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Research Article

# Artificial neural network (ANN) model for prediction and optimization of bacoside A content in *Bacopa monnieri*: a statistical approach and experimental validation

Bhuban Mohan Padhiari, Asit Ray,

Bibhuti Bhusan Champati, Sudipta Jena,

Ambika Sahoo, Ananya Kuanar, Tarun Halder,

Biswajit Ghosh , Pradeep Kumar Naik,

Jeetendranath Patnaik, Sujata Mohanty,

Pratap Chandra Panda  & Sanghamitra Nayak 

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Received 29 Jul 2021, Accepted 21 Feb 2022, Accepted author version posted online: 02 Mar 2022, Published online: 28 Mar 2022

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# Geographical analysis of income and well-being: Revisiting old debate

## Authors

Bailochan Behera

## Abstract

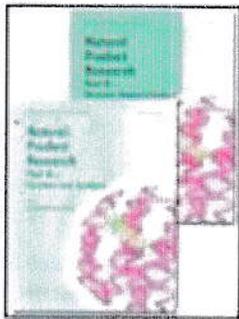
This paper uses data from the online statistical database (2012) of the World Bank and the United Nation Human Development Report (2011) to investigate intra-income distribution in different income-groups countries and study the relationship and the impact of per capita income over subjective and objective social well-being. The results from cross countries are unearthed that high income countries have less disparity or inequality among themselves than the low income countries and middle income countries in the world. The per capita income has significantly positive relation and strong impacts on subjective as well as objectives well-being or happiness.

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**Natural Product Research**  
Formerly Natural Product Letters



ISSN: 1478-6419 (Print) 1478-6427 (Online) Journal homepage: <http://www.tandfonline.com/loi/npri20>

## Chemical composition and antioxidant activity of essential oil from leaves and rhizomes of *Curcuma angustifolia* Roxb

Sudipta Jena, Asit Ray, Anwesha Banerjee, Ambika Sahoo, Noohi Nasim, Suprava Sahoo, Basudeba Kar, Jeetendranath Patnaik, Pratap Chandra Panda & Sanghamitra Nayak

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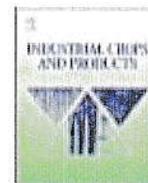
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## Assessment of the terpenic composition of *Hedychium coronarium* oil from Eastern India



Asit Ray<sup>a</sup>, Biswabhusan Dash<sup>a</sup>, Ambika Sahoo<sup>a</sup>, Noohi Nasim<sup>a</sup>, Pratap Chandra Panda<sup>b</sup>, Jeetendranath Patnaik<sup>c</sup>, Biswajit Ghosh<sup>d</sup>, Sanghamitra Nayak<sup>a</sup>, Basudeba Kar<sup>a,\*</sup>

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### ABSTRACT

*Hedychium coronarium* J. Koenig (Zingiberaceae) is well known for its medicinal and aromatic properties because of its terpenic components. The paper aims to characterize the terpenic composition present in the essential oil of *Hedychium coronarium* J. Koenig by two-dimensional gas chromatography with time-of-flight mass spectrometry (GCxGC-TOF-MS). A total of 101 terpenic constituents were identified, 53 of which were reported for the first time. On the basis of their chemical structure, the constituents were grouped into four classes: hydrocarbon monoterpenes, oxygenated monoterpenes, sesquiterpene hydrocarbons and oxygenated sesquiterpenes. The identified compounds include 35 alcohols, 14 hydrocarbons, 12 ketones, 7 aldehydes, 7 oxides, 3 ethers and 3 esters. The predominant compounds identified by GCxGC-TOF-MS were eucalyptol, *p*-cymene and *p*-menth-1-en-8-ol. A database containing retention indices of terpenoids was created for the bi-dimensional column, thus proving to be a remarkable step for analysis of terpenoids using a two dimensional gas chromatography (GCxGC) system. GCxGC enhanced the separation efficiency of constituents as well as resolved a number of co-eluting components that were unresolved on a one dimensional gas chromatography column. The current research enabled in comprehensive profiling of terpenic composition present in *H. coronarium* oil, an important initiative that could add to the valuation and bioprospecting potential of *H. coronarium* as a source of terpenic constituents.

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### 1. Introduction

The *Hedychium* genus of the family Zingiberaceae comprises around 80 species and is widely distributed in Asia and Madagascar (Joshi et al., 2008). Essential oils extracted from flowers, leaves and rhizomes of these plants possess many medicinal and pharmacological properties (Martini et al., 2014).

*Hedychium coronarium* J. Koenig commonly known as white ginger lily belongs to genus *Hedychium*. It is widely distributed in Southern China, India, Brazil, and Southeast Asian countries (Morikawa et al., 2002). Rhizomes of this plant are strongly aromatic and the essential oil obtained from the rhizomes are widely used in perfumery (Matsumoto et al., 1993; Gau et al., 2008). Rhizomes are consumed as stimulant and carminative (Chan and

Wong, 2015). They are also effective in alleviating fever and used as excitant in the Indian Ayurvedic system (Mehta et al., 2014; Parida et al., 2015). Rhizomes are utilized for the medication of diabetes, headache, rheumatism, cancer (Bhandary et al., 1995; Kunnumakkara et al., 2008). Essential oil of *H. coronarium* possesses significant bioactive properties such as antimicrobial, antioxidant, anti-inflammatory as well as mosquito larvicidal activities (Joy et al., 2007; Sabulal et al., 2007; Joshi et al., 2008; Lu et al., 2009; Ho, 2011).

Plant essential oils are usually complex mixtures since they contain several hundred of constituents, including alcohols, aldehydes, ketones, esters, oxides and terpenoids (Zhu et al., 2005). Though gas chromatography mass spectrometry (GC-MS) has been used for many years for analysis of volatile constituents, it cannot offer adequate separation of complex compounds because of the poor resolution power of an individual column (Purcaro et al., 2009). Use of a combination of two columns can significantly improve the resolution to a greater extent. Further, owing to the isomeric nature of sesquiterpene compounds, they co-elute at a similar retention time,

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E-mail addresses: [basu.cht@gmail.com](mailto:basu.cht@gmail.com), [basudebakar@soanuniversity.ac.in](mailto:basudebakar@soanuniversity.ac.in) (B. Kar).

Original papers

# Application of Artificial Neural Network modeling for optimization and prediction of essential oil yield in turmeric (*Curcuma longa* L.)

Abdul Akbar <sup>a, 1</sup>, Ananya Kuanar <sup>a, 1</sup>, Jeetendranath Patnaik <sup>b</sup>, Antaryami Mishra <sup>c</sup>, Sanghamitra Nayak <sup>a</sup>  

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Received 4 December 2016, Revised 7 February 2018,  
Accepted 3 March 2018, Available online 20 March 2018,

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Articles

# **A Combined Approach Using ISSR and Volatile Compound Analysis for Assessment of Genetic and Phytochemical Diversity in *Zingiber zerumbet* (L.) from Eastern India**

Biswabhusan Dash, Asit Ray, Ambika Sahoo,  
Basudeba Kar, Tuhin Chatterjee, Tarun Halder,  
Pratap Chandra Panda, Jeetendranath Patnaik,  
Biswajit Ghosh  & Sanghamitra Nayak 

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Pages 31-49 | Received 13 May 2018, Accepted 08 Mar 2019,  
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## *De Novo* transcriptome sequencing explored cultivar specific sequence variation and differential expression of pigment synthesis genes in turmeric (*Curcuma longa* L.)

Ambika Sahoo <sup>a</sup>, Basudeba Kar <sup>a</sup>, Suprava Sahoo <sup>a</sup>, Sudipta Jena <sup>a</sup>, Ananya Kuanar <sup>a</sup>, Sriram Parameswaran <sup>b</sup>, Jeetendranath Patnaik <sup>c</sup>, Sanghamitra Nayak <sup>a</sup>  

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Research Article

## Quantitative and chemical fingerprint analysis for quality control of *Zingiber zerumbet* based on HPTLC combined with chemometric methods

Biswabhusan Dash, Asit Ray, Ambika Sahoo, Sudipta Jena, Subhashree Singh, Basudeba Kar, ...show all

Pages 711-720 | Received 22 Aug 2019, Accepted 01 Jun 2020, Accepted author version posted online: 12 Jun 2020, Published online: 08 Jul 2020

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🔗 <https://doi.org/10.1080/11263504.2020.1779840>

# Population genetic structure and diversity analysis in *Hedychium coronarium* populations using morphological, phytochemical and molecular markers

Asit Ray <sup>a, b</sup>, Sudipta Jena <sup>a</sup>, Tarun Haldar <sup>c</sup>, Ambika Sahoo <sup>a</sup>, Basudeba Kar <sup>a</sup>, Jeetendranath Patnaik <sup>d</sup>, Biswajit Ghosh <sup>c</sup>, Pratap Chandra Panda <sup>e</sup>, Namita Mahapatra <sup>b</sup>  , Sanghamitra Nayak <sup>a</sup>  

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# THE EFFECT OF RADIATION AND ELECTRIFICATION OF PARTICLES ON BOUNDARY LAYER FLOW AND HEAT TRANSFER OF DUSTY FLUID OVER AN INCLINED STRETCHING SHEET IN THE PRESENCE OF HEAT SOURCE / SINK

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<sup>2</sup>Lecturer, Department of Mathematics, D.A.V.Public School, Berhampur, Odisha, India

<sup>3</sup>Adjunct Professor, Department of Mathematics, CUTM, Paralakhemundi, Odisha, India

**Abstract:** - A steady incompressible boundary layer flow and heat transfer of dusty fluid with radiation and electrification of particles over an inclined stretching sheet in the presence of heat source / sink has been investigated. The governing partial differential equations are solved by reducing into ordinary differential equations using similarity transformations. Runge-Kutta method and Shooting technique are adopted to find the solutions. The effect of pertinent flow parameters such as Radiation parameter, Electrification parameter, Source/Sink parameter, Froud number, Grash of number, Prandtl number, Eckert number, Volume fraction, fluid interaction parameter etc on boundary layer flow and heat transfer are investigated with help of tables and graphs. We have found that our result is good agreement with previously published results. It is found that the thermal boundary layer thickness decreases with the increase of Prandtl number. It is also noticed that the rate of cooling is faster for higher Prandtl number. The temperature of both fluid phase as well as particle phase are enhanced with the increase of Eckert number, radiation parameter, source/sink parameter and electric parameter.

AMS classification: 76D10, 76D15

**Keywords:** *Boundary layer flow, Eckert number, Electrification, Fluid - Particle interaction parameter, Froud number, Grash of number, Inclined stretching sheet, Particle-Particle interaction, Prandtl number, Radiation, source/sink, Shooting techniques, Volume fraction.*

## INTRODUCTION

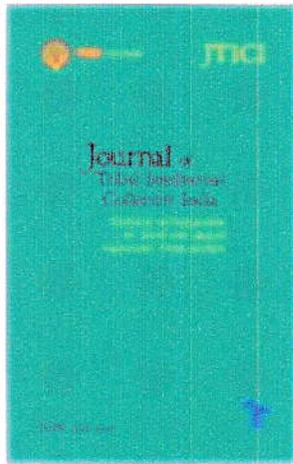
The practical applications of the steady two phase flow and heat transfer over a stretching sheet are underground disposal of radioactive waste materials, exothermic and endothermic reactions, centrifugal separation, of particles, blood rheology, flow through packed beds, sedimentation etc. The momentum and Heat transfer in the laminar boundary layer flow over a surface is important for both practical as well as theoretical point of view because of their wide applications in heat removal from nuclear fuel debris, the aerodynamic extrusion of plastic sheet, environmental pollution, glass blowing, cooling or drying of papers, drawing plastic films.

extrusion of polymer melt-spinning process and heat treated materials traveling on conveyer belt etc.

Many researchers have motivated to study the effect of various flow parameters on heat transfer over a stretching sheet. Grubka et.al [8] investigated the temperature field in the flow over a stretching surface when subject to uniform heat flux. Sharidan[19] presented similarity solutions for unsteady boundary layer flow and heat transfer due to stretching sheet. A numerical solution for laminar thermal boundary over a flat plate with convective surface boundary condition was analyzed by Aziz[2]. Chen [7] investigated mixed convection of a power law fluid past a stretching surface in presence of thermal radiation and magnetic field. Crane [12] has obtained the Exponential solution for planar viscous flow of linear stretching sheet. Adhikari et.al [1] has investigated the heat transfer on MHD viscous flow over a stretching sheet with prescribed heat flux. Subhas et.al [20] have studied the heat transfer in MHD visco-elastic fluid flow over a stretching sheet with variable thermal conductivity, non-uniform heat source and radiation. B.J. Gireesha et.al [3, 4, 5, 6] have studied the boundary layer flow and heat transfer of a dusty fluid over a vertical, horizontal, inclined, exponential stretching sheet by considering various flow parameters.

They have examined the heat transfer characteristics for two types of boundary conditions namely variable wall temperature and variable Heat flux. G.K.Ramesh et.al [14] has investigated the momentum and heat transfer characteristics in hydrodynamic flow of dusty fluid over an inclined stretching sheet with non uniform heat source/sink. Barik et.al. [16] have studied the heat and mass transfer on MHD flow through a porous medium over a stretching surface with heat source. Vajravelu et.al. [23] have studied the hydro magnetic flow of a dusty fluid over a stretching sheet. Tsou et.al.[21] have studied the flow and heat Transfer in the boundary layer on a continuous moving surface.

Many investigations have been conducted about the vertical stretching sheet, horizontal stretching sheet and exponential stretching sheet but a little study has been done over an inclined stretching sheet by considering restricted flow parameters. Here an



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IJDTSW Issue

Dalits' Access to Land in 21st Century Rural India: A Case of Punjab

IJDTSW Vol.6, Issue 1, No.4, Pp.  Padmaja Mondal and Bailochan Behera  
69 To 82, August 2019

# Dalits' Access To Land In 21st Century Rural India: A Case Of Punjab

Published On: Friday, August 16, 2019



**ORIGINAL ARTICLE**

## WOMEN'S REPRODUCTIVE SPANS IN ODISHA, INDIA: AN EVENT-HISTORY ANALYSIS

Subhadra Priyadarshini<sup>1</sup>, Prafulla Kumar Swain<sup>1</sup>, Bailochan Behera<sup>2</sup> and Dulumoni Das<sup>3</sup>

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<sup>4</sup>Department of Statistics, Cotton University, Assam - 781 001, India.

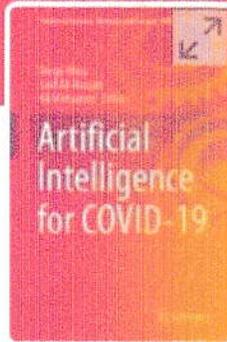
E-mail: [prafulla86@gmail.com](mailto:prafulla86@gmail.com)

**Abstract:** Decline trend of fertility is a global phenomenon of recent time and Indian is no exception to this. Fertility declined by almost a child in the last 23 years between NFHS-1 and NFHS-4 in India, however, many reasons for fertility decline are yet to be explored at present time. National Family Health Survey-4 (henceforth NFHS-4) 2015-16 data were used to study the reproductive span of ever-married women aged 15-49 years. The Cox Proportional Hazard Model has been used to identify the potential determinants associated with the reproductive span. During NFHS-3 and NFHS-4, the median age at marriage swift from 17.9 to 19.9 years. Sterilization is the primary contraceptive method among women and the age at which they adopted it decreased to 25 years. Reproductive spans of successive cohorts of women decreased from 23 years among those who married during the 1970s to 20 years among the 1980s, followed by 16 years among the 1990s, 10 years among the 2000s and 4 years among those who married in 2013-2016. Our finding demonstrates that current women are taking quick decision to end childbearing than older generations. Some critical factors such as age at marriage, number of children ever born, last birth a caesarean section ( $P$ -value  $< 0.05$ ) is significantly associated with shorter reproductive span.

**Key words:** Reproductive span, Sterilization, Women's health, Cox PH model.

### Cite this article

Subhadra Priyadarshini, Prafulla Kumar Swain, Bailochan Behera and Dulumoni Das (2020). Women's Reproductive Spans in Odisha, India: An Event-history Analysis. *International Journal of Agricultural and Statistical Sciences*. DocID: [https://connectjournals.com/03899\\_2020\\_16\\_959](https://connectjournals.com/03899_2020_16_959)



**Artificial Intelligence for  
COVID-19**

pp 295–309 | Cite as

# Spread of COVID-19 in Odisha (India) Due to Influx of Migrants and Stability Analysis Using Mathematical Modeling

[Aswin Kumar Rauta](#) , [Yerra Shankar Rao](#) &  
[Jangyadatta Behera](#)

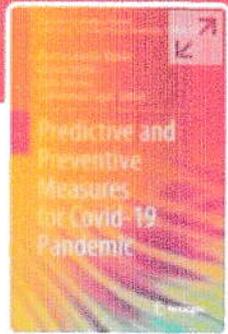
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## Abstract

**Aim/Objectives:** To ascertain the effect  
of migrant workers on the spread of



**Predictive and Preventive  
Measures for Covid-19  
Pandemic**

pp 35–50 | Cite as

## SIQRS Epidemic Modelling and Stability Analysis of COVID-19

[Aswin Kumar Rauta](#), [Yerra Shankar Rao](#) , ...

[Tarini Charan Panda](#) + Show authors

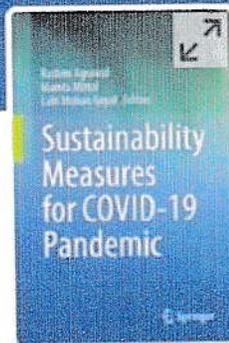
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### Abstract

In this research article, the spread of COVID-19 due to infectious immigrants with effect of quarantine is investigated using SIQRS epidemic model. The rate of



**Sustainability Measures for  
COVID-19 Pandemic**

pp 37–57 | Cite as

## Mathematical Modeling on Double Quarantine Process in the Spread and Stability of COVID-19

Jangyadatta Behera, Aswin Kumar Rauta,  
Yerra Shankar Rao & Sairam Patnaik

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Chapter | First Online: 29 October 2021

**202** Accesses

### Abstract

The transmission of COVID-19 and its stability are formulated in this chapter. In the susceptible class, pre-quarantine technique is implemented for the

## Susceptibility assessment of $F_1$ progeny of irradiated *Aedes aegypti* to toxins of *Bacillus thuringiensis israelensis*

Kiran Bala Bhuyan, T. Sarita Achari and Tapan Kumar Barik\*

Department of Zoology, Berhampur University, Berhampur - 760 007, Odisha, India

### ABSTRACT

This preliminary study highlights the compatibility between radiogenic method with the microbial insecticide. It's a proposal that SIT and  $F_1$  sterility techniques could be integrated with other microbial insecticides like Bti to control the mosquito population in the emergency situation or in high epidemic region as both the methods are compatible.

**Key words :** *Aedes aegypti*, *Bacillus thuringiensis*, radiogenic method, sterile insect technique

### INTRODUCTION

*Aedes aegypti* is a vector of numerous diseases like Zika, dengue, chikungunya, and yellow fever. Vector control is the only option to minimize the incidence of such diseases as there is no effective drugs and vaccine available. Although biological and chemical approaches show spectacular achievement in mosquito control, but not sufficient due to insecticide resistance, re-invasion, environmental damage, etc (Wilke et al. 2009). Therefore, an effective, sustainable and eco-friendly vector control method is highly essential. Attention towards radiogenic methods such as sterile insect technique (SIT) and  $F_1$  sterility technique has been directed for environmentally safe operation of mosquito vector control. These techniques are species specific, non-polluting and environmentally benevolent method for insect control (Fernandez-Salas et al., 2015). Similarly, among microbial control agents, *Bacillus thuringiensis* subsp. *israelensis* (Bti) represents a safe and effective alternatives that is now widely used for mosquito control because of its rapid killing efficacy and good toxicological profile.

### MATERIALS AND METHODS

Various stages of *Aedes* mosquitoes were collected from the field and reared in an insectary. All experiments were performed on  $F_1$  progeny of field-collected *A. aegypti*. Efficacy of Bti was ascertained on field collected *A. aegypti* and two doses such

as 1.0 ppm and 1.5 ppm were selected for this bioassay as higher Bti conc. causes more than 90% larval mortality. Further, we tried to understand the feasibility of combining biocontrol method using Bti with sterile insect technique or  $F_1$  sterility technique to develop a better control strategy for the suppression of mosquito vector population during emergency or in high epidemic region. Sterilization of insects by irradiation for these techniques remains the best adaptable approach to sterilize the insects for the suppression of insect population (Benedicta and Robinson, 2003). Pupae were collected the day before irradiation from trays (Heinisky et al., 2006). One day old pupae were irradiated with gamma radiation generated by cobalt 60 source (Gamma 5000 irradiator) available in Berhampur University, Odisha, India at different doses such as 40, 50, 60, 70, 80 and 90 Gy. The dose rate of radiation was approximately 3.65 KGy/h. Experiments were performed in a series. Each series having several different irradiation doses along with control (0 Gy). After adult emergence, irradiated male adults with normal adult female mosquitoes were kept together with 10% glucose solution soaked in cotton swabs after blood meal in 30 cm<sup>3</sup> cages in 1:1 ratio (Yadav et al., 2010; Shetty et al., 2016) for mating. For each cage, one egg bowl filled with water and lined with wet filter paper was offered two days after a blood meal. The eggs laid by female mosquito were counted and removed daily and transferred to larger trays for hatching. After hatching the  $F_1$  progeny were reared in an insectary for further experiments with Bti.

\*Corresponding author: E-mail: ksb44@rediffmail.com



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## Physica B: Condensed Matter

journal homepage: [www.elsevier.com/locate/physb](http://www.elsevier.com/locate/physb)Magneto dielectric coupling in  $\text{Bi}_2\text{Fe}_4\text{O}_9$ 

Alaka Panda, R. Govindaraj\*, G. Amarendra

Material Science Group, Indira Gandhi Centre for Atomic Research, HBNI, Kalpakkam, Tamil Nadu, 603102, India

## ARTICLE INFO

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$\text{Bi}_2\text{Fe}_4\text{O}_9$   
Multiferroic  
Magnetolectric

## ABSTRACT

This work reports multiferroic behaviour of bulk  $\text{Bi}_2\text{Fe}_4\text{O}_9$  exhibiting both weak ferromagnetic and ferroelectric behaviour at room temperature. Importantly the ferroelectric parameters and dielectric constant are observed to be sensitively dependent upon the magnetic field indicating the occurrence of spin charge coupling. Based on the dielectric measurements under the application of magnetic field, the magneto dielectric coupling (MD %) is found to vary from 0% to about -20% with increasing magnetic field. The observed variation in MD% is attributed to the weak magnetoelectric coupling in such systems.

## 1. Introduction

Recently there has been a surge of research activities on magneto-electric materials with respect to realization of memory devices [1–3]. Very few such materials exist due to mutual exclusiveness of magnetic and ferroelectric ordering [4]. The variation of dielectric constant with magnetic field is a property exclusive to some materials and these are called magneto dielectric (MD) materials whose origin is attributed to strong spin lattice coupling [5]. Observation of magnetic field dependent dielectric constant is an indirect way of verifying multiferroic nature of materials. This in addition would help significantly in fabrication of devices based on tunable ferroelectric and magnetic properties such as magnetic sensors and spin charge transducers [6,7]. Magnetism is associated with spin degrees of freedom whereas dielectric property by charge degree of freedom. The free energy in terms of polarization  $P$  and magnetization  $M$  can be expanded as follows [5]

$$F = (1/2\epsilon_0)P^2 - PE - \alpha PM + \beta PM^2 + \gamma P^2 M^2$$

Where  $\alpha$ ,  $\beta$ ,  $\gamma$  are coupling constants and  $\epsilon_0$  is dielectric susceptibility. As  $P$  and  $M$  are polar and axial vectors respectively, terms linear in both  $P$  and  $M$  will not yield any MD coupling. Also the term  $\beta PM^2$  is forbidden due to symmetry contributions and is crucial for a class of magnetoelectric multiferroics. Hence only the last term in the above equation is solely due to the MD effect and is a scalar irrespective of the lattice or magnetic structure.

$\text{Bi}_2\text{Fe}_4\text{O}_9$  has been reported to be multiferroic with anti-ferromagnetic ordering Néel temperature ( $T_N$ ) around 250 K and ferroelectric Curie temperature ( $T_C$ ) of 260 K exhibiting MD property as reported by Singh et al. [8]. The system is not only interesting being multiferroic but also has attracted numerous attentions due to its

application in semiconductor and nuclear industry [9,10]. In multiferroic systems where Néel temperature lags behind ferroelectric Curie temperature, MD effect is observed as finite polarization prevails in magnetic ordering region. But the MD coupling in such systems are very weak [11]. However the properties can be enhanced by means of suitable doping at A or B sites or by means of modulating its structure with external magnetic field.

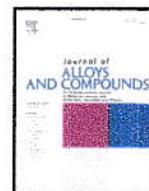
In this work we report magnetic and dielectric properties of bulk  $\text{Bi}_2\text{Fe}_4\text{O}_9$  exhibiting clear anomaly in temperature dependence of dielectric constant. Further this work reports direct evidence of MD coupling in bulk  $\text{Bi}_2\text{Fe}_4\text{O}_9$  in terms of the variation of PE loop with applied magnetic field.

## 2. Experimental details

$\text{Bi}_2\text{Fe}_4\text{O}_9$  was prepared by means of solid state route by taking stoichiometric ratio of starting oxides. The starting oxides  $\text{Bi}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  mixed thoroughly in agate mortar and pressed into 10 mm discs of thickness 2 mm approximately. The pellets are sintered at 973 K with intermittent grindings for 144 h. This is taken as starting sample. The as prepared powder was sintered at 923 K for one day and was taken for electrical measurements. XRD measurement was taken on the as prepared sample for phase confirmation in Inel 2000 X-ray diffractometer. 16 T Vibrating sample magnetometer and PE loop tracer were used for magnetization and ferroelectric measurements respectively. Dielectric measurements in presence of magnetic field were carried out using broadband dielectric spectrometer in parallel geometry with silver electrodes.  $^{57}\text{Fe}$  based Mössbauer spectroscopic studies have been carried out in transmission geometry to study the local structure and magnetic properties of bulk  $\text{Bi}_2\text{Fe}_4\text{O}_9$ .

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## Insights on the role of defects on the magnetic and magneto electric coupling effects in nano BiFeO<sub>3</sub>

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### ABSTRACT

BiFeO<sub>3</sub> nanoparticles prepared through sol-gel route using citric acid are studied for their structural, magnetic and magneto-electric coupling effects and are compared with that of calcined BiFeO<sub>3</sub> particles prepared with tartaric acid as the fuel. Nanoparticles of BiFeO<sub>3</sub> prepared with the use of citric acid were observed to be more strongly ferromagnetic and weakly ferroelectric, as compared to that of the bismuth ferrite nanoparticles prepared using tartaric acid as the fuel. Magneto-electric coupling effects were studied in BiFeO<sub>3</sub> prepared by these methods using Raman spectroscopy. These results were further confirmed based on the direct experimental evidence in terms of the variation of polarization with respect to electric field (P-E loop) studies carried out in the nanoparticles of BiFeO<sub>3</sub> under the application of magnetic field. This study brought out new insights on the important role of defects for the observed variations in magnetic and hence magneto-electric coupling effects in BiFeO<sub>3</sub> nano particles prepared using different fuels, as elucidated based on the Mössbauer studies.

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### 1. Introduction

BiFeO<sub>3</sub> continues to be one of the most interesting and technologically important functional materials with respect to realizing its application in magnetic data storage, logical switching and memory devices [1–4]. Functional iron oxide materials like hexaferrites have been shown to exhibit interesting magnetic and dielectric properties [5–8] at room temperature, while ferrite based composites are found to be technologically important displaying several applications including enhanced magnetoelectric properties [9–15]. Focussed research needs to be done towards obtaining appreciable magneto electric effect in terms of controlling ferroelectric (magnetic) properties by applied magnetic (electric) field in order to significantly improve the multiferroic properties and hence device applications of BiFeO<sub>3</sub>.

Bulk BiFeO<sub>3</sub> exhibits antiferromagnetic (AFM) ordering and ferroelectric properties. The magneto-electric coupling effect is rather little or almost absent in the case of bulk BiFeO<sub>3</sub> [16]. On the other hand, thin films of BiFeO<sub>3</sub> are reported to show excellent ferroelectric and ferromagnetic properties due to strain effects induced due to substrates [17,18]. Similarly, the BiFeO<sub>3</sub> nanoparticles are reported to exhibit weak ferromagnetic ordering [19–21] associated with the significantly reduced ferroelectric properties. In certain cases, nanostructures of BiFeO<sub>3</sub> are reported to result in unique ferroelectric and ferromagnetic properties [22–24]. Magneto-electric coupling effects are however

mostly established in these systems indirectly for example based on the results of Raman spectroscopy.

Invoking weak ferromagnetism in BiFeO<sub>3</sub> remains to be the main requisite for obtaining magneto-electric coupling and hence for paving ways for wide applications of BiFeO<sub>3</sub> as a potential multiferroic material. Though a number of research work have been carried out on the weak ferromagnetic ordering of nanoBiFeO<sub>3</sub>, the complete understanding of the occurrence of weak ferromagnetism in the case of nanoBiFeO<sub>3</sub> is yet to emerge [25–27]. It is important to understand the possible role of defects [28,29] leading to the observed weak ferromagnetic ordering in the case of nanoparticles of BiFeO<sub>3</sub>. Various efficient methods of preparation of nanoparticles of oxide materials based on green technology method and milling followed by heating in a controller manner have been reported [30–33]. As far as the preparation of nanoparticles of BiFeO<sub>3</sub> is concerned, sol-gel method remains as one of the outstanding methods for the easy synthesis and the purity of the phase. In order to address the dependence of defects and size of the nanoparticles on the weak ferromagnetic properties plausibly leading to magnetoelectric coupling effects, these investigations are carried out on the nanoparticles of BiFeO<sub>3</sub> prepared using sol-gel route with different fuels. The size and shape of the particles are highly controlled by the rate of combustion which is regulated by the use of fuel.

In order to form pure phase of BiFeO<sub>3</sub>, carboxyl groups are required for complexing the metal ions and hydroxyl groups are required for the