

**PROCESSING OF WILD YAM (*DIOSCOREA* SPP.) FOR  
DEVELOPMENT OF FUNCTIONAL FOODS**

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**By**

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Submitted

in fulfilment of the requirements of degree of Doctor of Philosophy  
to the



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*“Dedicated to My Late Father  
&  
Beloved Mother”*

## **CERTIFICATE**

This is to certify that the thesis entitled “**Processing of wild yam (*Dioscorea spp.*) for development of functional foods**”, being submitted by Ms. Monalisa Sahoo to the Indian Institute of Technology Delhi for the award of “Doctor of Philosophy” is a record of bonafide research work carried out by her. She has worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis. To the best of our knowledge, the results contained in this thesis have not been submitted in part or full to any other university or institute for the award of any degree or diploma.

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## ABSTRACT

Rising population, malnutrition, post-harvest losses, food insecurity and alarming prevalence of chronic diseases are the primary challenges that motivated to conduct scientific investigation on indigenous dietary sources. Root and tubers are the second major staple food sources after cereals and grains. Yam is the fourth most important tuber crop after potato, sweet potato and cassava. Thus, this Ph.D. thesis aimed to explore and utilize the under-utilized root and tubers such as yams for processing into value-added functional food products. The primary objective of this research was to document indigenous knowledge on the processing and utilization of root and tubers, the intervention of processing methods for lesser-known tubers, pre-treatment for removal of antinutrients, drying technology for enhanced shelf life and long-term storage and develop healthy food products.

A preliminary survey was conducted in the tribal area of Athamallik block, India for various roots and tubers. Based on the survey, the maximum popular and available three yam species, i.e., *karba kanda (Dioscorea pentaphylla)*, *masiha kanda (Dioscorea bulbifera)* and *kulhia kanda (Dioscorea hispida)* were selected for this study. Prior to the application as product development, the yam species were physicochemically characterized to assess the potentiality of these yam species towards various applications for food formulations. By evaluating the physicochemical properties, it was determined that all three species are starchy tubers rich in antioxidants, phenolics, and minerals. However, antinutrients such as oxalate, phytate, saponin, tannin and inhibitors were also recorded, which limits their comprehensive utilization. But the indigenous people process these tubers conventionally before consumption and use for various medicinal purposes.

To address the issue of antinutrients at domestic or industrial level, different processing methods such as boiling, steaming or autoclaving and soaking were employed for different time periods to remove or reduce the phytate, oxalate, tannin, saponin, trypsin inhibitors and  $\alpha$ -amylase inhibitors in the three yam species. All the treatment conditions significantly reduced the antinutrients, but boiling for 25 min was the most suitable for maximum removal of antinutrients. The level of reduction differed from one species to another due to variations in composition and

structure. Similar to the antinutrients, bioactive compounds and antioxidants were also significantly affected by different processing conditions. SEM micrographs, FTIR and XRD, revealed the structural changes after pre-treatment. In comparison to soaking and steaming, boiling severely influenced the morphology changes, which showed clearly visible starch damage. The drying experiment was conducted after successfully establishing the required protocol for quickly removing antinutrients.

Drying is a crucial unit operation in the post-harvest processing of perishable commodities. Thus, to produce safe dried products or flour from yams, the drying of pre-treated yam slices was conducted. Six different drying methods, including both the conventional and modern drying techniques such as sun drying (one sunlight day or 10h), shade drying (48h), hot air drying (60°C, 10h), microwave drying (450 watt, 35min), infrared drying (450 watt, 4h) and freeze-drying (-55°C, 48h) for untreated yam slices were employed for the drying experiments. All six different drying methods had a significant effect ( $p \leq 0.05$ ) on the physicochemical, structural, functional, morphological and pasting properties of yam flour. Furthermore, it was noticed that the influence of various drying methods has differed from one species to another species. Modern drying methods reduced the moisture content below the safe limit ( $< 10\%$ ) than the conventional methods ( $> 13\%$ ) for the given drying time. Different drying methods showed significant ( $p \leq 0.05$ ) effects on the diffraction pattern, functional groups, SEM morphology, pasting properties, functional properties, color attributes, antioxidants and nutritional properties of yam flour. Upon thermal processing of yam (pre-treatment and drying), the resistance starch content was reduced compared to freeze-dried one. Based on certain nutritional parameters (Starch, protein, resistance starch (RS), total phenolic content, total flavonoid content, DPPH scavenging activity and ferric reducing antioxidant power), shade drying, microwave drying and hot air drying were found to be suitable for *D. pentaphylla*, *D. bulbifera* and *D. hispida*, respectively. Thus, Shade dried yam flour of *D. pentaphylla* and microwave-dried *D. bulbifera* flour were used for application in product development.

Snacks are extensively consumed and constitute a significant portion of the human diet as a source of energy. Gluten-free yam flour-based functional cookies were prepared by incorporating varied proportions of yam flour (100-50%) and chickpea flour (0-50%). The formulated cookies were optimized based on the sensory score using Fuzzy logic analysis. Based on fuzzy logic

analysis, the cookie samples containing 60% yam and 40% chickpea flour showed the highest similarity value, mostly liked by the consumers in both the yam species. Adding chickpea flour enhanced the protein content, resistance starch and whiteness index of the prepared cookies. The RS of P60 (cookies containing 60% *D. pentaphylla* flour) and B60 (cookies containing 60% *D. bulbifera* flour) was 35.23% and 31.64%. The biological value and protein efficiency ratio of B60 (89.58%, 3.19) was higher than that of P60 (79.44%, 2.93). The findings of this study indicated that using these lesser-known yams to produce functional cookies is technically feasible and can be processed or developed phytonutrient rich snack products.

Similarly, another snacks product, extrudates, were formulated by mixing yam flour of Guinea yam (*Dioscorea cayenensis*) (100-70%, chick pea (0-15%) flour and sugar kelp flour (0-15%). The crude fat, protein, ash and moisture content ranged between 1.21-3.05%, 4.14-7.19%, 1.40-4.64% and 4.96-15.09%, respectively. Sample Y<sub>75</sub>C<sub>10</sub>S<sub>15</sub> (75% yam, 10% chickpea and 15% sugar kelp flour) and Y<sub>80</sub>C<sub>10</sub>S<sub>10</sub> (80% yam, 10% chickpea and 10% sugar kelp flour) were shown to have comparatively high nutritional value within unblanched and blanched samples. Adding chickpea and sugar kelp flour improved the extrudates' minerals, protein, fat and ash content. Thermally blanched yam flour-based extrudates exhibited higher antioxidants than unblanched yam flour-based extrudates. Like the cookies, yam-chickpea-sugar kelp-based extrudate processing is feasible and can be industrially produced. Utilizing the unexplored yams in the production of food products will increase their usage and aid in the battle against poverty, hunger, and chronic illnesses. In addition, using yam (an alternative carbohydrate source) in food production is a smart way to reduce postharvest losses and contributes to food and nutrition security, particularly in underdeveloped nations.

## सारांश

बढ़ती जनसंख्या, कुपोषण, फसल कटाई के बाद के नुकसान, खाद्य असुरक्षा और पुरानी बीमारियों की खतरनाक व्यापकता प्राथमिक चुनौतियां हैं जो स्वदेशी आहार स्रोतों पर वैज्ञानिक जांच करने के लिए प्रेरित हैं। अनाज के बाद जड़ और कंद दूसरे प्रमुख मुख्य खाद्य स्रोत हैं। आलू, शकरकंद और कसावा के बाद रतालू चौथी सबसे महत्वपूर्ण कंद फसल है। इस प्रकार, इस पीएचडी थीसिस का उद्देश्य मूल्य वर्धित कार्यात्मक खाद्य उत्पादों में प्रसंस्करण के लिए कम उपयोग किए गए जड़ और कंद जैसे कि रतालू का पता लगाना और उपयोग करना। इस शोध का प्राथमिक उद्देश्य जड़ और कंद के प्रसंस्करण और उपयोग पर स्वदेशी ज्ञान का दस्तावेजीकरण करना, कम ज्ञात कंदों के लिए प्रसंस्करण विधियों का हस्तक्षेप, एंटीन्यूट्रिएंट्स (antinutrients) को हटाने के लिए पूर्व-उपचार, बढ़ी हुई शैल्फ लाइफ और दीर्घकालिक भंडारण के लिए सुखाने की तकनीक और स्वस्थ खाद्य उत्पादों को विकसित करना।

विभिन्न जड़ों और कंदों के लिए भारत के अथमल्लिक ब्लॉक के आदिवासी क्षेत्र में प्रारंभिक सर्वेक्षण किया गया था। सर्वेक्षण के आधार पर, अधिकतम लोकप्रिय और उपलब्ध तीन रतालू प्रजातियों यानी, करबा कंद (डायोस्कोरा पेंटाफिला), मासिहा कंद (डायोस्कोरा बल्बिफेरा) और कुल्हिया कंद (डायोस्कोरा हिस्पिडा) को इस अध्ययन के लिए चुना गया। उत्पाद विकास के रूप में आवेदन करने से पहले, खाद्य योगों के लिए विभिन्न अनुप्रयोगों के प्रति इन कंद प्रजातियों की क्षमता का आकलन करने के लिए कंद प्रजातियों को भौतिक-रासायनिक रूप की विश्लेषण व्याख्या की गई। भौतिक रासायनिक गुणों का मूल्यांकन करके, यह निर्धारित किया गया था कि सभी तीन प्रजातियां एंटीऑक्सिडेंट, फेनोलिक, खनिजों से भरपूर स्टार्च वाले कंद हैं। हालांकि, ऑक्सालेट, फाइटेट, सैपोनिन, टैनिन और इनहिबिटर जैसे एंटीन्यूट्रिएंट्स भी दर्ज किए गए थे जो उनके व्यापक उपयोग को सीमित करते हैं। लेकिन स्वदेशी लोग इन कंदों को खपत से पहले पारंपरिक रूप से संसाधित करते हैं और विभिन्न औषधीय प्रयोजनों के लिए उपयोग करते हैं।

घरेलू या औद्योगिक स्तर पर एंटीन्यूट्रिएंट्स के मुद्दे को हल करने के लिए, तीन रतालू प्रजातियों में फाइटेट, ऑक्सालेट, टैनिन, सैपोनिन, ट्रिप्सिन इनहिबिटर और  $\alpha$ -एमाइलेज इनहिबिटर को हटाने या कम करने के लिए अलग-अलग समय अवधि के लिए विभिन्न प्रसंस्करण विधियों जैसे उबालना (boiling), स्टीमिंग (steaming) या ऑटोक्लेविंग (autoclaving) और भिगोना (soaking) का उपयोग किया गया था। सभी उपचार स्थितियों ने एंटीन्यूट्रिएंट्स को काफी कम कर दिया लेकिन 25 मिनट के लिए उबालना एंटीन्यूट्रिएंट्स को अधिकतम हटाने के लिए सबसे उपयुक्त पाया गया। संरचना में भिन्नता के कारण कमी का स्तर एक

प्रजाति से दूसरी प्रजाति में भिन्न होता है। एंटीन्यूट्रिएंट्स के समान, बायोएक्टिव यौगिक और एंटीऑक्सिडेंट भी विभिन्न प्रसंस्करण स्थितियों से काफी प्रभावित थे। एसईएम माइक्रोग्राफ (SEM micrographs), एफटीआईआर (FTIR) और एक्सआरडी (XRD) ने पूर्व-उपचार के बाद संरचनात्मक परिवर्तनों का खुलासा किया। भिगोने और स्टीमिंग की तुलना में, उबलने से आकृति विज्ञान में परिवर्तन गंभीर प्रभाव पड़ा जो स्टार्च क्षति के स्पष्ट दृश्यमान दिखाता है। एंटीन्यूट्रिएंट्स को तुरंत हटाने के लिए आवश्यक प्रोटोकॉल को सफलतापूर्वक स्थापित करने के बाद, सुखाने का प्रयोग किया गया था।

जल्दी खराब होने वाली वस्तुओं की कटाई के बाद के प्रसंस्करण में सुखाने (drying) का एक महत्वपूर्ण इकाई संचालन है। इस प्रकार, रतालू से सुरक्षित सूखे उत्पादों या आटे का उत्पादन करने के लिए, पूर्व-उपचारित रतालू स्लाइस को सुखाया गया था। पारंपरिक और आधुनिक सुखाने की छह अलग-अलग सुखाने के तकनीकों जैसे सूरज सुखाने (एक धूप दिन या 10 घंटे) (sun drying), छाया सुखाने (48 घंटे) (Shade drying), गर्म हवा सुखाने (60 डिग्री सेल्सियस, 10 घंटे) (hot air drying), माइक्रोवेव सुखाने (450 वाट, 35 मिनट) (microwave drying), इन्फ्रारेड सुखाने (450 वाट, 4 घंटे) (infrared drying) और फ्रीज सुखाने (-55 डिग्री सेल्सियस, 48 घंटे) (freeze drying) को सुखाने के प्रयोगों के लिए नियोजित किया गया था। इसके अलावा, यह देखा गया कि, विभिन्न सुखाने के तरीकों का प्रभाव एक प्रजाति से दूसरी प्रजाति में भिन्न था। आधुनिक सुखाने के तरीकों ने दिए गए सुखाने के समय के लिए पारंपरिक तरीकों (>13%) की तुलना में सुरक्षित सीमा (<10%) से नीचे नमी सामग्री (Moisture content) को कम कर दिया। विभिन्न सुखाने के तरीकों ने विवर्तन पैटर्न, कार्यात्मक समूहों, एसईएम आकृति विज्ञान, पेस्टिंग गुणों, कार्यात्मक गुणों, रंग विशेषताओं, एंटीऑक्सिडेंट और रतालू के आटे के पोषण गुणों पर महत्वपूर्ण ( $P \leq 0.05$ ) प्रभाव दिखाया। रतालू के थर्मल प्रसंस्करण (प्रथागत और सुखाने) पर फ्रीज सूखे की तुलना में प्रतिरोध स्टार्च सामग्री कम हो गई थी। कुछ पोषण संबंधी मापदंडों (स्टार्च, प्रोटीन, आरएस, टीपीसी, टीएफसी, डीपीपीएच और एफआरएपी) के आधार पर, छाया सुखाने, माइक्रोवेव सुखाने और गर्म हवा सुखाने को क्रमशः डी पेंटाफिला (*D. pentaphylla*), डी बल्बिफेरा (*D. bulbifera*) और डी हिस्पिडा (*D. hispida*) के लिए उपयुक्त पाया गया। इस प्रकार, उत्पाद विकास में आवेदन के लिए छाया सूखे डी पेंटाफिला और माइक्रोवेव सूखे डी बल्बिफेरा रतालू आटे का उपयोग किया गया था।

सैक्स का बड़े पैमाने पर सेवन किया जाता है और ऊर्जा के स्रोत के रूप में मानव आहार का एक महत्वपूर्ण हिस्सा बनता है। लस (gluten) मुक्त रतालू आटा आधारित कार्यात्मक कुकीज़ को रतालू के आटे

(100-50%) और काबुली चना के आटे (0-50%) के विभिन्न अनुपातों को शामिल करके तैयार किया गया था। तैयार कुकीज़ को फजी लॉजिक (fuzzy logic) विश्लेषण का उपयोग करके संवेदी स्कोर के आधार पर अनुकूलित किया गया था। फजी लॉजिक विश्लेषण के आधार पर, तैयार कुकीज़, जिनमें 60% रतालू और 40% छोले का आटा होता है, ने उच्चतम समानता मूल्य दिखाया, जो ज्यादातर दोनों रतालू (yam) प्रजातियों में उपभोक्ताओं द्वारा पसंद किया जाता है। काबुली चने के आटे के कारण तैयार कुकीज़ के प्रोटीन सामग्री, प्रतिरोध स्टार्च और सफेदी सूचकांक (whiteness index) में वृद्धि हुई। पी 60 (60% डी पेंटाफिला आटा युक्त कुकीज़) और बी 60 (कुकीज़ जिसमें 60% डी बल्बिफेरा आटा होता है) का आरएस (RS) 35.23% और 31.64% था। बी 60 का जैविक मूल्य और प्रोटीन दक्षता अनुपात (89.58%, 3.19) पी 60 (79.44%, 2.93) की तुलना में अधिक था। इस अध्ययन के निष्कर्षों ने संकेत दिया कि कार्यात्मक कुकीज़ के उत्पादन के लिए इन कम ज्ञात रतालू का उपयोग करना तकनीकी रूप से संभव है और इसे संसाधित या विकसित फाइटोन्यूट्रिएंट समृद्ध स्नैक्स उत्पादों को संसाधित या विकसित किया जा सकता है।

इसी तरह, एक अन्य स्नैक्स उत्पाद, एक्सट्रूडेट्स (extrudates) को गिनी रतालू (डायोस्कोरा केयेनसिस) (Guinea yam) (*Dioscorea cayenensis*) (100-70%), काबुली चना के आटे (0-15%) और चीनी केल्व (sugar kelp) (0-15%) के आटे को मिलाकर तैयार किया गया था। कच्चे वसा (crude fat), प्रोटीन (protein), राख (ash) और नमी (moisture content) की मात्रा क्रमशः 1.21-3.05%, 4.14-7.19%, 1.40-4.64% और 4.96-15.09% के बीच थी। सैंपल Y75C10S15 (75% रतालू, 10% चना और 15% चीनी केल्व आटा) और Y80C10S10 (80% रतालू, 10% चना और 10% चीनी केल्व आटा) को बिना ब्लैंच और ब्लैंच किए गए नमूनों के भीतर तुलनात्मक रूप से उच्च पोषण मूल्य दिखाया गया है। काबुली चना और चीनी केल्व आटे के कारण एक्सट्रूडेट्स के खनिज, प्रोटीन, वसा और राख सामग्री में सुधार हुआ। थर्मली ब्लैंच रतालू के आटे पर आधारित एक्सट्रूडेट्स ने बिना ब्लैंच रतालू के आटे पर आधारित एक्सट्रूडेट्स की तुलना में उच्च एंटीऑक्सिडेंट का प्रदर्शन किया। कुकीज़ के समान, रतालू-छोले-चीनी केल्व आधारित एक्सट्रूडेट्स प्रसंस्करण संभव है और औद्योगिक रूप से उत्पादित किया जा सकता है। खाद्य उत्पादों के उत्पादन में अस्पष्टीकृत रतालू का उपयोग करने से न केवल उनके उपयोग में वृद्धि होगी, बल्कि गरीबी, भूख और पुरानी बीमारियों के खिलाफ लड़ाई में भी सहायता मिलेगी। इसके अलावा, खाद्य उत्पादन में रतालू (एक वैकल्पिक कार्बोहाइड्रेट स्रोत) का उपयोग करना पोस्टहार्वेस्ट नुकसान (postharvest losses) को कम करने का एक स्मार्ट तरीका है और विशेष रूप से अविकसित देशों में खाद्य और पोषण सुरक्षा में योगदान देता है।

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## LIST OF SYMBOLS

DW: Distilled water

h: hour

HCl: Hydrochloric acid

HNO<sub>3</sub>: Nitric acid

I<sub>2</sub>: Iodine

KI: Potassium iodide

KOH: Potassium hydroxide

min: minute

mL: milliliter

mm: millimeter

mPas: millipascal second

N: Newton

NaOH: Sodium hydroxide

nm: nanometer

p-value: probability value

r: correlation coefficient

R<sup>2</sup>: co-efficient of determination or regression

rpm: rotation per minute

T: Temperature

v/v: volume by volume

w/v: weight by volume

w/w: Weight by weight

μM: Micro molar

## LIST OF ABBREVIATIONS

AACC: American association for cereal chemists

AIA:  $\alpha$  amylase inhibition activity

ANOVA: Analysis of variance

AOAC: Association of Official Analytical Chemists

BD: Bulk density

BF: *D. bulbifera* flour

BI: Brownness index

BV: Biological value

ChF: Chickpea flour

CI: Crystallinity Index

DNS: 3,5-dinitrosalicylic acid

DPPH: 2,2-Diphenyl-1-picrylhydrazyl

DSC: Differential scanning calorimetry

DTG: Differential thermogravimetric analysis

EAA: Essential amino acid

EAAI: Essential amino acid index

FRAP: Ferric reducing antioxidant power

FTIR: Fourier-Transform Infrared Spectroscopy

HPLC: High-performance liquid chromatography

LE: Lateral expansion

OAC: Oil absorption capacity

PCA: Principal component analysis

PER: Protein efficiency ratio

PF: *D. pentaphylla* flour

PHI: Peak height index

RDS: Readily digestible starch

RS: Resistance starch

SDS: Slowly digestible starch

SP: Swelling power

TAA: Total amino acid

TFC: Total flavonoid content

TGA: Thermogravimetric analysis

TIA: Trypsin inhibition activity

TPC: Total phenolic content

TPTZ: 2,4,6-tripyridyl-s-triazine

WAC: Water absorption capacity

WAI: Water absorption index

WI: Whiteness index

WSI: Water solubility index