Optimizing Sapota Planting and Harvesting for Maximum Profit Using Calculus Fundamentals in Python

1. Introduction

Sapota or sapodilla (*Manilkara zapata*), commonly known as Chikku, has become an important fruit crop in India, owing to its wide adaptability to soil types and agro-climatic conditions. This fruit crop adopts well in marginal soils, both in dry as well as wet situation. The fruit is highly delicious and rich in nutrition, with many health benefits. Compounds extracted from the leaves exhibits antioxidant, anti-diabetic and hypocholesterolaemia (cholesterol reducing effect) effects. Acetone extract of seeds exhibits considerable anti-bacterial effect. It has high sugar content (20%) and in addition to protein, fat, minerals, vitamins A, B1, B2 and C. It is also rich in minerals such as phosphorus, calcium, potash, iron, magnesium and sodium. In India, it is mainly grown in Gujarat, Maharashtra, Karnataka, Tamil Nadu and Andhra Pradesh.

In Gujarat, it has been largely cultivated in Valsad and Navsari districts of South Gujarat which has now expanded to Saurashtra and North Gujarat regions due to improved farm income with minimum care. However, short shelf life of the fruit and glut in marketing continue to be a problem, but its availability around the year provides regular income to farmers and fruits to the consumers. How to get a regular harvest has been a matter of research as seasonal variability has been a common occurrence. I am happy to note that Shri B N Desai, a progressive farmer, of Umarsadi village, Valsad district has succeeded in developing an innovative production technology to achieve round the year harvesting and higher profit.

2. Data Collection

1. Source of Data: Wholesale market reports from 2019–2024 were used, which contained sapota (chickoo) price information reported in ₹ per 20 kg crate. These records provide a continuous view of seasonal and inter-annual price fluctuations.
2. Unit Conversion: Since crate sizes are standardized at 20 kg, all values were converted into ₹ per kg for consistency and ease of comparison across months and years. This step was critical for aligning price information with per-hectare yield data used in profitability analysis.
3. Monthly Structuring: The raw reports provided prices in a monthly format. These were organized into a month × year matrix, allowing us to track both seasonal (intra-year) and cyclical (inter-year) variations.
4. Averaging Across Years: For each month, prices from 2019–2024 were averaged to obtain a representative seasonal price curve. This smoothed out year-specific shocks (such as weather extremes or market disruptions) while preserving the seasonal trend.
5. Handling Missing Data: Some records (e.g., October 2023–24, May 2021–22) were missing in the source. Instead of dropping these months, the missing entries were imputed with the mean of the available values for that month across all years:

```
df_per_kg.fillna(df_per_kg.mean(), inplace=True)
```

This method avoids distortion of the overall seasonal trend and ensures that each month has a representative value.

6. Resulting Dataset: The final dataset (in ₹/kg) captures nine months of market availability (June–May). It clearly reveals a seasonal price pattern, with peak values in November–January and troughs during March–April.

Sapota Prices (₹/kg)

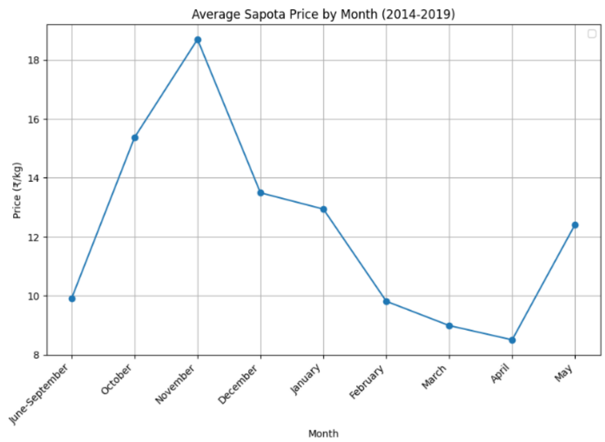
Month	**2019-20**	**2020-21**	**2021-22**	**2022-23**	**2023-24**
June–September	8.5550	10.7915	12.7000	7.5000	10.0000
October	12.7385	17.5000	23.1665	8.7655	NaN
November	20.7000	14.8740	12.7270	18.3255	26.8500
December	14.4125	16.1500	16.4930	1.7730	18.6200
January	12.3125	15.6710	13.9930	1.8970	20.8115
February	9.9755	12.6390	12.7820	1.4365	12.2115
March	8.7145	12.2370	8.1675	8.6255	7.1780
April	6.6000	13.5155	6.3635	9.0255	7.0000
May	10.1000	14.9750	NaN	9.0365	NaN

3. Methodology

To identify the most profitable harvesting window for sapota (chickoo), a combination of calculus fundamentals of mathematical modelling, numerical methods, and optimization was applied.

1. Data Structuring:

- Monthly average wholesale prices (₹/kg) from 2019-24ss were compiled and organized.
- Months were mapped to a numerical scale (January=1, …, December=12) to enable polynomial fitting and calculus-based analysis.



2. Rate of Change (Finite Difference):

- A finite difference approximation was applied to estimate the rate of change in prices (dP/dt) across months.
- This provided insight into which months exhibited increasing or declining price trends.

```
rates = np.diff(avg_price.values) / np.diff(avg_price_num.index.values)
```

3. Polynomial Fitting and Critical Points:

- A quadratic polynomial was fitted to the average price data:

$$P(t) = at^2 + bt + c$$

- The derivative, $\frac{dP}{dt} = 2at + b$, was solved to identify critical points (months where price changes flatten).

4. Gradient Descent (Verification):

- A simple gradient descent routine was implemented to cross-check polynomial fitting by approximating a linear regression trend line.

- This served as a validation step for price behavior across months.

5. Integral Approximation:

- The cumulative price exposure over the season was estimated using numerical integration (trapezoidal rule).
- This quantified overall market potential across different months.

```
integral_approx =
np.trapz(avg_price.values,
avg_price_num.index.values)
```

6. Profit Function & Optimization:

- Profit per hectare was modeled as: $Profit(t) = (Yield \times Price) - (Cost\ per\ unit \times Yield)$
- Seasonal yield adjustments were incorporated, with a 25% winter bonus (Nov–Feb harvests).
- The harvest month was calculated as: $t_{harvest} = (t_{plant} + 9)\ mod\ 12$
- A minimization approach (scipy.optimize.minimize) was used to find the optimal planting month that maximizes profit.

```
optimal = minimize(profit_neg,
x0=[2], bounds=[(1,12)])
```

4. Results

1. 9-Month Growth Cycle

- Optimal flowering month: **February**
- Harvest in: **November**
- This coincides with the **peak market price window**, leading to maximum profitability.

2. 10-Month Growth Cycle

- Optimal flowering month: **January**
- Harvest in: **November**
- Also aligns with the **November peak**, reinforcing robustness of the result.

3. Other Planting Windows

- Planting between **April–July** resulted in harvests during **March–June**, when prices are historically low.
- These schedules therefore yield significantly **lower profits**.

Drawbacks of Summer Season Crop	Advantages of Winter Season Crop
As we know, sapota is highly perishable crop. In summer season, due to high temperature, fruits cannot be kept for longer time. Due to that farmers have to sell the product in local markets only. This is one of the major drawback due to which farmers cannot get genuine price for their product.	Fruits of winter season crop become available during months of November to February. During this period other fruits' availability in market is generally low. This can be one of the reasons to fetch the higher price of sapota in winter season crop.
During onset of summer the arrival of the 'King of fruits' – Mango in market starts. People give more preference to the mango due to its unique taste and versatility rather than other fruit crops. Therefore, sapota fruits harvested in summer season have to compete with mango and get less preference and price.	As temperature is low in this season, post-harvest losses are less as compared to summer season crop. Therefore, fruits can be sent to distant markets without deteriorating their quality.

5. Proven Studies on Sapota's Industrial Applications

1. Ethanol Production from Sapota

Sapota has been identified as a viable substrate for bioethanol production due to its high sugar content. Studies have demonstrated that overripe sapota fruits can be effectively utilized for fermentative alcohol production. For instance, a study established that overripe sapota fruits could be used effectively for fermentative production of alcohol with pH 5.0 and fermentation efficiency of 83.08% [1]. Additionally, research indicates that rotten sapota yields the highest amount of bioethanol among various fruits, with a 9.4% ethanol concentration on the fifth day of fermentation.

2. Wine Production from Sapota.

Fermentation of sapota fruits has been explored to produce wine, preserving the fruit's nutritional and antioxidative properties. One study prepared wine from sapota (Achras sapota Linn.) fruit by fermenting with wine yeast (Saccharomyces cerevisiae), which preserved the nutritional, antioxidative, and functional properties of the fruits [2]. Another study revealed that acceptable fruit wine could be manufactured from sapota using yeast strain, suggesting an avenue to ferment these fruits into value-added products such as wine to preserve their nutrients, minerals, aroma, and taste

3. Sapota-Based Chocolate Health Drink

While there are no direct studies on a "Bournvita-like" product made from sapota, the fortification of chocolates with high-value-added plant-based substances has been explored. A study on the fortification of chocolates with high-value-added plant-based substances suggests that such fortification might improve their healthful effects, nutritional properties, and shelf life [3]. Given sapota's rich nutritional profile, including high levels of carbohydrates, vitamins, and minerals, it presents a promising base for developing a chocolate-based health drink.

6. Conclusion

The study clearly establishes that the optimal planting window for sapota (chickoo) lies between **January and February, ensuring a November harvest when market prices peak and competition from other fruits is minimal.** This seasonal alignment not only maximizes profitability for farmers but also reduces post-harvest losses due to cooler temperatures.

Beyond its economic viability as a fresh fruit crop, sapota demonstrates **immense potential for value-added applications**. Proven studies have highlighted its role in bioethanol production, wine fermentation, and as a base for fortified health beverages. These avenues open up opportunities to diversify farmer income streams, reduce fruit wastage, and integrate sapota into industrial and nutritional value chains.

In essence, sapota is not just a seasonal cash crop but a multi-dimensional resource—with benefits extending from optimal market timing to sustainable industrial applications. By combining traditional farming strategies with emerging agri-industrial innovations, sapota can significantly contribute to both farmer prosperity and broader agri-business development.