Copyright © 2026 by Cherkas Global University

Publisher: Cherkas Global University

Published since 2014
E-ISSN: 2413-7243
Publication frequency: Once a year
Open access

Journal homepage:
https://ercr.cherkasgu.press



Preparation and Characterisation of Nanosized Hydroxyapatite from Dumped Bovine Bones in Myanmar

Khin Maung Latt [a], Myo Han Ko [a], Su Myat Thu [a], Anastasia A. Tereshkina [b], Alena V. Dostovalova [b], Yuliya A. Enova [b], Darya S. Popova [b], Aleksandr N. Nakoskin [b], Artem V. Sharov [b], Pavel A. Nikolaychuk [b], Zaw Ye Maw Oo [a, b, *]

[a] Department of Chemistry, Higher Education Center, Defence Services Academy, Republic of the Union of Myanmar
[b] Laboratory of Advanced Materials for Industry and Biomedicine, Kurgan State University, Kurgan, Russian Federation

Abstract

In this work, hydroxyapatite nanosized powder was prepared from bovine bone waste from Pyin Oo Lwin township, Myanmar. The bone waste was first converted into bone waste powder, which was characterised by TG/DTA, ED-XRF and IR. The bone powder was then calcined at various temperatures, and it was found that the optimal calcination temperature was 1200 °C with a calcination time of 2 hours. The composition of the obtained hydroxyapatite powders was estimated by ED-XRF spectroscopy, and it was confirmed that the Ca:P molar ratio was similar to that of natural hydroxyapatite. The IR spectrum confirmed the presence of phosphate and hydroxide functional groups. The average particle size was estimated by XRD and equals 83 nm, the surface morphology was examined by SEM, and spherical particles were observed showing a tendency to agglomerate. The resulting material could have various biomedical applications, and the synthesis of hydroxyapatite from bone could also reduce the amount of bone waste stored in Myanmar.

Keywords: bovine bone waste, bovine bone powder, nanosized hydroxyapatite powder, thermal decomposition method, biomedical application.

1. Introduction

One naturally occurring type of calcium apatite is called hydroxyapatite (HAp, $Ca_{10}(PO_4)_6(OH)_2$). The colorations of naturally occurring apatite can range from brown to green,

Citation: *Latt, Khin Maung; Ko, Myo Han; Thu, Su Myat; Tereshkina, Anastasia A.; Dostovalova, Alena V.; Enova, Yuliya A.; Popova, Darya S.; Nakoskin, Aleksandr N.; Sharov, Artem V.; Nikolaychuk, Pavel A.; Oo, Zaw Ye Maw* (2026). Preparation and Characterisation of Nanosized Hydroxyapatite from Dumped Bovine Bones in Myanmar. *European Reviews of Chemical Research*. 13(1): 3-14. DOI: 10.13187/ercr.2026.1.3

* Corresponding author
E-mail addresses: zawyemawoo@gmail.com (Z.Y.M. Oo)

which are similar to the discolorations of dental fluorosis, whereas the pure hydroxyapatite powder is naturally white. A modified hydroxyapatite called a "bone mineral" makes up up to 50 % of the volume and 70 % of the weight of human bone (Priyadarshini et al., 2019). Owing to its outstanding osteoconduction, biocompatibility, and bioactivity, this makes it a very desirable material for biomedical applications, such as a bone substitute material in orthopedics and dentistry (Fiume et al., 2021; Harun et al., 2018). Under physiological circumstances, hydroxyapatite does not degrade like the other calcium phosphates do. In fact, it actively participates in bone bonding, generating solid chemical interactions with the surrounding bone, and it is thermodynamically stable at physiological pH. This characteristic has been used to mend bone quickly following major surgery or damage (Gross, 2002; Zakharov et al., 2004). Other atomic dopants may also be added to HAp in place of the calcium to improve its various characteristics pertinent to in vivo applications (Lim et al., 2016; Panda et al., 2021). The replaced HAp has been used in maxillofacial surgery as well as bone tissue engineering (Panda et al., 2021).

Hydroxyapatite can be prepared in a number of ways. It may be made using a variety of techniques, such as dry, wet, thermal, or a combination of these, and from the variety of chemical precursors, containing calcium and phosphorus (Pu'ad et al., 2020). HAp may also be extracted naturally from materials such animal bones and scales, which are high in calcium and phosphorus content, as an alternative to chemical manufacture. Different morphologies, sizes, and phase crystallinities are produced by various synthesising techniques. Because nanosized HAp resembles the human bone mineral most closely, and has superior clinical efficacy compared to microsized HAp, the goal of developing a nanosized HAp has garnered a lot of interest (Loo et al., 2010; Pu'ad et al., 2020; Roveri, Iafisco, 2010). Drug and gene delivery using nanosized HAp has been explored (Islam et al., 2020; Ma et al., 2008; Uskoković, Uskoković, 2011), as well as use as photocatalysts for environmental cleanup (Piccirillo, Castro, 2017). Additionally, the primary component of teeth and bones is nanocrystalline HAp (Kattimani et al., 2016).

Corals (Chattopadhyay et al., 2007; Miculescu et al., 2018; Sivakumar et al., 1996), cuttlebones (Kangkan et al., 2020; Miculescu et al., 2018; Tattanon et al., 2022), thorns (Miculescu et al., 2018), seashells (Miculescu et al., 2018; Rujitanapanich et al., 2014; Wu et al., 2011), eggshells (Abdulrahman et al., 2014; Chaudhuri et al., 2013; Gergely et al., 2010; Lee et al., 2012; Miculescu et al., 2018; Rivera et al., 1999; Sasikumar, Vijayaraghavan, 2006; Siva Rama Krishna et al., 2007; Sultana et al., 2021; Wu et al., 2015; Wu et al., 2016), exoskeletons (Baek et al., 2022; Mancilla-Sanchez et al., 2019; Miculescu et al., 2018; Ripamonti, 1991), marble (Gupta et al., 2018; Khan et al., 2022; Miculescu et al., 2018; Peng et al., 2023), and bones (Barakat et al., 2008; Barakat et al., 2009; Boutinguiza et al., 2012; Dabiri et al., 2018; Esmaeilkhanian et al., 2019; Khoo et al., 2015; Miculescu et al., 2018; Odusote et al., 2019; Sharifianjazi et al., 2021; Shi et al., 2018; Sobczak et al., 2009) are examples of biogenic natural resources that may be used to create hydroxyapatite. Large amounts of bovine bone waste have been dumped in the Mandalay region of Myanmar. While this poses a risk to the environment if left untreated, it may also be a useful supply of bone mineral for creating nanosized HAp for use in medicinal applications. Thus, the preparation and characterization of nanosized hydroxyapatite powder from biowaste bovine bones is the goal of this study.

2. Materials and methods

2.1. Reagents and equipment

Acetone (reagent grade), potassium bromide (spectral grade) and boric acid (spectral grade) were purchased from Sigma-Aldrich and used without further purification. The distilled water was produced using the aquadistiller Liston A1204 (LLC “Liston”). The samples were weighted using the precision balance FX-300i (A & D Weighing). The grinding machine IMZ-100 (IMZ GmbH) was used for grinding the samples. The electric oven Thermostable ON-W115 and the muffle furnace LabTech LEF-112S-1/112P-1 (DAIHAN Scientific) were used for heating. The autoclave STG-series, JSAT-100 (JS Research Inc.) was used for sterilisation.

The elemental analysis was performed using the ED-XRF spectrometer SPECTRO XEPOS (SPECTRO AMETEK, Inc.) in H_3BO_3 tablets. Infrared spectra were recorded using the spectrophotometer IR-408 (Shimadzu Corporation) in KBr pellets. The thermal analysis was performed using the TG/DTA 7300 analyzer (EXSTAR). The X-ray diffraction platform D8

ADVANCE (Bruker Corporation) was used for obtaining the XRD images. The SEM images were obtained using the electron microscope EVO 60 (Carl Zeiss GmbH).

2.2. Preparation of bovine bone powder

Bovine bone waste samples were collected from the dump (see Figure 1) located in Pyin Oo Lwin Township, Mandalay Region, in June 2022.



Fig. 1. The bovine bone waste dump, Pyin Oo Lwin Township

With a few minor adjustments, the process for preparing bone powder was taken from the work (Miculescu et al., 2018). After sawing the cow bones to the appropriate size, they were repeatedly cleaned with distilled water to get rid of any small particles that stuck to them. Then, they were autoclaved for an hour at 121 ± 5 ˚C and 1 atm. Following a 48-hour boil in distilled water to eliminate any remaining macroscopic adhering impurities, the bones were broken up into smaller pieces using a hammer (refer to Figure 2), repeatedly rinsed in distilled water, submerged in acetone for a full day, and then rinsed in distilled water once more to eliminate organic fat particles and prevent bacterial action.

After the cleansed bovine bones are exposed to sunlight for 72 hours, any remaining moisture is evaporated, and organic materials are removed by heating the bones for 60 hours at 160˚C in an oven. The heating causes the bones to become sufficiently brittle for grinding and crushing. Using a grinding mill, the dried bovine bones were reduced to a fine powder. To get a particle size of less than 44 μm, the powder was sieved. Figure 2 displays the bone powder that was produced.



Fig. 2. The samples of the bovine bone pieces and powder

2.3. Preparation of nanosized hydroxyapatite powder

The 100 g weightings were collected, placed in crucibles, and calcined for two hours at different temperatures — 800, 900, 1000, 1100, 1200, and 1300 ˚C — in the muffle furnace. After being cooled, the collected materials were crushed and sieved using a 325 mesh screen. Figure 3 displays the nanosized hydroxyapatite samples that were obtained.



Fig. 3. The nanosized hydroxyapatite samples after the calcination of bone powder at the different temperatures

2.4. Characterisation of bovine bone and nanosized hydroxyapatite powder

The prepared bovine bone powder samples were characterised by ED-XRF, IR and TG/DTA. The prepared nanosized HAp samples were characterised by ED-XRF, IR, XRD and SEM.

3. Results

3.1. TG / DTA Analysis of the bovine bone powder

A typical TG / DTA curve of the bovine bone powder sample is presented in Figure 4.

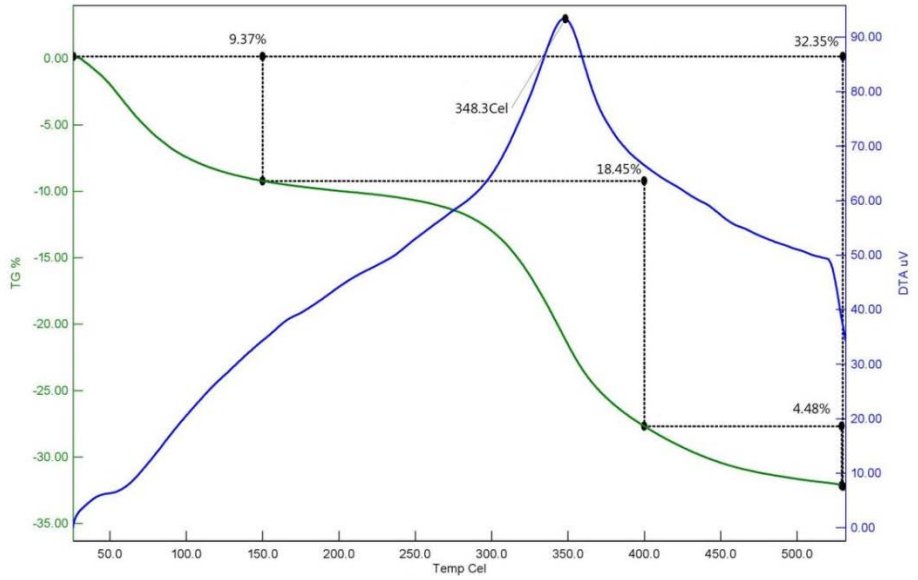


Fig. 4. A TG / DTA curve of the bovine bone powder

The bovine bone powder sample was thermally analysed at the temperature interval from 25 to 600 ˚C under normal atmospheric pressure in air. Three stages of weight loss were found on the TG curve, and the total weight loss was equal to 32.35 %. The first weight loss stage of 9.37 % was observed at the temperatures below 150 ˚C, and its nature is mostly due to moisture evaporation. The second state in the temperature range from 150 to 400 ˚C with the weight loss of 18.45 % is related to the combustion of organic material and the decomposition of carbonates. The third stage in the temperature range from 400 to 600 ˚C with the weight loss of 4.48 % is also related with the complete removal of the organic material. Further heating above 600 ˚C did not reveal any fluctuations on the TG curve, thus indicating the formation of a hydroxyapatite phase is completed.

The thermal analysis shows that the temperatures exceeding 600 ˚C are needed for bone powder calcination, and therefore, six calcination temperatures ranging from 800 to 1300 ˚C were chosen.

3.2. ED-XRF analysis of the bovine bone powder and nanosized hydroxyapatite powder

A typical ED-XRF spectrum of the bovine bone powder sample is presented in Figure 5. The elemental composition of the samples is listed in Table 1.

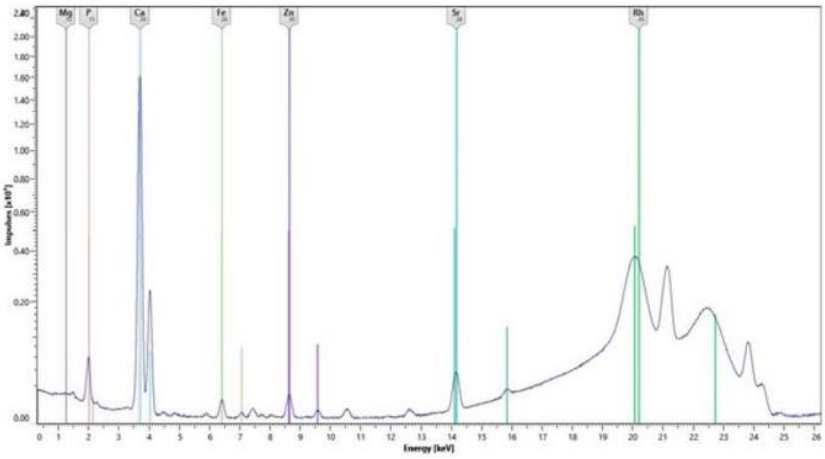


Fig. 5. An ED-XRF spectrum of the bovine bone powder

Table 1. The elemental composition of the prepared bovine bone powder and the nanosized hydroxyapatite powders obtained at the different calcination temperatures

Sample	Bovine bone powder	Hap 800 ˚C	Hap 900 ˚C	HAp 1000 ˚C	HAp 1100 ˚C	HAp 1200 ˚C	HAp 1300 ˚C
Content of the element, % by weight							
Ca	28.47 ± 0.01	38.28 ± 0.01	37.96 ± 0.01	38.32 ± 0.01	38.95 ± 0.01	38.15 ± 0.01	38.10 ± 0.01
P	13.10 ± 0.01	18.88 ± 0.01	18.94 ± 0.01	18.97 ± 0.01	18.49 ± 0.01	17.49 ± 0.01	17.19 ± 0.01
Mg	0.98 ± 0.01	1.47 ± 0.01	1.57 ± 0.01	1.42 ± 0.01	1.62 ± 0.01	1.92 ± 0.03	1.83 ± 0.03
Na	0.75 ± 0.03	0.94 ± 0.04	0.98 ± 0.04	0.72 ± 0.04	0.60 ± 0.04	0.73 ± 0.01	1.2 ± 0.1
Al	0.102 ± 0.003	0.071 ± 0.004	0.085 ± 0.004	0.091 ± 0.004	0.078 ± 0.004	0.596 ± 0.007	1.614 ± 0.009
Si	0.087 ± 0.001	0.029 ± 0.002	0.065 ± 0.002	0.046 ± 0.002	0.041 ± 0.002	0.077 ± 0.002	0.085 ± 0.002
S	0.0985 ± 0.0005	0.0243 ± 0.0005	0.0332 ± 0.0004	0.0349 ± 0.0005	0.0351 ± 0.0005	0.0299 ± 0.0004	0.0468 ± 0.0005
K	0.0273 ± 0.0006	0.0163 ± 0.0008	0.0037 ± 0.0008	< 0.0001	< 0.0001	0.0031 ± 0.0008	0.0445 ± 0.0007
Fe	0.0242 ± 0.0004	0.0331 ± 0.0005	0.0116 ± 0.0003	0.0202 ± 0.0004	0.0308 ± 0.0005	0.0161 ± 0.0004	0.0413 ± 0.0005
Zn	0.0148 ±	0.0142 ± 0.0002	0.0017 ± 0.0001	0.0020 ± 0.0001	0.0010 ± 0.0001	0.0088 ± 0.0001	0.0014 ±

Sample	Bovine bone powder	Hap 800 ˚C	Hap 900 ˚C	HAp 1000 ˚C	HAp 1100 ˚C	HAp 1200 ˚C	HAp 1300 ˚C
	0.0002						0.0001
Ca: P molar ratio	1.68	1.57	1.55	1.57	1.63	1.69	1.72

The elemental analysis shows that either in the bovine bone powder, and in the prepared nanosized hydroxyapatites the content of calcium and phosphorus is dominating, while magnesium and sodium are the noticeable impurities, and the minor elements are Al, S, Si, K, Fe, and Zn. During the annealing the percentage of Ca, P, and Mg in the samples increases, the content of sulphur decreases, and the content of other elements remains approximately the same.

According to the results, the observed Ca : P ratio in the samples lies in the range 1.57-1.71. The ideal Ca : P ratio of hydroxyapatite for biomedical and dental fields is 1.67 and it is chemically the same as a human bone mineral. This ratio provides a good compromise between maintaining the desired bioactivity, biocompatibility, and mechanical properties of the hydroxyapatite material (Miculescu et al., 2018). The Ca : P ratio of prepared nanosized hydroxyapatite sample at 1200 ˚C is the closest to the ideal value, and therefore, this calcination temperature was chosen for the further experiments.

3.3. IR spectra of the bovine bone powder and nanosized hydroxyapatite powder

An IR spectrum of the bovine bone powder sample is presented in Figure 6a, and that of the hydroxyapatite powder prepared at 1200 ˚C – at Figure 6b. The spectral bands are collected in Table 2.

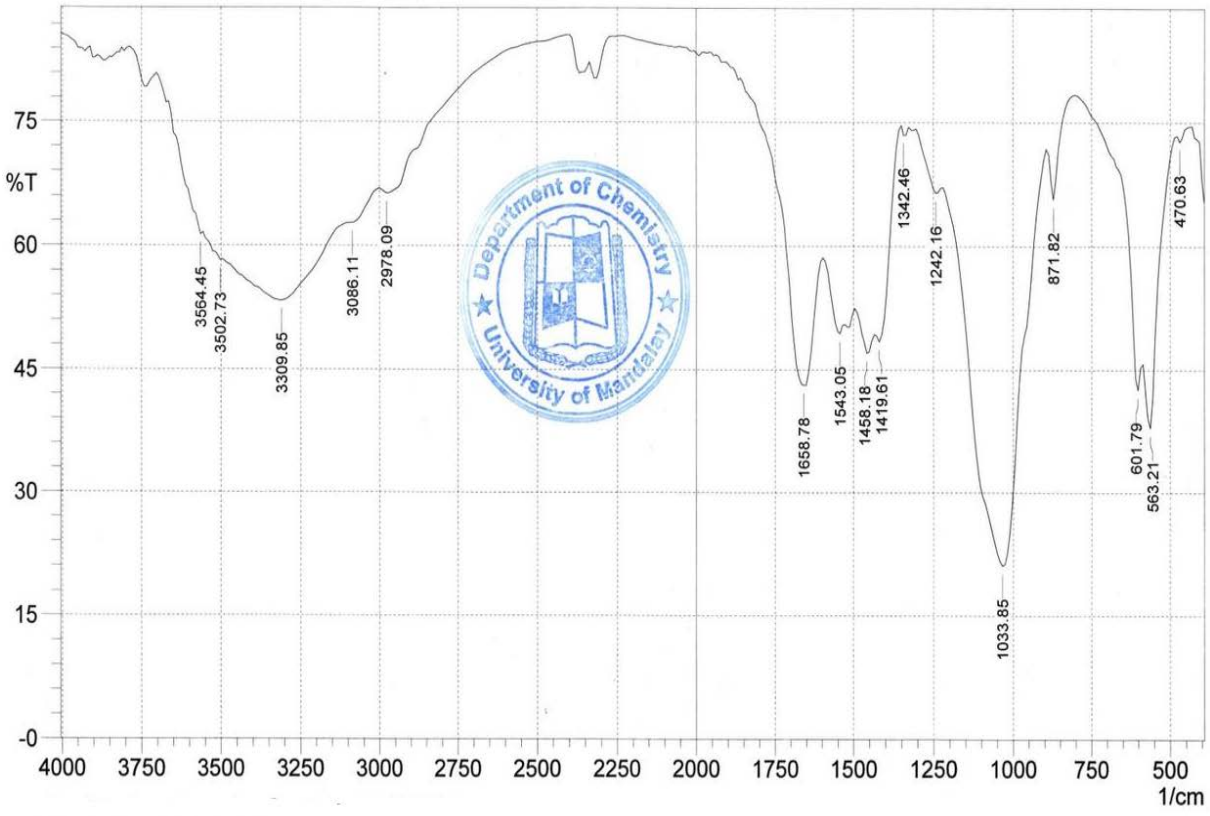


Fig. 6a. An IR spectrum of the bovine bone powder

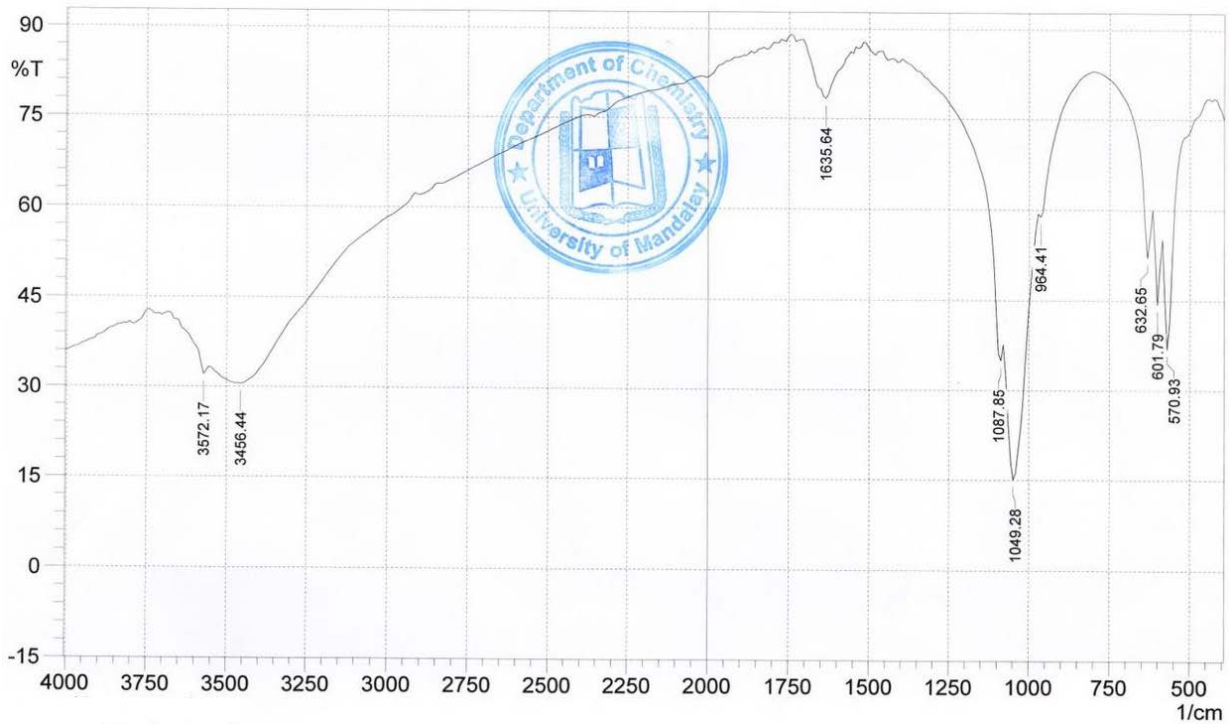


Fig. 6b. An IR spectrum of the hydroxyapatite powder prepared at 1200 ˚C

Table 2. The spectral bands in the IR spectra of the bovine bone powder and the nanosized hydroxyapatite powders prepared at 1200 ˚C

Band description	Wavenumber, cm^{-1}	
	Bovine bone powder	Hydroxyapatite powder
PO_4^{3-} bending	564, 601	570, 601, 632
PO_4^{3-} asymmetric stretching	1033	1049
Amide bending	1543, 1658	
Amide stretching	3086, 3310	
CH_2 bending	1419	
CH_2 asymmetric stretching	2978	
CO_3^{2-} bending	871	
CO_3^{2-} asymmetric stretching	1458	
OH stretching	3502, 3564	3457, 3572

The IR spectrum of the bovine bone powder sample reveals the presence of major inorganic phosphates, hydroxydes, and carbonates, and organic amides from the bone proteins. However, the bands related to amides and carbonates mostly disappear from the IR spectrum of the prepared hydroxoapatite. This confirms that the calcination of the bone powder at at 1200 ˚C effectively removes the carbonates and the organic components of the bone, leaving the purified hydroxyapatite. The obtained IR spectra of the bovine bone powder and the hydroxyapatite coincide with those presented in paper (Miculescu et al., 2018).

3.4. XRD analysis of the nanosized hydroxyapatite powder

The crystallite structure and particle sizes of prepared nanosized hydroxyapatite sample were analyzed by XRD. The X-ray difractogram of the synthesised nanosized hydroxyapatite sample at 1200 ˚C is presented in Figure 7.

The difractogram shows a series of characteristic peaks at 2θ values equal to 31.798, 32.173, 32.942, 46.694 and 49.424˚. The positions and relative intensities of the reflection peaks of prepared nanosized hydroxyapatite at 1200℃ agree with the XRD diffraction peaks of

standard hydroxyapatite with hexagonal crystal structure (JCPDS card No. 00-009-0432). Therefore, it is confirmed that the crystalline structure of the obtained hydroxyapatite nanoparticles is also hexagonal.

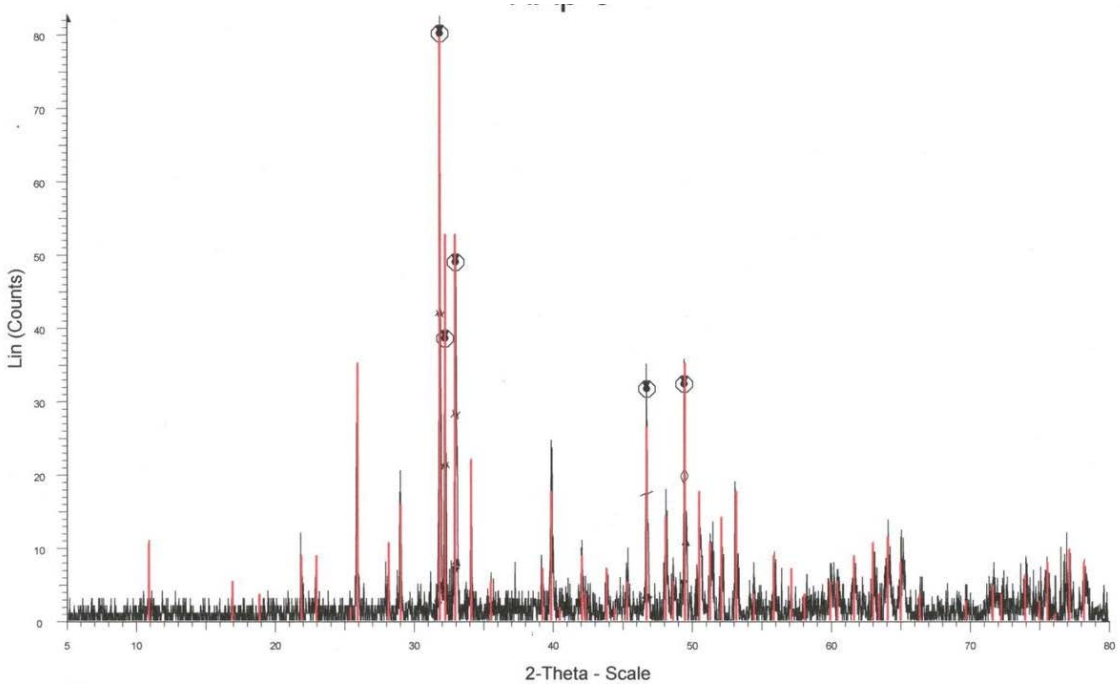


Fig. 7. A XRD image of the hydroxyapatite powder prepared at 1200 ˚C

The average crystallite size of the powder was estimated by Debye-Scherrer equation (Patterson, 1939), and it equals 82.96 nm for the nanosized hydroxyapatite prepared at 1200 ˚C.

3.5. SEM image of the nanosized hydroxyapatite powder

The SEM image of the synthesised nanosized hydroxyapatite sample at 1200 ˚C is presented in Figure 8.

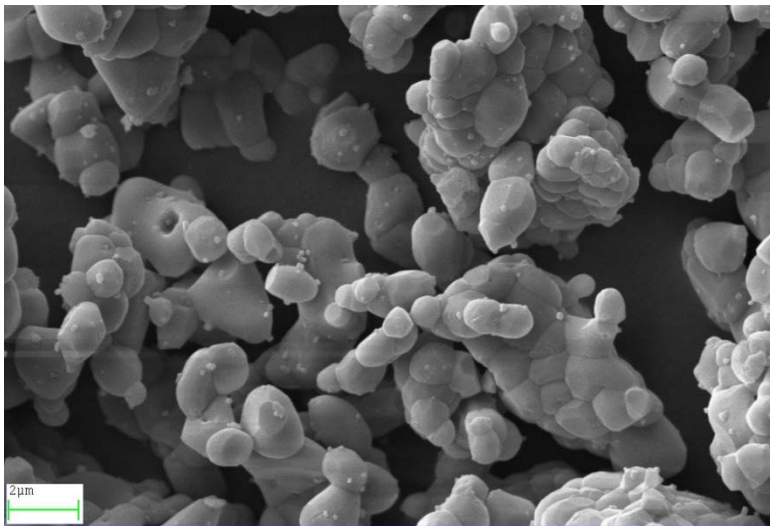


Fig. 8. A SEM image of the hydroxyapatite powder prepared at 1200 ˚C

The particles of the nanosized hydroxyapatite prepared at 1200 ˚C have the spherical shape and gather into the agglomerates. This indicates that the grain growth may be related to the rate of absorption of heat energy by the particles.

4. Discussion

According to the literature, the hydroxyapatite powder is usually produced from the fish (Boutinguiza et al., 2012; Dabiri et al., 2018; Shi et al., 2018), pigeon (Sharifianjazi et al., 2021), or bovine (Barakat et al., 2008; Barakat et al., 2009; Miculescu et al., 2018; Esmaeilkhanian et al., 2019; Khoo et al., 2015; Odusote et al., 2019; Sobczak et al., 2009) bones. The three common production methods (Barakat et al., 2008; Barakat et al., 2009) include calcination, alkaline hydrothermal synthesis, and synthesis in the supercritical water. From these methods calcination is the simplest methods that requires no additional reagents and a simple equipment. The synthesis method utilised in this work mostly coincides with those published earlier (Barakat et al., 2008; Barakat et al., 2009; Boutinguiza et al., 2012; Dabiri et al., 2018; Esmaeilkhanian et al., 2019; Khoo et al., 2015; Miculescu et al., 2018; Odusote et al., 2019; Sharifianjazi et al., 2021; Shi et al., 2018; Sobczak et al., 2009), and the ED-XRF, IR, XRD and SEM characterisation of the obtained powder confirm that a nanosized hydroxyapatite with the average particle size of 83 nm was obtained. The proposed method may be further implemented for the large-scale production of the nanosized hydroxyapatite for biomedical applications from the dumped bovine bones in Myanmar.

5. Conclusion

In the present work the nanosized hydroxyapatite powder was prepared from the bovine bone waste from the Pyin Oo Lwin Township in Myanmar. The optimal calcination temperature was found to be equal to 1200 °C at the calcination time of 2 hours. The composition of the prepared samples was estimated by the ED-XRF spectroscopy, and the Ca : P molar ratio close to that of the natural hydroxyapatite was confirmed. The IR spectrum confirmed the presence of the phosphate and hydroxide functional groups. The average particle size was estimated from the XRD and found to be equal to 83 nm, and the surface morphology was examined by SEM, and the spherical particles tending to agglomerate were observed. The obtained material may be used for different biomedical application, and the synthesis of hydroxyapatite from the bones may also reduce the quantity of dumped bone wastes in Myanmar.

6. Acknowledgements

The authors appreciate the help of our colleague from the University of Mandalay, Republic of the Union of Myanmar, who by personal reasons cannot be included into the authors list, and wished to remain anonymous, for recording the IR spectra presented in the paper.

7. Funding

This work was supported by the state assignment of the Ministry of Science and Higher Education of the Russian Federation (Project Reg. No. FZEE-2024-0008).

References

Abdulrahman et al., 2014 – *Abdulrahman, I., Tijani, H.I., Mohammed, B.A., Saidu, H., Yusuf, H., Jibrin, M.N., Mohammed, S.* (2014). From garbage to biomaterials: an overview on egg shell based hydroxyapatite. *Journal of Materials*. 2014: 802467. DOI: 10.1155/2014/802467

Baek et al., 2022 – *Baek, J.W., Rezk, A.I., Kim, K.S., Park, H., Chun, S., Kim, B.S.* (2022). Marine plankton exoskeleton-derived honeycombed hydroxyapatite bone granule for bone tissue engineering. *Materials & Design*. 224: 111372. DOI: 10.1016/j.matdes.2022.111372

Barakat et al., 2008 – *Barakat, N.A., Khalil, K.A., Sheikh, F.A., Omran, A.M., Gaihre, B., Khil, S.M., Kim, H.Y.* (2008). Physiochemical characterizations of hydroxyapatite extracted from bovine bones by three different methods: extraction of biologically desirable HAp. *Materials Science and Engineering: C*. 28(8): 1381-1387. DOI: 10.1016/j.msec.2008.03.003

Barakat et al., 2009 – *Barakat, N.A., Khil, M.S., Omran, A.M., Sheikh, F.A., Kim, H.Y.* (2009). Extraction of pure natural hydroxyapatite from the bovine bones bio waste by three different methods. *Journal of Materials Processing Technology*. 209(7): 3408-3415. DOI: 10.1016/j.jmatprotec.2008.07.040

Boutinguiza et al., 2012 – *Boutinguiza, M., Pou, J., Comesaña, R., Lusquiños, F., De Carlos, A., León, B.* (2012). Biological hydroxyapatite obtained from fish bones. *Materials Science and Engineering: C*. 32(3): 478-486. DOI: 10.1016/j.msec.2011.11.021

Chattopadhyay et al., 2007 – *Chattopadhyay, P., Pal, S., Wahi, A. K., Singh, L., Verma, A.* (2007). Synthesis of crystalline hydroxyapatite from coral (*Gergonacea sp*) and cytotoxicity evaluation. *Trends in Biomaterials and Artificial Organs*. 20(2): 142-145.

Chaudhuri et al., 2013 – *Chaudhuri, B., Mondal, B., Modak, D.K., Pramanik, K., Chaudhuri, B.K.* (2013). Preparation and characterization of nanocrystalline hydroxyapatite from egg shell and K_2HPO_4 solution. *Materials Letters*. 97: 148-150. DOI: 10.1016/j.matlet.2013.01.082

Dabiri et al., 2018 – *Dabiri, S.M.H., Rezaie, A.A., Moghimi, M., Rezaie, H.* (2018). Extraction of hydroxyapatite from fish bones and its application in nickel adsorption. *BioNanoScience*. 8(3): 823-834. DOI: 10.1007/s12668-018-0547-y

Esmaeilkhanian et al., 2019 – *Esmaeilkhanian, A., Sharifianjazi, F., Abouchenari, A., Rouhani, A., Parvin, N., Irani, M.* (2019). Synthesis and characterization of natural nano-hydroxyapatite derived from turkey femur-bone waste. *Applied Biochemistry and Biotechnology*. 189(3): 919-932. DOI: 10.1007/s12010-019-03046-6

Fiume et al., 2021 – *Fiume, E., Magnaterra, G., Rahdar, A., Verné, E., Baino, F.* (2021). Hydroxyapatite for biomedical applications: A short overview. *Ceramics*. 4(4): 542-563. DOI: 10.3390/ceramics4040039

Gergely et al., 2010 – *Gergely, G., Wéber, F., Lukács, I., Tóth, A. L., Horváth, Z. E., Mihály, J., Balázsi, C.* (2010). Preparation and characterization of hydroxyapatite from eggshell. *Ceramics International*. 36(2): 803-806. DOI: 10.1016/j.ceramint.2009.09.020

Gross, 2002 – *Gross, K.* (2002). Bioceramics: An overview including calcium phosphates, hydroxyapatite, alumina, zirconia and pyrolytic carbon. *Azo Materials*. [Electronic resource]. URL: https://www.azom.com/article.aspx?ArticleID=1743

Gupta, Agarwal, Dalai, 2018 – *Gupta, J., Agarwal, M., Dalai, A.K.* (2018). Marble slurry derived hydroxyapatite as heterogeneous catalyst for biodiesel production from soybean oil. *The Canadian Journal of Chemical Engineering*. 96(9): 1873-1880. DOI: 10.1002/cjce.23167

Harun et al., 2018 – *Harun, W.S.W., Asri, R.I.M., Sulong, A.B., Ghani, S.A.C., Ghazalli, Z.* (2018). Hydroxyapatite-based coating on biomedical implant. In: *Thirumalai, J.* (Ed.) Hydroxyapatite: Advances in Composite Nanomaterials, Biomedical Applications and its Technological Facets. London: InTech, pp. 69-88. DOI: 10.5772/intechopen.71063

Islam et al., 2020 – *Islam, M.S., Abdulla-Al-Mamun, M., Khan, A., Todo, M.* (2020). Excellency of hydroxyapatite composite scaffolds for bone tissue engineering. In: *Vizureanu, P., Manuela Da Cunha Ferreira Botelho, C.* (Eds.) Biomaterials. London: InTech, pp. 53-74. DOI: 10.5772/intechopen.92900

Kangkan et al., 2020 – *Kangkan, S., Arpornmaeklong, P., Ummartyotin, S.* (2020). Synthesis of hydroxyapatite from cuttlebone under various pH conditions: An approach for medical materials. *Journal of Metals, Materials and Minerals*. 30(2): 136-141. DOI: 10.55713/jmmm.v30i2.741

Kattimani et al., 2016 – *Kattimani, V.S., Kondaka, S., Lingamaneni, K.P.* (2016). Hydroxyapatite – Past, present, and future in bone regeneration. *Bone and Tissue Regeneration Insights*. 7: 9-19. DOI: 10.4137/BTRI.S36138.

Khan et al., 2022 – *Khan, A., Bhoi, R., Saharan, V.K., George, S.* (2022). Synthesis of titanium doped hydroxyapatite using waste marble powder for the degradation of Congo Red dye in wastewater. *Materials Today: Proceedings*. 57(4): 1645-1653. DOI: 10.1016/j.matpr.2021.12.251

Khoo et al., 2015 – *Khoo, W., Nor, F.M., Ardhyananta, H., Kurniawan, D.* (2015). Preparation of natural hydroxyapatite from bovine femur bones using calcination at various temperatures. *Procedia Manufacturing*. 2: 196-201. DOI: 10.1016/j.promfg.2015.07.034

Lee et al., 2012 – *Lee, S.W., Kim, S.G., Balázsi, C., Chae, W.S., Lee, H.O.* (2012). Comparative study of hydroxyapatite from eggshells and synthetic hydroxyapatite for bone regeneration. *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology*. 113(3): 348-355. DOI: 10.1016/j.tripleo.2011.03.033

Lim et al., 2016 – *Lim, P.N., Lam, R.N., Zheng, Y.F., Thian, E.S.* (2016). Magnesium-calcium/hydroxyapatite (Mg-Ca/HA) composites with enhanced bone differentiation properties for orthopedic applications. *Materials Letters*. 172: 193-197. DOI: 10.1016/j.matlet.2016.03.005

Loo et al., 2010 – *Loo, S.C.J., Moore, T., Banik, B., Alexis, F.* (2010). Biomedical applications of hydroxyapatite nanoparticles. *Current Pharmaceutical Biotechnology*. 11(4): 333-342. DOI: 10.2174/138920110791233343

Ma et al., 2008 – *Ma, M.Y., Zhu, Y.J., Li, L., Cao, S.W.* (2008). Nanostructured porous hollow ellipsoidal capsules of hydroxyapatite and calcium silicate: preparation and application in drug delivery. *Journal of Materials Chemistry*. 18(23): 2722-2727. DOI: 10.1039/B800389K

Mancilla-Sanchez et al., 2019 – *Mancilla-Sanchez, E., Gómez-Gutiérrez, C. M., Guerra-Rivas, G., Soto-Robles, C.A., Vilchis-Nestor, A.R., Vargas, E., Luque, P.A.* (2019). Obtaining hydroxyapatite from the exoskeleton and spines of the purple sea urchin *Strongylocentrotus purpuratus*. *International Journal of Applied Ceramic Technology*. 16(2): 438-443. DOI: 10.1111/ijac.13086

Miculescu et al., 2018 – *Miculescu, F., Mocanu, A.C., Maidaniuc, A., Dascălu, C.A., Miculescu, M., Voicu, Ş.I., Ciocoiu, R.C.* (2018). Biomimetic calcium phosphates derived from marine and land bioresources. In: *Thirumalai, J.* (Ed.) Hydroxyapatite: Advances in Composite Nanomaterials, Biomedical Applications and its Technological Facets. London: InTech, pp. 89-108. DOI: 10.5772/intechopen.71489

Odusote et al., 2019 – *Odusote, J. K., Danyuo, Y., Baruwa, A. D., Azeez, A. A.* (2019). Synthesis and characterization of hydroxyapatite from bovine bone for production of dental implants. *Journal of Applied Biomaterials & Functional Materials*. 17(2): 1-7. DOI: 10.1177/2280800019836829

Panda, Biswas, Paul, 2021 – *Panda, S., Biswas, C. K., Paul, S.* (2021). A comprehensive review on the preparation and application of calcium hydroxyapatite: A special focus on atomic doping methods for bone tissue engineering. *Ceramics International*. 47(20): 28122-28144. DOI: 10.1016/j.ceramint.2021.07.100

Patterson, 1939 – *Patterson, A.L.* (1939). The Scherrer formula for X-ray particle size determination. *Physical Review*. 56(10): 978-982. DOI: 10.1103/PhysRev.56.978

Peng et al., 2023 – *Peng, S.Y., Lin, Y.W., Lee, W.H., Lin, Y.Y., Hung, M.J., Lin, K.L.* (2023). Removal of Cu^{2+} from wastewater using eco-hydroxyapatite synthesized from marble sludge. *Materials Chemistry and Physics*. 293: 126854. DOI: 10.1016/j.matchemphys.2022.126854

Piccirillo, Castro, 2017 – *Piccirillo, C., Castro, P.M.L.* (2017). Calcium hydroxyapatite-based photocatalysts for environment remediation: Characteristics, performances and future perspectives. *Journal of Environmental Management*. 193: 79-91. DOI: 10.1016/j.jenvman.2017.01.071

Priyadarshini et al., 2019 – *Priyadarshini, B., Rama, M. C., Vijayalakshmi, U.* (2019). Bioactive coating as a surface modification technique for biocompatible metallic implants: a review. *Journal of Asian Ceramic Societies*. 7(4): 397-406. DOI: 10.1080/21870764.2019.1669861

Pu'ad et al., 2020 – *Pu'ad, N.M., Haq, R.A., Noh, H.M., Abdullah, H.Z., Idris, M.I., Lee, T.C.* (2020). Synthesis method of hydroxyapatite: A review. *Materials Today: Proceedings*. 29(1): 233-239. DOI: 10.1016/j.matpr.2020.05.536

Ripamonti, 1991 – *Ripamonti, U.* (1991). The morphogenesis of bone in replicas of porous hydroxyapatite obtained from conversion of calcium carbonate exoskeletons of coral. *The Journal of Bone & Joint Surgery*. 73(5): 692-703.

Rivera et al., 1999 – *Rivera, E.M., Araiza, M., Brostow, W., Castano, V.M., Dıaz-Estrada, J.R., Hernández, R., Rodrıguez, J.R.* (1999). Synthesis of hydroxyapatite from eggshells. *Materials Letters*. 41(3): 128-134. DOI: 10.1016/S0167-577X(99)00118-4

Roveri, Iafisco, 2010 – *Roveri, N., Iafisco, M.* (2010). Evolving application of biomimetic nanostructured hydroxyapatite. *Nanotechnology, Science and Applications*. 3: 107-125. DOI: 10.2147/NSA.S9038

Rujitanapanich et al., 2014 – *Rujitanapanich, S., Kumpapan, P., Wanjanoi, P.* (2014). Synthesis of hydroxyapatite from oyster shell via precipitation. *Energy Procedia*. 56: 112-117. DOI: 10.1016/j.egypro.2014.07.138

Sasikumar, Vijayaraghavan, 2006 – *Sasikumar, S., Vijayaraghavan, R.* (2006). Low temperature synthesis of nanocrystalline hydroxyapatite from egg shells by combustion method. *Trends in Biomaterials and Artificial Organs*. 19(2): 70-73.

Sharifianjazi et al., 2021 – *Sharifianjazi, F., Esmaeilkhanian, A., Moradi, M., Pakseresht, A., Asl, M.S., Karimi-Maleh, H., Varma, R.S.* (2021). Biocompatibility and mechanical properties of pigeon bone waste extracted natural nano-hydroxyapatite for bone tissue engineering. *Materials Science and Engineering: B*. 264: 114950. DOI: 10.1016/j.mseb.2020.114950

Shi et al., 2018 – *Shi, P., Liu, M., Fan, F., Yu, C., Lu, W., Du, M.* (2018). Characterization of natural hydroxyapatite originated from fish bone and its biocompatibility with osteoblasts. *Materials Science and Engineering: C*. 90: 706-712. DOI: 10.1016/j.msec.2018.04.026

Siva Rama Krishna et al., 2007 – *Siva Rama Krishna, D., Siddharthan, A., Seshadri, S. K., Sampath Kumar, T. S.* (2007). A novel route for synthesis of nanocrystalline hydroxyapatite from eggshell waste. *Journal of Materials Science: Materials in Medicine*. 18(9): 1735-1743. DOI: 10.1007/s10856-007-3069-7

Sivakumar et al., 1996 – *Sivakumar, M., Kumar, T.S., Shantha, K.L., Rao, K.P.* (1996). Development of hydroxyapatite derived from Indian coral. *Biomaterials*. 17(17): 1709-1714. DOI: 10.1016/0142-9612(96)87651-4

Sobczak et al., 2009 – *Sobczak, A., Kowalski, Z., Wzorek, Z.* (2009). Preparation of hydroxyapatite from animal bones. *Acta of Bioengineering and Biomechanics*. 11(4): 23-28.

Sultana et al., 2021 – *Sultana, S., Hossain, M.S., Mahmud, M., Mobarak, M.B., Kabir, M.H., Sharmin, N., Ahmed, S.* (2021). UV-assisted synthesis of hydroxyapatite from eggshells at ambient temperature: cytotoxicity, drug delivery and bioactivity. *RSC Advances*. 11(6): 3686-3694. DOI: 10.1039/D0RA09673C

Tattanon et al., 2022 – *Tattanon, T., Pongprayoon, T., Arpornmaeklong, P., Ummartyotin, S.* (2022). Development of hydroxyapatite from cuttlebone and gelatin-based hydrogel composite for medical materials. *Journal of Polymer Research*. 29(9): 364. DOI: 10.1007/s10965-022-03224-x

Uskoković, Uskoković, 2011 – *Uskoković, V., Uskoković, D.P.* (2011). Nanosized hydroxyapatite and other calcium phosphates: chemistry of formation and application as drug and gene delivery agents. *Journal of Biomedical Materials Research Part B: Applied Biomaterials*. 96(1): 152-191. DOI: 10.1002/jbm.b.31746

Wu et al., 2011 – *Wu, S.C., Hsu, H.C., Wu, Y.N., Ho, W.F.* (2011). Hydroxyapatite synthesized from oyster shell powders by ball milling and heat treatment. *Materials Characterization*. 62(12): 1180-1187. DOI: 10.1016/j.matchar.2011.09.009

Wu et al., 2015 – *Wu, S.C., Hsu, H.C., Hsu, S.K., Chang, Y.C., Ho, W.F.* (2015). Effects of heat treatment on the synthesis of hydroxyapatite from eggshell powders. *Ceramics International*. 41(9): 10718-10724. DOI: 10.1016/j.ceramint.2015.05.006

Wu et al., 2016 – *Wu, S.C., Hsu, H.C., Hsu, S.K., Chang, Y.C., Ho, W.F.* (2016). Synthesis of hydroxyapatite from eggshell powders through ball milling and heat treatment. *Journal of Asian Ceramic Societies*. 4(1): 85-90. DOI: 10.1016/j.jascer.2015.12.002

Zakharov et al., 2004 – *Zakharov, N.A., Polunina, I.A., Polunin, K.E., Rakitina, N.M., Kochetkova, E.I., Sokolova, N.P., Kalinnikov, V.T.* (2004). Calcium hydroxyapatite for medical applications. *Inorganic Materials*. 40(6): 641-648. DOI: 10.1023/B:INMA.0000032000.83171.9f