Optimizing Maturity Indices of Unripe Green Bananas (*Musa spp*. cv. Grand Naine) for Enhanced Resistant Starch Yield

***Kamble R.E.[1], Gadhe K.S.[1], Kshirsagar R.B.[2], Deshpande H.W.[3], Sadawarte S.K.[4] Wadmare V.B.[1], and Mane R.P.[5]**

[1] Department of Food Chemistry and Nutrition, College of Food Technology, VNMKV, Parbhani

[2] Department of Food Engineering, College of Food Technology, VNMKV, Parbhani.

[3] Department of Food Microbiology and Safety, Food Technology, VNMKV, Parbhani.

[4] Department of Food Process Technology, College of Food Technology, VNMKV, Parbhani.

[5] MIT College of Food Technology, Chh. Sambhajinagar (Aurangabad).

ABSTRACT

Unripe green banana flour (UGBF) is gaining prominence as a functional food ingredient due to its high resistant starch (RS) content and associated health benefits. This study aimed to optimize the maturity indices of unripe green bananas (*Musa spp*. cv. Grand Naine) to identify the ideal harvesting stage for maximizing RS yield and functional potential. Bananas were harvested at four distinct stages viz. 75, 90, 105, and 120 days after flowering (DAF) and evaluated for their physical characteristics, chemical attributes total starch, resistant starch content, and percent yield.

Results showed that fruit weight, pulp-to-peel ratio, and total starch increased progressively with maturity, while RS content peaked at 105 DAF (44.73%) before declining, likely due to enzymatic hydrolysis. The percent yield also reached a near-maximum value at 105 DAF (72.29%), with only a marginal increase thereafter. These findings indicate that 105 DAF represents the optimal physiological maturity stage for harvesting unripe green bananas, balancing high edible yield and peak RS content. This study provides a scientific basis for standardizing harvest timing to enhance the nutritional and economic value of UGBF in functional food applications.

KEYWORDS: Unripe green banana (UGB), resistant starch, maturity index, functional food, days after flowering, UGB yield.

1. INTRODUCTION:

Bananas (*Musa paradisica. L*), belongs to the genus Musa and the Musaceae family, are a significant tropical fruit crop with extensive global cultivation and consumption [1]. India's share in global fruit production was about 12.60% in 2023 which is second highest in the world only next to China. India annually produces 26.50 million tonnes of banana for 25.60% of the world's banana which is highest in the world [2]. Maharashtra is the top banana producing state in India and most commonly grown variety of banana in Maharashtra is cultivar Grand Naine [3].

Unripe green banana flour (UGBF) is emerging as a valuable functional food ingredient, primarily due to its high resistant starch content, ranging between 40–50% depending on maturity. The use of UGBF in functional food formulations presents a dual opportunity for value addition and post-harvest waste reduction [4]. Optimizing the maturity indices of unripe bananas is, therefore, critical for maximizing resistant starch yield and enhancing product functionality.

2. METHODOLOGY:

2.1 Optimal harvesting period for UGB

UGB (cv. Grand Naine) were collected at specific intervals after flowering from the local farms in Parbhani district, measured in days after flowering (DAF). Bananas were harvested at four maturity stages: 75, 90, 105, and 120 DAF.

- i) Harvesting at 75 days
- ii) Harvesting at 90 days
- iii) Harvesting at 105 days
- iv) Harvesting at 120 days

2.2 Assessment of physical and chemical characteristics of UGB

Banana fruits harvested at different maturity levels were assessed for physical and biochemical traits for standardization of maturity parameters as per the procedure described.

2.2.1 Weight of UGB, Weight of UGB Pulp and Peel:

Randomly selected ten fruits were measured individually for weight. The weight of the UGB, including the individual weights of the pulp and peel, was measured using an electronic balance. This method allowed for precise quantification of the various components of the fruit, ensuring accurate data collection for the study.

2.2.2 Angularity of UGB

Fruit angles were determined at 3 points on the outer surface by measuring individual fruit with a stainless-steel protractor. Angularity of fruit was expressed as degree. The angle established between the baseline and the tangent at the point of contact was meticulously documented in degrees. This procedure was systematically replicated for all three measurement points on each individual banana. Following the documentation of the measurements, the mean angularity was computed by aggregating the three angles and dividing by three. This resultant average value served to encapsulate the overall angularity of the banana [5].

2.2.3 Peel Colour of UGB

The colour of UGB peels was evaluated through physical observation and recorded at different maturity stages. This assessment provided insights into the gradual changes in peel colour, which serve as an indicator of fruit development and ripeness.

2.2.4 Pulp to peel ratio

The green banana was peeled manually using a sharp knife. The pulp to peel ratio was determined by dividing the mass of pulp by mass of peel with the help of electronic balance having least count of 0.01. Pulp and peel were separated, weighed individually and expressed as pulp to peel ratio (i.e. pulp weight divided by the peel weight) [6].

$$\textbf{Pulp to peel ratio (\%)} = \frac{\text{Weight of Pulp}}{\text{Weight of Peel}} \times 100$$

2.2.5 Percent yield

The percent yield of the banana fruit was determined by measuring the total fruit weight, the weight of the edible portion, and the weight of the peel and other inedible components. The yield was calculated using the formula:

$$\textbf{\% Yield} = \frac{\text{Weight of edible portion of fruit}}{\text{Total weight of fruit}} \times 100$$

2.2.6 pH

The pH was determined by using a digital pH meter (ELICO LI 612), before initiating the measurements, the pH meter was calibrated utilizing buffer solutions at pH 4.0 and pH 7.0 to ascertain the accuracy of the measurements [7].

2.2.7 Total acidity

The total acidity of unripe green bananas (UGB) was determined using the standard titration method. The total acidity was expressed as a percentage of citric acid equivalent using the following formula.

$$\text{Total Acidity} = \frac{(\text{Volume of NaOH (mL)} \times \text{Normality of NaOH} \times \text{Equivalent weight of citric acid} \times 100)}{\text{Volume of sample (mL)}}$$

2.2.8 TSS

The total soluble solids (TSS) content of unripe green bananas was measured using a hand refractometer. The measurement procedure followed the methodology described by [8], ensuring the use of a well-established and widely recognized technique in food science.

2.2.9 Reducing Sugars

The reducing sugar content of unripe green bananas was determined using the Lane and Eynon method, which is based on the principle of Fehling's solution reduction by reducing sugars. Fehling's solution, a mixture of copper sulfate (Fehling's A) and alkaline Rochelle salt (Fehling's B), reacts with reducing sugars to form red, insoluble cuprous oxide. To perform the analysis, Fehling's factor was first determined by titrating a standard invert sugar solution against Fehling's reagent to establish the amount of sugar required for complete reduction. The banana sample was then extracted and titrated against Fehling's solution using methylene blue as an oxidation-reduction indicator. The endpoint was identified by the decolourization of methylene blue, indicating the complete reduction of cupric ions. The reducing sugar content was then calculated based on the volume of the sample required for the reaction, ensuring an accurate quantification of the sugars present in unripe green bananas.

2.2.10 Total Starch

The total starch content was determined by acid hydrolysis, followed by quantification using the Lane and Eynon method. A known weight of dried banana pulp was hydrolyzed with HCl, neutralized with NaOH, and titrated using Fehling's solution. The starch content was calculated by applying a conversion factor of 0.9.

2.2.11 Resistant Starch

Resistant starch content was determined using the Megazyme K-RSTAR Kit (AACC Methods 32-40.01 and 76-13.01). Samples (100 mg) were enzymatically treated to remove digestible starch. RS was extracted with 2M KOH, precipitated with ethanol, and quantified using GOPOD reagent at 510 nm. Results were expressed as g RS per 100 g of sample, later on converted to % of total starch, with all measurements done in triplicate.

2.3 Statistical Analysis

The data of all experimental treatments were statistically analysed by Completely Randomized Design (CRD) using analysis of variance (ANOVA) by Panse and Shukhatame, method. The analysis of variance revealed at the significance of S.E. and C.D. at 5 per cent level is mentioned wherever required.

3. RESULTS:

3.1 Optimization of Maturity Indices of Unripe Green Bananas (UGB)

Maturity index is considered as one of the most important influential quality determination factors in postharvest handling of horticultural produce. It serves as a guidance in estimating the right maturity stage for harvesting. The criteria for maturity, which differ among varieties and species.

3.1.1 Physical Characteristics of Banana at various stages of harvesting stages days after flowering (DAF) of cultivar Grand Naine

Unripe green bananas (cv. Grand Naine) were harvested at 75, 90, 105, and 120 DAF to evaluate the evolution of physical characteristics, including peel colour, weight, angularity, and pulp-to-peel ratio.

The peel colour transitioned from dark green at 75 DAF to green with yellow marks at 120 DAF, indicating progressive maturity over time. This is a visual marker commonly associated with the onset of fruit ripening. Whereas the fruit weight exhibited a gradual increase from 88.76 g at 75 DAF to a peak of 139.47 g at 120 DAF. This increase reflects the accumulation of reserves in the pulp as the fruit matures. Angularity showed a fluctuating trend, with a peak value of 226.12° at 90 DAF followed by a decline to 138.31° at 120 DAF. This could be attributed to the loss of angular edges as the fruit approaches full ripeness.

The weight of the pulp increased consistently from 53.11 g at 75 DAF to 104.3 g at 120 DAF, while the weight of the peel demonstrated minor variations, peaking at 37.24 g at 105 DAF before declining to 35.47 g at 120 DAF. The pulp-to-peel ratio showed a significant increase from 1.53 at 75 DAF to 3.33 at 105 DAF, demonstrating an enrichment of edible pulp relative to the peel as maturity progresses. Interestingly, this ratio slightly declined to 2.04 at 120 DAF, suggesting possible changes in peel composition at later stages. This pattern indicates a shift in the pulp-to-peel ratio as the fruit ripens. The increase in banana weight during maturation is primarily due to starch accumulation in the pulp, which later converts into sugars like glucose, fructose, and sucrose, adding mass. Additionally, water uptake and cell expansion contribute significantly to the weight gain as the fruit grows and ripens. Similar findings have been reported by [9]

Table 3.1: Physical characteristics of banana at various stages of harvesting stages days after flowering (DAF) of (cv. Grand Naine)

Harvesting DAF	Peel Colour	Fruit Weight (g)	Angularity (°)	Weight of Pulp (g)	Weight of Peel (g)	Pulp to Peel Ratio
75	Dark Green	88.76	121.6	53.11	28.85	1.53
90	Green	109.52	226.12	60.15	27.62	2.08
105	Light Green	136	133.5	98.22	37.24	3.33
120	Green with Yellow Marks	139.47	138.31	104.3	35.47	2.04
SE±		0.009428	0.118126	0.013744	0.01587	0.011941
CD @5%		0.029051	0.363982	0.042349	0.0489	0.036795

*Each value is a mean if three determinations

3.1.2 Chemical Characteristics of Banana at various stages of harvesting stages days after flowering (DAF) of cultivar Grand Naine

Table 3.2 presents the variation in key chemical parameters pH, total acidity (% citric acid equivalent), total soluble solids (TSS, in °Bx), and reducing sugars (mg/g) of unripe green bananas (cv. Grand Naine) harvested at different maturity stages. The pH values ranged narrowly from 5.35 to 5.41, reflecting a stable acid-base balance during maturation. Total acidity decreased slightly from 0.64% at 75 DAF to 0.60% at 120 DAF, this trend is attributed to the utilization of organic acids during metabolic activities associated with fruit development. Both parameters showed no statistically significant variation. The TSS (Total Soluble Solids), which is an indicator of sugars and other soluble compounds, increased progressively with maturity from 2.1°Bx at 75 DAF to 4.2°Bx at 120 DAF. This rise highlights the accumulation

Table 3.2: Chemical Characteristics of unripe green bananas at various stages of harvesting stages days after flowering (DAF) of (cv. Grand Naine)

Harvesting DAF	pH	Total Acidity (%)	TSS (°Bx)	Reducing Sugars (mg/g)
75	5.4	0.64	2.1	3.42
90	5.39	0.61	2.7	3.66
105	5.41	0.63	3.2	4.19
120	5.35	0.60	4.2	5.09
SE±	0.095762	0.01472	0.080921	0.009718
CD @5%	0.295072	0.045356	0.249341	0.029945

*Each value is a mean if three determinations

of sugars and other soluble components as the fruit matures. Reducing sugar content exhibited a consistent increase, peaking at 5.09 mg/g at 120 DAF, signifying enzymatic conversion of starch to simple sugars during ripening. The data reflect a gradual chemical transformation in unripe green bananas with advancing maturity. While pH and acidity remained relatively stable, both TSS and reducing sugar content increased notably, signifying active starch degradation and sugar accumulation. These findings are in close agreement with the results reported by [10,11], who observed a similar trend in TSS and reducing sugars during ripening These changes are important indicators for determining the optimal harvest time, particularly when targeting functional food applications such as high-resistant starch flour.

3.2 Total Starch and Resistant Starch in UGB at various stages of harvesting stages days after flowering (DAF) of cultivar Grand Naine

The Table 3.3 illustrates the changes in Total Starch (TS%) and Resistant Starch (RS%) content in unripe green bananas (UGB) of cultivar Grand Naine harvested at different maturity stages, The Total Starch (TS%) content showed a consistent and significant increase with advancing maturity from 16.33% at 75 DAF to 24.22% at 120 DAF. This trend indicates the progressive accumulation of starch in the fruit pulp as it matures, reflecting enhanced carbohydrate biosynthesis during fruit development.

In contrast, the Resistant Starch (RS%) content followed a different pattern. RS increased from 36.68% at 75 DAF to a peak of 44.73% at 105 DAF, indicating the highest concentration of indigestible starch at this stage. However, RS content declined to 36.38% at 120 DAF, despite the continued increase in total starch. This reduction in RS at full maturity is due to enzymatic hydrolysis of resistant starch into digestible forms like simple sugars, as ripening advances, as reported in the findings of [12, 13].

Table 3.3: Total Starch and Resistant Starch Content of UGB at various stages of harvesting

Harvesting Days after Flowering	TS (%)	RS (%)
75	16.33	36.68
90	18.54	38.92
105	22.45	44.73
120	24.22	36.38
SE±	0.014011	0.013608
CD @5%	0.043171	0.041931

*Each value is a mean if three determinations

The Standard Error (SE±) values for TS (0.014011) and RS (0.013608) indicate low variability among replicates, confirming the reliability of the data. The Critical Difference (CD) at 5% was 0.043171 for TS and 0.041931 for RS, suggesting that differences exceeding these values are statistically significant. While total starch accumulation increases linearly with maturity, resistant starch reaches its optimum at 105 DAF and declines thereafter. This finding implies that 105 DAF is the most suitable harvest stage for maximizing functional starch content, especially for food applications targeting gut health and glycemic control.

3.3 Yield of UGB at various stages of harvesting

At 75 DAF, the yield was recorded at 57.23%, indicating an early developmental stage where the edible pulp had not yet accumulated significantly. As the fruit matured, the yield increased to 63.58% at 90 DAF, followed by a substantial rise to 72.29% at 105 DAF. This marked increase suggests a rapid buildup of pulp mass and physiological maturity of the fruit. By 120 DAF, the yield reached 75.12%, showing only a marginal increase over 105 DAF. This slight gain indicates that the fruit had reached its full maturity, and further increase in pulp content was minimal. Similar findings were recorded by [14,15]

The standard error (SE±) for yield was 0.12536, indicating high consistency and low variability among replicates. The critical difference (CD) at the 5% significance level was 0.41133, which means that differences in yield greater than this value are statistically significant. The difference between 105 and 120 DAF (0.83%) is above the CD value but relatively small, suggesting a plateau in yield gain beyond 105 DAF.

Table 3.4: Yield of UGB at various stages of harvesting

Harvesting Days after Flowering	**Yield (%)**
75	57.23
90	63.58
105	72.29
120	75.12
SE±	0.12536
CD @5%	0.41133

*Each value is a mean if three determinations

Therefore, 105 DAF appears to be the optimal stage for harvesting UGB, offering a high pulp content without compromising on functional qualities such as resistant starch content, which begins to decline at later and earlier stages. These findings support 105 DAF as the most suitable harvesting time for maximizing both yield and nutritional quality in unripe green bananas intended for functional food applications.

CONCLUSION:

The present study evaluated the physical, chemical, and nutritional attributes of unripe green bananas (cv. Grand Naine) harvested at different maturity stages (75, 90, 105, and 120 days after flowering) to determine the optimal harvest time for maximizing resistant starch (RS) content and yield. The results revealed that as the fruit matured, parameters such as fruit weight, pulp-to-peel ratio, and yield progressively increased, with significant improvements observed between 90 and 105 DAF. Chemical analysis showed a gradual rise in total soluble solids and reducing sugars, indicative of starch hydrolysis and metabolic activity during ripening. Although total starch content continued to increase up to 120 DAF, resistant starch peaked at 105 DAF and declined thereafter, likely due to enzymatic conversion into simpler sugars.

The findings demonstrate that 105 DAF represents a critical physiological maturity stage where the fruit exhibits a favorable balance between high yield (72.29%), desirable physical characteristics, and maximum resistant starch content (44.73%). Beyond this stage, further ripening contributes marginally to yield and compromises the RS content. Thus, harvesting unripe green bananas at 105 DAF is optimal for enhancing both the nutritional functionality and economic value of UGB-derived products. These standardized maturity indices serve as a valuable guideline for postharvest handling and processing aimed at functional food development.

REFERENCES:

1. Maseko, K. H., Regnier, T., Meiring, B., Wokadala, O. C., & Anyasi, T. A. (2024). Musa species variation, production, and the application of its processed flour: A review.Scientia Horticulturae. https://doi.org/10.1016/j.scienta.2023.112688
2. FAO. 2023. *World Food and Agriculture – Statistical Yearbook 2023*. Rome. https://doi.org/10.4060/cc8166en
3. Vasane, S. R. (2011). Performance studies of different cultivars of tissue culture raised banana under jalgaon condition. In *V International Symposium on Acclimatization and Establishment of Micropropagated Plants 988* (pp. 143-148).
4. Vaclavik, V. A., & Christian, E. W. (2014). Starches in Food. https://doi.org/10.1007/978-1-4614-9138-5_4
5. Soltani, M., Alimardani, R., & Omid, M. (2011). Some Physical Properties of Full-Ripe Banana Fruit (Cavendish variety). International Journal of Agricultural Science, Research and Technology in Extension and Education Systems.
6. Ayorinde, O. J., Olu-egbor, O. G., Precious, I., & God'sfavour, O. I. (2022). Comparative Analysis of Nutritional and Proximate Compositions of Peel and Pulp of Unripe Plantain. *SunText Review of Virology*, *3*(2), 132.
7. Pragati, S., Genitha, I., & Ravish, K. (2014). Comparative study of ripe and unripe banana flour during storage. *Journal of Food Processing & Technology*, *5*(11), 1-6.
8. Ranganna S 1997 Hand book analysis and quality control for fruit and vegetable products. Publisher –Tata McGraewHill, New Delhi. 182-189.

9. Amin, M. N., Hossain, M. N., Rahim, M. A., & Uddin, M. B. (2015). Determination of optimum maturity stage of banana. *Bangladesh Journal of Agricultural Research*, *40*(2), 189-204.
10. Watharkar, R. B., Chakraborty, S., Srivastav, P. P., & Srivastava, B. (2021). Physicochemical and mechanical properties during storage-cum maturity stages of raw harvested wild banana (Musa balbisiana, BB). *Journal of Food Measurement and Characterization*, *15*, 3336-3349.
11. Watharkar, R. B., Pu, Y., Ismail, B. B., Srivastava, B., Srivastav, P. P., & Liu, D. (2020). Change in physicochemical characteristics and volatile compounds during different stage of banana (Musa nana Lour vs. Dwarf Cavendish) ripening. *Journal of Food Measurement and Characterization*, *14*, 2040-2050.
12. Kanchana, R. & Vaz, Sancia & Reddy, Divya & Antao, Abigail & Shirodkar, Trusha & Ravedar, Surthi. (2020). Sensory Evaluation of Nutritionally Potential High Protein Low Glycemic Index Noodles. Journal of scientific research. 64. 131-134. 10.37398/JSR.2020.640218.
13. Hana Mohd Zaini, Jumardi Roslan, Suryani Saallah, Elisha Munsu, Nurul Shaeera Sulaiman, Wolyna Pindi, Banana peels as a bioactive ingredient and its potential application in the food industry, Journal of Functional Foods, Volume 92, 2022, 105054, ISSN 1756-4646, https://doi.org/10.1016/j.jff.2022.105054.
14. Ahmed, Z. F., Taha, E. M., Abdelkareem, N. A., & Mohamed, W. M. (2020). Postharvest properties of unripe bananas and the potential of producing economic nutritious products. *International Journal of Fruit Science*, *20*(sup2), S995-S1014.
15. Nyanjage, M. O., Wainwright, H., Bishop, C. F. H., & Cullum, F. J. (2001). A comparative study on the ripening and mineral content of organically and conventionally grown Cavendish bananas. *Biological agriculture & horticulture*, *18*(3), 221-234.