The objective is to utilize zero wastage rice hull material which contains silica as a major component in amorphous form and is used as reinforcement material for various applications. Burning of rice hull (RH) under controlled condition after removal of metal ions leads to white silica of high purity. An inexpensive method for extraction of amorphous silica by thermochemical treatment (pyrolysis process) is performed. Pyrolyzed biomass at four different temperatures is observed for treated and untreated rice hull. Calcination of the rice hull at 600ºC in a muffle furnace turns it into white amorphous silica. In this research, HCl was used to retrieve silica from the rice hull. Extracted silica was characterized by X-ray diffraction analysis, which indicates that the silica is in amorphous form, and displayed a strong broad peak at 22.32º and 21.52º (2θ). The FTIR data revealed the existence of peaks at 4000 cm⁻¹ & 400 cm⁻¹ showing the presence of siloxane and silanol groups. UV-Visible (absorption) band maxima was demonstrated at 367 nm, photoluminescent (emission) spectra displayed a short peak at 453 nm and a sharp intensity peak at 488 nm is comparable with amorphous nano-silica. Less amount of silica appeared at the inner surface of rice hull fiber revealed by SEM analysis. Other element traces were absent, high purity of amorphous silica is observed by EDS.

Keywords Agricultural waste · Rice hull ash (RHA) · acid leaching · photoluminescent · XRD · SEM & EDS

1 Introduction

Rice hull is biomass and a good source of silica considering rice is a major crop [1, 2]. A variety of sources are available for extraction of amorphous silica, among which one of the most abundant sources is rice hull, which has a large amount of silica (up to 22 %). Rice hull on weight basis accounts for an average 20 % by-product from the milling process of paddy [3, 4]. RH is the agricultural waste available abundantly in huge volume and acts as a source for the production of amorphous silica. Mass production of RH and can be used economically as a low-cost source of amorphous silica [5]. Combustion of RH under constrained conditions leads to rice hull ash (RHA), which is a rice source of pure silica. The metal impurities, i.e. Fe, Mn, Na, Ca, K and Mg, which affect the color and purity of SiO₂ are removed by the pre-treatments with like HCl, H₂SO₄ or HNO₃ before combustion [6]. Two forms of SiO₂ occur in nature such as amorphous and crystalline. Opal is the amorphous form of silica while crystalline form occurs in three forms namely cristobolite, quartz and tridymite. Normally silica in RH being bioquenic is essential by being amorphous in nature. At different temperatures and heat treatment crystalline form of silica is obtained [7].

The importance of the amorphous silica is explained by its form, but when crystalline structure of silica is formed which is inactive and unable to form chemical reactions [8]. RH is one of the abundant sources of natural amorphous silica [9]. Silicates acquired from SiO₂ are used in the ceramics industry, cement production, biomedical, cosmetics, and detergents as filler material [10]. silica was employed as the primary substance for the production of many inorganic materials, metal-based complexes, and organic materials, also used as a catalyst for the chemical productions and optical coating materials [11]. At present SiO₂ materials are extracted using various methods, such as sodium silicate, sol-gel route, template synthesis, emulsions-based synthesis, and bio-inspired methods [12]. Leaching by acids [13] and gasification [14] processes have been used for recovering SiO₂ from RH. Amorphous
silica solubility is being less at pH < 10 and penetratingly raise pH > 10. This unique behavior concerning solubility can extract SiO₂ in the purest form under alkaline conditions and simultaneously precipitate it at a low PH value [15]. Metallic sulphate formations which are insoluble in water are normally used as organic acid (H₂SO₄) during the acid pretreatment stage of RH. Also, HNO₃ is not as much as efficient as HCl. Due to the eutectic reaction, some of the metal impurities were removed when extracting silica from RHA. Burning of rice hulls gives 0.1 %-N, 41 %-C, 1.4 %-N, 6.5 %- ash content and 6.5 %- H by weight was analyzed approximately by experiments [16, 17].

The inorganic compounds contained within RH reached about 20 %wt of the dry hull with silica occupying 94 %wt of the total weight while K₂O, CuO, MgO, Al₂O₃, and P₂O₅ constitute the remaining 6 % in descending order of concentrations [18].

In this paper, the effect of hydrochloric acid was studied on the removal of organics and metallic impurities from RH during acid pretreatment stage. The properties examined include functional groups determination by FTIR spectroscopy and measuring the percentage purity of silica particles ascertained by XRD, fluorescence spectrometer; surface morphology by SEM and wt% by EDS analysis.

2 Materials and Methods

2.1 Acid Washing

Inorganic acid washing was used to remove impurities and minerals before extracting silica from RHA using the following method. Initially, 1 M HCl solution was prepared (i.e., 8.36 ml of conc. HCl was added to 91.64 ml of tap water). Now 20 g of RHA samples were immersed in 100 ml solution. This solution is leached for 2 h on a hot pan at 80ºC and water washed then filtered by filter paper to remove impurities.

RHA deposits were finally washed with 100 ml of tap water as shown in Fig. 1. The residues were utilized for the extraction of silica. Draining off acid from the RH the deposit was again rinsed with tap water until it was free from acids or was converted to neutral pH, then filtered by filter paper and air-dried. The acid-treated RH was dried over sunlight for up to 48 h. The untreated RH and acid-treated RH were placed in a muffle furnace at 550, 600, 650, and 700 ºC for 3 h; this resulted in un-leached RHA and acid-leached RHA respectively. Treating rice hull at boiling temperatures with acid resulted in un-leached RHA and acid-leached RHA respectively. Rice hull procured from a rice mill was soaked for 1 h in salt water and dried till moisture was removed. Dried RH was treated with 1 M Conc. HCl. The same procedure was adopted with small modifications [22]. Leaching operation was carried out for 2 h along with continuous stirring till the temperature was 80ºC. The acid solution was removed from the boiled rice hull employing water wash and then dried again for 24 h. The dried acid-treated RH was kept in the muffle furnace for 3 h at 550, 600, 650 and 700 ºC and cooled overnight and the powder which was extracted was white amorphous silica [23, 24].

2.2 Extraction of Silica

X-Ray diffraction was done using PAN analytical X’Pert PRO using Cu Kα radiation. The silica powder was placed on Bragg-Brentano optics on a flat plate. Divergence slit was fixed in order to limit the beam flow on the sample at angles of 2θ. X-ray Diffraction (XRD) of the sample powder was earned out for crystallography analysis and identification of phases. The parameters taken were scatter angle of 5º to 90º for a time period of 13 min with step size of 0.016º. Fourier transform infrared spectroscopy (FTIR, Bruker, USA) was an additional characterization which was done with the silica powder is mixed with KBr window material in a ratio of 1:100 and blended to obtain smooth surface for testing, then compacted in hydraulic press in order to form pellets for transmittance measurements.

SEM analysis was conducted using VEGA3 while TESCAN of the powdered sample was performed at 15.0 kV accelerating voltage under high vacuum and at a magnification of 7.00 kx. Agilent cary eclipse fluorescence spectrometer was used for fluorescent measurements with high sensitivity.

3 Results and Discussions

The microstructural, compositional analysis and morphological analysis of RHA-Silica was executed through material characterization techniques such as an XRD, FTIR, Fluorescence Spectrometer, SEM and EDS.

X-Ray diffraction (XRD) was performed at 45 kV & 30 mA and 2θ in the range of 5º to 50º. The structural pattern of the sample was analyzed and recorded in Software. XRD patterns of the untreated silica and HCl treated silica at the different combustion temperatures are represented in Fig. 2A and B, respectively. Curve at 550ºC a peak was observed with a maximum intensity at 2θ = 22º; which reveals the
amorphous silica presence at temperature 550°C. And curve at 600°C also noticed similar results obtained, absence of sharp peaks [25]. As there was no sharp or regular pattern in the plot, the biomasses are amorphous in nature. The peak near diffraction angle of 22.532° was the representation of moissanite 75R or silicon carbide presence for untreated silica. XRD result for 1 M HCl treated rice hulls the peak at 22.345° represents silicon carbide in acid treated rice hulls. However, an increase in the sharpness of this peak increases combustion temperatures and this was to be less amorphous/less crystalline in nature at lower temperatures of 550°C for untreated silica shown in Fig. 2A. It indicates that untreated silica and treated silica at 600 °C changes the color where untreated silica to ash and treated silica to white ash. With increase in temperature, the crystal nature of silica increased, showing that crystallization of silica does not occur until 700°C. Crystallization of silica begins at a temperature 725°C it was mentioned in [26].

Meanwhile, extracted silica was shown to be completely amorphous in nature below 700°C; based on different temperature ranges, extracted silica shows a sharp clean peak with the appearance of amorphous nature at 600°C. This is due to the alkali metal removal while leaching and also because of eutectic reaction with SiO₂. Silica XRD spectra are shown in Fig. 2A, with a broad strong peak at 22.32° and 21.52° observed for both treated and untreated SiO₂ which reveals the amorphous nature of silica [27–31]. The empirical broad halo
(SiO₂ T2) with maximum intensity at θ = 22° was confirmed at the amorphous structure of silica obtained, and similar results were obtained in [32] from SiO₂ nanoparticles extracted from RH which resulted in a broad peak at an angle of 22° [33].

An investigation of sharp peaks absence in the (scanning angles) range reports that no crystalline structures were evident [34].

The sample was prepared in the form of KBr pellets and the range was detected from 4000 cm⁻¹ and 400 cm⁻¹. The FTIR spectra of untreated amorphous silica and acid-treated amorphous silica at 600 oC is displayed in Fig. 3 (combustion at 600 oC was taken as an example and the spectra of the amorphous silica at another combustion temperatures exhibiting features similar to that of amorphous silica). The strong absorption peaks were displayed at 810 cm⁻¹ and 452 cm⁻¹. These absorption band peaks revealed the formation of the Si–O–Si bond, which is an important aspect of amorphous silica. The peak shown at 1096 cm⁻¹ revealed the formation of Si–O–Si asymmetric stretching vibration in the fingerprint region [6]. The stretching vibration of the functional group O-H broadband with a broad band is shown at 3800 – 3000 cm⁻¹ region with various forms of hydroxyl groups, i.e. silanol hydroxyl groups (O-H). Based on previous reports, [35] also reports that -OH peak expansion can occur due to physically and chemically adsorbed water molecules.

A Somewhat sharp peak was observed at 3750 – 3740 cm⁻¹ region to the stretching frequency of the hydroxyl group (O-H) and the peak displayed around at 1633 cm⁻¹ was recognized to be bending vibrations of O-H bonds in adsorbed water molecule on the outside of amorphous silica. Extracted from RHA, the molecules were present in the amorphous form of silica [36].

Silanol group was diatomite that removes heavy metals from dirty water and actively reacts with various functional groups [37]. In addition, silaxone was present in diatomite helps to remove water molecules that were hydrogen bonded in vacuum in amorphous silica [38].

FTIR spectrographs and analysis of treated and untreated silica are described in Fig. 3A and B respectively.

The structure of silica is shown in Fig. 4. Extracted silica was characterized by UV-Visible (absorption) and photoluminescent (emission) spectra were studied in 1 mM solubilized in CHCl₃ at room temperature. Towards this, the wavelength of UV-Visible absorption (wavelength range is 350 nm to 450 nm) band maxima were demonstrated at 367 nm (as represented in Fig. 5(A)), which shows an impressive absorption band which coincided with amorphous nano-silica [39], and in agreement with previous reports [40].

The corresponding photoluminescent (emission) spectra displayed a short peak at 453 nm and a sharp intensity peak at 488 nm as shown in Fig. 5B. It is comparable with amorphous nano-silica [41] and in comparison to nm for sterilized SiO₂ nanoparticles [42], its strong PL emission enhances the photostability [43]. These photophysical data showed changes with respect to other sterilized SiO₂ nanoparticles and amorphous silica nanoparticles [44].

The silica emission spectra were exhibiting correlation with SiO₂ nanoparticles.

Outer surface morphology is shown in Fig. 6. of acid-treated rice hull. The morphology of the rice hull is
irregular and not smooth. The outer surface appearance has rugged patterns that indicate the presence of silica. Very less amount of silica appeared at the inner surface of rice hull fiber. After completion of acid treatment, significant changes were observed in rice hull morphology. Degree of agglomerations has been reduced increased after ball milling process of treated silica [44–46].

The surface of untreated rice hull reveals higher roughness than that treated with acids because of hydrolysis with some of the organic components by the acid. SEM analysis showed agglomerated ORHA, which may be due to the presence of hydrogen bonding between Silanol groups on the surface of rice hull ash for FRHA [47]. This confirmed that the high percentage purity of amorphous silica particles extracted shows that other elements traces were absent based on the peaks indicated in Fig. 7. The presence of Oxygen and Silicon were revealed by the formation of Si-OH groups (silanol) and Si-O-Si bonds (siloxane) bonds. The amorphous silica particles were composed of 45.56 % Si and 54.44 % O as detected by EDS and based on the stoichiometric composition of SiO₂. The comparison is shown in Table 1.

### 4 Conclusion

The quality of silica from the rice hull leads to a problem, as it agglomerates. By a specific sample preparation method, size reduction could be accomplished, and an amorphous silica sample was acquired by burning rice hull at 600 °C, after leaching the raw material with 1 M HCl, existing a

| Table 1 | Chemical compositions of SiO₂ for commercial type and extracted type |
|---------|---------------------------------------------------------------|
| Type of Silica | Silica (wt %) | O (wt %) | C (wt %) |
| Commercial Silica | 47.68 | 44.64 | 7.68 |
| Extracted Silica | 45.56 | 54.44 | - |
homogeneous particle size distribution. The X-ray diffractograms exhibit a strong broad peak at 22.14°. It reveals that extracted silica from RHA was amorphous. However, the XRD results showed the presence of silica and its derivative suggests that materials fabricated from the biomass will certainly promise good results from the strength point of view. Absorption (367 nm) and fluorescent (488 nm) spectra showed sharp peaks which indicated the presence of natural silica while FTIR data showed the occurrence of hydrogen-bonded siloxane group (Si-O-Si) and silanol (Si-OH) groups in amorphous silica. The chemical compositions of amorphous silica were close to that of commercially available silica. The rice hull ash (RHA) has various applications; it increases hydrophobic property in the case of concrete and cement, acts as an additive in rubber making and is also used in the fabrication of ceramics.

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Author Contribution Prof. Suresh babu, professor in the Mechanical Engineering Department, NIT Warangal framed the design and development of the project.

Dr. Raghavendra is one of the principal investigator of the project and also corresponding author for the current research paper, alongside proof reading he provided important insights in revising the article with appropriate suggestions.

Swapna, Research scholar at Mechanical Engineering Department, NIT Warangal worked on the processing of fabrication and conducted all the studies and wrote the research article.

Rakesh K, Research scholar in the Department of Mechanical Engineering, National Institute of Technology, Warangal worked on material characterization for microstructural studies which helped us in completing a part of a project on time.

Shakuntala Ojha, Assistant Professor Department of Mechanical Engineering, KITS Warangal, India helped in characterization studies/expiriments.

Data Availability The experimental data are available and all the information is provided in the paper.

Declarations The research work is original work and all ethical standards have been compiled with.

Ethics Approval and Consent to Participate Not applicable.

Consent for Publication Yes.

Conflict of Interest No conflict of interest.

Research Involving Human Participants and/or Animals No animals or humans were involved.

Informed Consent Not applicable.

References

1. Bazargan A, Bazargan M, McKay G (2015) Optimization of rice husk pretreatment for energy production. Renew Energ 77:512 – 20. https://doi.org/10.1016/j.renene.2014.11.072

2. Armstrong RT, Wildenschild D, Bay BK (2015) The effect of pore morphology on microbial enhanced oil recovery. J Petrol Sci Eng 130:16–25. https://doi.org/10.1016/j.petrol.2015.03.010
3. An D, Guo Y, Zhu Y, Wang Z (2010) A green route to preparation of silica powders with rice husk ash and waste gas. Chem Eng J 162:509–514. https://doi.org/10.1016/j.cej.2010.05.052

4. Ng EP, Awala H, Tan KH, Adam F, Retoux R, Mintova S (2015) EMT-type zeolite nanocrystals synthesized from rice husk. Microporous Mesoporous Mater 204:204–209. https://doi.org/10.1016/j.micromeso.2014.11.017

5. Dominic M, Joseph R, Begum PS, Kanoth BP, Chandra J, Thomas S (2010) Green tire technology: Effect of rice husk derived nanocellulose (RHNC) in replacing carbon black (CB) in natural rubber (NR) compounding. Carbohydr Polym 230:115620. https://doi.org/10.1016/j.carbpol.2019.115620

6. Yalcin N, Sevine V (2001) Studies on silica obtained from rice husk. Ceram Int 27:219–224. https://doi.org/10.1016/S0272-8842(00)00068-7

7. Todkar BS, Deourulkhar OA, Deshmukh SM (2016) Extraction of silica from rice husk, Int J Eng Res Dev 12:69–74

8. Al Soubaihi RM, Saoud KM, Ye F, Myint Z (2020) Synthesis of hierarchically porous silica aerogel supported palladium catalyst for low-temperature CO oxidation under ignition/extinction conditions. Microporous Mesoporous Mater 292:109758. https://doi.org/10.1016/j.micromeso.2019.109758

9. Chun J, Gu YM, Hwang J, Oh KK, Lee JH (2010) Synthesis of ordered mesoporous silica with various pore structures using high-purity silica extracted from rice husk. J Ind Eng Chem 81:135–143. https://doi.org/10.1016/j.jiec.2019.08.064

10. Anon (1997) Soluble silicates and their applications. Crossfield Publication, Crossfield, Issue No. 2

11. Le NH, Hajjar-Garreau S, Bonne M, Megias-Sayago C, Louis B, Lebeau B, Balan L (2020) Photo-induced generation of size controlled Au nanoparticles on pure siliceous ordered mesoporous silica for catalytic applications. Microporous Mesoporous Mater 295:109952

12. Liou TH, Wu SJ (2010) Kinetics study and characteristics of silica nanoparticles produced from biomass-based material. Ind Eng Chem Res 49:8379–8387. https://doi.org/10.1021/ie100500t

13. Chakraverty A, Kaleemullah S (1991) Conversion of rice husk into amorphous silica and combustible gas. Energy Convers Manag 32:565–70. https://doi.org/10.1016/0196-8904(91)90116-Z

14. Luan TC, Chou TC (1990) Recovery of silica from the gasification of rice husks/coal in the presence of a pilot flame in a modified fluidized bed. Ind Eng Chem Res 29:1922–1927. https://doi.org/10.1021/ie00105a026

15. Mahmoud A, Megiu-Yusoff PS, Ahmad F, Fareezzuan AA (2016) Acid leaching as efficient chemical treatment for rice husk in production of amorphous silica nanoparticles. ARPN J Eng Appl Sci 11:13384

16. Shackley S, Carter S, Knowles T, Middelink E, Haefele S, Sohi S, Cross A, Haszeldine S (2012) Sustainable gasification–biochar systems? A case-study of rice-husk gasification in Cambodia, Part I: Context, chemical properties, environmental and health and safety issues. Energ Policy 42:49–58. https://doi.org/10.1016/j.enpol.2011.11.026

17. Ojha S, Anjali A, Gujjala R (2010) Extraction and characterization of carbon from bio waste. Silicon. https://doi.org/10.1007/s12633-019-00165-x

18. Amick JA (1982) Purification of rice hulls as a source of solar grade silicon for solar cells. J Electrochem Soc 129:864. https://doi.org/10.1149/1.2123999

19. Ramko MK, Cardoso AL, Bevilacqua DB, Rizzetti TM, Ramos LA, Korn dorfer GH, Martins AF (2011) Silica from rice husk ash as an additive for rice plant. J Agron Crop Sci 10:99–104. https://doi.org/10.3923/ja.2011.99.104

20. Della VP, Kühn I, Hotza D (2002) Rice husk ash as an alternate source for active silica production. Mater Lett 57:818 – 21. https://doi.org/10.1016/S0167-577X(02)00879-0

21. Chauhan RP, Kumar A (2013) Radon resistant potential of concrete manufactured using Ordinary Portland Cement blended with rice husk ash. Atmos Environ 81:413–420. https://doi.org/10.1016/j.atmosenv.2013.09.024

22. Reel C, Alcala MD, Criado JM (1996) Preparation of silica from rice husks. J Am Ceram Soc 79:2012–2016. https://doi.org/10.1111/j.1151-2916.1996.tb08931.x

23. Azat S, Sartova Z, Beksetiova K, Askaruly K (2019) Extraction of high-purity silica from rice husk via hydrochloric acid leaching treatment. Turk J Chem 43:1258–1269. https://doi.org/10.3906/kim-1903-53

24. Abualnour Ajeel S, Sukkar KA, Zedin NK (2020) Extraction of high purity amorphous silica from rice husk by chemical process. In: IOP Conference Series: Materials Science and Engineering 881:012096. https://doi.org/10.1088/1757-899X/881/1/012096

25. Hamad MA, Khattab IA (1981) Effect of the combustion process on the structure of rice hull silica. Thermochim Acta 48:343–349. https://doi.org/10.1016/0040-6031(81)90116-Z

26. Bartha P, Huppertz EA (1974) Proc. Rice By-products Conf., Valencia, Spain, 89

27. He JR, Kuo WC, Su CS, Lin HP (2014) Isolation of Bio-Mesoporous Silica from Rice Husk. J Chin Chem Soc-Tag 61:836–840. https://doi.org/10.1002/jcsc.2013006522

28. Rohaeti E, Hikmatawi I (2010) Production of semiconductor materials silicon from silica rice husk waste as alternative silicon sources. J Mater Sci Technol 265–272

29. Liou TH, Yang CC (2011) Synthesis and surface characteristics of nanosilica produced from alkali-extracted rice husk ash. Mater Sci Eng B-Adv 176:521–529. https://doi.org/10.1016/j.mseb.2011.01.007

30. Rafiee E, Shahebrahimi S, Feyzi M, Shaterzadeh M (2012) Optimization of synthesis and characterization of nanosilica produced from rice husk (a common waste material). Int Nano Lett 2:1–8

31. Liu Y, Guo Y, Zhu Y, An D, Gao W, Wang Z, Ma Y, Wang Z (2011) A sustainable route for the preparation of activated carbon and silica from rice husk ash. J Hazard Mater 186:1314–1319. https://doi.org/10.1016/j.jhazmat.2010.12.007

32. Sarangi M, Nayak P, Tiwari TN (2011) Effect of temperature on nanocrystalline silica and carbon composites obtained from rice-husk ash. Compos Part B-Eng 42:1994–1998. https://doi.org/10.1016/j.compositesb.2011.05.026

33. Kalaphaty U, Proctor A, Shultz J (2002) An improved method for production of silica from rice hull ash. Biosourc Tech 85:285–289. https://doi.org/10.1016/S0960-8524(02)00116-5

34. Ma X, Zhou B, Gao W, Qu Y, Wang L, Wang Z, Zhu Y (2012) A recyclable method for production of pure silica from rice hull ash. Powder Technol 217:497–501. https://doi.org/10.1016/j.powtec.2011.11.009

35. Liu Y, Guo Y, Gao W, Wang Z, Ma Y, Wang Z (2012) Simultaneous preparation of silica and activated carbon from rice husk ash. J Clean Prod 32:204–209. https://doi.org/10.1016/j.jclepro.2010.12.007

36. Guo Y, Wang M, Zhang H, Liu G, Zhang L, Qu X (2008) The surface modification of nanosilica, preparation of nanosilica/acyllic core-shell composite latex, and its application in toughening PVC matrix. J Appl Polym Sci 107:2671–2680. https://doi.org/10.1002/app.27310

37. Premaratne WA, Priyadarshana WM, Gunawardena SH, de Alwis AA (2013) Synthesis of nanosilica from paddy husk ash and their surface functionalization. J Sci Univ Kelaniya 8:33–48. https://doi.org/10.4038/josuk.v8i0.7238

38. Jyoti A, Singh RK, Kumar N, Amran AK, Kar M (2021) Synthesis and properties of amorphous nanosilica from rice husk and its composites. Mater Sci Eng B-Adv 263:114871. https://doi.org/10.1016/j.mseb.2020.114871
39. Al-Degs Y, Khraisheh MA, Tutunji MF (2001) Sorption of lead ions on diatomite and manganese oxides modified diatomite. Water Res 35:3724–3728
40. Zhuravlev LT (2000) The surface chemistry of amorphous silica. Zhuravlev model. Colloid Surf A 173:1–38
41. Sankar S, Kaur N, Lee S, Kim DY (2018) Rapid sonochemical synthesis of spherical silica nanoparticles derived from brown rice husk. Ceram Int 44:8720–8724. https://doi.org/10.1016/j.ceramint.2018.02.090
42. Park SB, Jung WH, Kim KY, Koh B (2020) Toxicity assessment of SiO2 and TiO2 in normal colon cells, in vivo and in human colon organoids. Molecules 25:3594. https://doi.org/10.3390/molecules25163594
43. Xie T, Zhong X, Liu Z, Xie C (2020) Silica-anchored cadmium sulfide nanocrystals for the optical detection of copper (II). Microchim Acta 187. https://doi.org/10.1007/s00604-020-04295-6
44. Liu H, Huang Z, Huang J, Xu S, Fang M, Liu YG, Wu X, Zhang S (2016) Morphology controlling method for amorphous silica nanoparticles and jellyfish-like nanowires and their luminescence properties. Sci Rep-Uk 6:1–8. https://doi.org/10.1038/srep22459
45. Bello SA, Agunsoye JO, Adebisi JA, Anyanwu JE, Bamigbaiye AA, Hassan SB (2017) Potential of carbonised coconut shell as a ball-milling interface for synthesis of aluminium (1xxx) nanoparticles. Ann Fac Eng Hunedoara 15:149
46. Pokropivny V, Lohmus R, Hussainova I, Pokropivny A, Vlassov S (2007) Introduction to nanomaterials and nanotechnology. Tartu University Press, Ukraine
47. Jonathan KM, Kuria KP, Mwangi GJ, Gichuki NF (2020) Characterization of rice husk ash prepared by open air burning and furnace calcination. J Chem Eng Mater Sci 11:24–30. https://doi.org/10.5897/JCEMS2020.0348

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