery of herbal extracts and bioactives	2016	118	[9]
4	MG Morais, VG Martins, D Steffens…	Biological applications of nanobiotechnology	2014	93	[10]
5	MO Wassel, MA Khattab	Antibacterial activity against Streptococcus mutans and inhibition of bacterial induced enamel demineralization of propolis, miswak, and chitosan nanoparticles based dental varnishes	2017	92	[11]
6	P Szweda, K Gucwa, E Kurzyk, E Romanowska…	Essential oils, silver nanoparticles and propolis as alternative agents against fluconazole resistant Candida albicans, Candida glabrata and Candida krusei Clinical Isolates	2015	91	[12]
7	IPS Fernando, WW Lee, EJ Han, G Ahn	Alginate-based nanomaterials: Fabrication techniques, properties, and applications	2020	90	[13]
8	A Ullah, S Ullah, MQ Khan, M Hashmi, PD Nam…	Manuka honey incorporated cellulose acetate nanofibrous mats: Fabrication and in vitro evaluation as a potential wound dressing	2020	88	[14]
9	NM Elbaz, IA Khalil, AA Abd-Rabou…	Chitosan-based nano-in-microparticle carriers for enhanced oral delivery and anticancer activity of propolis	2016	75	[15]
10	S Derman	Caffeic acid phenethyl ester loaded PLGA nanoparticles: effect of various process parameters on reaction yield, encapsulation efficiency, and particle size	2015	74	[16]
11	R Conte, V Marturano, G Peluso, A Calarco…	Recent advances in nanoparticle-mediated delivery of anti-inflammatory phytocompounds	2017	71	[17]
12	S Sharaf, ME El-Naggar	Wound dressing properties of cationized cotton fabric treated with carrageenan/cyclodextrin hydrogel loaded with honey bee propolis extract	2019	70	[18]
13	S Sabra, DM Ragab, MM Agwa, S Rohani	Recent advances in electrospun nanofibers for some biomedical applications	2020	63	[19]
14	A Eskandarinia, A Kefayat, M Gharakhloo…	A propolis enriched polyurethane-hyaluronic acid nanofibrous wound dressing with remarkable antibacterial and wound healing activities	2020	61	[20]
15	K Khoshnevisan, H Maleki, H Samadian…	Antibacterial and antioxidant assessment of cellulose acetate/polycaprolactone nanofibrous mats impregnated with propolis	2019	58	[21]

16	R Liu, D Ji, G Zhou, Z Liu, Q Xu…	Electrospun nanofibers for personal protection in mines	2021	58	[22]
17	M Rezaeigolestani, A Misaghi, A Khanjari…	Antimicrobial evaluation of novel poly-lactic acid based nanocomposites incorporated with bioactive compounds in-vitro and in refrigerated vacuum-packed cooked …	2017	56	[23]
18	M Kurakula, GSNK Rao	Moving polyvinyl pyrrolidone electrospun nanofibers and bioprinted scaffolds toward multidisciplinary biomedical applications	2020	49	[24]
19	A Kamkar, E Molaee-Aghaee, A Khanjari…	Nanocomposite active packaging based on chitosan biopolymer loaded with nano-liposomal essential oil: Its characterizations and effects on microbial, and chemical …	2021	48	[25]
20	T Mehdizadeh, AM Langroodi	Chitosan coatings incorporated with propolis extract and Zataria multiflora Boiss oil for active packaging of chicken breast meat	2019	48	[26]
21	Y Wu, YH Li, XH Gao, HD Chen	The application of nanoemulsion in dermatology: an overview	2013	48	[27]
22	KM Kamel, IA Khalil, ME Rateb, H Elgendy…	… /oregano-loaded solid lipid nanoparticles to augment 5-fluorouracil cytotoxicity for colorectal cancer: extract standardization, nanoparticle optimization, and cytotoxicity …	2017	44	[28]
23	AD Permana, RN Utami, AJ Courtenay…	Phytosomal nanocarriers as platforms for improved delivery of natural antioxidant and photoprotective compounds in propolis: An approach for enhanced both …	2020	42	[29]
24	ES Abamor	Antileishmanial activities of caffeic acid phenethyl ester loaded PLGA nanoparticles against Leishmania infantum promastigotes and amastigotes in vitro	2017	42	[30]
25	A Stähli, CU Maheen, FJ Strauss, S Eick…	Caffeic acid phenethyl ester protects against oxidative stress and dampens inflammation via heme oxygenase 1	2019	41	[31]
26	L Moradkhannejhad, M Abdouss, N Nikfarjam…	Electrospinning of zein/propolis nanofibers	2018	39	[32]
27	P Tatli Seven, I Seven, B Gul Baykalir…	Nanotechnology and nano-propolis in animal production and health: An overview	2018	37	[33]
28	M Contardi, D Kossyvaki, P Picone, M Summa…	Electrospun polyvinylpyrrolidone (PVP) hydrogels containing hydroxycinnamic	2021	36	[34]

		acid derivatives as potential wound dressings			
29	M Azarifar, B Ghanbarzadeh, A Abdulkhani	The effects of gelatin-CMC films incorporated with chitin nanofiber and Trachyspermum ammi essential oil on the shelf life characteristics of refrigerated raw beef	2020	33	[35]
30	LD Pérez-Vergara, MT Cifuentes, AP Franco…	Development and characterization of edible films based on native cassava starch, beeswax, and propolis	2020	33	[36]
31	M Azarifar, B Ghanbarzadeh, A Abdulkhani	The effects of gelatin-CMC films incorporated with chitin nanofiber and Trachyspermum ammi essential oil on the shelf life characteristics of refrigerated raw beef	2020	33	[35]
32	E Adomavičiūtė, S Pupkevičiūtė, V Juškaitė…	Formation and investigation of electrospun PLA materials with propolis extracts and silver nanoparticles for biomedical applications	2017	32	[37]
33	M Yousefi, N Khorshidian, AM Mortazavian…	Preparation optimization and characterization of chitosan-tripolyphosphate microcapsules for the encapsulation of herbal galactagogue extract	2019	32	[38]
34	S Khaledi, S Jafari, S Hamidi, O Molavi…	Preparation and characterization of PLGA-PEG-PLGA polymeric nanoparticles for co-delivery of 5-Fluorouracil and Chrysin	2020	31	[39]
35	O Catchpole, K Mitchell, S Bloor, P Davis…	Anti-gastrointestinal cancer activity of cyclodextrin-encapsulated propolis	2018	30	[40]
36	HS Ching, N Luddin, TP Kannan…	Modification of glass ionomer cements on their physical-mechanical and antimicrobial properties	2018	29	[41]
37	A Raza, U Hayat, M Bilal, HMN Iqbal…	Zein-based micro-and nano-constructs and biologically therapeutic cues with multi-functionalities for oral drug delivery systems	2020	28	[42]
38	SM Azab, AM Fekry	The application of a bee glue-modified sensor in daclatasvir dual effect detection	2017	19	[43]
39	Y Shahbazi, N Shavisi	A novel active food packaging film for shelf-life extension of minced beef meat	2018	19	[44]
40	T Khare, SS Palakurthi, BM Shah, S Palakurthi…	Natural product-based nanomedicine in treatment of inflammatory bowel disease	2020	19	[45]
41	CC Carrion, M Nasrollahzadeh, M Sajjadi…	Lignin, lipid, protein, hyaluronic acid, starch, cellulose, gum, pectin, alginate and chitosan-based nanomaterials for cancer nanotherapy: Challenges and opportunities	2021	19	[46]

42	K Villalobos, H Rojas, R González-Paz…	Production of starch films using propolis nanoparticles as novel bioplasticizer	2017	18	[47]
43	E Adomavičiūtė, J Baltušnikaitė-Guzaitienė…	Formation and characterization of melt-spun polypropylene fibers with propolis for medical applications	2018	18	[48]
44	T Sato, D Mello, L Vasconcellos, AJM Valente…	Chitosan-based coacervate polymers for propolis encapsulation: Release and cytotoxicity studies	2020	18	[49]
45	S Patil, N Desai, K Mahadik, A Paradkar	Can green synthesized propolis loaded silver nanoparticulate gel enhance wound healing caused by burns?	2015	17	[50]
46	S Ceylan	Propolis loaded and genipin-crosslinked PVA/chitosan membranes	2021	17	[51]
47	S El-Guendouz, B Lyoussi, JP Lourenço…	Magnetite nanoparticles functionalized with propolis against methicillin resistant strains of Staphylococcus aureus	2019	16	[52]
48	F Zeighampour, F Alihosseini…	Comparison of prolonged antibacterial activity and release profile of propolis-incorporated PVA nanofibrous mat, microfibrous mat, and film	2018	16	[53]
49	D Fasolo, B Pippi, G Meirelles, G Zorzi…	Topical delivery of antifungal Brazilian red propolis benzophenones-rich extract by means of cationic lipid nanoemulsions optimized by means of Box-Behnken …	2020	16	[54]
50	AA Elgendy, DM Fayyad	Cell viability and apoptotic changes of dental pulp stem cells treated with propolis, chitosan, and their nano counterparts	2017	13	[55]

3.2. Development and research in the field of nano propolis

The development of research in the field of propolis nanoparticles published in google scholar indexed journals is shown in **Table 2**. Based on the data presented, it can be seen that the number of studies on the topic of propolis nanoparticles is 1000 articles from 2012-2021. During 2012 there were 9 articles published. In 2013 there were 10 articles. In 2014 there were 25 articles. In 2015 there were 26 articles. In 2016 there were 42 articles. In 2017 there were 63 articles. In 2018 there were 81 articles. In 2019 there were 119 articles. In 2020 there were 171 articles. In 2021 there were 248 articles and as of September 2022 there have been 195 published articles. **Figure 1** shows the development of propolis nanoparticle research over the last 10 years in the 2012-2022 range. Based on **Figure 1** the number of publications on nano propolis has increased steadily, these data indicate that the popularity of research in the field of propolis nanoparticles tends to increase.

Table 2. Data on the number of publications of propolis nanoparticles

Year	Number of publications
2012	9
2013	10
2014	25
2015	26
2016	42
2017	63
2018	81
2019	119
2020	171
2021	248
2022	195
Total	989
Average	89,91

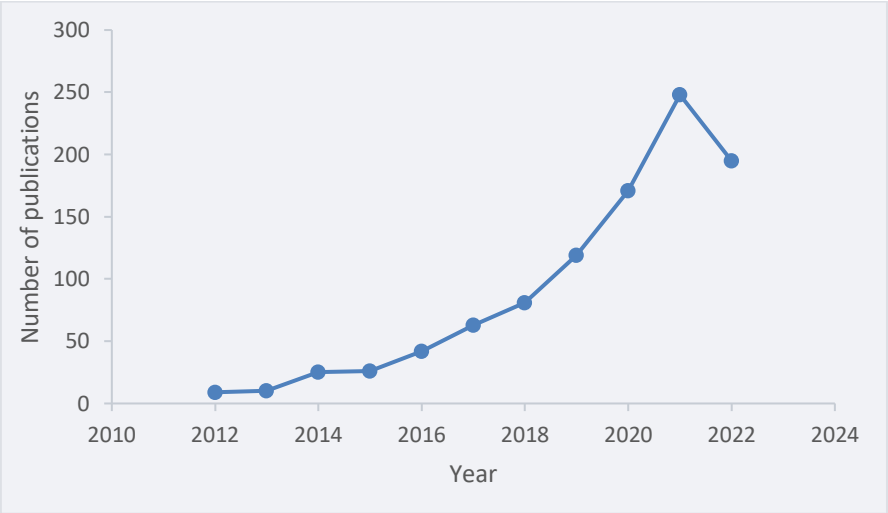


Figure 1. Graph of the number of studies in the field of propolis nanoparticles

3.3. Visualization nano propolis topic area using VOSviewer

For computational mapping carried out on article data, VOSviewer is used. From the computational mapping data available in **Figure 2**, 201 items were found. Each item found related to propolis nanoparticles in the data is divided into 8 clusters, namely:

a) Cluster 1 has 33 items marked in red, the 33 items are ability, anticancer activity, beeswax, bioavailability, biocompatibility, carrier, cell, characterization, chemical composition, controlled release, cycolodextrin, cytotoxicity, data, drug, drug delivery system, efficiency, formulation, lipid nanoparticle, liposome, malvern, nano carrier, nanoparticle size, nanostructured lipid carrier, niosome, oil, optimazion, paper, polymeric nanoparticle, propolis wax, solid lipid nanoparticle, solubility, stability, zeta potential.

b) Cluster 2 has 31 items marked in green, the 31 items are antibacterial property, aqueous solution, caffeic acid, case, chrysin, compound, drug delivery, effect, electrode, stimulation, ethanol, honey, incorporation, laccase, magnetic nanoparticle, magnetite nanoparticle, matrix, mechanical property, nano formulation, parameter, particle, phenolic compound, preparation, process, propolis, simultaneous determination, solution, structure, technique, total flavonoid content, vitro evaluation.
c) Cluster 3 has 28 items marked in blue, the 28 items are antibacterial effect, antimicrobial activity, antimicrobial effect, antimicrobial efficacy, antimicrobial property, assessment, brazilian red propolis, chitosan nanoparticle, chlorhexidine, combination, comparative study, dentisty, enterococcus faecali , evaluation, gel, intracanal medicament, miswak, nano chitosan, nano propoli, nano silver, nano size, propoli, propolis nanoparticle, silver nanoparticle, sodium hypochlorite, mutant streptococcus, vitro study.
d) Cluster 4 has 28 items marked in yellow, the 28 items are antibiotic, antioxidant activity, cellulose, comprehensive review, curcumin, dimension, electrospun nanofiber, encapsulation, food, healing, influence, liver, mechanism, medical application, membrane, nano emulsion, nanofiber, poly, recent advance, research, strach, vinyl alchol, vitro, vivo study, wound, wound dressing, wound healing, wound healing application.
e) Cluster 5 has 27 items marked in purple, the 27 items are activity, addition, application, bacterial cellulose, bee, bone tissue engineering, caffeic acid phenethyl ester, cancer cell, CAPE, efficiency, enhancement, flavonoid, morphology, nano, nanoemulsion, nanotechnology, oxideative stress, PLGA nanoparticle, polymer, production, propolis extract, protective effect, quercetin, skin, temperature, toxicity, water.
f) Cluster 6 has 22 items marked with sky blue, the 22 items are aggregation, agriculture, analysis, antifungal activity, AUNP, biomedical application, characterization, concentration, copper nanoparticle, flavonid content, gold nanoparticle, green synthesis, growth, nanocomposite, nanoparticle, perspective, plant, potential application, presence, reduction, synthesis, synthesized nanoparticle.
g) Cluster 7 has 20 items marked in orange, the 20 items are active packaging, biological activity, biopolymer, bosynthesis, cellulse nanoparticle, chemical, coating, essential oil, extract, film, food packaging application, microbe, preservation, protein, rainbow trout, shelf life, storage, surface, surface charge, type.
h) Cluster 8 has 12 items marked with brown color, the 12 items are Ag nanoparticle, antibacterial activity, anticancer, biological application, development, fabrication, lycopene, medicine, metallic nanoparticle, nanoencapsulation, natural product, plan extract.

The relationship between one term and another is shown in each existing cluster. A label is given to each term with a different colored circle for each cluster. The frequency with which the term occurs affects the size of the circle. The larger the circle, the more frequently the term is found. The mapping visualization analyzed in this study consists of 3 parts: Network visualization (see **Figure 2**), Density visualization (see **Figure 3**), and Overlay visualization (see **Figure 4**).

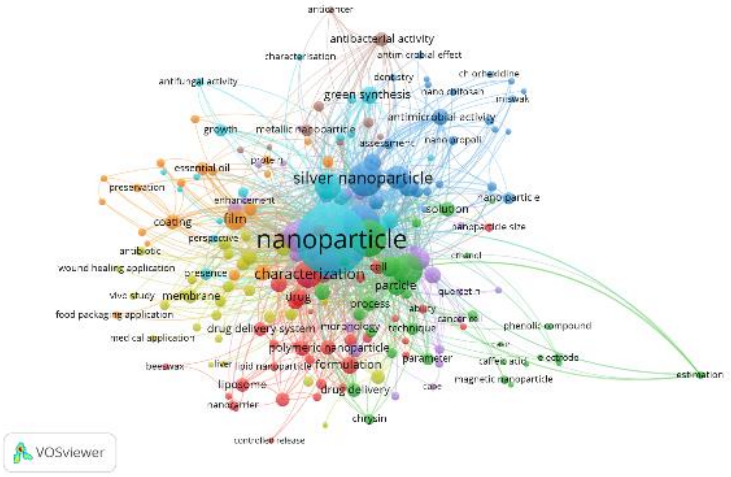


Figure 2. Network visualization for keywords nano propolis and nanoparticles

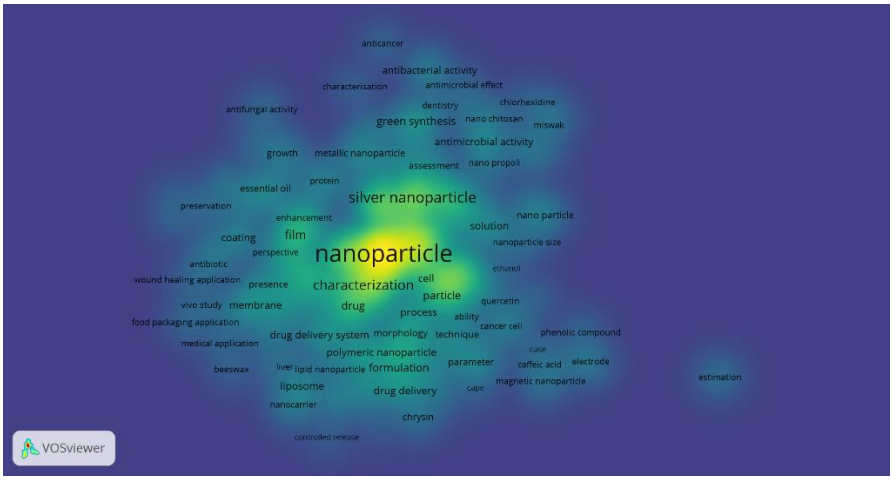


Figure 3. Density visualization for keywords nano propolis and nanoparticles

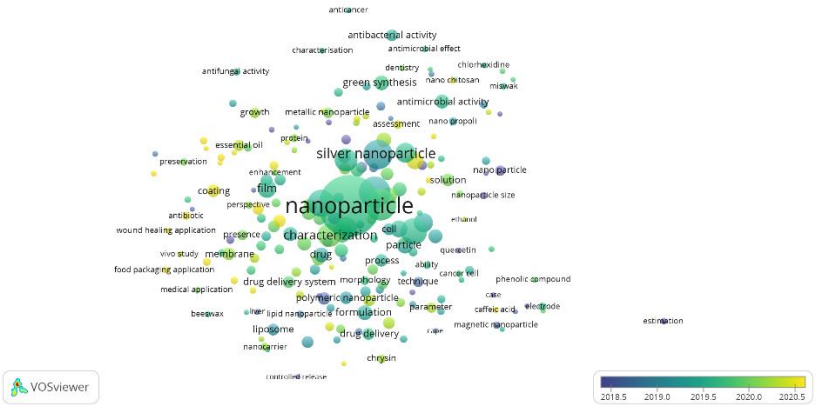


Figure 4. Overlay visualization for keywords nano propolis and nanoparticles

Figure 2 shows the relationship between the terms. The clusters on each of the terms in **Figure 2** show terms that are often studied in the topic of nano propolis. From the clusters contained in the network visualization, it can be seen that research on nano propolis is divided into 3 main fields, namely nanoparticles, propoli, and propolis. In the nanoparticle cluster belonging to cluster 6 with a total of 199

links, 2408 total link strength, and 646 occurrences (see **Figure 5**). Next for the term propoly which is included in cluster 3 with a total of 172 links, 795 total strength, and 169 occurrences (see **Figure 6**). Lastly, propolis belonging to cluster 2 has 151 links, 558 total link strength, and 120 occurrences (see **Figure 7**).

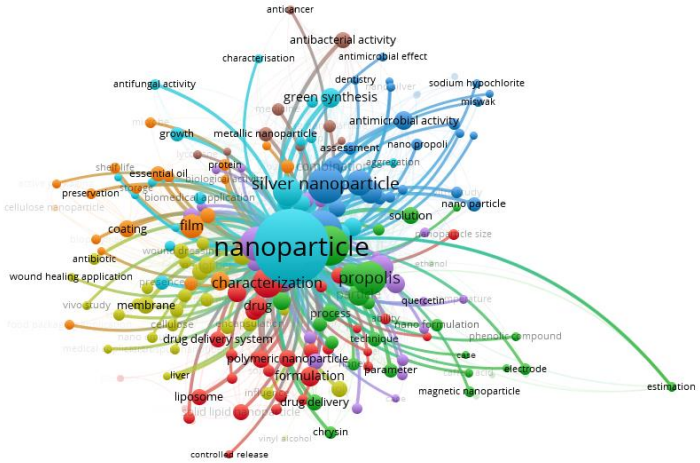


Figure 5. Network visualization of nanoparticle term

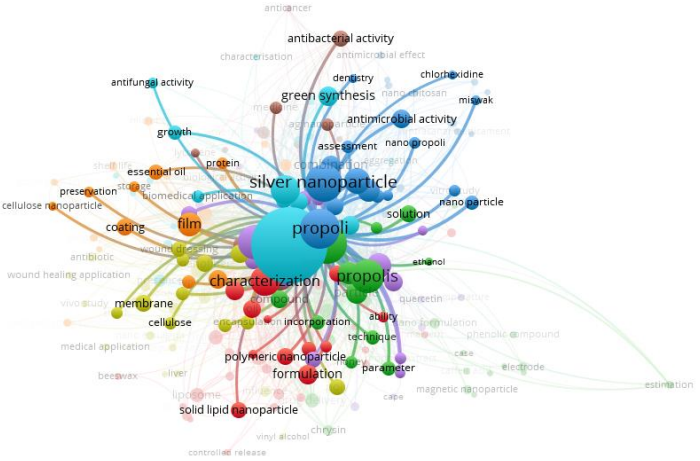


Figure 6. Network visualization of propoli term

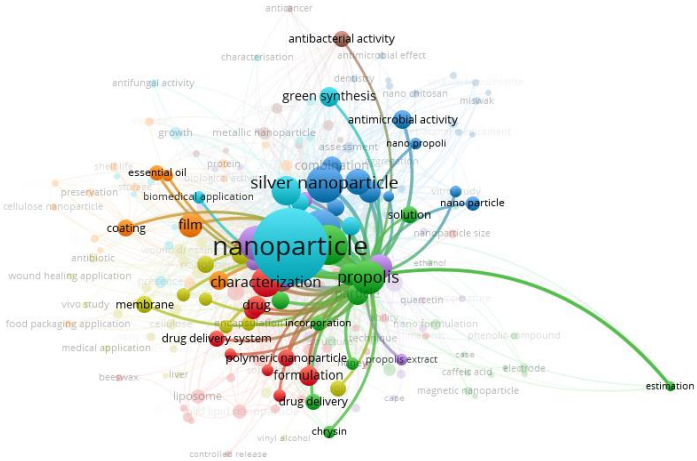


Figure 7. Network visualization of propolis term

Figure 3 shows the density visualization. In this visualization, the terms that appear most often will show a bright yellow color and the diameter of the circle of term labels will be large. This shows that research on this topic is being carried out a lot. Based on Figure 3, it can be seen that the topic of nanoparticles, propolis, films, silver nanoparticles has a yellow color indicating that the term has a high number of studies.

Figure 4 shows overlay visualization in nanopropolis research. The color difference in the circles indicates the novelty of research on related terms. It shows that research on propolis began in 2020 until now. The term nanopropolis has begun to be studied in research in 2019. For nanoparticles in 2018 many studies have been carried out. With this it can be assumed that new research on nanopropolis can be carried out.

Figure 5 shows a network visualization of nanoparticles related to other terms such as propolis, nanopropoli, silver nanoparticle, film, characterization, drug, metallic nanopartcle, essential oil, antifungal activity, green synthesis, density, antimicrobial effect, sodium hypochlorite, miswak, solution, quercetin, electrode, magnetic nanoparticle, case, technique, parameter, ability, process, polymeric nanoparticle, drug dekivery system, liver, membrane, healing application, antibiotic, growth, liposome, and antimicrobal activity. Figure 6 shows a network visualization of propoli related to propolis, nano particle, nano propoly, miswak, chlorhexidine, assessment, silvernanoparticle, solution, ability, densitry, green synthesis, anti-tubacretial activity, antimicrobal activity, protrin, growth, antifungal activity, essential oil , preservation, nanoparticle, coating, film, membrane, cellulose, solid lipid nanoparticle, polymeric nanoparticle, characterization, and parameters. Figure 7 shows a network visualization of propolis related to other terms such as nanoparticle, solution, propolis extract, polumeric nanoparticle, drug delivery, chyrsin, formulation, drug, drug delivery system, film, characterixzation, coating, essential oil, biomedical application, membrane, green synthesis, antibacterial activity, antimicrobial activity, nano propoly, silver nanoparticles, and estimation. Based on network visualization data, propolis has 151 links and is connected with 21 terms, this number is less than the nanoparticle and propoli fields which have a higher level of relevance. So it can be concluded that the field of study for propolis is still very possible to be researched and associated with other terms, of course this will make research have a high impact on novelty in the field of nanoparticle studies.

From the data collected, it can be seen that the keywords for propolis in the nanoparticle field are still rarely used in research, this can be seen from the mapping of the article data. So the study of nano propolis or nano particle propolis can be an option if we are looking for a newer or up to date field of study

4. Conclusion

This research was conducted for computational mapping of bibliometric analysis of published data in the field of nano propolis. The data used in this study came from articles indexed on Google Scholar and filtered using Publish or Perish software. So it was found 1000 articles related to nanoparticles and nano propolis in the range of 2012-2022. Based on mapping visualization using VOSviewer software, it shows an increase in research interest on nano propolis in 2019-2020. As the result it can be concluded that the research topic in the field of nano propolis can be an option by researchers to be further developed.

Acknowledgements

The author would like to thank the family who have provided psychological and material support so that this research can be completed.

References

[1] P. Cerqueira, A. Cunha, and C. Almeida-Aguiar, “Potential of propolis antifungal activity for

clinical applications," *J. Appl. Microbiol.*, no. April, pp. 1207–1228, 2022, doi: 10.1111/jam.15628.
[2] N. Zabaiou *et al.*, "Biological properties of propolis extracts: Something new from an ancient product," *Chemistry and Physics of Lipids*, vol. 207. 2017, doi: 10.1016/j.chemphyslip.2017.04.005.
[3] D. F. Al Husaeni and A. B. D. Nandiyanto, "Bibliometric Computational Mapping Analysis of Publications on Mechanical Engineering Education Using Vosviewer," *J. Eng. Sci. Technol.*, vol. 17, no. 2, pp. 1135–1149, 2022.
[4] N. Comerio and F. Strozzi, "Tourism and its economic impact: A literature review using bibliometric tools," *Tour. Econ.*, vol. 25, no. 1, 2019, doi: 10.1177/1354816618793762.
[5] B. X. Tran *et al.*, "Global evolution of research in artificial intelligence in health and medicine: A bibliometric study," *J. Clin. Med.*, vol. 8, no. 3, 2019, doi: 10.3390/jcm8030360.
[6] N. N. Azizah, R. Maryanti, and A. B. D. Nandiyanto, "How to search and manage references with a specific referencing style using google scholar: From Step-by-step Processing for Users to the Practical Examples in the Referencing Education," *Indones. J. Multidiciplinary Res.*, vol. 1, no. 2, 2021, doi: 10.17509/ijomr.v1i2.37694.
[7] H. Wang, J. Qian, and F. Ding, "Emerging Chitosan-Based Films for Food Packaging Applications," *Journal of Agricultural and Food Chemistry*, vol. 66, no. 2. 2018, doi: 10.1021/acs.jafc.7b04528.
[8] C. J. Martínez Rivas *et al.*, "Nanoprecipitation process: From encapsulation to drug delivery," *International Journal of Pharmaceutics*, vol. 532, no. 1. Elsevier B.V., pp. 66–81, Oct. 30, 2017, doi: 10.1016/j.ijpharm.2017.08.064.
[9] A. Alexander, Ajazuddin, R. J. Patel, S. Saraf, and S. Saraf, "Recent expansion of pharmaceutical nanotechnologies and targeting strategies in the field of phytopharmaceuticals for the delivery of herbal extracts and bioactives," *Journal of Controlled Release*, vol. 241. 2016, doi: 10.1016/j.jconrel.2016.09.017.
[10] M. G. De Morais, V. G. Martins, D. Steffens, P. Pranke, and J. A. V. Da Costa, "Biological applications of nanobiotechnology," *Journal of Nanoscience and Nanotechnology*, vol. 14, no. 1. 2014, doi: 10.1166/jnn.2014.8748.
[11] M. O. Wassel and M. A. Khattab, "Antibacterial activity against Streptococcus mutans and inhibition of bacterial induced enamel demineralization of propolis, miswak, and chitosan nanoparticles based dental varnishes," *J. Adv. Res.*, vol. 8, no. 4, 2017, doi: 10.1016/j.jare.2017.05.006.
[12] P. Szweda *et al.*, "Essential Oils, Silver Nanoparticles and Propolis as Alternative Agents Against Fluconazole Resistant Candida albicans, Candida glabrata and Candida krusei Clinical Isolates," *Indian J. Microbiol.*, vol. 55, no. 2, 2015, doi: 10.1007/s12088-014-0508-2.
[13] I. P. S. Fernando, W. W. Lee, E. J. Han, and G. Ahn, "Alginate-based nanomaterials: Fabrication techniques, properties, and applications," *Chemical Engineering Journal*, vol. 391. 2020, doi: 10.1016/j.cej.2019.123823.
[14] A. Ullah *et al.*, "Manuka honey incorporated cellulose acetate nanofibrous mats: Fabrication and in vitro evaluation as a potential wound dressing," *Int. J. Biol. Macromol.*, vol. 155, 2020, doi: 10.1016/j.ijbiomac.2020.03.237.
[15] N. M. Elbaz, I. A. Khalil, A. A. Abd-Rabou, and I. M. El-Sherbiny, "Chitosan-based nano-in-microparticle carriers for enhanced oral delivery and anticancer activity of propolis," *Int. J. Biol. Macromol.*, vol. 92, 2016, doi: 10.1016/j.ijbiomac.2016.07.024.
[16] S. Derman, "Caffeic Acid Phenethyl Ester Loaded PLGA Nanoparticles: Effect of Various Process Parameters on Reaction Yield, Encapsulation Efficiency, and Particle Size," *J. Nanomater.*, vol. 2015, 2015, doi: 10.1155/2015/341848.
[17] R. Conte, V. Marturano, G. Peluso, A. Calarco, and P. Cerruti, "Recent advances in nanoparticle-mediated delivery of anti-inflammatory phytocompounds," *International Journal of Molecular Sciences*, vol. 18, no. 4. 2017, doi: 10.3390/ijms18040709.

[18] S. Sharaf and M. E. El-Naggar, “Wound dressing properties of cationized cotton fabric treated with carrageenan/cyclodextrin hydrogel loaded with honey bee propolis extract,” *Int. J. Biol. Macromol.*, vol. 133, 2019, doi: 10.1016/j.ijbiomac.2019.04.065.
[19] S. Sabra, D. M. Ragab, M. M. Agwa, and S. Rohani, “Recent advances in electrospun nanofibers for some biomedical applications,” *European Journal of Pharmaceutical Sciences*, vol. 144. 2020, doi: 10.1016/j.ejps.2020.105224.
[20] A. Eskandarinia *et al.*, “A propolis enriched polyurethane-hyaluronic acid nanofibrous wound dressing with remarkable antibacterial and wound healing activities,” *Int. J. Biol. Macromol.*, vol. 149, 2020, doi: 10.1016/j.ijbiomac.2020.01.255.
[21] K. Khoshnevisan, H. Maleki, H. Samadian, M. Doostan, and M. R. Khorramizadeh, “Antibacterial and antioxidant assessment of cellulose acetate/polycaprolactone nanofibrous mats impregnated with propolis,” *Int. J. Biol. Macromol.*, vol. 140, 2019, doi: 10.1016/j.ijbiomac.2019.08.207.
[22] R. Liu, D. Ji, G. Zhou, Z. Liu, Q. Xu, and S. Ramakrishna, “Electrospun nanofibers for personal protection in mines,” *Chemical Engineering Journal*, vol. 404. 2021, doi: 10.1016/j.cej.2020.126558.
[23] M. Rezaeigolestani, A. Misaghi, A. Khanjari, A. A. Basti, A. Abdulkhani, and S. Fayazfar, “Antimicrobial evaluation of novel poly-lactic acid based nanocomposites incorporated with bioactive compounds in-vitro and in refrigerated vacuum-packed cooked sausages,” *Int. J. Food Microbiol.*, vol. 260, 2017, doi: 10.1016/j.ijfoodmicro.2017.08.006.
[24] M. Kurakula and G. S. N. Koteswara Rao, “Moving polyvinyl pyrrolidone electrospun nanofibers and bioprinted scaffolds toward multidisciplinary biomedical applications,” *European Polymer Journal*, vol. 136. 2020, doi: 10.1016/j.eurpolymj.2020.109919.
[25] A. Kamkar *et al.*, “Nanocomposite active packaging based on chitosan biopolymer loaded with nano-liposomal essential oil: Its characterizations and effects on microbial, and chemical properties of refrigerated chicken breast fillet,” *Int. J. Food Microbiol.*, vol. 342, 2021, doi: 10.1016/j.ijfoodmicro.2021.109071.
[26] T. Mehdizadeh and A. Mojaddar Langroodi, “Chitosan coatings incorporated with propolis extract and Zataria multiflora Boiss oil for active packaging of chicken breast meat,” *Int. J. Biol. Macromol.*, vol. 141, 2019, doi: 10.1016/j.ijbiomac.2019.08.267.
[27] Y. Wu, Y. H. Li, X. H. Gao, and H. D. Chen, “The application of nanoemulsion in dermatology: An overview,” *Journal of Drug Targeting*, vol. 21, no. 4. 2013, doi: 10.3109/1061186X.2013.765442.
[28] K. M. Kamel, I. A. Khalil, M. E. Rateb, H. Elgendy, and S. Elhawary, “Chitosan-Coated Cinnamon/Oregano-Loaded Solid Lipid Nanoparticles to Augment 5-Fluorouracil Cytotoxicity for Colorectal Cancer: Extract Standardization, Nanoparticle Optimization, and Cytotoxicity Evaluation,” *J. Agric. Food Chem.*, vol. 65, no. 36, 2017, doi: 10.1021/acs.jafc.7b03093.
[29] A. D. Permana, R. N. Utami, A. J. Courtenay, M. A. Manggau, R. F. Donnelly, and L. Rahman, “Phytosomal nanocarriers as platforms for improved delivery of natural antioxidant and photoprotective compounds in propolis: An approach for enhanced both dissolution behaviour in biorelevant media and skin retention profiles,” *J. Photochem. Photobiol. B Biol.*, vol. 205, 2020, doi: 10.1016/j.jphotobiol.2020.111846.
[30] E. S. Abamor, “Antileishmanial activities of caffeic acid phenethyl ester loaded PLGA nanoparticles against Leishmania infantum promastigotes and amastigotes in vitro,” *Asian Pac. J. Trop. Med.*, vol. 10, no. 1, 2017, doi: 10.1016/j.apjtm.2016.12.006.
[31] A. Stähli, C. U. Maheen, F. J. Strauss, S. Eick, A. Sculean, and R. Gruber, “Caffeic acid phenethyl ester protects against oxidative stress and dampens inflammation via heme oxygenase 1,” *Int. J. Oral Sci.*, vol. 11, no. 1, 2019, doi: 10.1038/s41368-018-0039-5.
[32] L. Moradkhannejhad, M. Abdouss, N. Nikfarjam, S. Mazinani, and V. Heydari, “Electrospinning of zein/propolis nanofibers; antimicrobial properties and morphology investigation,” *J. Mater. Sci. Mater. Med.*, vol. 29, no. 11, 2018, doi: 10.1007/s10856-018-

6174-x.
[33] P. Tatli Seven, I. Seven, B. Gul Baykalir, S. Iflazoglu Mutlu, and A. Z. M. Salem, "Nanotechnology and nano-propolis in animal production and health: an overview," *Italian Journal of Animal Science*, vol. 17, no. 4. 2018, doi: 10.1080/1828051X.2018.1448726.
[34] M. Contardi *et al.*, "Electrospun polyvinylpyrrolidone (PVP) hydrogels containing hydroxycinnamic acid derivatives as potential wound dressings," *Chem. Eng. J.*, vol. 409, 2021, doi: 10.1016/j.cej.2020.128144.
[35] M. Azarifar, B. Ghanbarzadeh, M. Sowti khiabani, A. Akhondzadeh basti, and A. Abdulkhani, "The effects of gelatin-CMC films incorporated with chitin nanofiber and Trachyspermum ammi essential oil on the shelf life characteristics of refrigerated raw beef," *Int. J. Food Microbiol.*, vol. 318, 2020, doi: 10.1016/j.ijfoodmicro.2019.108493.
[36] L. D. Pérez-Vergara, M. T. Cifuentes, A. P. Franco, C. E. Pérez-Cervera, and R. D. Andrade-Pizarro, "Development and characterization of edible films based on native cassava starch, beeswax, and propolis," *NFS J.*, vol. 21, 2020, doi: 10.1016/j.nfs.2020.09.002.
[37] E. Adomavičiute *et al.*, "Formation and investigation of electrospun PLA materials with propolis extracts and silver nanoparticles for biomedical applications," *J. Nanomater.*, vol. 2017, 2017, doi: 10.1155/2017/8612819.
[38] M. Yousefi, N. Khorshidian, A. M. Mortazavian, and K. Khosravi-Darani, "Preparation optimization and characterization of chitosan-tripolyphosphate microcapsules for the encapsulation of herbal galactagogue extract," *Int. J. Biol. Macromol.*, vol. 140, 2019, doi: 10.1016/j.ijbiomac.2019.08.122.
[39] S. Khaledi, S. Jafari, S. Hamidi, O. Molavi, and S. Davaran, "Preparation and characterization of PLGA-PEG-PLGA polymeric nanoparticles for co-delivery of 5-Fluorouracil and Chrysin," *J. Biomater. Sci. Polym. Ed.*, vol. 31, no. 9, 2020, doi: 10.1080/09205063.2020.1743946.
[40] O. Catchpole, K. Mitchell, S. Bloor, P. Davis, and A. Suddes, "Anti-gastrointestinal cancer activity of cyclodextrin-encapsulated propolis," *J. Funct. Foods*, vol. 41, 2018, doi: 10.1016/j.jff.2017.12.023.
[41] H. S. Ching, N. Luddin, T. P. Kannan, I. Ab Rahman, and N. R. N. Abdul Ghani, "Modification of glass ionomer cements on their physical-mechanical and antimicrobial properties," *Journal of Esthetic and Restorative Dentistry*, vol. 30, no. 6. 2018, doi: 10.1111/jerd.12413.
[42] A. Raza, U. Hayat, M. Bilal, H. M. N. Iqbal, and J. Y. Wang, "Zein-based micro- and nano-constructs and biologically therapeutic cues with multi-functionalities for oral drug delivery systems," *Journal of Drug Delivery Science and Technology*, vol. 58. 2020, doi: 10.1016/j.jddst.2020.101818.
[43] S. M. Azab and A. M. Fekry, "The application of a bee glue-modified sensor in daclatasvir dual effect detection," *New J. Chem.*, vol. 41, no. 20, 2017, doi: 10.1039/c7nj01517h.
[44] Y. Shahbazi and N. Shavisi, "A novel active food packaging film for shelf-life extension of minced beef meat," *J. Food Saf.*, vol. 38, no. 6, 2018, doi: 10.1111/jfs.12569.
[45] T. Khare, S. S. Palakurthi, B. M. Shah, S. Palakurthi, and S. Khare, "Natural product-based nanomedicine in treatment of inflammatory bowel disease," *International Journal of Molecular Sciences*, vol. 21, no. 11. 2020, doi: 10.3390/ijms21113956.
[46] C. C. Carrion, M. Nasrollahzadeh, M. Sajjadi, B. Jaleh, G. J. Soufi, and S. Iravani, "Lignin, lipid, protein, hyaluronic acid, starch, cellulose, gum, pectin, alginate and chitosan-based nanomaterials for cancer nanotherapy: Challenges and opportunities," *International Journal of Biological Macromolecules*, vol. 178. 2021, doi: 10.1016/j.ijbiomac.2021.02.123.
[47] K. Villalobos *et al.*, "Production of starch films using propolis nanoparticles as novel bioplasticizer," *J. Renew. Mater.*, vol. 5, no. 3–4, 2017, doi: 10.7569/JRM.2017.634109.
[48] E. Adomavičiūtė, J. Baltušnikaitė-Guzaitienė, V. Juškaitė, M. Žilius, V. Briedis, and S. Stanys, "Formation and characterization of melt-spun polypropylene fibers with propolis for medical applications," *J. Text. Inst.*, vol. 109, no. 2, 2018, doi: 10.1080/00405000.2017.1341295.

[49] T. Sato, D. Mello, L. Vasconcelos, A. Valente, and A. Borges, “Chitosan-based coacervate polymers for propolis encapsulation: Release and cytotoxicity studies,” *Int. J. Mol. Sci.*, vol. 21, no. 12, 2020, doi: 10.3390/ijms21124561.
[50] S. Patil, N. Desai, K. Mahadik, and A. Paradkar, “Can green synthesized propolis loaded silver nanoparticulate gel enhance wound healing caused by burns?,” *Eur. J. Integr. Med.*, vol. 7, no. 3, 2015, doi: 10.1016/j.eujim.2015.03.002.
[51] S. Ceylan, “Propolis loaded and genipin-crosslinked PVA/chitosan membranes; characterization properties and cytocompatibility/genotoxicity response for wound dressing applications,” *Int. J. Biol. Macromol.*, vol. 181, 2021, doi: 10.1016/j.ijbiomac.2021.05.069.
[52] S. El-Guendouz *et al.*, “Magnetite nanoparticles functionalized with propolis against methicillin resistant strains of Staphylococcus aureus,” *J. Taiwan Inst. Chem. Eng.*, vol. 102, 2019, doi: 10.1016/j.jtice.2019.05.018.
[53] F. Zeighampour, F. Alihosseini, M. Morshed, and A. A. Rahimi, “Comparison of prolonged antibacterial activity and release profile of propolis-incorporated PVA nanofibrous mat, microfibrous mat, and film,” *J. Appl. Polym. Sci.*, vol. 135, no. 6, 2018, doi: 10.1002/app.45794.
[54] D. Fasolo *et al.*, “Topical delivery of antifungal Brazilian red propolis benzophenones-rich extract by means of cationic lipid nanoemulsions optimized by means of Box-Behnken Design,” *J. Drug Deliv. Sci. Technol.*, vol. 56, 2020, doi: 10.1016/j.jddst.2020.101573.
[55] A. Elgendy and D. Fayyad, “Cell viability and apoptotic changes of dental pulp stem cells treated with propolis, chitosan, and their nano counterparts,” *Tanta Dent. J.*, vol. 14, no. 4, 2017, doi: 10.4103/tdj.tdj_27_17.

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220207-01 ~ 0220207-09
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.13378

Feasibility Study of Solar Power Generation System for Public Street Lighting

Muhammad Fadel Ibrahim[1*], Imadudin Harjanto[2], Bambang Hadi Kunaryo[3]

[1] Faculty of Engineering and Informatics, Universitas PGRI Semarang, Jl. Sidodadi-Timur No.24 Semarang, Central Java 50232, Indonesia

m.gadelibrahim@gmail.com

Abstract. One of the uses of electricity that is widely used by society today is as a source of lighting. The increasing level of community mobility makes all activities require lighting. One part that is important and requires lighting is a highway or public road. PJU is a lighting lamp that is public (for the common good) and is usually installed on roads and certain places such as parks and other public places. PJU (street lighting) or road lighting is a light source that is installed as street lighting at night. Public street lighting using solar power is a cheap and economical alternative to be used as a source of lighting electricity because it uses a new and unlimited renewable energy source that comes from nature, namely solar energy. This study aims to determine the feasibility of solar street lighting in the future as a substitute for conventional public street lighting in the future by looking at the Net present cost, and Break even point assisted by HOMER software version 3.10.3. And the results obtained from the calculation of the Net present cost of conventional street lighting costs less, which is only Rp. 30,245,473 and the Net present cost of solar street lighting costs an initial investment of Rp. 128,341,312 and the BEP (Break even point) graph that has not been found to break even.

Keywords: Break Even Point, Lamp, Net Present Cost, Public Street Lighting, Software, Solar Power

1. Introduction

One of the uses of electricity that is widely used by society today is as a source of lighting. The increasing level of community mobility makes all activities require lighting. One part that is important and requires lighting is a highway or public road. PJU is a lighting lamp that is public (for the common good) and is usually installed on roads and certain places such as parks and other public places. PJU (street lighting) or road lighting is a light source that is installed as street lighting at night. Public street lighting using solar power is a cheap and economical alternative to be used as a source of lighting electricity because it uses a new and unlimited renewable energy source that comes from nature, namely solar energy. The purpose of this study is to determine whether or not it is appropriate for solar street lighting to replace conventional street lighting on the Bumiayu wage market street with the help of Homer software and calculations outside of Homer software and a comparison of NPC, COE and BEP within a period of 25 years.

2. Methods

This research was conducted to plan a solar street lighting lamp (Solar Cell) for a feasibility study to replace conventional street lighting lamps. The research procedure in this research is assisted by Homer software which is used as a simulation tool for planning solar street lighting (Solar cell) as well as calculations outside the Homer software. The simulation process on Homer is carried out to determine the characteristics or performance of a generating system. And the process carried out outside the Homer software is merging the results of the Homer software with components that are not included in the software. The parameters are total production (kWh/year), energy consumption (kWh/year), Net present cost (NPC), Cost of energy (COE), and Break event point (BEP). The design of this study was carried out based on an analysis to determine the optimal system configuration based on costs in Figure 1 and Figure 2 shows the implementation flowchart.

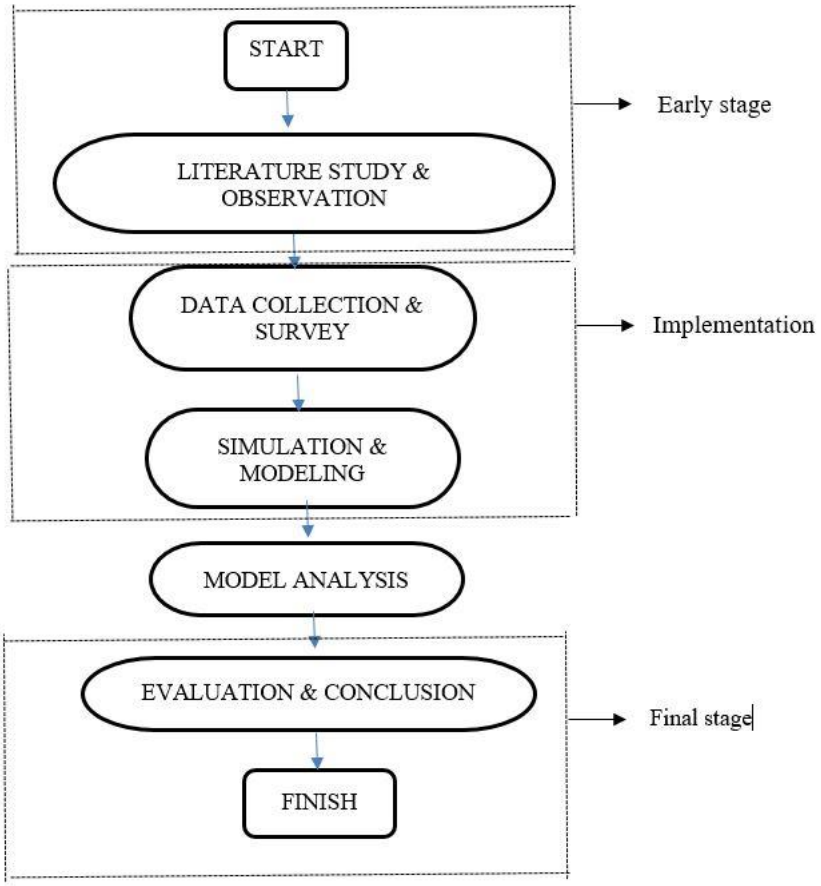


Figure 1. Research Design Flowchart

2.1 Figure 1 explains how the research process is carried out starting from literature studies, simulations and modeling to getting results.

2.1.1 Early stage

In the early stages, literature studies and observations are carried out to find relevant information about the research.

2.1.2 Implementation

In this section, data collection and surveys as well as simulation and modeling are carried out.

2.1.3 Final Stage

and in the last stage, evaluation and conclusion from the data and simulation are carried out

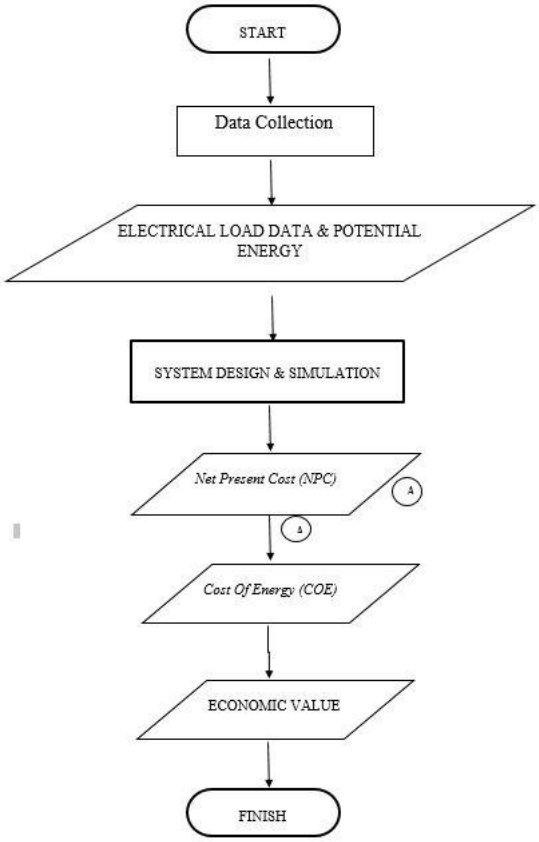


Figure 2. Implementation Flowchart

2.2 Figure 2 shows a flowchart of the implementation carried out by researchers to get the results along with the stages :

2.2.1 Data collection

The data collection carried out by the study was data collection from PLN UPJ Bumiayu and the Brebes Regency Transportation Service and data obtained from the NASA website. The data taken are electrical load data, specifications for lamps and public street lighting poles and solar radiation data.

2.2.2 Design and simulation

In design and simulation, the data taken is designed and will be simulated by Homer software, the Homer software will simulate several data components that have been obtained then will be combined with data that cannot be entered into Homer software and will produce the Net present cost and cost of energy.

2.2.3 Economic value

The economic value in this study is BEP (Break even point), after getting the results from planning and simulation, a comparison of the accumulation between conventional public street lighting and solar street lighting is carried out and a BEP graph is made.

3 Results and Discussion

3.1 Specifications of Solar Street Lights

In doing the calculations, the writer needs to know the specifications of the components of public street lighting that will be used in this study. Below are the components that will be used in planning a feasibility study for solar street lighting that will be installed at 10 points. Can be seen in Table 1.

Table 1. Specifications of solar street lighting components

Num	Component	Unit
1	LAMP PJU OSRAM LED 12V 60 Watt	10
2	BATTERY CHARGE REGULATOR CMTP02 PWM 15A	10
3	SMT 1265 LEAD ACID BATTERY 12V 65AH	10
4	SOLAR PANEL SUNLITE 200Wp	10
5	SOLAR POWER KNVERTTER 1500 W	10
6	POLE PJU OCTAGONAL	10
7	INSTALLATION & ACCESSSORIES	10

3.2 System Design

In carrying out the calculations, the researcher was assisted by the HOMER software, where this software helped researchers to design a schematic of solar street lighting to generate Net Present Cost (NPC), and others. here is the link or web to access the HOMER software: https://www.homerenergy.com/products/pro/index.html.However, in using the HOMER software, the researcher did not include all the components that would be used, because the HOMER software contained several components that the researcher could not input such as PJU lamps, battery charge control, lamp posts and other installations and accessories. in Table 2 components that exist in the Homer software and components outside the Homer software.

Table 2. Components in Homer and outside Homer

Component on HOMER			
Component	**Value**	**Unit**	**Size**
PV SUNLITE 200Wp	Rp.1.325.000	10	200 Wp
CONVERTER	Rp.450.000	10	1.500 Watt
BATTERY LEAD ACID SMT1265	Rp.1.585.000	10	12v 65AH
Component outside HOMER			
LAMP PJU OSRAM	Rp.1.700.000	10	60 watt 12v
BCR PWM	Rp.220.000	10	15 A
POLE OCTAGONAL	Rp.1.500.000	10	8 Meter
INSTALLATION & ACC	Rp.1.000.000	-	-

There are 7 components or tools that will be used for solar street lighting on Jalan Pasar Wage Bumiayu. There are two separate component parts between components that can be included in the software and those that are not included in the software. The HOMER software can only include a few components, such as Photovoltaic (solar cell), converter, and battery. And other components that cannot be included in the HOMER software are PJU lamps (public street lighting), battery charge control, octagonal light poles, as well as necessary installations and accessories.

3.3 Load Data

The load data used in this study were obtained from PLN UPJ Bumiayu. The load data used, namely the consumption of electrical energy (kWh) of conventional public street lighting per month during 2021 can be seen in Table 3.

Table 3. Monthly data on conventional 2021 PJU electricity bills

Month	Power	kWh	Bills
January	1300	196	Rp.283.161
February	1300	196	Rp.283.161
March	1300	178	Rp.257.157
April	1300	196	Rp.283.161
May	1300	187	Rp.270.159
June	1300	193	Rp.278.827
July	1300	173	Rp.248.488
August	1300	213	Rp.307.721
September	1300	191	Rp.275.938
October	1300	188	Rp.271.604
November	1300	189	Rp.273.048
December	1300	189	Rp.273.048
Total		2.288kWh	Rp.3.305.473

The data obtained from PLN UPJ Bumiayu shows energy consumption in a year and electricity bills in a year. The energy consumption of conventional PJU in 2021 is 2,288 kWh and the electricity bill is Rp. 3,305,473.

Table 4. Component data of conventional public street lighting

Component	Cost	Unit
Lamp HPS 250w	Rp.1.370.000	10
Lampshade E27	Rp.3.000.000	10
Pole Lamp	Rp.4.500.000	3
Installation & Acc	Rp.10.000.000	10

Table 4 shows some of the components used in conventional public street lighting lamps on Jalan Pasar Wage Bumiayu, it appears that there are only 3 lamp pole units because, after a field survey, 7 other lamps are attached to the electricity pole and there are only 3 which uses a standalone lamppost.

3.4 Economic analysis of conventional PJU techniques

3.4.1 *Net present cost (NPC)*

The net present cost (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each Component in the system, and of the system as a whole. The *net present cost* is used to determine the total costs incurred. The division of component costs for calculating the results of the Net present cost can be seen in the following equation:

NPC = Capital costs + Replacement costs + O&M costs + Fuel costs – salvage
= Rp.22.175.473 + Rp.7.850.000 + Rp.220.000 + Rp.0 – Rp.0
= Rp.30.245.473

From the following equation, the results of the net present cost of conventional public street lighting can also be seen in more detail in Table 5.

Table 5. *Net present cost* of conventional public street lighting

Component	Value	Raplacement	O&M	Fuel	Salvage
Lamp HPS 250w	Rp.1.370.000	Rp.6.850.000	Rp.0	Rp.0	Rp.0
Lampshade E27	Rp.3.000.000	Rp.0	Rp.0	Rp.0	Rp.0
Pole Lamp	Rp.4.500.000	Rp.0	Rp.0	Rp.0	Rp.0
Installation & Acc	Rp.10.000.000	Rp.1.000.000	Rp.220.000	Rp.0	Rp.0
Grid (PLN)	Rp.3.305.473	Rp.0	Rp.0	Rp.0	Rp.0
Total	Rp.22.175.473	Rp.7.850.000	Rp.220.000	Rp.0	Rp.0
Total				Rp.30.245.473	

3.4.2 *Annualized cost* (AC)

The total annualized cost is the annualized value of the total net present cost ,Annualized cost is used to find out the total annual costs incurred. The annual cost of conventional public street lighting is Rp. 1,835,900.

AC = capital costs + Replacement cost + O&M costs + Fuel costs – salvage
= Rp.1.346.051+ Rp.476.495 + Rp.13.354 +Rp.0 – Rp.0
= Rp.1.835.900

3.4.3 *Cost of energy* (COE)

COE as the average cost per kWh of useful electrical energy produced by the system.,The cost of energy produced is Rp.802.4/kWh.

3.5 *Economic analysis of solar power PJU engineering with Homer*

3.5.1 *Net Present Cost* (NPC)

As for the costs that will be incurred to buy components in the solar street lighting project, which costs have been combined with components that are not included in the HOMER software system, the cost is Rp. 112,663,064 and can be seen in Table 6

NPC = *Capital costs* + *Replacement costs* + *O&M costs* + *Fuel costs* – *salvage*
= Rp.78.300.000 + Rp.122.100.000 + Rp.1.253.386 + Rp.0 – Rp.88.990.332
= Rp.112.663.064

Table 6. Combined cost results (NPC)

Component	Value	Raplacement	O&M	Fuel	Salvage	
PV 200Wp Sunlite	Rp.13.250.000	Rp.0	Rp.0	Rp.0	Rp.0	
Converter	Rp.4.500.000	Rp.0	Rp.1.253.386	Rp.0	Rp.1.840.322	
Battery 65 Ah 12v	Rp.15.850.000	Rp.31.700.000	Rp.0	Rp.0	Rp.15.850.000	
Lamp PJU OSRAM 60W	Rp.17.000.000	Rp.85.000.000	Rp.0	Rp.0	Rp.68.000.000	
BCR PWM	Rp.2.200.000	Rp.4.400.000	Rp.0	Rp.0	Rp.3.300.000	
Pole PJU Ocragonal	Rp.15.000.000	Rp.0	Rp.0	Rp.0	Rp.0	
Installation & Acc	Rp.10.500.000	Rp.1.000.000	Rp.0	Rp.0	Rp.0	
Total	Rp.78.300.000	Rp.122.100.000	Rp.1.253.386	Rp.0	Rp.88.990.332	Rp.112.663.064

3.5.2 *Annualized cost* (AC)

AC = *capital costs* + *Replacement cost* + *O&M costs* + *Fuel costs* – *salvage*
= Rp.4.752.810 + Rp. 7.411.470 + Rp. 76.080 + Rp.0 – Rp.5.401.712
= Rp.6.840.648

the total annual cost incurred is Rp. Rp.6.840,648

3.5.3 *Cost Of Energy* (COE)

The cost of energy is calculated to determine the costs incurred 1 kWh of the system design. The cost of energy produced is Rp.2,300 kWh.

3.5.4 *Break even point*

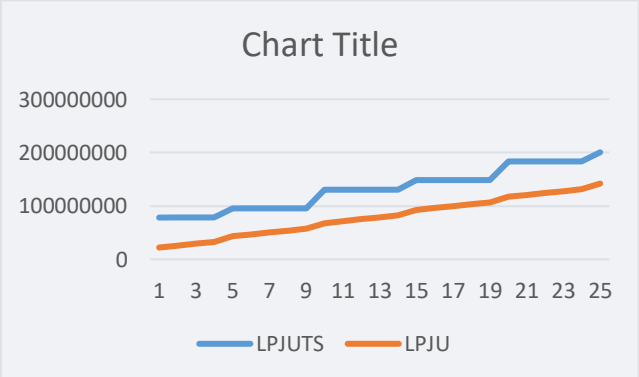


Figure 4. BEP Grap with PV 200 Wp

It can be seen in Figure 4 the researcher uses the 200 Wp which is in accordance with the load requirements and in Figure 4 the break-even point or (BEP) within a period of 25 years has not occurred. the break-even point (BEP), shown in Figure 4, the blue line shows the graph of solar street lighting and the orange line shows the graph of conventional public street lighting, the graphic form of the solar street lighting continues to climb, which means the public street lighting lamp Solar power for the Pasar Wage road has not been able to replace conventional public street lighting at this time.

3.6 Analysis Results

The electrical energy produced is used for the needs of public street lighting on Jalan Pasar Wage Bumiayu, to illuminate public roads at night. As many as 10 solar street lightings have been installed along Pasar Wage Bumiayu Street. In the results of this analysis, the results of the comparison between solar street lighting lamps and lighting lamps. The electrical energy produced is used for the needs of public street lighting on Jalan Pasar Wage Bumiayu, to illuminate public roads at night. As many as 10 solar street lightings have been installed along Pasar Wage Bumiayu Street. In the results of this analysis, the results of the comparison between solar street lighting lamps and conventional public street lighting lamps are obtained. And the comparison can be seen in Figure 16, the comparison table for conventional public street lighting with solar street lighting.

Table 7. LPJUTS comparison table with conventional LPJU

Parameter	Solar LPJU	Convensional LPJU
Energy total (kWh)	2.974 kWh	2.288kWh
Net Present Cost (Rp.)	Rp.112.663.064	Rp.30.245.473
Annualized Cost (Rp.)	Rp.6.840.648	Rp.1.835.900
Cost Of Energy	Rp.2.300 per kWh	Rp.802 Per kWh
Renewable Penetration	95,3%	-

4 Conclusion

From the results of the research that has been carried out, it can be concluded several things as follows:

From this study, obtained by using PV 160 Wp is still not able to meet the needs of the load which only produces 0.411 kW, therefore in this study using PV 200 Wp which is able to meet the needs of the load by producing 0.77kW where the load requirement is 0.72 kW. And the results of these calculations come from simulations in the Homer application where pV 160 Wp in simulations and calculations in Homer produces 114 kW, while PV 200Wp produces 0.72kW in simulations and calculations in Homer software.

When viewed from the calculation of the Net present cost, conventional street lighting costs less, which is only Rp. 30,245,473 and Net presnt cost of solar street lighting, the initial investment cost is Rp. 112,663,064 difference Rp.82,417,591

And if you look at the BEP (Break even point) in the graph, the break even point has not been found where this BEP comes from the accumulation of Capital (price), Placement (replacement) and Operations, which means solar street lighting planned by researchers As an energy saving, public street

lighting is currently not feasible to replace conventional public street lighting on Jalan Pasar Wage Bumiayu in terms of economic value.

For further research, further studies need to be carried out by covering more data and getting better results regarding the comparison of energy savings in solar street lighting on Pasar Wage Bumiayu Street.

Acknowledgements
The author would like to thank PT. PLN UPJ BUMIAYU & Dinas Perhubungan Kabupaten Brebes who are willing to provide the data needed for research.

References

[1] A. Budiman, "Perancang solar home system," *Perancang solar home system,* 2012.

[2] A. W. Akbar, "Perencanaan Sistem Pembangkit Listrik Dengan Energi Terbarukan," *Perencanaan Sistem Pembangkit Listrik Dengan Energi Terbarukan,* 2019.

[3] A. Nurrochim, "Perencanaan Lampu Penerangan Jalan Umum Tenaga Surya (LPJUTS) di Jl. laut Kendal," *Perencanaan Lampu Penerangan Jalan Umum Tenaga Surya (LPJUTS) di Jl. laut Kendal,* 2018.

[4] M. Hidayat, "Perancanga Penerangan Jalan Umum Tenaga surya (Solar Cell) Untuk Alternatif Penenrangan Kampus Universitas Muhammadiyah Makassar," *Perancanga Penerangan Jalan Umum Tenaga surya (Solar Cell) Untuk Alternatif Penenrangan Kampus Universitas Muhammadiyah Makassar,* 2020.

[5] I. Razak, "Studi Kelayakan Pemasangan Pembangkit Listrik Energi Terbarukan Tenaga Hybrid," *Studi Kelayakan Pemasangan Pembangkit Listrik Energi Terbarukan Tenaga Hybrid,* 2019.

[6] Kunaifi, "Program Homer Untuk Kelayakan Pembangkit Listrik Hibrida Di Provinsi Riau," *Program Homer Untuk Kelayakan Pembangkit Listrik Hibrida Di Provinsi Riau,* 2010.

[7] N. Kunaisih, "Analisis mode Sistem Pembangkit Listrik Tenaga Hybrid Microhydro-Photovoltaic Array Menggunakan Homer," *Analisis mode Sistem Pembangkit Listrik Tenaga Hybrid Microhydro-Photovoltaic Array Menggunakan Homer,* 2015.

[8] F. S. Nasution, "Perencanaan Sistem penenrangan Jalan Dan Taman Denggan Menggunakan Teknologi Surya," *Perencanaan Sistem penenrangan Jalan Dan Taman Denggan Menggunakan Teknologi Surya,* 2017.

[9] A. F. Irawan, "Analisis Peningkatan Efesiensi Peneranggan Jalan Umum (PJU) Di Kabupaten Jember," *Analisis Peningkatan Efesiensi Peneranggan Jalan Umum (PJU) Di Kabupaten Jember.*

[10] A. Thohir, "Analisis Efesiensi Daya Penerangan Jalan Umum (PJU) Denggan Menggunakan Sistem Peredupan Yang dipengaruhi Oleh Volume Kepadatan Lalu Lintas," *Analisis Efesiensi Daya Penerangan Jalan Umum (PJU) Denggan Menggunakan Sistem Peredupan Yang dipengaruhi Oleh Volume Kepadatan Lalu Lintas,* 2017.

[11] B. (. B. S. N.), "Spesifikasi Penenrangan Jalan Di Kawasan Perkotaan," *Spesifikasi Penenrangan Jalan Di Kawasan Perkotaan,* 2008.

[12] D. P. K. Brebes, "Laporan Data PJU 2022," Brebes, 2022.

[13] P. L. N. (. U. Bumiayu, "Laporan Tagihan Listrik Dijalan Pasar Wage Bumiayu," Brebes,Bumiayu, 2021.

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220208-01 ~ 0220208-09
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.13507

Financial Accounting Information System With Method Commonsize To Know Financial Performance

Sindhu Rakasiwi[1*], Haryo Kusumo[1], Yuli Fitrianto[2]

[1]Faculty of vocational studies, Universitas Sains dan Teknologi Komputer, Jl.Majapahit 605 Semarang, Central Java, Indonesia

[2]Faculty of academic studies, Universitas Sains dan Teknologi Komputer, Jl.Majapahit 605 Semarang, Central Java, Indonesia

*sindhu@stekom.ac.id

Abstract. PT XXX which is located on Jl. Pantura Semarang- Kendal, KawayuhanWest, Nolokerto, Kaliwungu District, Kendal Regency, Central JavaCompanies that sell building materials for the construction of buildings androad construction. Some of the building materials are self-produced such as gravel andconcrete. PT. XXX is still using the help of MSrecord financial data. And in the calculations stillusing the manual method, which must be calculated one by one. In compilingthe report is not yet structured. So that the company in readingfinancial statements still use the estimation method. Which if it continuescan cause losses to the company due to performance calculationsfinance.This study designs a financial accounting information system withcommonsize method to determine the financial performance of web-based companies.Which uses the PHP and MySQL programming languages. The purpose of existenceThe system can help companies perform financial calculationscompany and conduct financial performance analysis. It enables a company to well manage their financial performance

Keywords: Accounting Information System, Financial Performance, Commonsize

(Received 2022-08-09, Accepted 2022-10-31, Available Online by 2022-10-31)

1. Introduction

In this case, company data collection is still done manually takes quite a long time. This causes the data that has been recorded prone to loss. Company calculations are still done manually,very prone to calculation errors generated. In this case cause the company to have difficulty in analyzing the report finance.

To analyze company reports, PT XXX still uses non-computerized way. Recording and calculating data still available done manually, so that the analysis carried outtakes a long time. This is less effective

because it is very time consuming company work. The existence of a computer has not been used optimally because it is not there is an application that helps complete financial statement analysis in the company to find out how much increase or decrease in performance finance[1]. Data input using Microsoft Office Excel is still calculated manually. Calculation of the financial statements of the company admin only make an income statement. So it's hard to know the way effectiveness of financial performance in a predetermined period[2].
The benefits of the company's performance appraisal are as follows:To measure the achievements achieved by an organization in a period which reflects the level of success of the implementation of its activities[3]. Besides used to see the performance of the organization as a whole, then the measurement of Performance can also be used to assess the contribution of a part to achievement overall company goals[4]. Can be used as a basis for determining company strategy for the future[5]. Give instructions in making decisions and activities of the organization in general and the division or part of the organization in particular[6]. As a basis for determining investment policies in order to improve company efficiency and productivity. In the end the use or The benefit of the common size analysis itself lies entirely in the ability and the company's skills in interpreting it[7].

Based on the problems that occurred at PT XXX, the author tried implementing an accounting information system using the common size method. Therefore, an accounting information system is needed on the company's financial performance as a form of financial control. This aims to minimize the occurrence of errors in the use of company funds[8]. By common size method make it easier for the company to find out how much the increase or decline in financial performance in detail. A good information system can provide accounting information on the percentage increase or decrease in financial performance clearly as a support in decision making company.
.

2. Methods

2.1. System Basic Concept

A system is a collection or group of sub-systems or parts or components or anything, whether physical or non-physical that is related to each other and can work together to achieve a certain goal.Systems and procedures are a unity that cannot be separated from one another[9].
A new system can be formed if there are several procedures in it follow it. The system is a network of procedures created according to a pattern or an integrated pattern for carrying out the main activities of the company or organization[10].

2.2. System Development Concept

System development is a stage in which there are identification of information system components to be designed in detail which aims to provide an overview to the user or user about the new system. In providing an overview and design of the system new ones can be created in Process Model, Data Flow Diagram (DFD), Model Data, Flowchart and Data Dictionary[11].

2.3. Common Size Method Analysis

Common Size analysis is an analytical technique which makes comparisons and calculates each account in the report profit and loss and balance sheet the proportion of total sales for the income statement or from total assets for the balance sheet[12].
Understanding Common Size Common size is an analysis method for knowing the percentage of investment in each asset to the total its assets, as well as to find out its capital structure and cost

composition is related to the number of sales. Common size is an analytical tool which describes the change of each component to be obtained a common basis that can be used for the division between financial statements.Common-size analysis is an analysis that is compiled by calculating each accounts in the income statement and balance sheet as a proportion of total sales(for the income statement) or from total assets (for the balance sheet). Financial statements in percentage per-component (Common-size statement) states each post in percent on the basis of the total group, how This preparation of financial statements is called the common-size analysis technique and includes:vertical analysis method[13].

2.4. Development Method

In developing an accounting information system, it is necessary to prepare and careful planning. In this development, the development model will be discussed as a basis for product development. The model to be developed will refer to on the Research and Development (R & D) model of Borg and Gal. Where is the destination of The development plan with the R&D design has the aim of:develop and validate products[14].
In this research, the writing uses the Research and Development procedure Development (R&D) is a research method used to produce products the Conceptually, the Research and Development (R&D) development procedure based on considerations of suitability and the nature of the research to be carried out.
The following are the ten stages of Research and Development (R&D), namely:

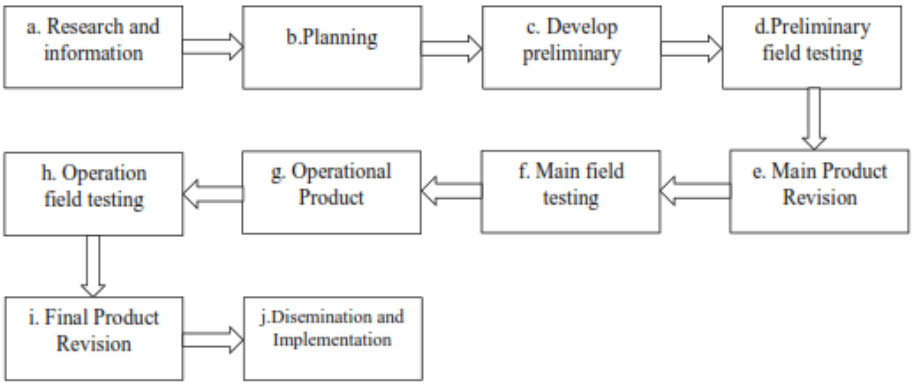


Figure 1.R&D Steps

3. Results and Discussion

3.1. Evaluation of the Old System

The process of recording transaction data at "PT .XXX" so far less effective because it is still conventional, causing:

1. The process of recording transactions and making financial reports often occurs errors due to missing or damaged document files because they are still record manually.
2. It takes a long time to search transaction data and reports finance.
3. Difficult to read financial reports made by employees because the report has not been structured so it is difficult to know company's financial performance.

3.2. Troubleshooting Proposal

Based on the evaluation of the old system, the author wishes to offer the new system, namely the Financial Accounting Information System with the Common size web-based at “PT XXX” which later is expected to be able to become one of the alternative solutions to the problems that are being faced by "PT XXX”. This new system offers convenience for related user switch the process of recording data into a database, so that the parties involved can easily operate it.

3.3. System Development Results

The targets of the developed system are as follows:
1. Designing an accounting information system for sales and purchase transactions with using a computer as a data processing tool to make it more effective and efficient valid.
2. Make financial reports, especially financial reports quickly and effectively as well as practical.
3. The information conveyed to the leadership of PT XXX will be easy to understand and the results become more valid.

3.4. Interface Design

Interface design is one form of display of the program to be created for the needs of the interface with the user.
Information System Interface Design At PT XXX:
a. Login Form

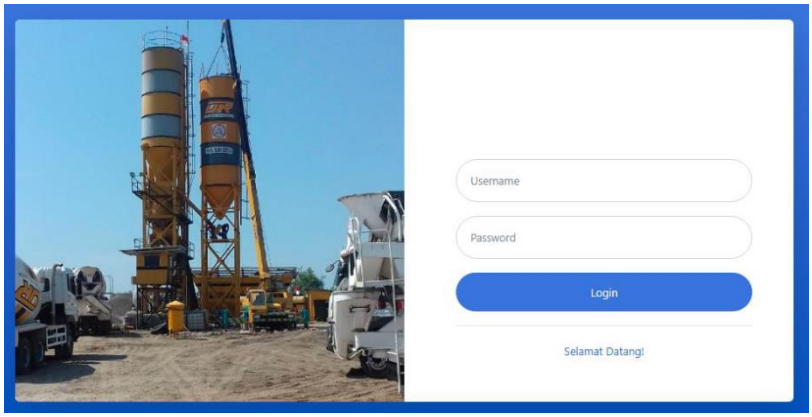


Figure 2. Login Form

Before entering the system, the user who will use the application these must be logged in accordance with the access rights they have, then that the first time that appears is the User Login view.
There are three users (admin, manager, leader) the three users must enter the username and password in accordance with the access rights owned by each user. The user who forced to enter the system that do not match the access rights will refuse and will appear notification “Invalid Username or Password!”

b. Customer Form

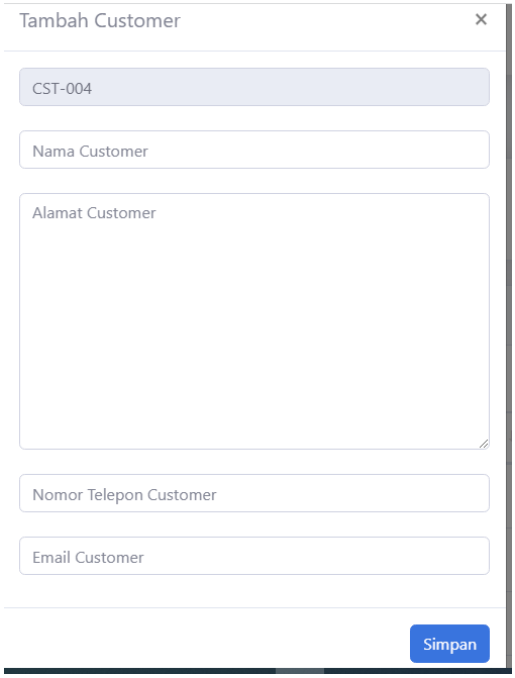


Figure 3. Customer Form

Consumer form is a field to add consumer data.consisting of name, address, telephone number and e-mail.

c. Account Form

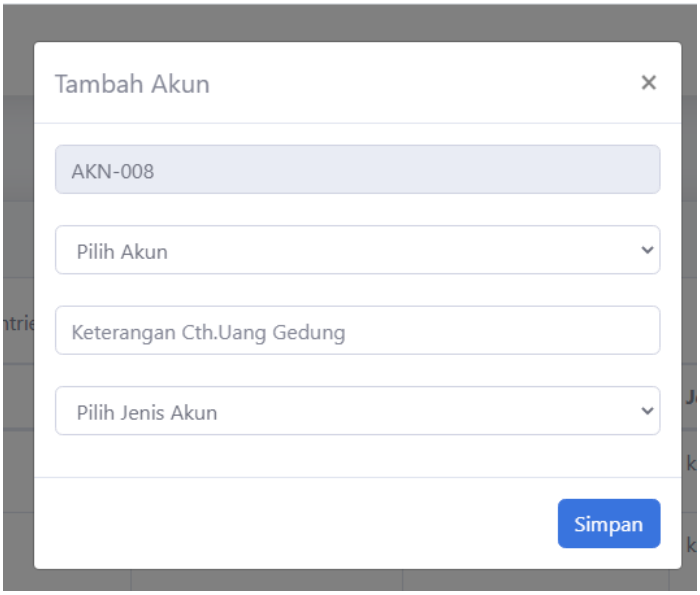


Figure 4. Account Form

Account form is a form to add an accounting account. Which consists of account number, account choice, description, choice of account type.

d. Item Form

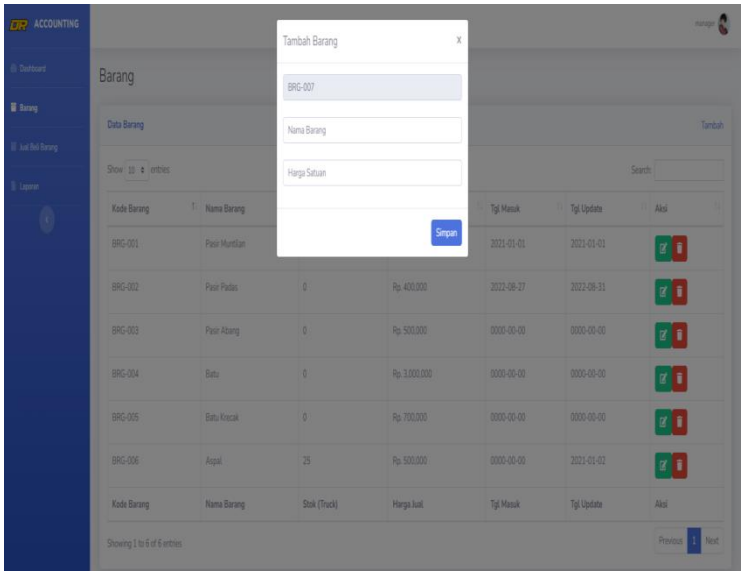


Figure 5. Item Form

Item form is a format for adding items, consisting of item code, item name, and unit price.

e. Entry Form

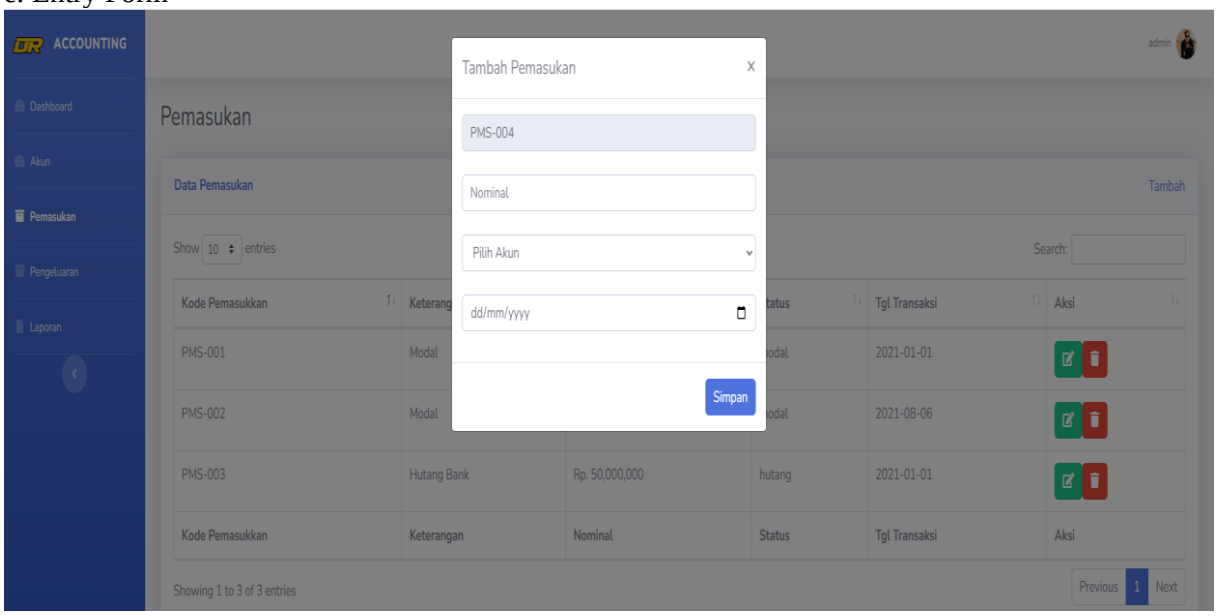


Figure 6. Entry Form

The entry form is a form to add income which consists of an entry code, nominal, select account, and date.

f. Add Expense Form

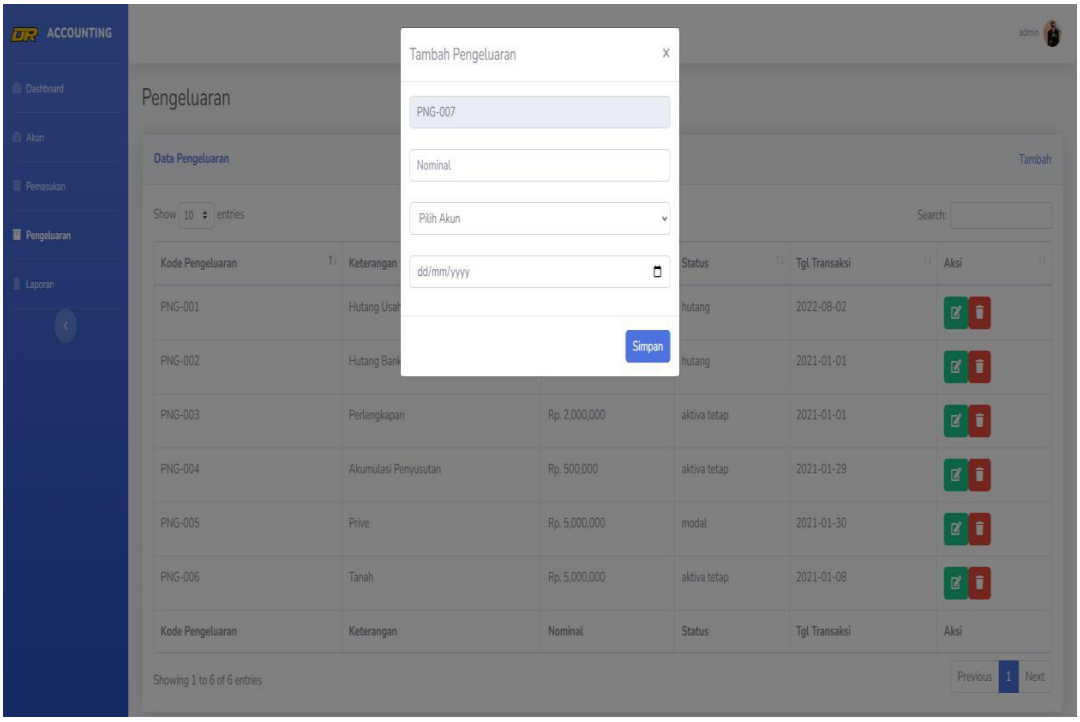


Figure 7. Add Expense Form

The added expense form is a form that contains the expense code, nominal, select account, and date.

g. Purchase Form

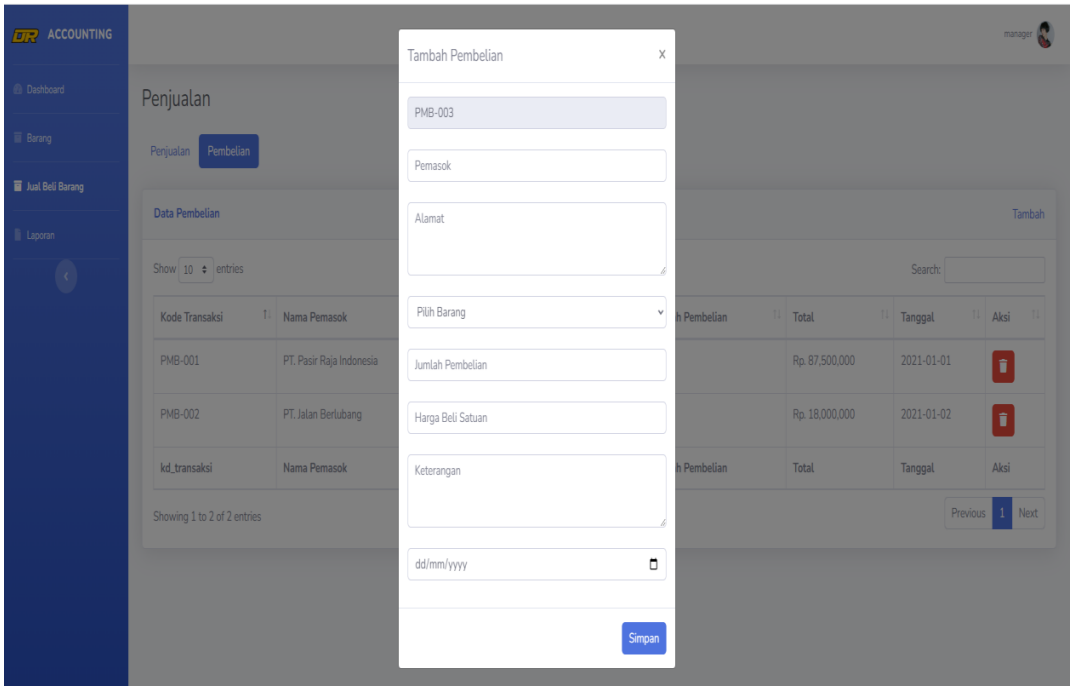


Figure 8. Purchase Form

The purchase form is a form that contains the code, supplier, address, select goods, purchase amount, unit price, description, and date.

4. Conclusion

Financial accounting information system with the common size method to find out web-based company's financial performance has been built and studied against the system, it can be concluded that this system makes it easy for users to process sales and purchase data into the accounting system because the transaction input process can be faster than Previously, which still used the manual method, namely handwriting. This matter aimed at testing the validator to users with an aspect value of 3 which shows good descriptions and can be used with minor revisions.The output results are in the form of complete financial reports and graphs showing an overview of the level of financial performance where the output was only reports profit and loss and even then the report made is still wrong in the calculation because it is still using the manual method. While the output results reports with this accounting system are more accurate and quite helpful for users manage the displayed information in a short time. It can reconfirmation on the validator test score sheet with a validation test value of 30 with program descriptions can be used properly without revision.Processing results as expected and display them quickly.Balanced with the results of stock items that are always right and a clear picture regarding the company's financial performance because of the accounting system program in PT XXX. This result gets a score of 3 from users with show program descriptions make it easier for users to access information.

References

[1] D. K. Sharma, "Analysis of profitability through common size profit and loss statement," *Int. J. Eng. Adv. Technol.*, vol. 8, no. 6 Special Issue, 2019, doi: 10.35940/ijeat.F1171.0886S19.

[2] A. Mehta and G. Bhavani, "Financial statements analysis on Tesla," *Acad. Account. Financ. Stud. J.*, vol. 22, no. 6, 2018.

[3] M. Rao, "Financial Statement Analysis of ONGC LTD. with reference to: Horizontal Analysis & Common Size Analysis," *J. Manag. Sci.*, vol. 1, no. 2, 2013, doi: 10.26524/jms.2013.27.

[4] D. V. Shrotriya, "Common Size Statement : a Technique of Financial Analysis," *Int. J. Res. Anal. Rev.*, vol. 6, no. 2, 2019.

[5] C. C. Toniga, W. S. Manoppo, and J. J. Rogahang, "Analisis Common Size pada Perusahaan PT. Federal International Finance (FIF GROUP) Cabang Manado," *Productivity*, vol. 2, no. 6, 2021.

[6] I. Farida, T. Suharti, and D. Yudhawati, "ANALISIS METODE COMMON SIZE UNTUK MENGUKUR KINERJA KEUANGAN PADA PERUSAHAAN," *Manag. J. Ilmu Manaj.*, vol. 2, no. 2, 2019, doi: 10.32832/manager.v2i2.2561.

[7] N. Riani and Z. Zulkarnain, "ANALISIS COMMON SIZE DAN RASIO KEUANGAN PADA SUBSEKTOR WHOLESALE (DURABLE & NON-DURABLE GOODS) YANG TERCATAT DI BEI," *Prog. J. Pendidikan, Akunt. dan Keuang.*, vol. 3, no. 2, 2020, doi: 10.47080/progress.v3i2.939.

[8] H. Kusumo and S. Rakasiwi, "Information System Supply Chain Management with FIFO Pertetual Method," *Adv. Sustain. Sci. Eng. Technol.*, vol. 3, no. 2, 2021, doi: 10.26877/asset.v3i2.9722.

[9] R. Rifardi *et al.*, "Analisis Kinerja Keuangan Dengan Menggunakan Metode Common Size Pada Pt. Holcim Indonesia Tbk Analysis of Financial Performance Using Common Size Method in Pt. Holcim Indonesia Tbk," *J. Econ. Bus. Account.*, vol. 3, no. 1, 2019.

[10] S. Subarsyah and Y. Firdaus, "PERBAIKAN CITRA PENAMPANG SEISMIK MENGGUNAKAN METODE COMMON REFLECTION SURFACE : APLIKASI TERHADAP DATA SEISMIK PERAIRAN WAIGEO," *J. Geol. Kelaut.*, vol. 13, no. 2, 2016, doi: 10.32693/jgk.13.2.2015.267.

[11] A. Magdalena, M. Hatta, and D. Martha, "ANALISA BIAYA GAJI KARYAWAN

BERBASIS WEB DENGAN METODE ANALISIS INDEKS DAN COMMON SIZE (STUDI KASUS : UD. MONAS BAKERY)," *J. Digit*, vol. 9, no. 1, 2020, doi: 10.51920/jd.v9i1.132.
[12] L. K. D. Raharjo, "Rancangan Sistem Informasi Pencatatan Administrasi Keuangan Menggunakan Metode Common Size Pada Sd Solafide Ungaran dan Berbasis Multiuser," *J. Ilm. KOMPUTERISASI Akunt.*, vol. 10, no. 1, 2017.
[13] T. H. E. Implementation, O. F. Information, and T. On, "Global Conference on Business and Management (GCBM)," vol. 1, no. 1, p. 2021, 2021.
[14] R. R. Dale and W. R. Borg, "Educational Research: An Introduction," *Br. J. Educ. Stud.*, vol. 14, no. 1, 1965, doi: 10.2307/3119062.

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220209-01 ~ 0220209-13
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.12678

Genome-Wide Association Study of Complex Traits in Maize Detects Genomic Regions and Genes for Increasing Grain Yield and Grain Quality

Yheni Dwiningsih[1]*, Jawaher Al-Kahtani[2]

[1]Department of Crop, Soil and Environmental Sciences, University of Arkansas, Fayetteville, Arkansas, United States of America

[2]Department of Botany and Microbiology, College of Science, King Saud University, Riyadh, Saudi Arabia

*ydwining@uark.edu

Abstract. This review describes the current status of genome-wide association study (GWAS) of the major crops in maize (Zea mays L.) concentrate on performing association mapping as a novel method in associating genetic and complex traits, current strategy in analyzing of phenotype and genotype data to identify population structure and linkage disequilibrium. GWAS has an important role in food security because this method identified many crucial genomic regions of important traits in the most commercialize crops of the world, such as maize. These complex traits including yield, grain quality, biofortification, biotic and abiotic resistance. GWAS has many advantages correlated with reducing genotyping cost and research time, increasing mapping resolution and larger allele number. Meanwhile, GWAS has two main limitations related to population size and the number of markers. There are many software packages for data analysis in GWAS. The most commonly software that was used in GWAS especially in this crop is TASSEL because frequently updated. Recently, many research papers concentrated on GWAS in maize. GWAS analysis accelerated identification of genetic regions, candidate genes within these genomic regions and their metabolomic analysis correlated to the complex traits in maize for increasing grain yield and grain quality to fulfill the market demands.

Keywords: complex traits, genomic regions, GWAS, maize, grain yield, grain quality

(Received 2022-08-09, Accepted 2022-10-31, Available Online by 2022-10-31)

1. Introduction

Genome-wide association study (GWAS) identified variation of the genetic characteristics within the genome in order to analyze correlation of the complex traits [1,2,3]. GWAS increases the acceleration and accuracy of locating quantitative loci and candidate genes that can be used for crop improvement. Functional analysis of these candidate genes will enhance our understanding related to the crop response mechanism to the environments. This mapping is very affordable to plant research programs because of

the development in genomic technology and statistical analysis methods [4]. Population of the maize for GWAS have to contain optimum sample size that show population structure and kinship relationships with diverse genetic variation of the complex traits [5,6]. Compared to QTL analysis, GWAS can identify many alleles at the same spot and detect genes associated with the complex traits with higher resolution [7,8]. Thus, GWAS is an effective way to identify the genomic regions that regulate the complex traits in maize. For example, seed and grain morphology, plant morphology, plant development (flowering time), yield, abiotic and biotic stress, cooking, eating and nutritional quality-related traits that correlated with environmental variations.

In 2005, GWAS was used for the first time to detect the relationship between age and molecular degeneration. Right now, GWAS have been widely used to detect the genomic regions correlated with the complex traits in human, animals, and plants. In plants, GWAS have been detected many genes associated to the complex traits, such as in Arabidopsis, rice, maize, sorghum, wheat, barley, and many other plants [2,9-22]. Phenotypic data and genome-wide genotypes are required in GWAS. GWAS simultaneously screened large number of genetic accessions. The power of the GWAS can be enhanced by using a large number of sample size to increase the variation of the genetic characteristics of the complex traits. GWAS became a new method for identification genes related to the important traits influenced by the rapid development in the sequencing techniques, such as next-generation sequencing that can sequence faster, better, and cheaper compared to the previous sequencing techniques. The design of the GWAS consists of population structure identification, case subject selection, control subject selection, and genotyping a million single nucleotide polymorphisms (SNPs). Recently, SNPs has been using widely due to their density within the genome, higher resolution in mapping, and more cost effective [1]. GWAS has many advantages in reducing genotyping cost and research time, increasing mapping resolution and larger allele number. Several challenges in GWAS that related to multiple hypothesis testing, population structure and statistical power and resolution [23,24,25].

Several statistical methods can be applied to reduce false positive due to population structure and kinship. Various software packages for data analysis in GWAS. The most commonly software that was used in GWAS especially in maize is TASSEL because frequently updated [26,27]. For advanced researchers usually used SAS software [28] or R [29] because it requires programming skills to develop various methods. STRUCTURE software is used to estimate population structure [30]. Kinship relationship among the samples can be estimated by using SPAGeDi [31]. The principal components analysis can be analyzed with EINGENSTRAT software [32]. PowerMarker is used to detect genetic distance among the accessions.

High-resolution genetic mapping in GWAS enhance the accuracy of the candidate genes and identify novel genes related to the important traits. GWAS plays an important role in maize breeding programs. Hundreds of genes correlated with important traits have been clone and targeted genome editing with increasing accuracy and resolution [33-40]. This review describes the current status of GWAS in maize concentrate on performing association mapping as a novel method in associating genetic and complex traits, current strategy in analyzing of phenotype and genotype data to identify population structure and linkage disequilibrium.

2. Methods

The literature studies, published between 1996 and 2022 were collected from the main International data bases, including PubMed, Scopus, and Web of Science. The following keywords were used in the title and abstracts, such as “maize” OR “GWAS” OR “complex traits” OR “genomics regions” OR “grain yield” OR “grain quality” OR “genes”. The reference list in the published studies was also checked to identify more relevant studies. Articles from the literature search were identified and selected based on the selection criteria, including (a) full-text published articles in the English language; (b) studies that have reported the GWAS in maize. The required information that was found from all eligible articles was as follows: the year of publications, population of study, sample size, background markers, complex traits, loci, and chromosome.

3. Results and Discussion

In maize, GWAS conducted in 300 maize inbred lines [41]. Based on the carotenoid content trait, GWAS identified genomic region lycopene epsilon cyclase (lcyE) correlated with carotenoid biosynthetic pathway in diverse maize inbred lines [42]. Furthermore, the correlation between beta-carotene and grain color is low, so screening and selection to produce maize with high vitamin A level is more effective based on lcyE alleles than grain color. This research is very useful in high provitamin A maize breeding program. According to Wang et al. [24], GWAS is a crucial method to identify genetic factors related to head smut resistance in maize that causes reduction in quality and yield of maize every year. In this research, used Illumina MaizeSNP50 array, 45,868 SNPs and 144 inbred lines maize. GWAS identified 18 candidate genes correlated with head smut resistance that very important to develop head smut-resistant maize cultivars.

Based on Tian et al. [10], 1.6 million SNPs and 4,892 diverse lines were used for GWAS of leaf architecture, such as leaf length, width, and angle that associated with the light capture efficiency. Furthermore, maize yield will increase as the light capture become more efficient. GWAS also identified Dwarf8 (D8) gene that regulated flowering time in maize by using 375 maize inbred lines and 275 maize landraces with 55 simple sequence repeat (SSR) markers [43,44,45]. In Belo et al. [46], GWAS detected genomic regions on chromosome 4 that controlled oleic acid content in maize using 553 maize inbred lines and 8,590 SNPs.

GWAS in husk tightness of maize was identified by Jiang et al. [47] that very useful for genetic improvement related to the protection of maize kernel from pathogen and pest, and also mechanical damage in harvesting process. In this study used 508 maize inbred lines. Based on the phenotypic analysis, maize from temperate environments showed more loosely compared to tropical and subtropical environments. This study identified 27 candidate genes by using husk tightness phenotypic data and ~1.25 million SNPs. These candidate genes have important functions in husk senescence, morphogenesis, and abiotic stress defense.

In 2021, Zheng et al. [48] identified 49 loci on chromosome 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 associated with grain quality of the maize by GWAS analysis. These grain quality traits, including moisture, protein, oil, starch, and lysine contents. A total of twenty-nine candidate genes identified within the loci that correlated to biological processes, cellular components, and molecular functions. These results provide an important strategy to develop high-quality varieties in maize breeding program. A total of 63 loci and 189 candidate genes associated with root system architecture in maize were identified by Wu et al. [22] using GWAS analysis. This GWAS analysis performed by using 1.25 million SNPs and 421 maize inbred lines. The results of this GWAS analysis are important to develop maize varieties with improved root systems. Many research papers were published related to GWAS analysis in maize from 2011 until 2022 (see Table 1).

Table 1: Genome wide association studies in maize (*Zea mays*)

Year	Population	Sample Size	Background Markers	Traits	Loci	Chromosome	References
2011	Diverse inbred lines	4,892	1.6 million SNPs	Leaf architecture (leaf length, leaf width and upper leaf angle)	-	2 and 3	(Tian et al., 2011) [10]
	Recombinant inbred lines	5,000	1.6 million SNPs	Southern leaf blight disease	32	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Kump et al., 2011) [49]
	Inbred-line nested association	5,000	1.6 million SNPs	Northern leaf blight resistance	29	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Poland et al., 2011) [50]
	Diverse inbred lines	284	55,000 SNPs	Plant height	105	5	(Weng et al., 2011) [51]
2012	Diverse inbred lines	144	1.6 million	Head smut resistance	19	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Wang et al., 2012) [24]
	Diverse inbred lines	289	56,110 SNPs	Leaf metabolic profiles	-	1, 3, 4, 5, 6, 9, and 10	(Riedelsheimer et al., 2012) [11]

	Diverse inbred lines	543	56,110 SNPs	a-tocopherol content	-	2, 4, and 5	(Li et al., 2012) [52]
2013	Diverse inbred lines	368	1.03 million SNPs	Kernel oil concentration and fatty acid composition	74	1, 2, 3, 4, 5, 6, 7, 8, and 10	(Li et al., 2013) [53]
	Diverse inbred lines	267	47,445 SNPs	Fusarium ear rot resistance	3	1, 5, and 9	(Zila et al., 2013) [54]
	Diverse inbred lines	281	591,822 SNPs	Tocochromanol levels in maize grain	16	5	(Lipka et al., 2013) [55]
	Diverse inbred lines	284	39,166 SNPs	Flowering time, kernel composition, and disease resistance	46	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Schaefer et al., 2013) [56]
	Diverse inbred lines	350	44,314 SNPs	Grain yield and related phenotypic traits under drought stress:			(Xue et al., 2013) [57]
				- Grain yield (GY)	6	1, 8, 9, and 10	
				- Hundred kernel weight (HKW)	3	1, 8, and 9	
				- Kernel number (KNO)	2	5 and 9	
				- Ear height (EH)	10	1, 4, 6, and 9	
				- Plant height (PH)	4	1, 2, 3, and 10	
				- Relative ear position (EPO)	11	1, 3, 4, 6, and 10	
				- Female flowering, (days to silk DTS)	2	4	
				- Male flowering, (days to anthesis DTA)	4	1, 8, and 9	
				- Anthesis-silking interval (ASI)	5	1, 3,and 9	

Table 2: Genome wide association studies in maize (*Zea mays*) (*continued*)

Year	Population	Sample Size	Background Markers	Traits	Loci	Chromosome	References
2014	Diverse inbred lines	368	56,110 SNPs	Metabolites	1459	1, 2, 8, and 9	(Wen et al., 2014) [58]
	Diverse inbred lines	281	462,702 SNPs	Carotenoid levels	8	6, 8, 9, and 10	(Owens et al. 2014) [59]
	Diverse inbred lines	3,381	26.5 million SNPs	Hypersensitive defense response	32	1, 2, 3, 4, 5, 6, 8, 9, and 10	(Olukolu et al., 2014) [60]
	Diverse inbred lines	513	556,809 SNPs	17 agronomic traits:	34		(Yang et al., 2014) [37]
				-Plant height		1, 2, 3, 4, 5, 9, and 10	
				-Ear height		1, 2, 3, 4, 5, 6, 8, 9, and 10	
				-Ear leaf width		2, 3, 4, 5, 7, 8, 9, and 10	
				-Ear leaf length		2, 3, and 9	
				-Tassel main axis length		2, 3, 4, 5, 7, and 10	
				-Tassel branch number		2, 4, 5, 6, 7, 8, 9, and 10	
				-Leaf number above ear		2, 3, and 9	
				-Ear length		1, 2, 3, 5, 7, 9, and 10	
				-Ear diameter		1, 3, 4, 5, 7, 9, and 10	
				-Cob diameter		1, 2, 3, and 5	

				-Kernel number per row		1, 5, 6, 8, and 9	
				-100-grain weight		1 and 9	
				-Cob weight		2	
				-Kernel width		1, 2, 5, and 7	
				-Days to anthesis		1, 2, 3, 4, 5, 6, 7, and 8	
				-Days to silking		1, 3, 4, 5, 6, 7, and 10	
				-Days to heading		1, 2, 4, 5, and 10	
2015	Diverse inbred lines	384	681,257 SNPs	Seedling root development	268	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Pace et al., 2015) [61]
	Diverse inbred lines	615	2,000 SNPs	Lethal necrosis disease resistance	24	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Gowda et al., 2015) [62]
	Diverse inbred lines	300	261,184 SNPs	*Aspergillus flavus* and Aflatoxin Accumulation Resistance	107	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Warburton et al., 2015) [63]
	Diverse inbred lines	5,000	1.6 million SNPs	Carbon and Nitrogen Metabolism	-	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Zhang et al., 2015) [64]

Table 2: Genome wide association studies in maize (*Zea mays*) (*continued*)

Year	Population	Sample Size	Background Markers	Traits	Loci	Chromosome	References
2016	Diverse inbred lines	367	525,104 SNPs	Drought tolerance	83	1, 2, 4, 7, 8, 9, and 10	(Wang et al., 2016) [65]
	Diverse inbred lines	508	543,641 SNPs	Genetic architecture of four husk traits	9	4, 5, 6, 8, 9, and 10	(Cui et al., 2016) [66]
	Diverse inbred lines	368	559,285 SNPs	Stalk cell wall components: lignin (LIG), cellulose (CEL) and hemicellulose (HC)	64	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Li et al., 2016) [67]
	Diverse inbred lines	274	246,497 SNPs	Common rust resistance	3	2, 3, and 8	(Olukolu et al., 2016) [68]
	Diverse inbred lines	318	156,599 SNPs	Drought-related metabolic changes:	63		(Zhang et al., 2016) [69]
				-Sucrose (Suc)		1, 2, 2, 5, 5, 5, 6, and 10	
				- Total sugars (Tsug)		1, 1, 2, 2, 2, 3, 4, and 6	
				- Phaseic acid (Pa)		1, 1, 1, 3, 3, 4, 4, 4, 5, 5, 6, 6, 6, 6, 7, 7, and 7	
				- Glucose (Glc)		1, 1, 2, 3, 4, 4, 5, 6, 6, and 6	
				- Abscisic acid glucose ester (ABA-GE)		1, 1, 2, 2, 4, 4, 6, and 6	
				- Proline (Pro)		1, 1	
				- Starch (Str)		2, 10, and 10	
				- Abscisic acid (ABA)		2, 3, 3, 3, 5, 5, 8, 9, and 10	
				- Specific leaf weight (Slw)		5 and 7	
				- Physiological traits including dry mass (Dw)		6 and 7	
2017				Review GWAS from 2011 until 2016			(Xiao et al., 2017) [70]

2018	Diverse inbred lines	292	25,331 SNPs	Major ear quantitative traits	20	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Zhu et al., 2018) [71]
	Diverse inbred lines	157	355,972 SNPs	Gray leaf spot resistance	7	1, 2, 3, 4, 6, 7, and 10	(Kuki et al., 2018) [72]
	Diverse inbred lines	287	260,550 SNPs	Corn earworm resistance	51	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Warburton et al., 2018) [73]
	Diverse inbred lines	300	62,077 SNPs	Root system architecture traits	19	1, 2, 5, 7, and 8	(Sanchez et al., 2018) [18]
2019	Diverse inbred lines	356	541,575 SNPs	13 traits in maize seedlings under low phosphorus stress	551	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Wang et al., 2019) [74]
	Diverse inbred lines	555	681,257 SNPs	Goss's wilt resistance	10	1, 2, and 5	(Singh et al., 2019) [75]
	Diverse inbred lines	282	39,991 SNPs	Metabolites	31	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Zhou et al., 2019) [76]

Table 2: Genome wide association studies in maize (*Zea mays*) (*continued*)

Year	Population	Sample Size	Background Markers	Traits	Loci	Chromosome	References
2020	Diverse accessions	419	955,690 SNPs	Northern corn leaf blight resistance	17	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Rashid et al., 2020) [20]
	Diverse inbred lines	639	42,667 SNPs	Kernel row number	7	1, 2, 3, 5, 9, and 10	(An et al., 2020) [77]
	Diverse inbred lines	410	7,490 SNPs	Gray leaf spot resistance	22	1, 2, 6, 7, and 8	(Kibe et al., 2020) [78]
2021	Diverse inbred lines	412	779,855 SNPs	Aboveground Dry Matter Accumulation at Seedling Stage	678	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Lu et al., 2021) [79]
	Diverse inbred lines	281	1.25 million SNPs	Genetic architecture of root hair length	11	1, 2, 4, 5, 6, and 10	(Liu et al., 2021) [80]
	Diverse accessions	424	955,690 SNPs	Stover quality traits	12	1, 2, 3, 5, 6, and 7	(Vinayan et al., 2021) [81]
	Diverse inbred lines	179	1,490,007 SNPs	Root architectural traits at multiple seedling stages	8	1, 2, 4, and 10	(Moussa et al., 2021) [82]
	Diverse inbred lines	248	83,057 SNPs	Grain quality traits	49	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Zheng et al., 2021) [48]
2022	Diverse inbred lines	421	1.25 million SNPs	Root system architecture	63	1, 2, 3, 4, 5, 6, 7, 8, 9, and 10	(Wu et al., 2022) [22]

GWAS analysis reported accurate loci and candidate genes related to many complex traits in maize, including seed development, phenotypic plant morphology, plant development, yield, kernel quality, abiotic and biotic stress-related traits [83-92]. These research papers provide important information to enhance maize breeding program that develop improved maize varieties in grain yield and the quality.

4. Conclusion

GWAS analysis accelerated identification of genetic regions, putative genes, and various metabolic pathways correlated with important economic traits in maize to fulfill the market demands. These traits are related with grain yield and grain quality that supported by agronomic traits, biotic and abiotic stress resistance. GWAS has many advantages in reducing genotyping cost and research time, increasing mapping resolution and larger allele number. Development of the software package for GWAS determined accelerating improvement of the maize characteristics.

References

1. Dwiningsih Y. Molecular Genetic Analysis of Drought Resistance and Productivity Traits of Rice Genotypes; University of Arkansas: Fayetteville, AR, USA. 2020.

2. Atwell S., Huang Y. S., Vilhjalmsson B. J., Willems G., Horton M., Li Y., Meng D., Platt A., Tarone A. M., Hu T. T., Jiang R., Muliyati N. M., Zhang X., Amer M. A., Baxter I., Brachi B., Chory J., Dean C., Debieu M., de Meaux J., Ecker J. R., Faure N., Kniskern J. M., Jones J. D. G., Michael T., Nemri A., Roux F., Salt D. E., Tang C., Todesco M., Traw M. B., Weigel D., Marjoram P., Borevitz J. O., Bergelson J., Nordborg. Genome-wide association study of 107 phenotypes in *Arabidopsis thaliana* inbred lines. *Nature*, 2010;465(3). doi:10.1038/nature08800
3. Risch N., Merikangas, K. The future of genetic studies of complex human diseases. *Science*, 1996;273:1516-1517.
4. Zhu C., Gore M., Buckler E. S., Yu J. Status and Prospects of Association Mapping in Plants. *The Plant Genome*, 2008;1:5-20. doi:10.3835/plantgenome2008.02.0089
5. Yu J., Buckler E. S. Genetic association mapping and genome organization of maize. *Curr. Opin. Biotechnol*., 2006;17:155-160.
6. Yu J., Pressoir G., Briggs W. H., Bi I. V., Yamasaki M., Doebley J. F., McMullen M. D., Gaut B. S., Nielsen D. M., Holland J. B., Kresovich S., Buckler E. S. A unified mixed-model method for association mapping that accounts for multiple levels of relatedness. *Nat. Genet*. 2006;38:203-208.
7. Dwiningsih, Y. & Alkahtani, J. Genetics, Biochemistry and Biophysical Analysis of Anthocyanin in Rice (Oryza sativa L.). Advance Sustainable Science, Engineering and Technology (ASSET), 2022, 2022b, 4(1). https://doi.org/10.26877/asset.v4i1.11659
8. Dwiningsih Y., Kumar A., Thomas J., Ruiz C., Alkahtani J., Al-hashimi A., Pereira A. Identification of Genomic Regions Controlling Chalkiness and Grain Characteristics in a Recombinant Inbred Line Rice Population Based on High-Throughput SNP Markers. *Genes*, 2021;12(1690). doi:10.3390/genes12111690
9. Dwiningsih Y., Kumar A., Thomas J., Gupta C., Ruiz, C., Baisakh N., Pereira A. QTLs analysis and identification of candidate genes for flag leaf characteristics related to grain yield in US RIL rice population under drought conditions. American Society of Agronomy (ASA), Crop Science Society of America (CSSA), Soil Science Society of America (SSSA) International Annual Meeting, Salt Lake City, UT. 2021.
10. Tian F., Bradburry P. J., Brown P. J., Hung H., Sun Q., Flint-Garcia S., Rocheford T. R., McMullen M. D., Holland J. B., Buckler E. S. Genome-wide association study of leaf architecture in the maize nested association mapping population. *Nature Genetics*, 2011;43:2. doi:10.1038/ng.746
11. Riedelsheimer C., Lisec J., Czedik-Eysenberg A., Sulpice R., Flis A., Grieder C., Altmann T., Stitt M., Willmitzer L., Melchinger A. E. Genome-wide association mapping of leaf metabolic profiles for dissecting complex traits in maize. *PNAS*, 2012;109,23. doi:10.1073/pnas.1120813109
12. Morris G. P., Ramu P., Deshpande S. P., Hash C. T., Shah T., Upadhyaya H. D., Riera-Lizarazu O., Brown P. J., Acharya C. B., Mitchell S. E., Harriman J., Glaubitz J. C., Buckler E. S., Kresovich S. Population genomic and genomic-wide association studies of agroclimatic traits in sorghum. *PNAS*, 2013;110 2:453-458.
13. Chen W., Gao Y., Xie W., Gong L., Lu K., Wang W., et al. Genome-wide association analyses provide genetic and biochemical insights into natural variation in rice metabolism. *Nat. Genet*., 2014;46,714-721. doi:10.1038/ng.3007
14. Dwiningsih Y., Rahmaningsih M., & Alkahtani J. Development of single nucleotide polymorphism (SNP) markers in tropical crops. *Advance Sustainable Science, Engineering and Technology (ASSET)*, 2020; 2020c; 2(2).
15. McCouch S. R., Wright M. H., Tung C., Maron L. G., McNally K. L., Fitzgerald M., Singh N., DeClerck G., Perez F. A., Korniliev P., Greenberg A. J., Naredo M. E. B., Mercado S. M. Q., Harrington S. E., Shi Y., Branchini D. A., Kuser-Falcao P. R., Leung H., Ebana K., Yano M., Eizenga

G., McClung A., Mezey J. Open access resources for genome-wide association mapping in rice. *Nature Communication*, 2016;7:10532. doi:10.1038/ncomms10532

16. Yano K., Yamamoto E., Aya K., Takeuchi H., Lo P. C., Hu L., et al. Genome-wide association study using whole-genome sequencing rapidly identifies new genes influencing agronomic traits in rice. *Nat. Genet*. 2016;48,927-934. doi:10.1038/ng.3596
17. Zhou H., Li P., Xie W., Hussain S., Li Y., Xia D., Zhao H., Sun S., Chen J., Ye H., Hou J., Zhao D., Gao G., Zhang Q., Wang G., Lian X., Xiao J., Yu S., Li X., He Y. Genome-wide Association Analyses Reveal the Genetic Basis of Stigma Exsertion in Rice. *Mol. Plant*., 2017;10:634-644.
18. Sanchez D. L., Liu S., Ibrahim R., Blanco M., Lubberstedt. Genome-wide association studies of doubled haploid exotic introgression lines for root system architecture traits in maize (*Zea mays* L.). *Plant Science*, 2018;268:30-38. doi:10.1016/j.plantsci.2017.12.004
19. Chen J., Zhou H., Xie W., Xia D., Gao G., Zhang Q., Wang G., Lian X., Xiao J., He Y. Genome-wide association analyses reveal the genetic basis of combining ability in rice. *Plant Biotechnology,* 2019;12:2211-2222. doi:10.1111/pbi.13134
20. Rashid Z., Sofi M., Harlapur S. I., Kachapur R. M., Dar Z. A., Singh P. K., Zaid P. H., Vivek B. M., Nair S. K. Genome-wide association studies in tropical maize germplasm reveal novel and known genomic regions for resistance to Northern corn leaf blight. *Scientific Reports*, 2020;10. doi:10.1038/s41598-020-78928-5
21. Zhang G., Wang R., Ma J., Gao H., Deng L., Wang N., Wang Y., Zhang J., Li K., Zhang W., Mu F., Liu H., Wang Y. Genome-wide association studies of yield-related traits in high-latitude japonica rice. *BMC Genomic Data*, 2021;22(39). doi:10.1186/s12863-021-00995-y
22. Wu B., Ren W., Zhao L., Li Q., Sun J., Chen F., Pan Q. Genome-Wide Association Study of Root System Architecture in Maize. *Genes*, 2022;13:181. doi:10.3390/genes13020181
23. Dwiningsih, Y., Kumar, A., Thomas, J., Yingling, S., & Pereira, A. Molecular genetic analysis of drought resistance and productivity in US rice cultivars. Plant and Animal Genome XXVII Conference (January 12-16, 2019). 2019.
24. Wang M., Yan J., Zhao J., Song W., Zhang X., Xiao Y., Zheng Y. Genome-wide association study (GWAS) of resistance to head smut in maize. *Plant Science*, 2012;196:125-131.
25. Dwiningsih, Y., Thomas, J., Kumar, A., Gupta, C., Ruiz, C., Yingling, S., Crowley, E., & Pereira, A. Molecular genetic analysis of drought resistance and productivity mechanisms in rice. Plant and Animal Genome XXVIII Conference, January 11-15, 2020. 2020b.
26. Zhang Z., Ersoz E., Lai C. Q., Todhunter R. J., Tiwari H. K., Gore M. A. Mixed linear model approach adapted for genome-wide association studies. *Nat. Genet.* 2010;42,355-360. doi:10.1038/ng.546
27. Bradbury P. J., Zhang Z., Kroon D. E., Casstevens T. M., Ramdoss Y., Buckler E. S. TASSEL: Software for association mapping of complex traits in diverse samples. *Bioinformatics*, 2007;23:2633-2635.
28. SAS Institute. SAS/STAT user's guide. Version 8 SAS Institute, Inc, Cary, NC. 1999.
29. Ihaka R., Gentlemen R. R: A language for data analysis and graphics. *J. Comput. Graph. Stat.* 1996;5:299-314.
30. Pritchard J. K., Stephens M., Donnelly P. Inference of population structure using multi-locus genotype data. *Genetics*, 2000;155:945-959.
31. Hardy O. J., Vekemans X. SPAGeDi: A versatile computer program to analyse spatial genetic structure at the individual or population levels. *Mol. Ecol. Notes*, 2002;2:618-620.
32. Price A. L., Patterson N. J., Plenge R. M., Weinblatt M. E., Shadicl N. A., Reich, D. Principal components analysis corrects for stratification in genome-wide association studies. *Nature Genetics*, 2006;38(8). doi:10.1038/ng1847

33. Purcell S., Neale B., Todd-Brown K., Thomas L., Ferreira M. A., Bender D., Maller J. et al. PLINK: a tool set for whole-genome association and population-based linkage analyses. *Am. J. Human Genet*. 2007;81:559-575.
34. Brachi B., Morris G. P., Borevitz J. O. Genome-wide association studies in plants: the missing heritability is in the field. *Genome Biology*, 2011;12(232).
35. Wen Y. J., Zhang H., Ni Y. L., Huang B., Zhang J., Feng J. Y., et al. Methodological implementation of mixed linear models in multi-locus genome-wide association studies. *Brief. Bioinform*. 2018;19:700-712. doi:10.1093/ bib/bbw145
36. Wu T. T., Chen Y. F., Hastie T., Sobel E., Lange K. Genome-wide association analysis by lasso penalized logistic regression. *Bioinformatics*, 2009;25:714-721. doi:10.1093/bioinformatics/btp041
37. Yang N., Lu Y., Yang X., Huang J., Zhou Y., Ali F., Wen W., Liu J., Li J., Yan J. Genome wide association studies using a new nonparametric model reveal the genetic architecture of 17 agronomic traits in an enlarged maize association panel. *PLoS Genet*. 2014;(10)9:004573. doi:10.1371/journal.pgen.1004573
38. Wang Q., Tian F., Pan Y., Buckler E. S., Zhang Z. A SUPER Powerful Method for Genome Wide Association Study. *PLoS ONE*, 2014;9(9):107684. doi:10.1371/ journal.pone.0107684
39. Lippert C., Listgarten J., Liu Y., Kadie C. M., Davidson R. I., Heckerman D. FaST linear mixed models for genome-wide association studies. *Nature Methods*, 2011;8833-835.
40. Dwiningsih Y., Kumar A., Thomas J., Ruiz C., Alkahtani J., Baisakh N., Pereira A. Quantitative trait loci and candidate gene identification for chlorophyll content in RIL rice population under drought conditions. *Indonesian Journal of Natural Pigments*, 2021;3(2):54-64. doi:10.33479/ijnp.2021.03.2.54
41. Flint-Garcia S. A., Thornsberry J. M., Buckler E. S. Structure of linkage disequilibrium in plants. *Annu. Rev. Plant Biol*. 2003;54:357-374.
42. Harjes C. E., Rocheford T. R., Bai L., Brutnell T. P., Kandianis C. B., Sowinski S. G., Stapleton A. E., Vallabhaneni R, Williams M., Wurtzel E. T., Yan J., Buckler E. S. Natural genetic variation in lycopene epsilon cyclase tapped for maize biofortification. *Science*, 2008;319:330-333.
43. Andersen J. R., Schrag T., Melchinger A. E., Zein I., Lubberstedt T. Validation of Dwarf8 polymorphisms associated with flowering time in elite European inbred lines of maize (*Zea mays* L.). *Theor. Appl. Genet*. 2005;111:206-217.
44. Thornsberry J. M., Goodman M. M., Doebley J., Kresovich S., Nielsen D., Buckler E. S. Dwarf8 polymorphisms associate with variation in flowering time. *Nat. Genet*. 2001;28:286-289.
45. Camus-Kulandaivelu L., Veyrieras J. B., Madur D., Combes V., Fourmann M., Barraud S., Dubreuil P., Gouesnard B., Manicacci D., Charcosset A. Maize adaptation to temperate climate: relationship between population structure and polymorphism in the Dwarf8 gene. *Genetics*, 2006;172:2449-2463.
46. Belo A., Zheng P., Luck S., Shen B., Meyer D. J., Li B., Tingey S., Rafalski A. Whole genome scan detects an allelic variant of fad2 associated with increased oleic levels in maize. *Mol. Genet. Genomics*, 2008;279:1-10. doi:10.1007/s00438007-0289-y
47. Jiang S., Zhang H., Ni P., Yu S., Dong H., Zhang A., Cao H., Zhang L., Ruan Y., Cui Z. Genome-Wide Association Study dissects the genetic architecture of maize husk tightness. *Front. Plant Sci*. 2020;11:861. doi:10.3389/fpls.2020.00861
48. Zheng Y., Yuan F., Huang Y., Zhao Y., Jia X., Zhu L., Guo J. Genome-wide association studies of grain quality traits in maize. *Scientific reports*, 2021;11(9797). doi:10.1038/s41598-021-89276-3
49. Kump K. L., Bradbury P. J., Wisser R. J., Buckler E. S., Belcher A. R., Oropeza-Rosas M. A., Zwonitzer J. C., Kresovich S., McMullen M. D., Ware D., Balint-Kurti P. J., Hollad J. B. Genome-wide association study of quantitative resistance to southern leaff blight in the maize nested association mapping population. *Nature Genetics*, 2011;43(2). doi:10.1038/ng.747

50. Poland J. A., Bradbury P. J., Buckler E. S., Nelson R. J. Genome-wide nested association mapping of quantitative resistance to northern leaf blight in maize. *PNAS*, 2011;108(17):6893-6898. doi:10.1073/pnas.1010894108
51. Weng J., Xie C., Hao Z., Wang J., Liu C., Li M., Zhang D., Bai L., Zhang S., Li X. Genome-wide association study identifies candidate genes that affect plant height in Chinese elite maize (*Zea mays* L.) inbred lines. *PLoS ONE*, 2011;6(12):29229. doi:10.1371/journal.pone.0029229
52. Li Q., Yang X., Xu S., Cai Y., Zhang D., Han Y., Li L., Zhang Z., Gao S., Li J., Yan J. Genome-wide association studies identified three independent polymorphisms associated with a-tocopherol content in maize kernels. *PLoS ONE*, 2012;7(5):36807. doi:10.1371/journal.pone.0036807
53. Li H., Peng Z., Yang X., Wang W., Fu J., Wang J., Han Y., Chai Y., Guo T., Yang N., Liu J., Warburton M. L., Cheng Y., Hao X., Zhang P., Zhao J., Liu Y., Wang G., Li J., Yan J. Genome-wide association study dissect the genetic architecture of oil biosynthesis in maize kernels. *Nature Genetics*, 2013;45(1).
54. Zila C. T., Samayoa F., Santiago R., Butron A., Holland J. B. A genome-wide association study reveals genes associated with fusarium ear rot resistance in a maize core diversity panel. *Gene, Genomes, Genetics,* 2013;3. doi:10.1534/g3.113.007328
55. Lipka A. E., Gore M. A., Magallanes-Lundback M., Mesberg A., Lin H., Tiede T., Chen C., Buell C. R., Buckler E. S., Rocheford T., DellaPenna D. Genome-wide association study and pathway-level analysis of tocochromanol levels in maize grain. *Gene, Genomes, Genetics,* 2013;3. doi:10.1534/g3.113.006148
56. Schaefer C. M., Bernardo R. Genomewide association mapping of flowering time, kernel composition, and disease resistance in historical minnesota maize inbreds. *Crop Science*, 2013;*53*(6):2518-2529. doi:10.2135/cropsci2013.02.0121
57. Xue Y., Warburton M. L., Sawkins M., Zhang X., Setter T., Xu Y., Grudloyma P., Gethi J., Ribaut J. M., Li W., Zhang X., Zheng Y., Yan J. Genome-wide association analysis for nine agronomic traits in maize under well-watered and water-stressed conditions. *Theor App Genet*. 2013. doi:10.1007/s00122-013-2158-x
58. Wen W., Li D., Li X., Gao Y., Li W., Li H., et al. Metabolome-based genome-wide association study of maize kernel leads to novel biochemical insights. *Nat. Commun*. 2014;5:3438. doi:10.1038/ncomms4438
59. Owens B. F., Lipka A. E., Magallanes-Lundback M., Tiede T., Diepenbrock C. H., Kandianis C. B., Kim E., Cepela J., Mateous-Hernandez M., Buell R., Buckler E. S., DellaPenna D., Gore M .A., Rocheford T. A foundation for provitamin A biofortification of maize: genome-wide association and genomic prediction models of carotenoid levels. *Genetics*, 2014;198:1699-1716. doi:10.1534/genetics.114.169979
60. Olukolu B. A., Wang G. F., Vontimitta V., Venkata B. P., Marla S. et al. A Genome-Wide Association Study of the Maize Hypersensitive Defense Response Identifies Genes That Cluster in Related Pathways. *PLoS Genet*. 2014;10(8):1004562. doi:10.1371/journal.pgen.1004562
61. Pace J., Gardner C., Romay C., Ganapathysubramanian B., Lubberstedt. Genome-wide association analysis of seedling root development in maize (*Zea mays L.*). *BMC Genomics*, 2015;16(47). doi:10.1186/s12864-015-1226-9
62. Gowda M., Das B., Makumbi D., Babu R., Semagn K., Mahuku G., Olsen M. S., Bright J. M., Beyene Y., Prasanna B. M. Genome-wide association and genomic prediction of resistance to maize lethal necrosis disease in tropical maize germplasm. *Theor Appl Genet.* 2015;128:1957-1968. doi:10.1007/s00122-015-2559-0

63. Warburton M. L., Tang J. D., Windham G. L., Hawkins L. K., Murray S. C., Xu W., Boykin D., Perkins A., Williams W. P. Genome-wide association mapping of *Aspergillus flavus* and aflatoxin accumulation resistance in maize. *Crop Sci.* 2015;55, 1-11. doi:10.2135/cropsci2014.06.0424
64. Zhang N., Gibon Y., Wallace J. G., Lepak N., Li P., Dedow L., Chen C., So Y., Kremling K., Bradbury P. J., Brutnell T., Stitt M., Buckler E. S. Genome-wide association of carbon and nitrogen metabolism in the maize nested association mapping population. *Plant Physiology*, 2015;168:575-583.
65. Wang X., Wang H., Liu S., Ferjani A., Li J., Yan J., Yang X., Qin F. Genetic variation in *ZmVPP1* contributes to drought tolerance in maize seedling. *Nature Genetics*, 2016;48,10. doi:10.1038/ng.3636
66. Cui Z., Luo J., Qi C., Ruan Y., Li J., Zhang A., Yang X., He Y. Genome-wide association study (GWAS) reveals the genetic architecture of four husk traits in maize. *BMC Genomics*, 2016;17,946. doi:10.1186/s12864-016-3229-6
67. Li K., Wang H., Hu X., Liu Z., Wu Y., Huang C. Genome-Wide Association Study Reveals the Genetic Basis of Stalk Cell Wall Components in Maize. *PLoS ONE*, 2016;11(8):0158906. doi:10.1371/ journal.pone.0158906
68. Olukolu B., Tracy W. F., Wisser R., De Vries B., Balint-Kurti P. J. A genome-wide association study for partial resistance to maize common rust. *Phytopathology*, 2016;106:745-751. doi:10.1094/PHYTO-11-15-0305-R
69. Zhang X., Warburton M. L., Setter T., Liu H., Xue Y., Yang N., Yan J., Xiao Y. Genome-wide association studies of drought-related metabolic changes in maize using an enlarge SNP panel. *Theor Appl Genet.* 2016;129:1449-1463. doi:10.1007/s00122-016-2716-0
70. Xiao Y., Liu H., Wu L., Warburton M., Yan J. Genome-wide association studies in maize: praise and stargaze. *Molecular Plant*, 2017;10:359-374. doi:10.1016/j.molp.2016.12.008
71. Zhu X. M., Shao X. Y., Pei Y. H., Guo X. M., Li J., Song X. Y., Zhao M. A. Genetic Diversity and Genome-Wide Association Study of Major Ear Quantitative Traits Using High-Density SNPs in Maize. *Front. Plant Sci*. 2018;9:966. doi:10.3389/fpls.2018.00966
72. Kuki M. C., Scapim C. A., Rossi E. S., Mangolin C. A., Amaral Ju´nior A. Td., Pinto R. J. B. Genome wide association study for gray leaf spot resistance in tropical maize core. *PLoS ONE*, 2018;13(6):0199539. doi:10.1371/journal.pone.0199539
73. Warburton M. L., Womack E. D., Tang J. D., Thrash A., Smith J. S., Xu W., Murray S. C., Williams W. P. Genome-wide association and metabolic pathway analysis of corn earworm resistance in maize. *Plant Genome*, 2018;11:170069. doi:10.3835/plantgenome2017.08.0069
74. Wang Q. J., Yuan Y., Liao Z., Jiang Y., Wang Q., Zhang L., Gao S., Wu F., Li M., Xie W., Liu T., Xu J., Liu Y., Feng X., Lu Y. Genome-wide association study of 13 traits in maize seedlings under low phosphorus stress. *Plant Genome*, 2019;12:190039. doi:10.3835/plantgenome2019.06.0039
75. Singh A., Li G., Brohammer A. B., Jarquin D., Hirsch C. N., Alfano J. R., Lorenz A. J. Genome - wide association and gene co-expression network analyses reveal complex genetics of resistance to Gross's Wilt of Maize. *Genes Genomes Genetics*, 2019;9. doi:0000-0002-4361-1683
76. Zhou X., Huang X. Genome-wide association studies in rice: how to solve the low power problems? *Mol Plant*. 2019;12:10-12.
77. An Y., Chen L., Li Y. X., Li C., Shi Y., Zhang D., Li Y., Wang T. Genome-wide association studies and whole-genome prediction reveal the genetic architecture of KRN in maize. *BMC Plant Biology*, 2020;20(490). doi:10.1186/s12870-020-02676-x
78. Kibe M., Nair S. K., Das B., Bright J. M., Makumbi D., Kinyua J., Suresh L. M., Beyene Y., Olsen M. S., Prasanna B. M., Gowda M. Genetic Dissection of Resistance to Gray Leaf Spot by Combining

Genome-Wide Association, Linkage Mapping, and Genomic Prediction in Tropical Maize Germplasm. *Front. Plant Sci.* 2020;11:572027. doi:10.3389/fpls.2020.572027

79. Lu X., Wang J., Wang Y., Wen W., Zhang Y., Du J., Zhao Y., Guo X. Genome-Wide Association Study of Maize Aboveground Dry Matter Accumulation at Seedling Stage. *Front. Genet*. 2021;11:571236. doi:10.3389/fgene.2020.571236
80. Liu L., Jiang L. G., Luo J. H., Xia A. A., Chen L. Q., He Y. Genome-wide association study reveals the genetic architecture of root hair length in maize. *BMC Genomics*, 2021;22:664. doi:10.1186/s12864-021-07961-z
81. Vinayan M. T., Seetharam K., Babu R., Zaidi P. H., Blummel M., Nair S. K. Genome wide association study and genomic prediction for stover quality traits in tropical maize (*Zea mays* L.). *Scientific Reports*, 2021;11:686. doi:10.1038/s41598-020-80118-2
82. Moussa A., Mandozai A., Jin Y., Qu J., Zhang Q., et al. Genome-wide association screening and verification of potential genes associated with root architectural traits in maize (*Zea mays L.*) at multiple seedling stage. *BMC Genomics*, 2021;22,558. doi:10.1186/s12864-021-07874-x
83. Ge, X., Khan, Z.I., Chen, F., Akhtar, M., Ahmad, K., Ejaz, A., Ashraf, M.A., Nadeem, M., Akhtar, S., Alkahtani, J., Dwiningsih, Y., & Elshikh, M.S. A study on the contamination assessment, health risk and mobility of two heavy metals in the soil-plants-ruminants system of a typical agricultural region in the semi-arid environment. Environmental Science and Pollution Research, 2022;29,14584–14594. https://doi.org/10.1007/s11356-021-16756-4
84. Maqsood, A., Khan, Z.I., Ahmad, K., Akhtar, S., Ashfaq, A., Malik, I.S., Sultana, R., Nadeem, M., Alkahtani, J., Dwiningsih, Y., & Elshikh, M. Quantitative evaluation of zinc metal in meadows and ruminants for health assessment: implications for humans. *Environmental Science and Pollution Research*, 2022; 29, 15, 21634–21641. https://doi.org/10.1007/s11356-021-17264-1
85. Sitrarasi, R., Nallal, U.M., Razia, M., Chung, W.J., Shim, J., Chandrasekaran, M., Dwiningsih, Y., Rasheed, R.A., Alkahtani, J., Elshikh, M.S., Debnath, O., & Ravindran, B. Inhibition of multi-drug resistant microbial pathogens using an ecofriendly root extract of Furcraea foetida silver nanoparticles. Journal of King Saud University-Science, 2022, 34, 2, 101794. https://doi.org/10.1016/j.jksus.2021.101794
86. Bashir, S., Gulshan, A.B., Iqbal, J., Husain, A., Alwahibi, M.S., Alkahtani, J., Dwiningsih, Y., Bakhsh, A., Ahmed, N., Khan, M.J., Ibrahim, M., & Diao, Z-H. Comparative role of animal manure and vegetable waste induced compost for polluted soil restoration and maize growth. Saudi Journal of Biological Sciences, 2021, 28, 4, 2534-2539. https://doi.org/10.1016/j.sjbs.2021.01.057
87. Ali, M.H., Khan, M.I., Bashir, S., Azam, M., Naveed, M., Qadri, R., Bashir, S., Mehmood, F., Shoukat, M.A., Li, Y., Alkahtani, J., Elshikh, M.S., & Dwiningsih, Y. Biochar and *Bacillus* sp. MN54 Assisted Phytoremediation of Diesel and Plant Growth Promotion of Maize in Hydrocarbons Contaminated Soil. Agronomy, 2021, 11, 9, 1795. https://doi.org/10.3390/agronomy11091795
88. Adil M, Bashir S, Bashir S, Aslam Z, Ahmad N, Younas T, Asghar RMA, Alkahtani J, Dwiningsih Y and Elshikh MS (2022) Zinc oxide nanoparticles improved chlorophyll contents, physical parameters, and wheat yield under salt stress. Front. Plant Sci. 2022, 13, 932861. https://doi.org/10.3389/fpls.2022.932861
89. Alkahtani, J., Elshikh, M.S., Dwiningsih, Y., Rathi, M.A., Sathya, R., & Vijayaraghavan, P. In-vitro antidepressant property of methanol extract of *Bacopa monnieri*. Journal of King Saud University – Science, 2022, 34, 102299. https://doi.org/10.1016/j.jksus.2022.102299
90. Alshiekheid, M. A., Dwiningsih, Y., Sabour, A. A., & Alkahtani, J. Phytochemical Composition and Antibacterial Activity of Zingiber cassumunar Roxb. against Agricultural and Foodborne Pathogens. 2022. https://doi.org/10.20944/preprints202208.0511.v1
91. Dwiningsih, Y.; Alkahtani, J. Phenotypic Variations, Environmental Effects and Genetic Basis Analysis of Grain Elemental Concentrations in Rice (*Oryza sativa* L.) for Improving Human Nutrition. *Preprints* 2022, 2022090263. https://doi.org/10.20944/preprints202209.0263.v1

92. Dwiningsih, Y.; Alkahtani, J. Rojolele: a Premium Aromatic Rice Variety in Indonesia. Preprints 2022, 2022100373. https://doi.org/10.20944/preprints202210.0373.v1).

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220210-01 ~ 0220210-10
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.13025

3D-Printed Ergonomic Tool Handles

Rheianne Mae Herrera[1*], Ma. Andrea Blanco[1], John Carlo Carabeo[1], Faye Dannah Ramilo[1], John Renmar de Silva[1], Neil Oliver Nuqui[1], Michaela T. Espino[1, 2], Brian J. Tuazon [2], John Ryan C. Dizon[1, 2]

[1]Department of Industrial Engineering, College of Engineering and Architecture, Bataan Peninsula State University – Main Campus, City of Balanga, Bataan, 2100, Philippines

[2]DR3AM Center, Bataan Peninsula State University – Main Campus, City of Balanga, Bataan, 2100, Philippines

*rheianne24@gmail.com

Abstract. Although hand tools serve as an instrument for extending one's capabilities through the use of hands, the comfort it brings is important especially since the welfare of the user is at stake. Aside from using the hand tools repetitively and with an awkward posture, the tool handle compositions and design also contribute to accumulating some work-related musculoskeletal disorders that require further attention in the long run. To provide a long-term solution, 3D-printed new designs of six commonly used hand tools that fit the average hand measurements of Filipinos have been developed. The hand tools are printed using two filaments namely; thermoplastic polyurethane (TPU) which was found to be skin-friendly and polylactic acid (PLA) which is proven to be more functional, both are used on the outer and inner layer of the handle, respectively. The 3D-printed tool handles were evaluated through the use of a comfort questionnaire for hand tools distributed to 10 respondents per tool handle testing, results show that 3D-printed tool handles are found to be more comfortable and convenient rather than the commercial ones. Meanwhile, the researchers note that the adequate length of tool handles may also vary according to functions and not rely alone on the average hand measurements.

Keywords: Additive Manufacturing, Musculoskeletal Disorder, Tool handles

(Received 2022-08-30, 2022-10-31, Available Online by 2022-10-31

1. Introduction

In this contemporary world, the adaptation of automated machines and advanced technologies is frequently seen in different industries. Regardless, many workers still opt to use manual hand tools that they are very familiar with instead of other variations with a touch of newer technology. Hand tools, in layman's terms, can be referred to as something that can be used easily by hands. The establishment of the past generation primarily relied on the utilization of hand tools accessible at that time. Nowadays,

using these hand tools is frequently seen everywhere, and a flawed design of tools in a production area could affect almost 10% of workers annually. These hand tools have paved the way for humans to showcase their skills of making crafts or any other works. Albeit hand tools serve as an instrument for extending one's capabilities through the use of hands, the discomfort it brings is challenging, especially since the welfare of the user/worker is at stake [1]. Aside from using the hand tools repetitively and with an awkward posture, the tool handle compositions and design also contribute to accumulating some work-related musculoskeletal injuries that require attention in the long run as the user's health might be put in peril—in some severe cases. As defined by the Centers for Disease and Prevention, work-related musculoskeletal disorders (WMSDs) are mostly injuries or disorders of the muscles and nerves on the hands, wrist, and the other parts of the body that are painful and hard to endure over the long run [2]. Such disorder is often a result of the hazardous environment where the work takes place and even the prolonged usage of equipment like hand tools. Based on the studies by Cupar et al., designing the appropriate tool handles must be addressed to avoid the WMSDs, since the users' comfort rely primarily on the tool handles [3]. Therefore, a proper design of tool handles that focuses on the size, material used, and the average hand size of the Filipino workers is necessary to have an ergonomic and comfortable connection between the user and the tool itself. An ergonomically designed tool handle is important in preventing various disorders such as shoulder acute trauma diseases (ATD) and cumulative trauma disorders (CTD). Carpal Tunnel Syndrome is a type of CTD that causes numbness, tingling, or weakness in the hand, blisters on the hand, hand tendinitis, and certain other conditions under musculoskeletal disorders (MSDs) [4].

Several researchers have also demonstrated that a well-designed handle may improve the entire user-product system's safety, performance, and comfort. They have established recommendations and mathematical analysis for calculating handle sizes and forms to enhance finger-force exertion, grip force to the handle, contact area, comfort, and lower the likelihood of ATD and CTD development [3]. So, in this study, the application of the Additive Manufacturing process has been adapted in making a 3D-printed tool handle to customize further the designs and the materials in constructing a new tool handle. Additive Manufacturing (AM) or 3D Printing is now widely used in different applications such as electronics, robotics, construction, automotive, agriculture, medicine, aerospace, desalination, education, satellites, oil & gas, and many others [5]–[14]. 3D printing is the process of creating three-dimensional objects through a layering method from a 3D computer-aided design model. The 3D modeling software, such as Fusion 360, allows the ability to design and customize models based on the desired product. This study will use a subjective comfort questionnaire to assess further the quality and comfortability of various 3D-printed tool handles. It aims to give an answer or enlightenment if producing customized and ergonomically designed 3D-printed tool handles would prevent the accumulation of ergonomic-related injuries when using ordinary hand tools.

2. Materials and Methods

2.1 Material

The materials used in the study were thermoplastic polyurethane (TPU) and polylactic acid (PLA). The comfort of using thermoplastic polyurethane (TPU) on the hand tool's outer handle was ensured and backed up by the study of Cupar et al. [3]. TPU can realistically emulate elastomeric characteristics because it can provide a comparable degree of softness and flexibility to a rubber. It also has excellent properties of abrasion, hardness, and thermal and chemical resistance. TPU is the most used type of Thermoplastic elastomers (TPE) in Fused Filament Fabrication (FFF) 3D printing [7]. The TPU-made handle was then supported by the inner core made from PLA, as shown in Figure 1. The reason behind using this is that it can reinforce the outer layer made from TPU and could transfer the forces from the hand back to the handle and handle back to the hand, as stated in the study of Cupar et al. [3]. PLA is a

versatile and inexpensive bioplastic; thus, it is environmentally friendly and mostly made from green renewable resources. PLA is the most popular 3D printing material because almost all FFF 3D printers can use it due to its lower melting point. And it is also known for its strength and high dimensional accuracy [15].

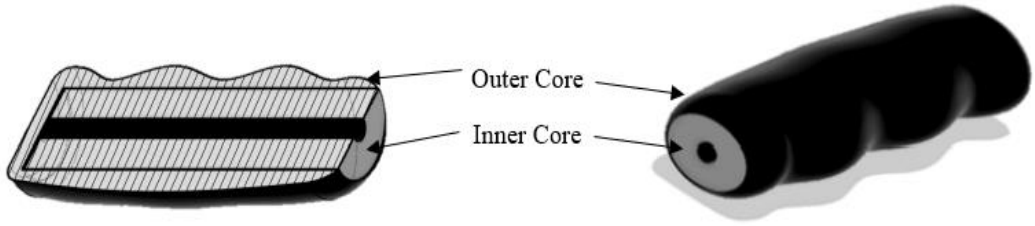


Figure. 1 General design configuration of tool handle

2.2 Experimental Method

2.2.1 Average Hand Measurements of the Filipinos

To obtain the appropriate dimension and design of tool handles, hand measurement of sixty (60) randomly selected adults from the province of Bataan and some parts of the province of Zambales was conducted. The participants consisted of 30 females and 30 males with an average age of 41. The hand measurements or dimensions were obtained based on the study of Ching-yi Wang et al. [16]. The dimensions were; hand length, hand breadth, which indicated how long the tool handle should be, and major and minor grip diameter, which could be measured only when the hand was on a grip gesture. The grip gesture that the proponents and the participants followed were based on the biodynamic hand coordinate system defined in ISO 8727 [5]. Based on the data gathered (see Table 1), the average hand length of the Filipinos is 175.23 mm, the hand breadth (the width where the fingers join the palms) is 72.92 mm, and the major and minor grip breadth is 34.43 to 38.91 mm. The length of the tool handle was indicated by the average hand breadth of the Filipinos, which is 72.92 mm—signifying that the minimum length should be 100 mm to allow the hands to glide up and down on the tool handle itself. At the same time, the minor and major diameter of the tool handle is around 34.43 to 38.91 mm, which is within the average measurement of the Filipino's minor and major grip breadth. Moreover, the data were gathered by only measuring the right hand of the respondents as it is the most dominant side, and almost 90% of them are right-handed. The hand dimensions were measured carefully using a digital Vernier caliper and tape measure.

Table 1. Hand Measurement of the Respondents

Dimension	Male		Female		Over-all	
	Mean (mm)	SD	Mean (mm)	SD	Mean (mm)	SD
Hand Length	184.87	13.73	165.29	9.49	175.23	13.56
Hand Breadth	75.87	7.71	69.97	13.39	72.92	13.00
Grip Breadth (W)	40.67	6.63	37.16	18.29	38.91	5.45
Grip breadth (L)	35.72	5.80	33.13	4.27	34.43	5.54

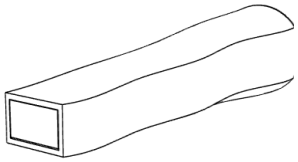
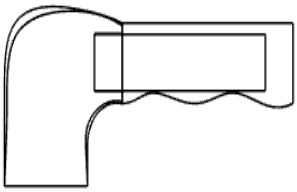
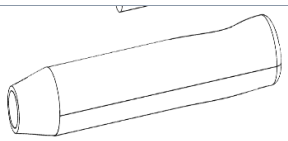
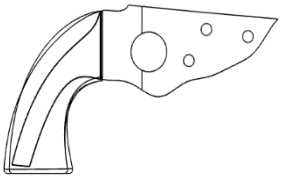
2.2.2 Design and Manufacturing of 3D-Printed Tool Handles

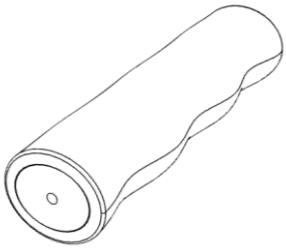
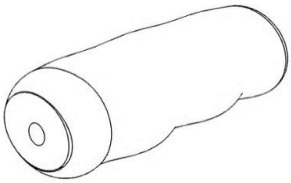
The design specifications of each tool handle should be in accordance with Filipinos' average hand measurements, as shown in Table 1. The shape must be in ellipse form to provide comfortability and a better grip for the users [17]. It is also crucial to identify the accurate sizes for the users to avoid unnecessary inconvenience and discomfort. The handle diameter must be related to Filipinos' average

major and minor breadth diameter, which is 34.43 to 38.91 mm. This measurement is similar to the studies of Cupar et al., which stated that the average grip diameter must be within 30 to 40 mm [4].

A profound consideration was given in selecting the type of materials to be used in the 3D-printed hand tool, as it could affect the overall comfortability of the tool handles. TPU is used as the outer layer of the tool handle because of its high resistance to scratch and abrasion, thus ensuring an aesthetic value for the 3D-printed tool handle. It was printed using the Flashforge Creator Pro with an infill pattern of hexagonal as it is the strongest and best pattern available on that printer. At the same time, the infill density is 14%, as it provides comfortability and good grasping force for the user of the tools [4]. On the other hand, the inner layer of the tool handle was printed on Anycubic i3 Mega and Ultimaker 3 Extended using the PLA or polylactic acid filament with 30-50% infill density and was used to serve as a support to the force exerted by the hand on grasping the handle. Gyroid was used on the inner layer as it has a lighter weight, is easier to print, and has a shear strength as it has a uniform strength to all directions suitable for functional uses. The cross-sectional design in 2D and 3D along with the 3D-printed prototype of the tool handles are shown in Table 2.

Table 2. Cross-sectional design and 3D-printed prototype of tool handles.

Types of Tool Handle	2D Design	3D Design	3D-Printed tool handle
Hammer Handle			
Brush Handle			
Mallet Handle			
Saw Handle			

Shovel Handle			
Trowel handle			

2.2.3 Testing and subjective comfort rating


Brush


Trowel


Mallet


Hammer


Hand Saw


Shovel

Figure 2. Actual photos of 3D-printed tool handle in their corresponding tools

After manufacturing, the 3D-printed tool handles were assembled and attached to their corresponding type of tool, as shown in Figure 2. Each of them will be tested and evaluated in terms of comfortability. Per testing of the tool handles, 10 Filipino respondents working in the construction field were gathered with ages ranging from 21 to 59 years old without any disorders on their arms and had a complete set of hands and fingers. The hand tools were evaluated using the comfort descriptor questionnaire which was adapted from the study of Kuijt-Evers et al., as shown in Table 3 [18].

Table 3. Sample of questionnaire used for evaluation of hand tools.

Comfort Descriptors	**Scale**						
	7	6	5	4	3	2	1
Adequate size which fits the hand perfectly							
Functional and can complete a task							
Easy to use and to grip							
Has a good force transmission when in use							
High quality product							
Emits great feeling to the user							
Results to great performance when using it							
Gives excellent outcome of the product/task when in use							
Seems professional and high quality							
Does not need much force to exert in gripping when using it							
Has a good friction between handle and the hand							
Results to inflammation of skin when used							
Produces wounds, redness, or blisters to the hand when used							
Feels sweaty or slimy							
Causes insensibility of and lack of tactile feeling in hand							
Hand muscles cramped while using it							
Give rise to spike in hand pressure while in used.							

Each hand tool was tested and evaluated by comparing the feedback of every respondent after using the hand tool with an ergonomically designed 3D-printed tool handle to the hand tool with its ordinary handle. But for every hand tool, the respondents were given and followed a specific task, and specific resting time was allotted before they could switch from one tool handle to another to avoid fatigue. For the hammer, the respondents were required to pound 2 inches of common wire nails five (5) times on a good lumber wood using the hammer with two different handles. One minute interval is allotted for rest before changing handle type. While for the paintbrush, the respondents were tasked to paint using the 3D-printed brush handle and the ordinary wooden brush for a few hours during their working day. They painted wood for about 5 minutes using paint brushes with different handles. For the hand saw, the respondents were tasked to create a 50 mm deep cut on a good lumber wood (50.8mm by 50.8 mm by 24.38 mm) for 5 to 10 minutes with a 3-minute interval after using each hand saw with a different handle for adequate rest to avoid fatigue. In the case of a mallet, the respondents were tasked to pound a particular wood using the mallet with different handles. The task was repeated five (5) times with a 5-minute interval for resting before changing the mallet. For the shovel, the respondents were tasked to scoop a blade full of sand using two different shovels with different handles. This process was done ten (10) times per shovel with 5-minute intervals for rest when switching from one type of shovel to another to avoid fatigue. Lastly, for the trowel, respondents were tasked to used the trowel for about 1.5 hours per kind of trowel: the 3D-printed and the ordinary wooden handle. After completing each task, respondents will rate each specific hand tool with two types of handles based on the comfort descriptors and overall comfort rating. Figure 3 shows the above procedures.

(a) (b) (c)

(d) (e) (f)

Figure 3. Actual testing and evaluation of (a) Hammer, (b) Paint Brush, (c) Hand Saw, (d) Mallet, (e) Shovel, and (f) Trowel.

3. Results and Discussion

Figure 4 represents the difference in overall comfort rating between the 3D-printed tool handles and the ordinary hard handles. Some are made of hard plastic or wood, which shows that the 3D-printed handles are far more comfortable than the other variation of handles. The data shows that the shovel and mallet's 3D-printed handle are model fit as it has a perfect mean score of 7 and a standard deviation of 0. While the hand saw obtained the lowest mean score of 6.2 and an SD of 0.42, it still delivers an overall good result, but improvements should be made, as suggested by the respondents.

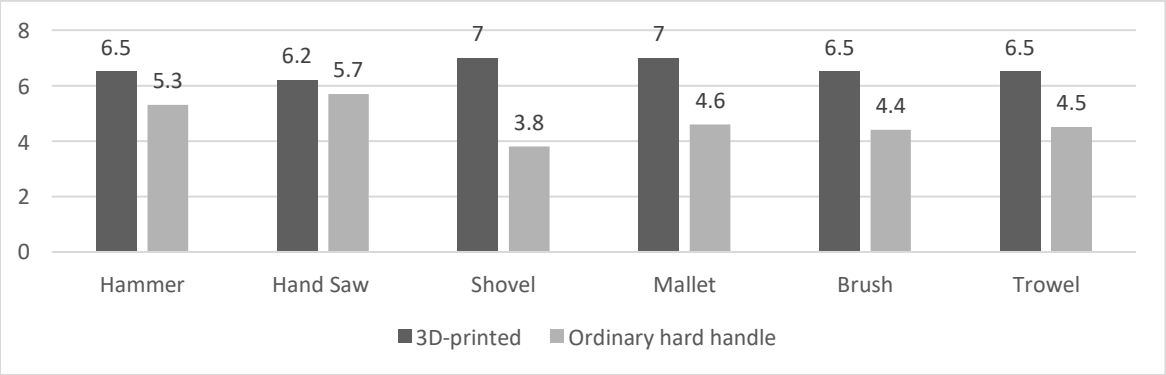


Figure 4. Overall Comfort Rating

The suitable material, ergonomic design, and exact size of the handle of the hand tools can improve the quality of work. Based on the results, it can be concluded that 3D-printed tool handles bring better comfort to end users, especially those who use it every day, thus avoiding work-related musculoskeletal disorders. They are also much better than those products made from wood or hard plastics as they were given as being hard and cannot be deformed when being grasped by the hand. The infill density of the outer layer and the infill pattern contributed massively to making these ergonomic tool handles. The creation of the outer layer using a TPU material with a 14% infill pattern and the hexagonal pattern created a very comfortable handle, as shown in the results compared to the ordinary wooden or hard handle. Also, it took less time for the 3D-printed tool handles to print, lesser material consumption, and at the same time, offering greater strength and durability.

4. Conclusion and Recommendations

This research investigated and designed ergonomic handles for six different hand tools: hammer, shovel, mallet, paintbrush, trowel, and hand saw, to provide comfortability and fitness to the users. Based on the questionnaire survey findings, the newly designed handles of hand tools are comfortable and fit the hand, except for hammer and trowel, as the length of their handles is too short stated by the subjects. Nevertheless, the overall ratings on all six tool handles indicate comfortability, functional, and professional looks in using the hand tools. The respondents are inclined to use hand tools with ergonomically designed handles as their work tools. Also, 3D printing consumes lesser materials than traditional manufacturing of hand tools through injection molding and others. Moreover, 3D-printed tool handles increase the performance of the workers, provide a long- term comfort, and may reduce the accumulation of hand injuries.

Acknowledgments

The authors would like to thank the support of Design, Research and Extension in Additive Manufacturing, Advanced Materials, and Advanced Manufacturing (DR3AM) Center at Bataan Peninsula State University-Main Campus for letting us utilize their facility and guiding the researchers throughout the process of completing this study. The authors also owe a deep sense of gratitude to Mr. Dan Erick P. Dominguez who rendered his help during the period of this study.

References

[1] A. Hedge, "HAND TOOL DESIGN Ergonomic Tools? Hand Tool Design Issues Wrist Flexor Strain and Hand Posture Wrist Deviation and Grip Strength Tool Design: Shape."

[2] Centers for Disease Control and Prevention, "Work-Related Musculoskeletal Disorders & Ergonomics," Feb. 12, 2020.

[3] A. Cupar, J. Kaljun, B. Dolšak, and G. Harih, "Design of 3D Printed Cellular Meta-materials for Improved Tool-Handle Ergonomics," 2020, pp. 110–116. doi: 10.1007/978-3-030-51981-0_14.

[4] WebMD Editorial Contributors, "Carpal Tunnel Syndrome," *WebMD*, Nov. 19, 2021.

[5] A. H. Espera, J. R. C. Dizon, A. D. Valino, and R. C. Advincula, "Advancing flexible electronics and additive manufacturing," *Jpn J Appl Phys*, vol. 61, no. SE, p. SE0803, Jun. 2022, doi: 10.35848/1347-4065/ac621a.

[6] J. R. R. Diego, D. W. C. Martinez, G. S. Robles, and J. R. C. Dizon, "Development of Smartphone-Controlled Hand and Arm Exoskeleton for Persons with Disability," *Open Engineering*, vol. 11, no. 1, pp. 161–170, Jan. 2021, doi: 10.1515/eng-2021-0016.

[7] B. J. Tuazon, N. A. v. Custodio, R. B. Basuel, L. A. D. Reyes, and J. R. C. Dizon, "3D Printing Technology and Materials for Automotive Application: A Mini-Review," in *Key Engineering Materials*, vol. 913 KEM, Trans Tech Publications Ltd, 2022, pp. 3–16. doi: 10.4028/p-26o076.

[8] M. B. de Leon *et al.*, "3D-Printing for Cube Satellites (CubeSats): Philippines' Perspectives," *Engineering Innovations*, vol. 1, pp. 13–27, Mar. 2022, doi: 10.4028/p-35niy3.

[9] E. C. Macaraeg, C. G. Rivera, R. D. dela Rosa, and J. R. C. Dizon, "Establishment of An Academic Makerspace at the Bataan Peninsula State University: Prospects and Challenges," *Advance Sustainable Science, Engineering and Technology*, vol. 3, no. 2, p. 0210202, Nov. 2021, doi: 10.26877/asset.v3i2.9655.

[10] E. B. Caldona, J. R. C. Dizon, R. A. Viers, V. J. Garcia, Z. J. Smith, and R. C. Advincula, "Additively manufactured high-performance polymeric materials and their potential use in the oil and gas industry," *MRS Commun*, vol. 11, no. 6, pp. 701–715, Dec. 2021, doi: 10.1557/s43579-021-00134-9.

[11] D. W. Martinez, M. Espino, H. M. Cascolan, J. L. Crisostomo, and J. R. Dizon, "A Comprehensive Review on the Application of 3D Printing in the Aerospace Industry," in *Key Engineering Materials*, vol. 913 KEM, Trans Tech Publications Ltd, 2022, pp. 27–34. doi: 10.4028/p-94a9zb.

[12] J. L. B. Crisostomo and J. R. C. Dizon, "3D Printing Applications in Agriculture, Food Processing, and Environmental Protection and Monitoring," *Advance Sustainable Science, Engineering and Technology*, vol. 3, no. 2, p. 0210201, Nov. 2021, doi: 10.26877/asset.v3i2.9627.

[13] L. Tijing, J. R. Dizon, and G. Cruz Jr., "3D-Printed Absorbers for Solar-Driven Interfacial Water Evaporation: A Mini-Review," *Advance Sustainable Science, Engineering and Technology*, vol. 3, no. 1, p. 0210103, Apr. 2021, doi: 10.26877/asset.v3i1.8367.

[14] R. N. M. Delda, R. B. Basuel, R. P. Hacla, D. W. C. Martinez, J.-J. Cabibihan, and J. R. C. Dizon, "3D Printing Polymeric Materials for Robots with Embedded Systems," *Technologies (Basel)*, vol. 9, no. 4, p. 82, Nov. 2021, doi: 10.3390/technologies9040082.

[15] Jakub Spiryn, "What's the Difference Between PLA and ABS?," *ZMorph 3D*, Oct. 29, 2019.

[16] C. Wang and D. Cai, "Hand tool handle design based on hand measurements," *MATEC Web of Conferences*, vol. 119, p. 01044, Aug. 2017, doi: 10.1051/matecconf/201711901044.

[17] N. J. Seo and T. J. Armstrong, "Effect of elliptic handle shape on grasping strategies, grip force distribution, and twisting ability," *Ergonomics*, vol. 54, no. 10, pp. 961–970, Oct. 2011, doi: 10.1080/00140139.2011.606923.

[18] L. F. M. Kuijt-Evers, P. Vink, and M. P. de Looze, “Comfort predictors for different kinds of hand tools: Differences and similarities,” *Int J Ind Ergon*, vol. 37, no. 1, pp. 73–84, Jan. 2007, doi: 10.1016/j.ergon.2006.09.019.

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220211-01 ~ 0220211-09
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.13011

Development of an Ergonomically – Designed Violin Chinrest Using Additive Manufacturing

John Kenneth J. Barinque[1,*], Alshaheen T. Borja[1], Jeferson C. Cubangbang[1], Ulysses Ron C. Cruz[1], Marien P. Teopengco[1], Marjorie R. Tolentino[1], Michaela T. Espino[1, 2], Brian J. Tuazon [2], John Ryan C. Dizon[1, 2]

[1]Department of Industrial Engineering, College of Engineering and Architecture, Bataan Peninsula State University – Main Campus, City of Balanga, Bataan, 2100, Philippines

[2]DR3AM Center, Bataan Peninsula State University – Main Campus, City of Balanga, Bataan, 2100, Philippines

*kennethbarinque@gmail.com

Abstract. A violin chinrest is used to ease the pain and prevent injuries of violinists. However, some of them experienced discomfort using normal chinrest. It causes injuries, irritations, and pains that affect the performance of violinists. In that problem, the researcher works toward a goal of not curing the problem but instead avoiding pain, injuries, and discomfort when playing it. A convenience sampling method was used in gathering anthropometric data. The study is limited to the ergonomically designed chin rest itself, which will only be installed at the standard violin size with a length of 60 cm. The designed chinrest is fitted only for the violinists of Jose De Piro Kabataan Orkestra. Three ergonomically designed violin chinrests were produced, which are: side-mounted, semi-centered, and fully centered. The researchers used a paired-samples t-test to compare the means in the results of testing between the normal chinrest and the ergonomically designed chinrest using additive manufacturing. The study concludes that the ergonomically designed violin chinrests using additive manufacturing are light-weight, less expensive, more comfortable to use, and lessen the pain of the violinists based on the overall mean compared to the normal violin chinrest in terms of side-mounted, semi-centered, and centered chinrest.

Keywords: Additive Manufacturing, Chinrest, Ergonomics, Violin

(Received 2022-08-29, Accepted 2022-10-31, Available Online by 2022-10-31)

1. Introduction

As a country of many indigenous cultures in the Philippines, many precolonial rituals are practiced even after four centuries of Western occupation. In addition to strong oral and written traditions, modern

Filipino music has helped maintain these indigenous societies. Filipino composers of the second half of the 20th century and beyond were able to incorporate vernacular musical concepts into Western compositional languages, producing a new style of contemporary music unique to the Philippines. This development not only educates townspeople about native music Filipinos but also the entire Western music community. Today, the violin works of contemporary Filipino composers are largely unrecognized [1].

The medieval fiddle, the Italian lira da braccio of the 16th century, and the rebec of the Renaissance all served as inspiration for the violin's development as a bowed stringed musical instrument. In terms of musical instruments, the violin is the most popular and widely used instrument in the world [1]. The violin, also named fiddle, is a type of wooden chordophone in the violin family. The majority of violins feature a hollow wooden body. It is the family's smallest and thus highest-pitched instrument in common usage. A chinrest is a tool that has been specially designed to assist the jaw of the player or the chin posture while playing a violin. It is connected to the body of the instrument besides the tailpiece. A variety of materials are used to construct chinrests such as plastic or wood. The chinrest is necessary for instrument support; however, it was only invented in the 1820s. German composer Louis Spohr, who invented the chinrest, contributed to the development of current violin performing techniques. The tailpiece was supposedly damaged by Spohrs aggressive playing style, so he put a little block to the bout to preserve it. This was formerly viewed as a response to the increased complexity of the repertoire, which necessitated the use of more sophisticated free left-hand techniques. The instrument quickly acquired recognition among the majority of violists and violinists due to the support of well-known violinists of the time, such as Pierre Baillot and Giovanni Battista Viotti, and is today considered an integral element of both instruments' repertoires. With one or two metal clamps that loop over the instrument's rear edge, the chinrest is attached. To keep the chin rest in place, a small clamping force is applied by turnbuckles or machine screws. Hill-style clamps are usually used in pairs, and each clamp has its own foot and screw. In most cases, a metal bar that fits around the back edge of the instrument is used instead. Cork, leather, or felt is commonly used to cushion the clamps and chinrest which have direct contact with the instrument [2].

Chinrests are available at a local violin shop that also offers violin accessories. These are available in over a hundred various patterns to accommodate a range of structures of the jaw, and also a range of performing habits and positions. It is common for violinists and violists to experience soreness and discomfort from an improperly fitted chinrest, as well as a head tilted too far to the left, resulting in an unnaturally right-angled appearance.

When a chinrest is adjusted properly, the distance between the jaw and the chinrest's top should be around half an inch. The player should keep his or her gaze straightforward. With the help of a cork riser, the height may be altered. A chinrest that stretches above the tailpiece may be preferred for players with limited shoulder joint flexibility. Through the collarbone, a correctly fitted chinrest transmits pressure first from the arm to the spine, the body's natural support system. This frees up the left arm for vibrato and fingerboard shifting [2].

There are many different types of instruments that need to be played in a non-symmetrical manner. When it comes to damage, a variety of things might come into play. Some experiences of the violinist different problems and injuries using the existing chin rest. In a study conducted by Caero and Cohen, there is a case report that a twenty-six-year-old had a skin lesion on her left submandibular and supraclavicular neck was the reason she came in. When the subject used the chinrest, her left submandibular lesion felt particularly thick and indurated on occasion [3].

Additive Manufacturing (AM) is a general term that refers to technologies in which a product is constructed by layering materials on top of one another. These processes are fundamentally dissimilar to subtractive or consolidation processes. Rapid prototyping is the most frequently used word to refer to additive fabrication. AM, widely known as 3D Printing, is improving the way things are designed, manufactured, and serviced. Today, 3D printing is widely used in a wide range of industries, including

those involving electronics, robotics, engineering, architecture, transportation, manufacturing, agriculture, medical, aircraft, desalination, education, satellites, oil & gas, and many more [4]–[17]. There are many various ways to produce an ergonomically designed violin chinrest. AM is one of the most efficient and effective ways of doing it. It is the method of assembling materials to create 3D objects from 3D model data. A digital design tool can be used and it has industry-leading performance and flexibility, all without the need for specialized tools or equipment. As a method of producing the ergonomically designed chinrest, AM has a high customization feature that enables the researcher to produce the design that would ergonomically fit to the end-user. Unlike the commercially available chinrest, the ergonomically designed chinrest is more affordable, lightweight, and more improved in its design parameters [4].

This study will focus on designing and developing an ergonomic violin chinrest utilizing additive manufacturing technology to avoid injuries and fractures caused by a standard or commercially available chinrest. The research study is limited to the ergonomically designed chin rest itself and it will be installed to the 4/4 standard violin size with a length of 60 cm with 40 mm thickness. Also, the violin should rest on the collarbone and should be supported by the left hand and by the left shoulder. The designed chinrest is custom-fitted for the 30 violinists in Jose De Piro Kabataan Orkestra, both male and female. The study aims to produce 3 ergonomically designed chinrests which are, side-mounted, semi-centered and fully-centered.

2. Materials and Methods

2.1 Design Requirements

In product development, process management, and design engineering, TRIZ is commonly utilized [18]. In this study, the set of contradictions to solve is the object-generated harmful factors and shape as shown in Figure 1. The TRIZ matrix proposes the following principles to solve this contradiction: the transformation of the physical and chemical states of an object, parameter change, and changing properties. It will interest you to know that every object in existence undergoes a state change. Parameters can be changed so that the function can be used properly. Changing properties, replace wood with hypoallergenic plastic filament as a material.

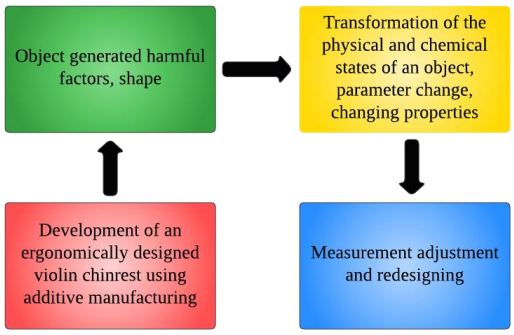


Figure 1. TRIZ Methodology for Violin Chinrest

In order to create the ergonomic violin chinrest design, it is important to identify first the design parameters and factors that affect the violin chinrest. The researchers use the study of Richard Ward 2020 "How to choose the right chinrest for violin/viola" [19]. It depends on a variety of things, including the playing posture, the body, and where they want to place the chin rest. All of these aspects must come together to satisfy your musical demands and personal comfort, and this guide hopes to assist you in determining what is best. Most violinists and violists, however, must find the best fit for their individual

anatomy and playing style. Because head anatomy varies greatly, particularly the jaw, chin, and neck, one size does not fit all when it comes to chin rests. In measuring the said head anatomy, particularly the Jaw, Chin, and Neck which greatly affects the use of the violin chinrest, the usage of caliper (manual and digital) was utilized as well as the usage of tape measure when needed. Also, to avoid confusion, the only measure is the left-sided violinist player since is the most dominant side and common, as shown in Table 1.

Table 1. Measurement Guide for the Design

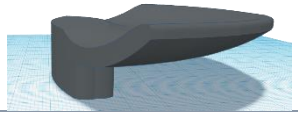
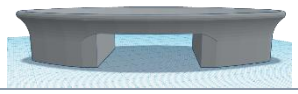
Jaw Length Measurement (mm)	Chin Width Measurement (mm)	Neck Height Measurement (mm)
		

2.2 Materials and Fabrication Procedures

The material used in this study is PLA or polylactic acid, it is a thermoplastic monomer produced by renewable natural sources such as starch granules or sugar cane. It is biodegradable, is considered the safest 3D printing material, and can reduce allergy issues [20].

Autodesk Inventor software and Tinker CAD were used in creating the 3D models after a careful examination of the chinrest designs. The 3D models were then exported to an STL file format in preparation for the FDM 3D printer software to determine the printing time, filament quantity, infill density, infill pattern, and sizes. Center-mounted, semi-centered, and side-mounted chinrest designs were developed as a result of these considerations as shown in Table 2.

Table 2: Types of Chinrest Final Designs and Specifications

Side-Mounted Chinrest		**Dimension: 100mm x 70mm x 30mm**
Semi-Centered Chinrest		**Width: 70mm** **Height: 35mm**
Centered Chinrest		**Length: 100mm**

The side-mounted chinrest features a deeper and larger cup than the chinrest next to the tailpiece. You should aspire to build a body that is not just light but also incredibly strong. It is composed of PLA, is practically unbreakable, and will not create any form of reaction. Furthermore, it provides a better grip and a more natural playing position.

Simple oval-shaped chin rest with a higher ridge, deeper cup, and sharply curved design to give stability and sit securely next to the tailpiece of the violin. This semi-centered mounted chinrest is made of PLA for its strength and lightweight, making it more ergonomically.

The center-mounted chinrest is flatter and has a much larger cup; the depth is correct, the footing is long, and it matches the tailpiece of the violin, making it more centered across the instrument. This final design improves the tonality. This is also lifted to clear the tailpiece and make the design more ergonomically.

Post-processing was done after printing the ergonomic chinrest. Procedures such as sanding and acetone vapor polishing were used to smoothen the surface of the 3D-printed ergonomically designed chinrest.

3. Results and Discussion

A t-test is the best tool that can be used in comparing the means of two groups. Also, it is often used in hypothesis testing to find out if a procedure or treatment really has an effect on the population of interest.

Using a dependent t-test or paired-samples t-test, the means were compared in the results of testing between the normal chinrest and the ergonomically designed chinrest using additive manufacturing. Where the null hypotheses states that, there is no significant difference between normal chinrest and ergonomically design chinrest using additive manufacturing. While the alternative hypotheses states, there is a significant difference between normal chinrest and ergonomically design chinrest using additive manufacturing.

Table 3: t-test comparison of the 3D-printed Violin Chinrest and Normal Chinrest in terms of the Characteristics

3D vs. Normal	**Normal Violin Chinrest and 3D-printed Violin Chinrest**					**t**	**df**	**Sig. (2-tailed)**
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Side-Mounted Chinrest	-0.37333	0.63839	0.11655	-0.61171	-0.13496	-3.203	29	0.003
Semi-Centered Chinrest	-0.43333	0.68246	0.12460	-0.68817	-0.17850	-3.478	29	0.002
Centered Chinrest	-0.44000	0.78635	0.14357	-0.73363	-0.14637	-3.065	29	0.005

Table 3 above shows the t-test comparison of 3D-printed Violin Chinrest and Normal Chinrest in terms of characteristics. It is evident that the p-value of each indicator is less than the significance level of 0.05. The null hypothesis is rejected. Therefore, there is a significant difference between the characteristics of 3D-printed Violin Chinrest and Normal Chinrest.

Table 4: t-test of the overall perception to 3D-printed Chinrest and Normal Violin Chinrest

3D vs. Normal	**Normal Violin Chinrest and 3D-printed violin chinrest**					**t**	**df**	**Sig. (2-tailed)**
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Side-Mounted Chinrest	0.73333	0.73968	0.13505	0.45713	1.00953	5.430	29	0.000
Semi-Centered Chinrest	0.33333	0.66089	0.12066	0.08655	0.58012	2.763	29	0.010

Centered Chinrest	0.40000	0.56324	0.10283	0.18968	0.61032	3.890	29	0.001

Table 4 above shows the overall perception to the 3D-printed Chinrest and Normal Violin Chinrest. It is evident that the p-value of each indicator is less than the significance level of 0.05. The null hypothesis is rejected. Therefore, there is a significant difference between the overall perception of 3D-printed Violin Chinrest and Normal Chinrest.

Table 5: Comparison in Weight Between Normal Chinrest and 3D-printed Chinrest

Type of Chinrest	Normal Chinrest	3D-printed Chinrest
Side-Mounted Chinrest	45 grams	30 grams
Semi-Centered Chinrest	45 grams	38 grams
Centered Chinrest	55 grams	50 grams

Table 5 above shows the comparison between the weight of the commercially available violin chinrest and the 3D-printed violin chinrest. For the basis weight of the normal chinrest, the specification of violin chinrest stated in the market was used while the 3D-printed violin chinrest used a weighing scale.

Table 6: Comparison in Weight Between Normal Chinrest and 3D-printed Chinrest

Type of Chinrest	Normal Chinrest (Php)	3D-printed Chinrest (Php)
Side-Mounted Chinrest	1200	600
Semi-Centered Chinrest	1400	800
Centered Chinrest	1200	700

Table 6 above shows the price comparison between commercially available violin chinrests and 3D-printed violin chinrests. For the basis pricing of normal chinrest, the researcher uses Amazon, an online shopping platform, to know the price of the normal chinrest since most violinist players buy their chinrest outside the Philippines. For the basis pricing of the 3D-printed chinrest, a quotation from ADEAS was used. ADEAS is a type of business/marketing that sells 3D-printed objects. It uses online platforms like FB page as a marketing strategy. The researcher consulted ADEAS for the pricing of the 3D-printed chinrest and came up with the price stated in the table above.

Table 7: Overall Mean of Normal Violin Chinrest

Pain	Mean	Rank	Verbal Interpretation
Neck Pain	2.44	1	Mild Pain
Jaw Pain	2.34	2	Mild Pain
Chin Pain	1	3	No Pain

The mean of overall data with the different kinds of pain and the degree of pain that violinists are experiencing while using a normal violin chinrest is shown in Table 7 below. It displays that neck pain has been found with the highest degree of pain that violinists are experiencing, with a weighted mean of

2.44 and a mild degree of pain, followed by jaw pain, with a weighted mean of 2.34 and mild pain. Lastly, no pain experience with a weighted mean of 1 is the chin.

Table 8: Overall Mean of 3D-printed Violin Chinrest

Pain	Mean	Rank	Verbal Interpretation
Neck Pain	1.47	1	No Pain
Jaw Pain	1.39	2	No Pain
Chin Pain	1	3	No Pain

While Table 8 shows the mean of overall data with the different kinds of pain and the degree of pain that violinists are experiencing while using a 3D-printed violin chinrest. It shows that neck pain has been found to have the highest degree of pain that violinists are experiencing, with a weighted mean of 1.47, followed by jaw pain, with a weighted mean of 1.39. Lastly, with a weighted mean of 1, is the chin. All of their verbal interpretations are no pain.

Table 9: Overall Mean Comfortability Between Normal Chinrest and 3D-printed Chinrest

INDICATOR	Mean of Normal Violin Chinrest	Descriptive Equivalent	Mean of 3D-printed Violin Chinrest	Descriptive Equivalent
Side-Mounted Chinrest	5.68	Comfortable	6.05	Comfortable
Semi-Centered Chinrest	5.70	Comfortable	6.13	Comfortable
Centered Chinrest	5.87	Comfortable	6.31	Comfortable
OVERALL	5.75	Comfortable	6.33	Comfortable

Table 9 above shows the overall summary of the violin chinrest. All of the indicators are in favor to the 3D-printed Violin Chinrest. Overall, 3D-printed Violin Chinrest got a higher rating of 6.33 compared to the normal chinrest of 5.75.

4. Conclusion and Recommendations

Based on the findings, the following conclusions are drawn, the ergonomically designed chinrest using additive manufacturing causes no pain to the violinist, rather than the normal chinrest causes mild pain to the violinist. It is more comfortable to used based on the overall mean compared to the normal violin chinrest in terms of sided, semi centered and centered chinrest. These are low cost compared to the normal the chinrest in terms of sided, semi centered and centered chinrest. In terms of side, semi-centered, and centered chinrest, the ergonomically designed chinrest using additive manufacturing is lighter than the normal chinrest. There is a significant difference between the characteristic of the ergonomically designed chinrest using additive manufacturing and normal violin chinrest. There is also a significant difference between the overall perception of the ergonomically designed chinrest using additive manufacturing and the normal violin chinrest.

The study concludes that the ergonomically designed chinrest using additive manufacturing is fitted only to the violinist player of Jose De Piro Kabataan Orkestra because, as a result of this study, the pain of the violinist is lessened and the comfortability of the violinist using ergonomically designed chinrest is better than their normal chinrest because the design parameters of making ergonomically designed

chinrest are their own anthropometric measurement and also chinrest should alleviate discomfort and protect against injury. It is essential that they be correctly selected. When selecting a chinrest, the player's anthropometric dimensions are of the utmost importance. Furthermore, proper playing technique is essential. When playing, movement is critical; if a musician does not move correctly, it will affect both the music and their physical health.

In order to help the ergonomically designed chinrest using additive manufacturing be more comfortable, violinists must apply the following considerations, first, the violinists must use shoulder rest to avoid injuries to their collarbones and meet the highest comfortability while playing the violin. Second, the violinists must be aware of proper posture when playing the violin, whether they are sitting or standing. Lastly, is to use a stainless-steel violin clamp to avoid fiddlers' neck or irritation on the neck skin.

Moreover, the following ideas are suggested by the researchers in order to improve the ergonomically designed chinrest using additive manufacturing. Future research can adopt the statements below for further research. The numbness got the lowest mean in the ergonomically designed chinrest using additive manufacturing. It is recommended to improve the device to lower the numbness experienced by violinists. Comfortability got the lowest mean for the ergonomically designed chinrest using additive manufacturing. It is also recommended to focus on improving the comfortability of the chinrest when used as a semi-centered violin chinrest. The ergonomically designed chinrest should tailor-fitted to the anthropometric measurement of the violinist. Use a large scale of respondents and design different sizes and use their anthropometric measurement as a guide in making ergonomically designed chinrest. The future researcher can adapt this study to the customization of violin chinrest.

Acknowledgments

This work would not be possible without the support from the Design, Research and Extension in Additive Manufacturing, Advanced Materials, and Advanced Manufacturing (DR3AM) Center at Bataan Peninsula State University-Main Campus. The authors also owe a deep sense of gratitude to Mr. Dan Erick P. Dominguez who rendered his help during the period of this study.

References

[1] R. Alfonso, C. Soberano, D. Jiang, K. Mclin, and S. Feisst, "The Contemporary Filipino Violin An In-Depth Study and Performance Guide of Ramon Santos' 'Abot-Tanaw II' for Solo," 2021. [Online]. Available: https://www.youtube.com/watch?v=6w0UBSajVaM&t=2121s.

[2] M. Staff, "Violin 101: What Is a Violin Chinrest? Learn About 5 Types of Violin Chinrests, and 2 Things To Keep In Mind When Choosing the Right Chinrest," 2021.

[3] J. E. Caero and P. R. Cohen, "Fiddler's neck: Chin rest-associated irritant contact dermatitis and allergic contact dermatitis in a violin player," *Dermatol Online J*, vol. 18, no. 9, Sep. 2012, doi: 10.5070/D30T23P44W.

[4] Y. Shi *et al.*, "Overview of additive manufacturing technology and materials," in *Materials for Additive Manufacturing*, Elsevier, 2021, pp. 1–8. doi: 10.1016/B978-0-12-819302-0.00001-8.

[5] M. T. Espino, B. J. Tuazon, G. S. Robles, and J. R. C. Dizon, "Application of Taguchi Methodology in Evaluating the Rockwell Hardness of SLA 3D Printed Polymers," *Materials Science Forum*, vol. 1005, pp. 166–173, Aug. 2020, doi: 10.4028/www.scientific.net/MSF.1005.166.

[6] B. J. Tuazon, M. T. Espino, and J. R. C. Dizon, "Investigation on the effects of acetone vapor-polishing to fracture behavior of abs printed materials at different operating temperature," in *Materials Science Forum*, 2020, vol. 1005 MSF, pp. 141–149. doi: 10.4028/www.scientific.net/MSF.1005.141.

[7] G. S. Robles, R. N. M. Delda, R. L. B. del Rosario, M. T. Espino, and J. R. C. Dizon, "Dimensional Accuracy of 3D-Printed Acrylonitrile Butadiene Styrene: Effect of Size, Layer

Thickness, and Infill Density," in *Key Engineering Materials*, vol. 913 KEM, Trans Tech Publications Ltd, 2022, pp. 17–25. doi: 10.4028/p-nxviqm.
[8] A. H. Espera, J. R. C. Dizon, A. D. Valino, and R. C. Advincula, "Advancing flexible electronics and additive manufacturing," *Jpn J Appl Phys*, vol. 61, no. SE, p. SE0803, Jun. 2022, doi: 10.35848/1347-4065/ac621a.
[9] J. R. R. Diego, D. W. C. Martinez, G. S. Robles, and J. R. C. Dizon, "Development of Smartphone-Controlled Hand and Arm Exoskeleton for Persons with Disability," *Open Engineering*, vol. 11, no. 1, pp. 161–170, Jan. 2021, doi: 10.1515/eng-2021-0016.
[10] B. J. Tuazon, N. A. v. Custodio, R. B. Basuel, L. A. D. Reyes, and J. R. C. Dizon, "3D Printing Technology and Materials for Automotive Application: A Mini-Review," in *Key Engineering Materials*, vol. 913 KEM, Trans Tech Publications Ltd, 2022, pp. 3–16. doi: 10.4028/p-26o076.
[11] M. B. de Leon *et al.*, "3D-Printing for Cube Satellites (CubeSats): Philippines' Perspectives," *Engineering Innovations*, vol. 1, pp. 13–27, Mar. 2022, doi: 10.4028/p-35niy3.
[12] E. C. Macaraeg, C. G. Rivera, R. D. dela Rosa, and J. R. C. Dizon, "Establishment of An Academic Makerspace at the Bataan Peninsula State University: Prospects and Challenges," *Advance Sustainable Science, Engineering and Technology*, vol. 3, no. 2, p. 0210202, Nov. 2021, doi: 10.26877/asset.v3i2.9655.
[13] E. B. Caldona, J. R. C. Dizon, R. A. Viers, V. J. Garcia, Z. J. Smith, and R. C. Advincula, "Additively manufactured high-performance polymeric materials and their potential use in the oil and gas industry," *MRS Commun*, vol. 11, no. 6, pp. 701–715, Dec. 2021, doi: 10.1557/s43579-021-00134-9.
[14] D. W. Martinez, M. Espino, H. M. Cascolan, J. L. Crisostomo, and J. R. Dizon, "A Comprehensive Review on the Application of 3D Printing in the Aerospace Industry," in *Key Engineering Materials*, vol. 913 KEM, Trans Tech Publications Ltd, 2022, pp. 27–34. doi: 10.4028/p-94a9zb.
[15] J. L. B. Crisostomo and J. R. C. Dizon, "3D Printing Applications in Agriculture, Food Processing, and Environmental Protection and Monitoring," *Advance Sustainable Science, Engineering and Technology*, vol. 3, no. 2, p. 0210201, Nov. 2021, doi: 10.26877/asset.v3i2.9627.
[16] L. Tijing, J. R. Dizon, and G. Cruz Jr., "3D-Printed Absorbers for Solar-Driven Interfacial Water Evaporation: A Mini-Review," *Advance Sustainable Science, Engineering and Technology*, vol. 3, no. 1, p. 0210103, Apr. 2021, doi: 10.26877/asset.v3i1.8367.
[17] R. N. M. Delda, R. B. Basuel, R. P. Hacla, D. W. C. Martinez, J.-J. Cabibihan, and J. R. C. Dizon, "3D Printing Polymeric Materials for Robots with Embedded Systems," *Technologies (Basel)*, vol. 9, no. 4, p. 82, Nov. 2021, doi: 10.3390/technologies9040082.
[18] Six Sigma Daily, "Six Sigma Terms: What is TRIZ – The Theory of Inventive Problem Solving?," May 14, 2020.
[19] Richard Ward, "How To Choose the Right Chin Rest For Violin or Viola," *Strings Magazine*, Nov. 30, 2020.
[20] K. Deshmukh, M. Basheer Ahamed, R. R. Deshmukh, S. K. Khadheer Pasha, P. R. Bhagat, and K. Chidambaram, "Biopolymer Composites With High Dielectric Performance: Interface Engineering," in *Biopolymer Composites in Electronics*, Elsevier, 2017, pp. 27–128. doi: 10.1016/B978-0-12-809261-3.00003-6.

Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 4, No.2, October 2022, pp. 0220212-01 ~ 0220212-07
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v4i2.12950

Significance of Fundamental Metrology of 3D-Printed Parts for Engineering Design: Dimensional Accuracy

Gerald S. Robles[1, 2*], Michaela T. Espino[2, 3], Ray Noel M. Delda[2], John Ryan C. Dizon[2, 3]

[1]Department of Mechanical Engineering, College of Engineering and Architecture, Bataan Peninsula State University – Main Campus, City of Balanga, Bataan, 2100, Philippines

[2]DR3AM Center, Bataan Peninsula State University – Main Campus, City of Balanga, Bataan, 2100, Philippines

[3]Department of Industrial Engineering, College of Engineering and Architecture, Bataan Peninsula State University – Main Campus, City of Balanga, Bataan, 2100, Philippines

*engr_robles@yahoo.com

Abstract. This paper discusses some basic metrology considerations when 3D printing. The importance of ensuring correct measurements is highlighted especially for practical applications. The last part of the paper presents sample dimensional measurements of 3D-printed parts with varying sizes, infill density and layer thickness. Different cube sizes of 10 mm^3, 15 mm^3, and 20 mm^3 has been produced using a commercially-available 3D printer. Acrylonitrile butadiene styrene (ABS) has been used for the experiments. Important observations and insights are presented. The effect of layer thickness, infill density and specimen size on the dimensional accuracy of 3D-printed polymer parts have been investigated. It was found out that as the layer thickness increases, the accuracy of measured values decreases, and as the infill density increases, the accuracy of measured values also increases.

Keywords: 3D Printing, Additive Manufacturing, Acrylonitrile Butadiene Styrene, Metrology, Dimensional Accuracy

(Received 2022-08-25, Accepted 2022-10-31, Available Online by 2022-10-31)

1. Introduction

Additive Manufacturing (AM) or 3D Printing, has emerged as an alternative and complement for conventional manufacturing processes. 3D Printing techniques have been developed to cheaper and faster ways of production with high quality output. These advancements have changed the way products

are produced and used by both manufacturers and consumers. With AM, manufacturing period have actually been reduced from several weeks to a matter of hours while reducing production cost and improving efficiency of manufacturing [1]. For these reasons, AM is now being used in a wide range of applications such as in electronics, robotics, construction, automotive, agriculture, medicine, aerospace, desalination, education, satellites, oil & gas, and many others [2]–[15]. The widespread application of AM is being hindered by the limited number of available guidelines for metrology and inspection [16]. For practical engineering applications, 3D-printed parts should be accurate in terms of measurement [17]–[26] and should also withstand various amounts of mechanical and environmental stresses [1, 27]. It is important to achieve results similar to outputs manufactured using traditional methods [26], [28]. Fused Deposition Modelling (FDM), which is one of the most common 3D printing technologies, has a principle similar to a glue gun, wherein layers of thermoplastic material are extruded in the semi-molten state. Common materials being used for FDM include acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polycarbonate (PC), thermoplastic polyurethane (TPU), and others. Metrology pertains to measurement methods, standards, accuracy, precision and uncertainties, and other measurement concepts [29]. It includes the equipment, the measurements and analysis of obtained data [30]. Metrology involves the establishment of units, development of measurement protocols, production of artifacts to allow traceability of measurements, and analysis of measurement accuracies and uncertainties [31]. Metrology includes measurements quantified with numbers and of course expressed in units. The following are some of the common metrology methods: 1) Dimensional Metrology which includes Linear Measurement, Angular Measurement, Comparator; 2) Surface Metrology (Surface Roughness); 3) Coordinate Metrology which includes Coordinate Measuring Machine, Multilateral Optical GPS, X-ray Computed Tomography, Automated Inspection, Machine Vision and Magnetic Resonance Imaging; 4) Geometrical Dimensioning and Tolerancing (GD&T) includes roundness, flatness, straightness, etc.; and 5) Measurement of Material Properties [16].

One of the major issues in 3D printing technologies is the dimensional accuracy of the 3D-printed outputs. Dimensional accuracy is a vital aspect in any manufacturing and production process as it is a clear indicator of how exact a fabricated part is with reference to the designed part. Along with accuracy in dimension, tolerance is also important due to application of parts in assemblies. [19]–[22]. FDM offer several advantages but is still limited since only a few have analyzed the dimensional accuracy of FDM/FFF-produced parts and along with the effect of slicing parameters on the printed product [21], [26]. Several groups have already conducted studies on the metrology of 3D-printed parts. Ali compared the accuracy of two different 3D printing materials (ABS and PLA), and observed that there is no significant difference in the accuracy of the measured dimensions of the two materials [32]. Carneiro et al. studied the effects of 3D printing parameters such as the infill density, layer height and raster orientation in polypropylene produced via the FDM process. Their work concluded that layer height has less impact on the properties of the final output [33]. In another work, Robertson et al. studied the dimensional accuracy of 3D-printed parts produced by the MakerBot Replicator 2. However, effects of parameters such as the orientation, layer thickness and infill density were not studied. Mahesh et al. analyzed geometries through free form surfaces wherein deviations from the set dimension ranging from 5% to 15% were discovered [34]. Wang et al. [35] developed a process tool for the modification of the effects of parameters. Post-processing methods were also observed to create change in surface quality, these changes are attributed to manual or chemical changes in the material itself [33]–[34], [36]. More sophisticated measurement techniques have also been employed by various groups. Yankov et al. 3D-printed micro-squares using an SLA 3D printer. They measured the coordinates of the objects using a Carl-Zeiss optical microscope. The acquired micrographs were used to measure the micro-grid deviations of the objects. They observed higher and irregular deviations from CAD values depending on the location of the object on the build plate [37]. Li et al. developed a method for layer-by-layer mapping of 3D printed parts using a high-speed optical scanning system integrated in an FDM 3D printer. This set-up could scan the object during the printing process to validate and conduct in situ adjustment of the 3D printing parameters [38]. Kacmarcik et al. investigated the form, size, orientation and location accuracy of the FDM 3D-printed parts using a coordinate measuring machine (CMM). They observed

that the commercially-available 3D printer demonstrates higher accuracy than the home-made 3D printer. [39]. Dardzinska et al. measured the dimensional accuracy of 3D-printed parts using computed tomography (CT) and 3D scanner. The authors provided insights comparing different 3D printing methods such as Polyjet and FDM among others [40]. Jadayel et al observed improved accuracy using this three-dimensional metrology feedback and mesh morphing. The authors used a 3D geometric compensation method to eliminate systematic deviations by morphing the object's original surface mesh model by the inverse of the systematic deviations. Multiple sacrificial 3D-printed objects were scanned to measure the systematic deviations, and the average deviation vector was computed throughout the model [41]. While there are a lot of aspects that must be considered in studying the dimensional accuracy of parts, one of the least studied in the past is the size of the specimen or samples. It has been observed that the size of the specimen has an impact on its mechanical properties. This occurrence is known as the 'size effect' [42]. Recently, the authors used a factorial design to evaluate the optimal combinations of different sizes, layer thickness and infill density to ensure dimensional accuracy of the 3D-printed parts [43], [2]. The aim of this study is to assess the accuracy of 3D printed parts and understand the effects of specimen size as well as the printing parameters such as layer thickness and infill density.

2. Materials and Methods

ABS filament, a proprietary acrylonitrile butadiene styrene (ABS) material made by Zortrax, has been used in the study. A description regarding ABS has been reported elsewhere [43].

The specimen in the form of cubes were designed using Autodesk Inventor with reference to the previous work done by authors [43]. The designed part was exported to .stl format to prepare it for the slicing process in Z-Suite which a slicing software dedicated for the Zortrax M-200 3D Printer. The slicing process involves the modification of parameters such as the size, layer thickness and infill density. The sizes were printed with size variations – 10 mm3, 15 mm3and 20 mm3; for layer thickness – 0.9 mm, 0.19 mm and 0.39 mm. Lastly, the infill density were varied with ranges 0.09 mm, 0.19 mm and 0.39 mm. A Zortrax M200 FDM 3D Printer was used to print the samples. The dimension of the cubes was then quantified using a Mitutoyo Digimatic Micrometer and a Mitutoyo Digimatic Vernier Caliper shown in a recent study published elsewhere [43]. The manual measurement of the cubes provided important insights on the variation in dimensions due to variation of the parameters. The cubes were measured in an array of positions, i.e. (1) top-to-bottom (2) front-to-back and (3) left-to-right. The locations where the samples were measured have also been presented elsewhere [43]. In this paper, the measured values are said to be accurate if their average values are close to the designed values (of $10mm^3$, $15mm^3$ and $20mm^3$). Also, the measured values are said to be precise if the computed standard deviation is relatively small.

3. Results and Discussion

The average values of the measurements are shown in Table 1. It shows the measured values using the Digital Micrometer and those measured values using the Digital Vernier Caliper.

Several effects are observed under the following conditions

1. Effect of layer thickness on the dimensional accuracy: As the layer thickness increases, the accuracy of measured values decreases. Hence, with a layer thickness of 0.09 mm we can expect a relatively higher accuracy compared with the 0.39 mm layer thickness.
2. Effect of infill density on the dimensional accuracy: The data shows some scattering, but it may be safe to say that as the infill density increases, the accuracy of measured values also increases. This could mean that the infill materials serve as support structures which ensure the accurate placement of all the layers of the 3D-printed parts.
3. Effect of sample size on the dimensional accuracy: It can be observed also that as the size of the 3D printed object increases its dimensional accuracy also increases.

Table 1. Measured dimensions using a Digital Micrometer

		Digital Micrometer Caliper					Digital Vernier Caliper				
Print Parameter	Size	Top to Bottom Average	Front to Back Average	Left to Right Average	Average Size per Specimen	Standard Deviation per Specimen	Top to Bottom Average	Front to Back Average	Left to Right Average	Average Size per Specimen	Standard Deviation per Specimen
0.09 Thickness 30% Density	10mm	10.09	9.99	9.96	10.01	0.05	10.08	10.17	10.01	10.09	0.07
	15mm	15.07	15.02	14.97	15.02	0.04	15.10	15.13	15.13	15.12	0.01
	20mm	20.06	20.04	19.92	20.01	0.06	20.09	20.01	19.92	20.01	0.07
0.09 Thickness 60% Density	10mm	10.04	9.98	10.04	10.02	0.03	10.02	10.07	10.13	10.07	0.05
	15mm	15.01	14.94	15.00	14.98	0.03	15.05	15.07	15.14	15.08	0.04
	20mm	20.02	19.90	20.02	19.98	0.06	20.02	20.03	20.14	20.06	0.05
0.09 Thickness 90% Density	10mm	10.04	10.01	10.03	10.03	0.01	10.05	10.13	10.10	10.10	0.03
	15mm	15.00	14.96	15.02	15.00	0.02	15.03	15.11	15.13	15.09	0.04
	20mm	19.98	19.91	20.04	19.98	0.05	20.02	20.06	20.12	20.07	0.04
0.19 Thickness 30% Density	10mm	10.08	10.04	10.05	10.06	0.02	10.03	10.09	10.18	10.10	0.06
	15mm	15.02	14.97	15.03	15.01	0.03	14.98	15.05	15.16	15.07	0.07
	20mm	20.01	19.92	20.00	19.98	0.04	19.96	20.06	20.11	20.04	0.06
0.19 Thickness 60% Density	10mm	10.08	9.99	10.12	10.06	0.05	10.08	10.14	10.11	10.11	0.03
	15mm	15.06	14.99	14.93	14.99	0.05	15.09	15.18	15.16	15.14	0.04
	20mm	20.05	19.94	19.87	19.95	0.07	20.07	19.99	20.12	20.06	0.05
0.19 Thickness 90% Density	10mm	10.05	10.00	10.02	10.02	0.02	10.06	10.10	10.15	10.11	0.04
	15mm	15.03	14.93	15.00	14.99	0.04	15.06	15.08	15.19	15.11	0.05
	20mm	20.03	19.90	20.02	19.98	0.06	20.05	20.02	20.18	20.09	0.07
0.39 Thickness 30% Density	10mm	10.27	10.15	10.17	10.20	0.05	10.23	10.09	10.09	10.14	0.06
	15mm	14.91	15.01	15.10	15.01	0.08	14.89	15.05	15.16	15.03	0.11
	20mm	19.98	19.99	20.07	20.01	0.04	19.97	19.99	20.08	20.01	0.05
0.39 Thickness 60% Density	10mm	10.28	10.20	10.19	10.22	0.04	10.23	10.07	10.08	10.12	0.07
	15mm	14.66	15.06	15.10	14.94	0.20	14.94	15.12	15.09	15.05	0.08
	20mm	19.99	20.03	20.09	20.04	0.04	19.94	19.97	20.08	20.00	0.06
0.39 Thickness 90% Density	10mm	10.12	10.08	10.03	10.07	0.04	10.06	10.21	10.12	10.13	0.06
	15mm	15.04	15.06	14.97	15.02	0.04	15.06	15.22	15.01	15.09	0.09
	20mm	20.03	20.07	19.93	20.01	0.06	19.99	20.05	20.04	20.03	0.03

Table 2. Summary of the Average Standard Deviations of the measured dimensions

Thickness	Ave. SD	Density (%)	Ave. SD	Size	Ave. SD
0.09	0.04	30%	0.05	10 mm^3	0.04
0.19	0.05	60%	0.06	15 mm^3	0.06
0.39	0.07	90%	0.04	20 mm^3	0.05

Table 2 shows the summary of the average standard deviation of the measured dimensions for each condition. The standard deviation (SD) describes the data dispersion from the average value from each print setting/parameter. We can use this standard definition if we want to understand other factors such as precision and variability. It can be observed that the variability of data increases as the layer thickness and specimen size increases, while it can be said that generally, the variability decreases while the infill density increases. It should be pointed out that contrary to the accuracy measurements, the variability of data is affected differently by the specimen sizes. The reason could be that the accuracy and variability

of measured dimensions depend on the type and calibration of the 3D printer. More investigations are needed in order to understand the cause of this difference.

Conclusion:
In this paper, the effect of layer thickness, infill density and specimen size on the dimensional accuracy of 3D-printed polymer parts have been investigated. It was found out that as the layer thickness increases, the accuracy of measured values decreases, and as the infill density increases, the accuracy of measured values also increases. Lastly, as the size of the 3D printed object increases its dimensional accuracy also increases. Discussions on variability of data (and thus precision) using standard deviation values have also been included. It was observed that the variability of data increases as the layer thickness and specimen size increases, while it can be said that generally, the variability decreases while the infill density increases.

Acknowledgments: The authors would like to thank the support of the The Department of Science and Technology – Philippine Council for Industry, Energy, and Emerging Technology Research and Development (DOST-PCIEERD) and the Research and Development Office of the Bataan Peninsula State University (BPSU).

References

[1] J. R. C. Dizon, A. H. Espera, Q. Chen, and R. C. Advincula, "Mechanical characterization of 3D-printed polymers," *Addit. Manuf.*, vol. 20, pp. 44–67, 2018, doi: 10.1016/j.addma.2017.12.002.

[2] R. C. A. John Ryan C. Dizon, Ciara Catherine L. Gache, Honelly Mae S. Cascolan, Lina T. Cancino, "Post-processing of 3D-printed Polymers," *Technol.*, 2021.

[3] R. N. M. Delda, R. B. Basuel, R. P. Hacla, D. W. C. Martinez, J.-J. Cabibihan, and J. R. C. Dizon, "3D Printing Polymeric Materials for Robots with Embedded Systems," *Technologies*, pp. 1–26, 2021, doi: https://doi.org/10.3390/technologies9040082.

[4] L. D. Tijing, J. R. C. Dizon, and G. C. Cruz Jr., "3D-Printed Absorbers for Solar-Driven Interfacial Water Evaporation: A Mini-Review," *Adv. Sustain. Sci. Eng. Technol.*, vol. 3, no. 1, p. 0210103, 2021, doi: 10.26877/asset.v3i1.8367.

[5] R. N. R. C. Advincula, J. R. C. Dizon, Q. Chen, I. Niu, J. Chung, L. Kilpatrick, "Additive manufacturing for COVID-19: devices, materials, prospects, and challenges," *MRS Commun.*, vol. 10, no. 3, pp. 413–427, 2020.

[6] J. R. C. D. Jan Lloyd B. Crisostomo, "3D Printing Applications in Agriculture, Food Processing, and Environmental Protection and Monitoring," *Key Eng. Mater.*, vol. 913, pp. 17–25, 2022.

[7] J. R. C. D. Emmanuel C. Macaraeg, Cristina G. Rivera, Ronnell D. Dela Rosa, "Establishment of an Academic Makerspace at the Bataan Peninsula State University: Prospects and Challenges," *Adv. Sustain. Sci. Eng. Technol.*, vol. 3, no. 2, pp. 0210202-01 ~ 0210202-09, 2021, doi: https://doi.org/10.26877/asset.v3i2.9655.

[8] J. R. Diego, D. W. C. Martinez, G. S. Robles, and J. R. C. Dizon, "Development of Smartphone-Controlled Hand and Arm Exoskeleton for Persons with Disability," *Open Eng.*, vol. 11, no. 1, pp. 161–170, 2021.

[9] R. A. V. Rigoberto C. Advincula, John Ryan C. Dizon, Eugene B. Caldona and J. Francis Dave C. Siacor, Reymark D. Maalihan, Alejandro H. Espera, "On the Progress of 3D-Printed Hydrogels for Tissue Engineering," *MRS Commun. (in Press.*, 2021.

[10] Martinez, D. W., Espino, M. T., Cascolan, H. M., Crisostomo, J. L., & Dizon, J. R. C. (2022). A Comprehensive Review on the Application of 3D Printing in the Aerospace Industry. In Key Engineering Materials (Vol. 913, pp. 27–34). Trans Tech Publications, Ltd. https://doi.org/10.4028/p-94a9zb

[11] Espera Jr., Alejandro; Dizon, John Ryan; Valino, Arnaldo; Advincula, Rigoberto, Advancing

flexible electronics and additive manufacturing, Japanese Journal of Applied Physics, Special Issue: Flexible and Printed Electronics (ICFPE2021), 2022, https://doi.org/10.35848/1347-4065/ac621a.
[12] J-Rynelle Raymundo Diego, Dan William C. Martinez, Gerald S. Robles, John Ryan C. Dizon, Development of Smartphone-controlled Hand and Arm Exoskeleton for Persons with One-Arm Disability (SCHAX), Open Engineering, 2021; 11:161–170.
[13] Brian Jumaquio Tuazon, Nick Anthony V. Custodio, Rex B. Basuel, Lanz Andre Delos Reyes, John Ryan C. Dizon, 3D Printing Technology and Materials for Automotive Application: A Mini-Review, Key Engineering Materials, Vol. 913, 2022, https://doi.org/10.4028/p-26o076.
[14] Michael B. De Leon, Ulysses B. Ante, Madelene S. Velasco, Arvin Oliver S. Ng, Joseph Alfred V. Garcia, Fred P. Liza, Rigoberto C. Advincula, John Ryan C. Dizon, 3D-Printing for Cube Satellites (CubeSats): Philippines‘ Perspectives, Engineering Innovations, Vol. 1, 2022, https://doi.org/10.4028/p-35niy3.
[15] Eugene B. Caldona; John Ryan C. Dizon; Robert Andrew Viers; Vincent Joseph Garcia; Zane J. Smith; Rigoberto C. Advincula, Additively manufactured high performance polymeric materials and their potential use in the oil and gas industry, MRS Communications, Vol. 11, 701–715, 2021. https://doi.org/10.1557/s43579-021-00134-9.
[16] S. S. Hitesh D. Vora, “A comprehensive review: metrology in additive manufacturing and 3D printing technology,” *Prog. Addit. Manuf.*, vol. 5, pp. 319–353, 2020, doi: https://doi.org/10.1007/s40964-020-00142-6.
[17] G. W. Melenka, J. S. Schofield, M. R. Dawson, and J. P. Carey, “Evaluation of dimensional accuracy and material properties of the MakerBot 3D desktop printer,” *Rapid Prototyp. J.*, vol. 21, no. 5, pp. 618–627, 2015, doi: 10.1108/RPJ-09-2013-0093.
[18] M. M. Hanon, L. Zsidai, and Q. Ma, “Accuracy investigation of 3D printed PLA with various process parameters and different colors,” *Mater. Today Proc.*, vol. 42, pp. 3089–3096, 2021, doi: 10.1016/j.matpr.2020.12.1246.
[19] M. N. Islam, B. Boswell, and A. Pramanik, “An investigation of dimensional accuracy of parts produced by three-dimensional printing,” *Lect. Notes Eng. Comput. Sci.*, vol. 1 LNECS, pp. 522–525, 2013.
[20] A. Farzadi, M. Solati-Hashjin, M. Asadi-Eydivand, and N. A. A. Osman, “Effect of layer thickness and printing orientation on mechanical properties and dimensional accuracy of 3D printed porous samples for bone tissue engineering,” *PLoS One*, vol. 9, no. 9, pp. 1–14, 2014, doi: 10.1371/journal.pone.0108252.
[21] J. Kechagias, P. Stavropoulos, A. Koutsomichalis, I. Ntintakis, and N. Vaxevanidis, “Dimensional Accuracy Optimization of Prototypes produced by PolyJet Direct 3D Printing Technology,” pp. 61–65.
[22] K. Tiwari and S. Kumar, “Analysis of the factors affecting the dimensional accuracy of 3D printed products,” *Mater. Today Proc.*, vol. 5, no. 9, pp. 18674–18680, 2018, doi: 10.1016/j.matpr.2018.06.213.
[23] A. Boschetto and L. Bottini, “Accuracy prediction in fused deposition modeling,” *Int. J. Adv. Manuf. Technol.*, vol. 73, no. 5–8, pp. 913–928, 2014, doi: 10.1007/s00170-014-5886-4.
[24] P. Minetola and M. Galati, “A challenge for enhancing the dimensional accuracy of a low-cost 3D printer by means of self-replicated parts,” *Addit. Manuf.*, vol. 22, no. March 2017, pp. 256–264, 2018, doi: 10.1016/j.addma.2018.05.028.
[25] A. Boschetto and L. Bottini, “Design for manufacturing of surfaces to improve accuracy in Fused Deposition Modeling,” *Robot. Comput. Integr. Manuf.*, vol. 37, pp. 103–114, 2016, doi: 10.1016/j.rcim.2015.07.005.
[26] J. R. C. Dizon, A. D. Valino, L. R. Souza, A. H. Espera, Q. Chen, and R. C. Advincula, “3D Printed Injection Molds Using Various 3D Printing Technologies,” *Mater. Sci. Forum*, vol. 1005, pp. 150–156, 2020, doi: 10.4028/www.scientific.net/msf.1005.150.
[27] Espino, M. T., Tuazon, B. J., Robles, G. S., & Dizon, J. R. C. (2020). Application of Taguchi

Methodology in Evaluating the Rockwell Hardness of SLA 3D Printed Polymers. Materials Science Forum, 1005, 166–173. https://doi.org/10.4028/www.scientific.net/msf.1005.166
[28] J. R. C. Dizon, A. D. Valino, L. R. Souza, A. H. Espera, Q. Chen, and R. C. Advincula, "Three-dimensional-printed molds and materials for injection molding and rapid tooling applications," *MRS Commun.*, vol. 9, no. 4, pp. 1267–1283, 2019, doi: 10.1557/mrc.2019.147.
[29] A. Rusli, "Fundamental Metrology: Its Significance for Scientific Awareness in Higher Education," *Appl. Mech. Mater.*, vol. 771, pp. 187–190, 2015, doi: 10.4028/www.scientific.net/amm.771.187.
[30] S. S. Tyler Musgraves, Hitesh Vora, "Metrology for additive manufacturing (3D printing) technologies," *Int. J. Addit. Subtractive Mater. Manuf.*, vol. 2, no. 1, 2018.
[31] A. M. Badadhe, *Metrology and Quality Control*. Technical Publications, 2006.
[32] M. Ali, "Measuring Accuracy of Two 3D Printing Materials," Bowling Green State University, 2016.
[33] O. S. Carneiro, A. F. Silva, and R. Gomes, "Fused deposition modeling with polypropylene," *Mater. Des.*, vol. 83, pp. 768–776, 2015, doi: 10.1016/j.matdes.2015.06.053.
[34] M. Mahesh, Y. S. Wong, J. Y. H. Fuh, and H. T. Loh, "Benchmarking for comparative evaluation of RP systems and processes," *Rapid Prototyp. J.*, vol. 10, no. 2, pp. 123–135, 2004, doi: 10.1108/13552540410526999.
[35] T. M. Wang, J. T. Xi, and Y. Jin, "A model research for prototype warp deformation in the FDM process," *Int. J. Adv. Manuf. Technol.*, vol. 33, no. 11–12, pp. 1087–1096, 2007, doi: 10.1007/s00170-006-0556-9.
[36] Tuazon, B. J., Espino, M. T., & Dizon, J. R. C. (2020). Investigation on the Effects of Acetone Vapor-Polishing to Fracture Behavior of ABS Printed Materials at Different Operating Temperature. Materials Science Forum, 1005, 141–149. https://doi.org/10.4028/www.scientific.net/msf.1005.141
[37] M. P. N. Emil Yankov, "Comparison of the Accuracy of 3D Printed Prototypes Using the Stereolithography (SLA) Method with the Digital CAD Models," *MATEC Web Conf.*, vol. 137, p. 02014, 2017, doi: https://doi.org/10.1051/matecconf/201713702014.
[38] R. M. C. L. Li, R McGuan, P. Kavehpour, "Precision enhancement of 3D printing via in situ metrology," in *Solid Freeform Fabrication 2018: Proceedings of the 29th Annual International Solid Freeform Fabrication Symposium – An Additive Manufacturing Conference*, 2018, pp. 252–260, [Online]. Available: https://repositories.lib.utexas.edu/bitstream/handle/2152/90092/2018-19-Li.pdf?sequence=2.
[39] E. P. and N. Z.-U. J Kacmarcik, D Spahic, K Varda, "An investigation of geometrical accuracy of desktop 3D printers using CMM," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 393, p. 012085, 2018, doi: 10.1088/1757-899X/393/1/012085.
[40] A. D. and K. Fiedorczuk, "Geometric accuracy of rapid prototyping technologies using laser scanner and coordinate measurement machine," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 770, p. 012086, 2020, doi: 10.1088/1757-899X/770/1/012086.
[41] M. J. and F. Khameneifar, "Improving Geometric Accuracy of 3D Printed Parts Using 3D Metrology Feedback and Mesh Morphing," *J. Manuf. Mater. Process.*, vol. 4, no. 4, p. 112, 2020, doi: doi:10.3390/jmmp4040112.
[42] T. T. Zhu, A. J. Bushby, and D. J. Dunstan, "Materials mechanical size effects: A review," *Mater. Technol.*, vol. 23, no. 4, pp. 193–209, 2008, doi: 10.1179/175355508X376843.
[43] G. S. Robles, R. N. M. Delda, R. Lui, B. Rosario, M. T. Espino, and J. R. C. Dizon, "Dimensional Accuracy of 3D - Printed Acrylonitrile Butadiene Styrene : Effect of Size , Layer Thickness , and Infill Density," vol. 913, pp. 17–25, 2022.