Appendix

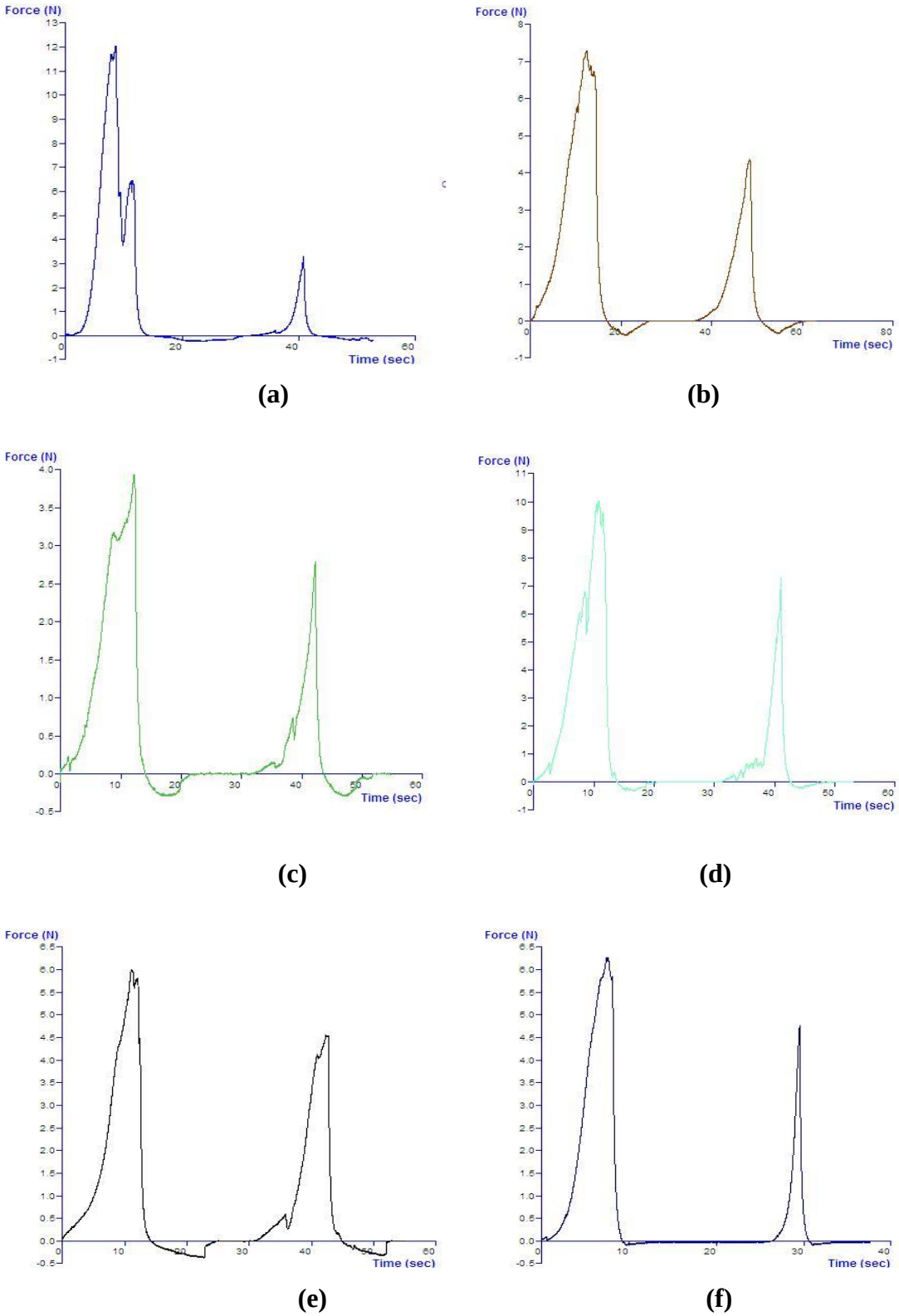

Figure i. Raw image of TPA of C. carp fish fillet at (a) 0 h, (b) 2 h, (c) 4 h, (d) 6 h, (e) 8 h, (f) 10 h.

Analog programming for web application

```
//function start
function average($img) {
   // Define the path to your image file
   //$imagePath = 'path_to_your_image.jpg';
   // Load the image
   //$image = imagecreatefromjpeg($imagePath);
   // Get the width and height of the image
   $width = imagesx($img);
   $height = imagesy($img);
   // Initialize total intensity
   $totalIntensity = 0;
   //echo "Average intensity: " . $averageIntensity;
   // Iterate over each pixel and calculate the intensity
   for ($x = 0; $x < $width; $x++) {
      for ($y = 0; $y < $height; $y++) {
         // Get the RGB values of the pixel
         $rgb = imagecolorat($img, $x, $y);
         // Extract the red, green, and blue components
         $red = ($rgb >> 16) & 0xFF;
         $green = ($rgb >> 8) & 0xFF;
         $blue = $rgb & 0xFF;
         // Calculate the intensity using a simple formula (average of RGB components)
         $intensity = ($red + $green + $blue) / 3;
         // Add the intensity to the total
         $totalIntensity += $intensity;
      }
   }
   // Calculate the average intensity
   $averageIntensity = $totalIntensity / ($width * $height);
   // Output the result
   //echo "Average intensity: " . $averageIntensity;
   $concentration = (137.66 - $averageIntensity)/0.1364;
   if($concentration <= 250){
     echo "Concentration " . $concentration;
     echo "</br><h1 style='color:green;'>FRESH</h1>";
   }
   elseif($concentration > 251 && $concentration <=300){
     echo "Concentration " . $concentration;
     echo "</br><h1 style='color:blue;'>INTERMEDIATE </h1>";
   }
   elseif($concentration >350){
     echo "Concentration " . $concentration;
     echo "</br><h1 style='color:red;'>SPOILED </h1>";
```

List of Publications

1. Yumnam, M., Gopalakrishnan, K., Dhua, S., Srivastava, Y., & Mishra, P. (2024). A Comprehensive Review on Smartphone-Based Sensor for Fish Spoilage Analysis: Applications and Limitations. *Food and Bioprocess Technology*, 1-23.

2. Yumnam, M., Hatiboruah, D., Mishra, R., Satyseelan, K., Nath, P., & Mishra, P. (2023). A Smartphone-based optical sensor with polyaniline label for quantitative determination of freshness of freshwater fish fillets. *Sensors and Actuators A: Physical*, 114557. https://doi.org/10.1016/j.sna.2023.114557.

3. Yumnam, M., Marak, P. R., Gupta, A. K., Rather, M. A., & Mishra, P. (2023). Effect of pomelo peel essential oil on the storage stability of a few selected varieties of freshwater fish. *Journal of Agriculture and Food Research*, *11*, 100472. https://doi.org/10.1016/j.jafr.2022.100472.

Indian patent

1. Monica Yumnam, Diganta Hatiboruah, K. Sathyaseelan, Pabitra Nath, Poonam Mishra, A portable device for the detection and quantification of perishable and adulterated food spoilage including fish spoilage (Ref. no.: 202211032587), jointly filed by Defence Research and Development Organization and Tezpur University.

Award

1. Recipient of **Society for Research and Initiatives for Sustainable Technologies and Institutions- Gandhi Young Technological Innovation (SRISTI-GYTI) Award-2023** for the work entitled "Customer-friendly smartphone-based portable optical device for determination of chemical spoilage of fish suitable for field analysis".

Book chapter(s)

1. Yumnam, M., Gupta, A. K., Koch, P., Mishra, P. (2022). Feasibility of Biosensor. In *Biosensors in Food Safety and Quality: Fundamentals and Applications* (pp. 243-251). Boca Raton and London: CRC Press.

Participation in National/International Conference

1. Yumnam, M. & Mishra, P. Monitoring of Fish Freshness through Image Analysis using Polyaniline-based Label (Virtual oral presentation). International Conference on Innovative Food System Transformations for Sustainable Development in Agro-Food and Nutrition Sector, organized by Department of Food Technology, Vignan's Foundation for Science, Technology & Research (Deemed to be University), Faculty of Agro-based Industry, Universiti Malaysia Lelantan (UMK), and Assoc. of Food Scientists & Technologists, CSIR- CFTRI Camus, Mysuru held online during 16^{th}- 17^{th} November 2022.

2. Yumnam, M. & Mishra, P. Smartphone and Polyaniline film based Optical sensor for Monitoring of Freshness of Fish (Virtual oral presentation). World Sensor Congress (WSC 2022) organized by the Centre for Materials for Electronics Technology (C-MET), Thrissur, in association with the Centre of Excellent in IIoT Sensors, held online during March 8-10, 2022.

3. Yumnam, M., Hatiboruah, D., Nath, P. & Mishra, P. Development of smartphone-based sensor for monitoring fish spoilage (Virtual oral presentation) (SAFETy-2021) on 24^{th} – 25^{th} June 2021 organized by the Department of Food Engineering and Technology, Tezpur University, Assam, India and Department of Food Science and Technology, University of Georgia, Georgia (US) in association with AFST (I) Tezpur Chapter (**Second prize for oral presentation**)

4. Yumnam, M., Marak, P., Medhi, M. & Mishra, P. A comparative study on the shelf-life enhancement of *Labeo calbasu* (Bahu) and *Labeo rohita* (Rohu) during cold storage by using essential oil extracted from *Citrus grandis* (pomelo) (Poster presentation). 9^{th} International Conference on Food Processing, Nutrition and Fortification with emphasis on Vitamin D, organized by the School of

Interdisciplinary Sciences and Technology and School of Unani Medical Education and Research held on 5-6 March 2020 at Jamia Hamdard, New Delhi

5. Yumnam, M., Marak, P. & Mishra, P. Characterization of essential oil from Citrus maxima (Pomelo) and its effects on the storage stability of *Labeo rohita* (Rohu) fillets (Poster presentation). 27th Indian Convention of Food Scientists and Technologists (ICFoST) organized by AFST (I)- HQ and Tezpur Chapter from 30th January 2020 – 1st February 2020 at Tezpur University, Tezpur, Assam (**First prize for best poster presentation**)

Food and Bioprocess Technology
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REVIEW

A Comprehensive Review on Smartphone-Based Sensor for Fish Spoilage Analysis: Applications and Limitations

Monica Yumnam[1] · Krishna Gopalakrishnan[1] · Subhamoy Dhua[1] · Yashi Srivastava[2] · Poonam Mishra[1]

Received: 23 November 2023 / Accepted: 25 March 2024

Abstract

Smartphone-based sensors (SPBS) along with communication and data as a part of the Internet of Things (IoT) have the potential to bring about a significant transformation in food safety by enabling customers to conduct screening tests. Additionally, fish spoilage is a critical issue in the fish industry, leading to economic losses and public health concerns. Traditional methods for assessing fish freshness are often labor-intensive and time-consuming. To address these challenges, it is crucial to comprehensively review ongoing research efforts and pinpoint key technological gaps. Consequently, we conducted a systematic review focusing on SPBS for fish spoilage analysis. We present an overview of the SPBS that were reviewed, emphasizing their performance characteristics. Additionally, we provided insights into the current state of the art concerning commercially available SPBS. This analysis has identified several notable technology gaps, with the most prominent ones being (i) the use of smartphone-based sensors in fish analysis, (ii) its applications using different modes of analysis, (iii) the advantages over analytical method, (iv) its limitation, and (v) recent development, challenges, and future trends. Advancements in optical sensor fabrication, miniaturization, and cost reduction, along with sophisticated machine learning algorithms and cloud computing capabilities, are driving significant developments in mobile diagnostics. Limited review and research were encountered for smartphone-based sensors for fish analysis. This opens the possibility areas for future researchers to detect fish spoilage using smartphone-based sensors.

Keywords Smartphone-based sensors · Fish spoilage analysis · Internet of Things (IoT) · Food safety · Advantages · Limitation

Introduction

Fish is highly susceptible to postmortem changes due to the complex interplay of various customers' key parameters, i.e., composition, type, source, environmental conditions, catching techniques, and storage methods, which leads to a strong struggle for clear prediction of shelf life. In fish production, India ranked 3rd largest with about 8% share. The total fish production was increased by 7.76% (> 12 million metric tons) in the financial year 2022 in India. This sector was previously held by the traditional practices from the past 75 years that have been revolution with 22-fold in terms of fish production (Ministry of Fisheries, Animal Husbandry & Dairying, 2023).

In the Indian scenario Fisheries Infrastructure Development Fund, Pradhan Mantri Matsya Sampada Yojana (PMMSY) and Kisan Credit Card with an investment of Rs. 27,500 crores have been coined to the fish industry for boosting this industry. By seeing the huge potential of this sector GOI has sanctioned INR 6000 crore under PMMSY for the fish market leading to the increase in income of fishermen, fish vendors, and MSME requirements of appropriate fish quality management system for establishing a proper supply chain (Freitas et al., 2021). This scheme envisages performing many changes like digitalization, value-chain efficiency, creation, and maintenance of women jobs in the fish-processing sector. GOI is promoting aquaculture export by 10% and 15% reduction in basic customs duty on fish meal, krill meal, and fish lipid oil, respectively.

Physiological and spoilage changes in fish result from a combination of biological, chemical, and physical factors.

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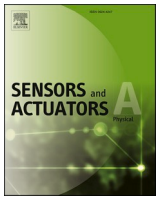

A Smartphone-based optical sensor with polyaniline label for quantitative determination of freshness of freshwater fish fillets

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[b] Department of Physics, Tezpur University, Napaam, Tezpur, Assam, India
[c] Department of Electronics and Communications, University of Allahabad, India
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ARTICLE INFO

Keywords:
Fish freshness
Polyaniline (PANI) label
Smartphone-based sensor
Spectrophotometer
Ammonia

ABSTRACT

We developed a cost-effective, user-friendly smartphone-based sensor equipped with a polyaniline (PANI) label along with optical components and monitored the freshness of three different varieties of fish fillets i.e., Rohu (*Labeo rohita*), Mullet (*Mugil cephalus*), and Common Carp (*Cyprinus carpio*) during storage. We designed an optical cradle as an accessory for a smartphone using ZW3D software and a 3D printer. The cradle with the smartphone was used to observe the spectrum of developed polyaniline deposited labels for ascertaining fish freshness. The sensor was calibrated using a standard ammonia solution (0–400 ppm) and the method was validated with a spectrophotometer and existing conventional techniques like TVB-N (total volatile basic nitrogen), TVC (total visible count), pH, and TPA (Texture Profile Analysis). The limit of detection (LOD), the limit of quantification (LOQ), %Bias, and %RSD of the sensor were 3.83 ppm, 12.96 ppm, 0.14 %, and 1.87 % respectively. The developed smartphone-based sensor used about 1139 pixels for wavelengths between 391.84 and 633.54 nm. A strong correlation could be established between TVB-N, TVC, and pH with the findings of the developed sensor. Application of PANI made the sensor specific for the detection of spoilage of fish therefore can be utilized as a platform for monitoring the freshness of fish. We successfully developed a web application using the present findings to evaluate fish fillet quality.

1. Introduction

Fish are particularly important for their valuable source of nutrients. They are well known worldwide for their high-quality protein, and natural source of polyunsaturated fatty acids, vitamins, and minerals. Global fish production has been increasing in the last few decades with an estimation of about 179 million tons in 2018 with an estimated loss of 30–35 %. However, around the world, fish consumption is evaluated to arrive at 21.4 kg per capita in 2031, from the base period per capita of 20.5 kg (average 2019–2021) [1–4]. Yet, fresh fish are highly prone to microbial spoilage and biological changes due to high moisture content, low acid, reactive endogenous enzymes, and enriched nutrient value. The deterioration in the quality of fresh fish leads to the breakdown of proteins and non-protein nitrogenous substances, which is mostly driven by the action of microorganisms, resulting in volatile amines. As the fish tissue is degraded by microorganisms the compound trimethylamine oxide (TMAO) converts into TMA (trimethylamine), DMA (dimethylamine), and ammonia. These compounds that produce during spoilage are collectively known as TVB-N (total volatile basic nitrogen) and considerably produce unpleasant off-odor. Sensory evaluation such as appearance, odor, and color has always been a key role in the fish industry, and pH, TVB-N value, and microbial count of the fish is the sensory characteristic that concerns their freshness conditions during storage [5–10]. Although the TVB-N value and microbial count are the standards for indication of fish freshness, it is a time-consuming process and involves multiple complicated steps for analysis [9]. Therefore, a customer-friendly rapid technique is required for the freshness determination of fish during storage.

Polyaniline (PANI) is a synthetic polymer that exhibits unique properties due to its simplicity in synthesis, stability in a different environment, and easy doping and dedoping. Polyaniline is chemically synthesized by oxidative polymerization of aniline in an acidic solution

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journal homepage: www.sciencedirect.com/journal/journal-of-agriculture-and-food-research

Effect of pomelo peel essential oil on the storage stability of a few selected varieties of freshwater fish

Monica Yumnam [a], Penima R. Marak [a], Arun Kumar Gupta [a], Muzamil Ahmad Rather [b], Poonam Mishra [a,*]

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[b] Department of Molecular Biology and Biotechnology, Tezpur University, Assam, 784028, India

ARTICLE INFO

Keywords:
Pomelo
Essential oil
Fish fillet
Antimicrobial
Antioxidant
Spoilage microorganisms

ABSTRACT

The antimicrobial effect of pomelo (*Citrus grandis* L. Osbeck) peels essential oil was investigated against a few selected varieties of freshwater fish (Rohu, Bahu, Silver carp) as well as tested against spoilage organisms (*Yersinia pestis, Bacillus cereus, Escherichia coli, Staphylococcus aureus, Mycobacterium smegmatis, Listeria monocytogenes, Pseudomonas aeruginosa, Candida albicans*) using the disc diffusion method. The yield of 2.66% (w/v) was obtained using hydro-distillation extraction. The essential oil demonstrated 65% of DPPH* scavenging activity, and D-limonene (90-89%) was found to be the predominant monoterpene hydrocarbon. Terpinyl acetate (2.8%), -pinene (2.3%), -pinene (2.2%), and terpinolene (0.3%) were the next most abundant monoterpene hydrocarbons, The pomelo peel oil exhibited antimicrobial activity against the majority of tested organisms and found to be effectively prevented the growth of spoilage microorganisms on Rohu, Bahu, and Silver carp fish fillets, as a result, the shelf life of the fishes were extended by 6–9 days. The essential oil obtained from waste pomelo peel has the potential to improve the storage stability of fish fillets.

1. Introduction

The *Citrus grandis* L. Osbeck fruit widely recognized as Pomelo is a native plant of Southern Asia, which is locally available in China, Japan, Vietnam, Malaysia, India, and Thailand [1,2]. It is believed to be the primary origin of grapefruit and a member of the Rutaceae family. Pomelo, along with lemon, orange, mandarin, and grapefruit is one of the citrus fruits that is currently grown and consumed most commonly in Southeast Asia and other regions of the world [3]. The fruit of the pomelo is commonly consumed fresh or in the form of juice while the peels, seeds, and other parts of the plant are generally discarded as waste. The plant's various parts, including the leaf, pulp, and peel, have been used in traditional medicine for centuries because they have been shown to have therapeutic potential and are safe for human consumption [2,4]. The leaves of the *Citrus grandis* plant and its oil are used in folk medicine to cure skin conditions, headaches, and stomach pain, respectively. *Citrus grandis* fruits are not just utilized for consumption, traditional remedies frequently treat cough, edema, epilepsy, and other ailments with fruit peels in addition to using them for cosmetic purposes [5]. The citrus species are the major source of essential oil and the oils derived from citrus peel have a strong desirable aroma with a refreshing effect. There has been increasing in recent years as a result the commercial importance is growing. Essential oils are naturally derived metabolites including terpenes, sesquiterpenes, terpenoids, and aromatic compounds with different groups of aliphatic hydrocarbons, aldehydes, acids, alcohols, phenols, esters, oxides, lactones, and ethers [6]. Essential oil containing such compounds are well known to have antimicrobial and antioxidant properties and serve as an alternative to synthetic additives with the moving interest in natural products [1,7]. Studies have convinced that the active components that exist in citrus essential oils such as limonene, pinene, and terpinolene exhibit a wide range of antimicrobials, antifungal, anti-inflammatory, and antioxidant activity [8–10]. Besides, the citrus essential oil has been classified as GRAS (Generally Recognized as Safe) due to its great nutraceuticals and economic importance [8]. Several studies have shown that essential oils have the potential to extend the shelf life and maintain the quality of fish and meat products [11–15].

According to FAO, 2020 (The State of World Fisheries and Aquaculture), global fish production has been increasing in the last few decades with an estimation of about 179 million tons in 2018 with an

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15

Feasibility of Biosensors

Monica Yumnam, Arun Kumar Gupta, Parismita Koch, Manisha Medhi, and Poonam Mishra
Tezpur University, Tezpur, India

CONTENTS

15.1 Introduction

The food and regulatory agencies consider quality and conformity as the common critical issues in all horticultural and industrial processes and products and thus are of prime economic importance (Ferreira et al., 2010). Because of the growing interest of consumers and food industries, a proper detection or control system of raw materials and food products, such as fruits and vegetables, are essential for food quality and safety (Ferreira et al., 2010). Food quality attributes include maturity index, respiratory rate, gas emission, etc. Also, food safety content may include pathogens causing diseases, hazardous microorganisms, toxic compounds, and pesticides (Ferreira et al., 2010).

The growing demand for quality products linked to society's requirements for more clean, eco-friendly manufacturing practices necessitates the steady improvement of quality foods and detection methods of abnormalities during pre and post-harvest (Ferreira et al., 2010). Over the years, different kinds of sensors have been used for different purposes, including process control, monitoring, detection of hazard, spoilage, and quality determination. These food applications solely rely on sensitivity, specificity, precision, and economic feasibility for rapid detection in food processing and agriculture (Hall, 2002).

There has been continuous research and expeditious efforts over the years in biosensor technology, as noticed from the publications, patents, and commercially available devices for welfare. This also highlights the strong perspective for in-field applications in areas such as health care, food analysis, and quality monitoring, agricultural application, biodefence, and biomedical devices (Scognamiglio et al., 2015, 2016).

It is quite noticeable that, except for the glucose monitoring devices, the other biosensors related to other sectors is still limited, as the introduction of a new device is tough, and feasibility, cost factor, specificity, and sensing technologies are a few of the major drawbacks. Advanced research is required to improve the shelf stability of baroreceptors, mass production, integration of components, production at mass level, and operational capability (Antonacci et al., 2016). Thus, this chapter deals with the marketability of biosensors, their potential and feasibility in the sectors like food processing and agriculture, in addition to the cost analysis.

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Honey Bee Network

Gandhian Young Technological Innovation Award

SRISTI

Society for Research and Initiatives for Sustainable Technologies and Institutions

Gandhian Young Technological Innovation (GYTI) Award - 2023

Customer friendly smartphone-based portable optical device for determination of chemical spoilage of fish suitable for field analysis

Monica Yumnam
(Tezpur University, Tezpur)

Guides: Prof. Poonam Mishra , Prof. Pabitra Nath

Social Technological Innovation

November 5, 2024

Prof. Anil K. Gupta
Founder, Honey Bee Network, SRISTI, GIAN & NIF
CSIR Bhatnagar Fellow 2018-21, Visiting Faculty, IIMA & IITB, Academy Professor, AcSIR

Department of
FOOD TECHNOLOGY

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Certificate of
Presentation

International Conference
on
Innovative Food System Transformations for Sustainable Development in Agro-Food and Nutrition Sector
(16th – 17th November, 2022)

This is to certify that Mr. / Ms. / Dr. / Prof. **Monica Yumnam** of **TEZPUR UNIVERSITY** presented (Oral presentation) on topic **Monitoring Of Fish Freshness Through Image Analysis Using Polyaniline- Based Label** in International Conference, organized by Department of Food Technology, VFSTR (Deemed to be University) Vadlamudi, Guntur, Andhra Pradesh.

Dr. M. Ramesh Naidu
Chief Convener

Dr. Dinkar B. Kamble
Organizing Secretary

Dr. Irshaan Syed
Co-ordinator, Food Tech.

WORLD SENSOR CONGRESS (WSC-2022)

08-10 MARCH 2022

Organized by

Centre for Materials for Electronics Technology (C-MET), Thrissur

in association with

Centre of Excellence in IIoT Sensors

Centre of Excellence Intelligent IoT Sensors
THINK GLOBALLY, MAKE LOCALLY

Certificate of Participation

This is to certify that **Ms. Monica Yumnam**

of **Tezpur University**

..... has

presented (Oral) in the World Sensor Congress held online during March 08-10, 2022.

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Dr. Bharat B. Kale	**Dr. N. Raghu**	**Dr. A. Seema**
C-MET Pune	*C-MET Thrissur*	*C-MET Thrissur*
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on
Sustainable Approaches in Food Engineering and Technology (SAFETy-2021)
24th-25th June, 2021

CERTIFICATE

This is to certify that the following paper has been awarded **SECOND POSITION** in the **Technical Session on Quality, Safety and Hygiene in Food Processing** at SAFETy-2021 organized by the Department of Food Engineering & Technology, Tezpur University, Assam, India, and Department of Food Science & Technology, University of Georgia, Georgia (US) in association with AFST(I) Tezpur Chapter.

Title: Development of smartphone-based sensor for monitoring fish spoilage during storage at room temperature
Authors: Yumnam, M., Hatiboruah, D., Nath, P & Mishra, P.

Dr. Amit Baran Das	Dr. Abhinav Mishra	Prof. Nandan Sit	Prof. Manpreet Singh
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CERTIFICATE

of

PARTICIPATION

This is to certify that Prof./Dr./Ms./Mr. MONICA YUMNAM participated as Delegate/presented oral lecture/poster entitled A comparative study on the shelf life enhancement of Labeo calbasu (Bahu) and Labeo rohita (Rohu) during cold storage using essential oil extracted from Citrus grandis (Pomelo) peel in the 9th International Conference on **"Food Processing, Nutrition and Fortification with emphasis on Vitamin D"** organized by School of Interdisciplinary Sciences and Technology and School of Unani Medical Education and Research held on **March 05-06, 2020** at Jamia Hamdard, New Delhi

Prof. (Dr.) Afrozul Haq
President of the Conference

27th Indian Convention of Food Scientists and Technologists

"Raising Agro-processing & Integrating Novel technologies for Boosting Organic Wellness" (RAINBOW)

30th January 2020 -1st February 2020 @ Tezpur University, Tezpur, Assam

ICFoST 2019

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Empowering the Food Professional

Best Poster

FMF-007

This is to certify that the following poster has been selected as the **Best Poster** at **27th ICFoST** organized by AFST(I)-HQ and Tezpur Chapter during 30th January 2020 -1st February 2020 at Tezpur University, Tezpur, Assam.

Title : Characterization of essential oil from Citrus maxima .....

Author (s): Monica Yumnam, Penima R Marak, Poonam Mishra

(Prof. Sankar Chanda Deka)
Local Organizing Secretary

(Dr. D D Wadikar)
Organizing Secretary

(Dr. Baskaran V)
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Giving Food a Future

Design and Development of Smartphone Sensing System for Determination of Freshness of Fish fillets During Storage

by Monica Yamnum

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Design and Development of Smartphone Sensing System for Determination of Freshness of Fish fillets During Storage

ORIGINALITY REPORT

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Riqin Lv, Xingyi Huang, Weitao Ye, Joshua Harrington Aheto, Haixia Xu, Chunxia Dai, Xiaoyu Tian. "Research on the reaction mechanism of colorimetric sensor array with characteristic volatile gases-TMA during fish storage", Journal of Food Process Engineering, 2018 Publication	<1%
2	Shaoyun Chen, Dong Xu, Long Chen, Yu Zhang, Chenglong Hu, Long Zhang, Jian Chen. "Hollow Polyaniline Helical Nanobelts toward Efficient Electrochemical Energy Storage and Adsorption Performance", ACS Applied Polymer Materials, 2023 Publication	<1%
3	Klug, Katherine E.. "Novel Portable Sensors and Techniques for Improving On-Site Water Quality and Environmental Monitoring.", The University of Arizona, 2018 Publication	<1%

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Monica Yumnam 14/6/24