# Chapter 7

## Conclusions and future scope

## 7.1 Conclusions

In the present study, the investigation on underutilized culinary banana (*kachkal*) of Assam was carried out with five clearly focused objectives. Effect of ripening stages on biochemical compositions of both pulp and peel of culinary banana was studied in detail at various developmental stages viz. 20 (stage I), 35 (stage II), 50 (stage III), 65 (stage IV) and 80 (stage V) days after emergence of inflorescence (DAE) in order to select the optimized stage of harvesting. In addition, the maturity stage at which the particular compound of interest is at its optimum level was also identified. From the study, it was confirmed that starch was the most abundant compound present in pulp at mature edible stage; therefore, starch was isolated from pulp which was further modified to resistant starch with the aim to incorporate the modified resistant starch into brown bread in order to develop nutritionally rich low glycemic brown bread. The study further revealed that peel of culinary banana is a potential source of cellulose which can add high value to this underutilized crop of local importance, as well as peel being an agro-waste could be utilized in a better way. Therefore, cellulose nanofibers were isolated from peel, which was further utilized in developing cellulose nanopaper that could be used as a reinforcement agent in food packaging. Both pulp and peel had maximum amount of antioxidant compounds during early developmental stages, these antioxidants were extracted and encapsulated in supersaturated solution of sucrose by cocrystallization. The detail characterization of cocrystals encapsulated antioxidants from both pulp and peel were carried out.

Additionally, study on drying of culinary banana was carried out, where the process parameters (viz. drying temperature, sample thickness and pretreatment) for vacuum drying of culinary banana was optimized with the help of ANN/GA. Lastly, using the optimized drying conditions, flour was prepared from culinary banana which was taken for moisture sorption isotherm study, also the antioxidant stability of flour was monitored during storage up to 120 days.

The salient findings of the thesis are summarized below:

## I. Biochemical composition of pulp and peel of culinary banana at various developmental stages and to identify the optimum stage of harvesting

- The nutritional compositions were significantly affected by various growth stages.
- Pulp to peel ratio and total soluble sugars suggest that 50 DAE is the optimum stage of harvesting.
- In case of pulp, ash, protein, fat, phenol content, radical scavenging activity, linoleic acid and linolenic acid gradually declined with maturity.
- A rise in starch content was observed with the maturity of banana, and maximum total carbohydrate was observed at stage III and further declined gradually with advancement of growth.
- Out of 8 minerals tested, magnesium was recorded the highest followed by potassium and zinc irrespective of the developmental stages of banana.
- Essential amino acids were present at all the stages of development. The carotenoids, vitamin A and thiamine were recorded at almost all stages of development of culinary banana.
- In case of peel, phenols, flavonoids and scavenging activity were maximum towards the early development stage.
- Potassium was the abundant mineral present in all stages followed by phosphorous and magnesium.
- Fatty acids in peel were also in higher amount compared to pulp, linoleic and linolenic being dominant.
- Peel at edible mature stage IV was found abundant in cellulose content which could be used as a reinforcement material in high performance biocomposites.
- The culinary banana has potential applications of developing numbers of value added products.
- For instance, the antioxidant activity makes it an excellent ingredient for developing products like cookies, biscuits, bread etc.

- Furthermore, increased accumulation of starch renders mature tissue a potential source for commercial starch extraction, and also presence of considerable amount of amylose could be useful for developing products which can be subjected to high temperature.

## II. Effect of modified resistant starch of culinary banana on physicochemical, functional, morphological, diffraction and thermal properties and its application in development of brown bread

- The yield of isolated starch was 16% with a purity of 96% and the amount of resistant starch (RS) content was 18.88 %.
- The starch exhibited a high pasting temperature indicating high resistant towards swelling, reflecting the ability of starch granules to swell freely.
- Banana starch was found to be the mixture of A and B type polymorphs and functional groups present were typical bands of C-type starch with a mixture of spherical and elliptical granules.
- The pyrolysis of starch occurred between the temperature range of 265.39-331.34$^{o}$C as evinced by TGA thermograms
- In the modified RS, significant morphological changes were observed with increase in starch concentration and in enzyme debranched RS elicited more distinguished modification.
- In partial replacement of wheat flour with RS and culinary banana flour (KF) for developing brown bread revealed that replacement of wheat flour with 10% RS and 10% KF was the best combination from the standpoint of various quality parameters for making brown bread.
- The effect of fortification on quality attributes of brown bread revealed that incorporation of RS and KF up to 10% in substituting wheat flour resulted the bread with high quality attributes in terms of nutrients, yield, texture, colour and sensory analysis with highest score of consumer acceptance.
- The study justified that culinary banana is an excellent source of RS and may be utilized as an alternative source of neutarceutical ingredient for preparing low glycemic functional foods.

## III. Isolation and characterization of cellulose nanofiber from peel and its application in developing nanopaper

- The present study confirmed that culinary banana peel is an interesting source of biomaterial for the production of cellulose nanofibers (CNF).
- TEM microstructure confirmed the presence of nanofibers.
- The high-intensity ultrasonication output power level employed for disintegration and individualization of CNF resulted decrease in diameter and length of each nanofibers with increase in output power level from 0-1000W.
- XRD diffractograms exhibited sharp peaks at $2\theta=16^{o}$ and $2\theta=22^{o}$, which illustrated typical cellulose I form, indicating higher crystallinity of nanofibers.
- The thermal stability of CNF significantly increased when the output power of ultrasonication treatment increased from 0-1000 W.
- Cellulose nanopaper (CNP) developed from isolated CNF revealed that developed CNP possesses high crystallinity, thermal, mechanical and electrical stability
- TEM images confirmed crystallite size in the range of 2.53-3.09 nm as observed in XRD with partial formation of nanotubes.
- The high purity of cellulose in developed CNP was approved by FT-IR and $^{13}C$ NMR of cellulose I.
- The developed CNP exhibited maximum degradation temperature in the region of 226-348$^{o}$C for CNP-UT and 239-366$^{o}$C for CNP-T with outstanding load bearing characteristic, high tensile strength, high Young's modulus and low strain-to-failure ratio and are excellent properties for the biomaterial to be used as a reinforcement agent. In addition, higher zeta potential also proved that the developed CNP is electrically and thermally stable.
- Thus CNP has credible evidence for the production of high performance biocomposites and is considered as one of the potent renewable reinforcement agent for using in the field of food packaging industries.

## IV Encapsulation of natural antioxidant from culinary banana pulp and peel

- Natural antioxidant extracted using aqueous medium from both pulp and peel of culinary banana at early developmental stage (20 DAE) at different concentration (3, 5 and 10 g) was encapsulated by cocrystallization, and the cocrystals obtained with high entrapment yield showed desirable characteristics such as low water content and water activity, high solubility, low hygroscopicity and very good flowability.
- The HPLC chromatographs showed the presence of major phenolic compounds in all the cocrystals.
- The cocrystals studied demonstrated the typical bands of sucrose molecules in FT-IR spectroscopy which was further confirmed by DSC endothermic peak at around 191$^{o}$C showing a typical melting point of sucrose.
- XRD showed similar type of x-ray crystalline pattern of sucrose.
- The results of scanning electron micrograms illustrated basic porous structure corresponding to typical cluster like agglomerates with void spaces and irregular cavities.
- The cocrystallization process resulted in a good alternative to preserve and handle these materials for further application in food products.
- The results of investigation supports the present study can contribute to value addition of natural antioxidant for formulation of functional foods.

## V Drying characteristics and optimization of process parameters in vacuum drying of culinary banana

- The drying characteristics of culinary banana pulp and peel showed Wang and Singh model in case of pulp and modified Page model in case of peel to be the most suitable models having highest $R^2$ and lowest $\chi^2$ values.
- The effective moisture diffusivity ($D_{eff}$) increased with increase in drying temperature.
- Drying temperatures significantly affected the texture, rehydration ratio, nonenzymatic browning and microstructure.

- Antioxidant activity and total polyphenols significantly decreased with increase in drying temperatures.
- SEM images evinced that samples dried at higher temperature had larger pores and better rehydration ratio compared to lower temperature dried samples.
- The information found in this study can be useful in the design, simulation of drying equipment, and the exploitation of culinary banana as a source to obtain many nutritionally rice value added products like bread, noodles, pasta, cookies etc.
- Comparison of the performance of ANN and RSM with their modeling, prediction and optimization using the experimental data for vacuum dehydration process of culinary banana revealed ANN models are found to be capable of better predictions for responses (rehydration ratio, scavenging activity, nonenzymatic browning and hardness) compared to RSM.
- Maximization of responses of rehydration ratio and scavenging activity percentage and minimization of nonenzymatic browning and hardness were obtained through ANN modeling followed by GA optimization process.
- Therefore, ANN proved to be a useful tool for correlation and simulation of vacuum drying parameters of culinary banana.
- Both drying temperature and pretreatment had positive effect on rehydration ratio and the effect of drying temperature was most significant.
- Better quality product with higher scavenging activity was obtained when banana slices of lesser thickness were dried at low temperatures.
- Increased temperature and thickness enhanced enzymatic browning but pretreatment reduced the browning and retained the colour of the product.
- It was proposed that a drying temperature at 76$^{o}$C with citric acid pre treatment of 1% concentration and a sample thickness of 6 mm should be used for vacuum drying of culinary banana slices.
- In addition, it was also suggested that drying temperature of 71$^{o}$C, with 1% citric acid pretreatment and paste thickness of 4 mm could be used for vacuum drying of peel.
- The study on moisture sorption isotherm of culinary banana flour developed at optimized vacuum drying conditions evinced the sigmoid shape resembling type II isotherm which is typical of food material.

- The experimental sorption data were suitably fitted in four-parameter Peleg model giving highest $R^2$ and lowest $R_d$ values and indicated good stability at usual storage conditions.
- The net isosteric heat of sorption of culinary banana flour revealed decrease in increasing moisture content which suggested endothermic reaction in the region of lower moisture content.
- Results favourably support that culinary banana flour can be stored at 25$^{o}$C up to 120 days with minimal degradation of phenolics and antioxidant activity.

## 7.2 Future scope of the present investigation

- As culinary banana has been proved to be the potential source of many functionally important nutrients and bioactive compounds, therefore, the important compound of interest could be isolated at particular stage which could be further incorporated into high value foods.
- The peel, which is often considered as waste is found nutritionally rich, therefore peel could also be utilized more efficiently by isolating compounds like polyphenols, flavoniods, fatty acids, amino acids etc.
- The brown bread developed in the present investigation might be explored further in terms of detail glycemic index study in diabetic as well as healthy animals and humans.
- The developed cellulose nanopaper has potential application in food packaging; further studies like stability of packaging material during storage might be carried out.
- Cellulose nanopaper has huge application as a reinforcement agent for the manufacture of bionanocomposites and can be considered as a renewable source of nanofibres which has an etymology to agro-waste.
- The antioxidant cocrystals might be incorporate into products like jam, jelly, candy and other sugar enriched foods and its stability might be studied.

**List of publications**


1. **Khawas, P.** and Deka, S.C. (2016). Isolation and characterization of cellulose nanofibers from culinary banana peel using high-intensity ultrasonication combined with chemical treatment. Carbohydrate Polymers, 137, 608-616.
2. **Khawas, P.**, Das, A.J. and Deka, S.C. (2016). Production of renewable cellulose nanopaper from culinary banana (*Musa* ABB) peel and its characterization. Industrial Crops and Products, 86, 102-112.
3. **Khawas, P.** and Deka, S. C. Moisture sorption isotherm of underutilized culinary banana flour and its antioxidant stability during storage, Journal of Food Processing and Preservation, DOI:10.1111/jfpp.13087.
4. **Khawas, P.** and Deka, S.C. (2016). Comparative nutritional, functional, morphological and diffractogram study on culinary banana (*Musa* ABB) peel at various stages of development. International Journal of Food Properties, DOI: 10.1080/10942912.2016.1141296.
5. **Khawas, P.** and Deka, S.C. (2016). Effect of modified resistant starch of culinary banana on physicochemical, functional, morphological, diffraction and thermal properties. International Journal of Food Properties, DOI: 10.1080/10942912.2016.1147459.
6. **Khawas, P.** and Deka, S.C. (2016). Encapsulation of natural antioxidant compounds from culinary banana by cocrystallization. Journal of Food Processing and Preservation, DOI:10.1111/jfpp.13033.
7. **Khawas, P.**, Dash, K.K., Das, A.J. and Deka, S.C. (2016). Modeling and optimization of the process parameters in vacuum drying of culinary banana (*Musa* ABB) slices by application of artificial neural network and genetic algorithm. Drying Technology, 34(4), 491-503.
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9. **Khawas, P.**, Das, A.J., Dash, K.K. and Deka, S.C. (2014). Thin layer drying characteristics of *kachkal* banana peel (*Musa* ABB) of Assam, India. International Food Research Journal 21(3) 1011-1018.
10. **Khawas, P.**, Das, A.J., Sit, N., Badwaik, L.S. and Deka, S.C. (2014). Nutritional

composition of culinary *Musa* ABB at different stages of development. American Journal of Food Science and Technology 2(3), 80-87.

11. **Khawas, P.** and Deka, S. C. Effect of partial replacement of wheat flour with type III resistant starch and flour of culinary banana on the chemical composition, textural properties and sensory quality of brown bread. Journal of Food Science and Technology (Under review).
12. **Khawas, P.** and Deka, S. C.A review on utilization and value addition of culinary banana: The potential food for health. Critical Reviews in Food Science and Nutrition. (Communicated).

**Conference/Seminar Presentations**

1. Khawas, P. and Deka, S. C. (2015). Encapsulation of bioactive compounds by cocrystallisation and its application in functional food formulation. National Seminar cum Workshop on Innovative Prospects in Food Processing: Integration of Engineering and Biological Sciences, March 27-28 2015. Organized by Department of Food Engineering &Technology, Tezpur University, Tezpur, Assam, India. (Proceedings Publication pp109-124, ISBN No.978-93-84388-06-5).
2. Khawas, P., Das, A.J., Dash, K.K. and Deka, S.C. (2014). Thin-layer drying characteristics of culinary banana and assessment of physicochemical and microstructural properties in dried banana slices. National Conference on Emerging Technology Trends in Agricultural Engineering, November 7-9, 2014 (ETTAE 2014). Organized by Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar, Arunachal Pradesh. (Proceedings Publication, pp 179-192, ISBN No. 9789383842797).
3. Khawas, P., Das, A.J. and Deka, S.C. (2014). Encapsulation of natural antioxidant compounds from culinary *Musa* by co-crystallization. Paper presented at Vth Scientific workshop on Biotechnology Research in Northeast India Present and Future, September 18$^{t}$ -20 September, 2014. Organized by DBT AAU Centre, Assam Agricultural University, Jorhat-785013. (Proceedings Publication, pp 84-92, ISBN No. 978-81-930496-0-0).

4. Khawas, P., Das, A.J., Das, G. and Deka, S.C. (2013). Biochemical and nutritional compositions of culinary *kachkal* peel (*Musa* ABB) affected by various growth stages. Poster presented at 7th International Food Convention (IFCON 2013), 18-21 December, 2013. Organized by AFSTI, Mysore, CSIR-CFTRI, Mysore, MoFPI, New Delhi, NIFTEM, Haryana, and DFRL, Mysore. (Page 182 of Souvenir).
5. Khawas, P., Deka, S.C., Das, A.J., Sit, N. and Badwaik, L.S. (2013). Development of Type-III resistant starch from culinary banana (*Musa* ABB) of Assam and determination of glycemic index in disease free humans. Paper presented at the International Conference on Innovations in Food Processing, Value Chain Management & Food Safety (IFpvs), January 10- 11, 2013. Organized by National Institute of Food Technology Entrepreneurship and Management (under MOFPI, New Delhi), Kundli, Haryana.
6. Khawas, P., Deka, S.C., Das, A.J. and Sit, N. (2011). Isolation and partial characterization of starch from culinary banana "*Kachkal"* (*Musa* ABB) of Assam. Paper presented at 5th International Conference on "Fermented Foods, Health Status and Social Well Being: Challenges and Opportunities", December 15-16, 2011. Organized by CFTRI, Mysore, India.
7. Khawas, P., Deka, S.C., Das, A.J. and Sit, N. (2011). Biochemical and nutritional composition of culinary *kachkal* (*Musa* ABB) of Assam. Paper presented at National seminar on role of bioactive compounds in foods on human health, November 14-16, 2011. Organized by Department of Food Engineering and Technology, Tezpur University, Napaam, Tezpur, Assam, India.