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Fruit Volume Unveiled: A Creative Exploration of Non-Destructive Mathematical Modeling Techniques, a Review

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Abstract:

Accurate estimation of fruit volume is crucial for agricultural productivity, supply chain management, and quality control. This study presents a comprehensive exploration of non-destructive mathematical modelling techniques aimed at estimating fruit volume, focusing on innovative approaches that preserve the integrity of the fruit during measurement. We systematically review existing methodologies, including geometric models, imaging techniques, and machine learning algorithms, highlighting their strengths, limitations, and practical applications. Through a meta-analysis of empirical data, we assess the effectiveness and accuracy of these methods across various fruit types. Our findings reveal a trend toward integrating multi-sensor data and advanced computational techniques to enhance precision. This exploration not only provides insights into current practices but also suggests future directions for research and application in agricultural technology, paving the way for sustainable and efficient fruit production.

Objectives: The objective is to evaluate and synthesize various measurement methodologies for assessing fruit integrity, aiming to identify best practices and propose innovative approaches that can improve accuracy and efficiency in agricultural technology.

Methods: study demonstrate a growing emphasis on automation and real-time data collection, which are crucial for optimizing yield and minimizing waste in fruit cultivation.

Results: indicate a significant improvement in measurement accuracy when utilizing hybrid approaches that combine traditional methods with innovative technologies.

Conclusions: In conclusion, the integration of innovative measurement techniques stands to significantly transform the agricultural landscape, promoting better yield assessments and quality control while ensuring that fruit integrity is maintained throughout the process

Keywords: Fruit volume estimation, non-destructive techniques, mathematical modelling, geometric models, imaging techniques, machine learning, meta-analysis, agricultural technology, data integration, sustainable production.

1. Introduction

The accurate estimation of fruit volume plays a vital role in various sectors, including agriculture, food processing, and supply chain management. Understanding fruit volume not only influences market pricing but also impacts post-harvest handling and quality assessment. Traditional methods of measuring fruit volume, often involving physical manipulation or destructive techniques, can lead to loss of product quality and valuable resources.In response to these challenges, non-destructive mathematical modelling techniques have emerged as innovative solutions that allow for accurate volume estimation without compromising the integrity of the fruit. These methods leverage advancements in imaging technology, geometric modelling, and data analytics, offering a range of applications across different fruit types and agricultural contexts.

This study aims to systematically explore and evaluate these non-destructive techniques, providing a comprehensive review of the current landscape. By synthesizing existing research and conducting a meta-analysis of their effectiveness, we seek to unveil the potential of these methods to enhance precision in volume estimation. Furthermore, this exploration highlights emerging trends and future directions in the field, emphasizing the importance of integrating technology and creativity in agricultural practices. Ultimately, our goal is to foster a deeper understanding of non-destructive techniques and their significance in promoting sustainable fruit production and distribution.

2. Methods

In this study, we meticulously reviewed 55 research articles published from 2007 to 2024. Our analytical exploration revealed that the modeling techniques employed by researchers predominantly fell into two distinct categories: statistical modeling and geometric modeling. The heterogeneity analysis yielded an impressive I-square statistic of 88.48%, highlighting a significant diversity within these approaches. To investigate potential publication bias, we conducted Egger's and Begg's tests, both of which provided no substantial evidence of bias. Additionally, we compared the coefficient of determination (R^2) for estimated versus actual fruit volumes across different modeling categories, employing effect measures such as odds ratios, risk ratios, and weighted odds ratios. A sensitivity analysis further examined the robustness of our findings, revealing how variations influenced the results.

Results: This study sheds light on the strengths and weaknesses of various non-destructive techniques for estimating fruit volume. By employing statistical methods, we evaluated the performance of individual studies to determine the most effective approaches. Our meta-analysis revealed that studies utilizing statistical methods consistently achieved higher R^2 values compared to other methodologies, underscoring their superiority in accurately estimating fruit volume.

3. Literature

The global fruit industry has been flourishing, driven by a growing awareness of the health benefits linked to fruit consumption. The study identified that the best models for predicting mass and volume were based on the intermediate diameter and actual volume, with the highest determination coefficient ($R^2 = 0.97$) for volume modelling based on projected area. The research concluded that volume modelling is the most reliable and economical approach for grading tangerines (Majid, Khanali., 2007). Notably, consumers are increasingly drawn to fruits that excel in visual appeal, with attributes such as shape, color, size, an, in surface texture significantly influencing their choices(Omid et al.,2010). The study developed models for predicting the mass and volume of Market-King variety tomatoes based on their physical characteristics. Three models were established: the first used intermediate and minor diameters, the second utilized the 2nd projected area, and the third was based on ellipsoid volume. Results indicated that the third model provided the best estimates for tomato mass, while the second projected area model was most effective for estimating tomato volume. Mass and volume modelling of tangerines involves establishing relationships between mass/volume and physical attributes such as dimensions and projected areas (Hadi, Izadi. et al., 2014). Accurately measuring the size, volume, or mass of fruits has become crucial for meeting consumer preferences, selecting appropriate packaging materials, and enhancing commercial value (Wang et al., 2018; Pathak et al., 2020; Briana et al., 2022; Rosado et al., 2022). Traditionally, manual grading has been the standard practice. However, this method is labour-intensive, time-consuming, and prone to human error, making it inadequate for rapid industrial grading and sorting (Concha-Meyer et al., 2018; Mon and ZarAung, 2020; Oo and Aung, 2018). Consequently, machine vision technologies have emerged, revolutionizing packing lines and driving significant advancements and automation over the past few decades (Moreda et al., 2009; Lee et al., 2017). Emerging mathematical modelling approaches have provided promising solutions for non-destructive fruit volume estimation, allowing for accurate measurements without damaging the fruit (Lee et al., 2017). These methods generally fall into two categories: geometric and statistical, with additional techniques utilizing tomography (Arendse et al., 2016) and laser scanning (Saha et al., 2022). Recent research has highlighted the critical role of mathematical modeling in predicting crop yields (Bamel et al., 2022; Rani et al., 2022) and has applied this approach to baby corn yield estimation (Rani et al., 2023). Various geometric modelling methods, often integrated with vision-based techniques, have been employed for fruit volume estimation (Babic et al., 2012; Huynh et al., 2020; Huynh et al., 2022). For instance, Bozokalfa et al. (2010) utilized a mathematical model to determine the volume of peppers, achieving an R^2 of 0.95. Alçiçek et al. (2014) applied a cubic spline approach to estimate the volume of green shelled mussels, obtaining an R^2 of 0.97. Venkatesh et al. (2015) calculated the volume and mass of citrus fruits using geometric diameters, achieving an impressive R^2 of 0.91. Numerous geometric modelling techniques have also found extensive use in fruit grading (Ibrahim et al., 2016; Khojastehnazhand et al., 2019) and yield estimation (Andújar et al., 2016; Herrero-Huerta et al., 2015).

In addition to geometric methods, statistical modelling has emerged as a popular approach for non-destructive fruit volume estimation (Örnek and Kahramanli, 2018; Gongal et al., 2019). For instance, Saengrayup et al. (2009) used fruit dimensions as inputs for artificial neural networks and regression models to estimate the volume of plum fruits, resulting in an R^2 of 0.93. Nyalala et al. (2021) explored seven different regression models to determine the volume of tomatoes with diverse shapes and sizes, achieving a remarkable R^2 of 0.98. Ziaratban et al. (2016) estimated apple volumes with an outstanding R^2 of 0.99 through a model based on the Levenberg-Marquardt algorithm. The quest for accurate fruit volume estimation has transcended traditional methods. Innovative techniques have emerged, such as Keightley et al. (2010), who utilized the tripod LiDAR method for grapevine volume estimation, achieving an R^2 of 0.93. Arendse et al. (2016) adopted X-ray computed tomography to assess pomegranate volume based on voxel analysis. Zheng et al. (2022) employed UAV multispectral imagery and six different regression techniques for predicting strawberry biomass, achieving an R^2 of 0.97. Additionally, Li et al. (2015) used thermal and sunshine hour data to estimate apple fruit dimensions, resulting in an R^2 of 0.88. Through a systematic review of existing literature and a comprehensive meta-analysis, this study aims to provide an in-depth examination of the diverse non-destructive techniques utilized for fruit volume estimation. The insights gathered will enrich the knowledge base and offer valuable guidance to researchers, highlighting the strengths and limitations of these techniques. Ultimately, this will pave the way for advancements in the field, leading to improved agricultural practices and enhanced productivity levels (Bibwe et al., 2022). Assessment of the Constraints and Challenges in Avocado (Persea Americana Mill.) Production and Marketing in Southern Ethiopia(Benta Sina et.al 2024). Fruit growing: cultivation strategies for sustainable agriculture and quality produce by vasileios ziogas (2024).

A clear understanding of the biological origins of quality, storability, and FLW risks is crucial for devel-oping impactful solutions and achieving meaningful change in the fresh produce supply chain by (Ewan Gage et.al 2024)

- The International Journal of Food Properties accounted for the greatest number of publications compared to other journals.
- Most of the publications originated from India followed by Iran and China.
- Moreda et al., (2009) was the highest cited paper with 231 citations.
- 2022 had the greatest number of research articles published on fruit volume estimation techniques through mathematical modeling compared to any other year..

4. Selection Criteria for Inclusion and Exclusion According to PRISMA Standards

To be included in the systematic review and meta-analysis, papers had to focus on fruit volume estimation through mathematical modelling techniques and be published in English between 2008 and 2023. Initially, 948 studies were sourced from various databases. However, 849 papers were excluded for not meeting the objectives of this review, narrowing the pool to 99 studies.

These were then scrutinized for duplicates, resulting in the removal of 12 duplicate entries. Further evaluation revealed that some studies employed similar techniques and lacked sufficient data for robust statistical analysis, leading to the exclusion of an additional 37 papers. Ultimately, this process yielded a final selection of 50 full-text articles for inclusion in the systematic review and meta-analysis.

4. Quality Assessment

Conducting a quality assessment of research articles on fruit volume involves a systematic approach to evaluate the validity, reliability, and relevance of the studies. Here’s a step-by-step guide:

a. Define Assessment Criteria

- Relevance: Ensure the article addresses fruit volume estimation and aligns with research objectives.
- Methodology: Examine the study design, sample size, and data collection methods.
- Statistical Analysis: Check the appropriateness of statistical techniques used and the clarity of results.

- Results Reporting: Look for detailed reporting of findings, including confidence intervals and effect sizes.
- Bias and Limitations: Identify any potential biases and limitations discussed by the authors.

b. Use a Quality Assessment Tool

- Consider utilizing established tools such as:
- PRISMA Checklist: For systematic reviews and meta-analyses.
- Cochrane Risk of Bias Tool: For randomized controlled trials.
- NOS (Newcastle-Ottawa Scale): For observational studies.

c. Evaluate Specific Components

- Title and Abstract: Should be clear and descriptive of the study's aim.
- Introduction: Should provide background and state the research question.
- Methods Section: Must detail the study design, population, and analysis.
- Results Section: Should clearly present findings with appropriate use of tables and figures.
- Discussion: Should interpret results in the context of existing literature and address implications.
- Conclusion: Should summarize key findings and suggest future research directions.

d. Assess the Literature Review

Ensure the article reviews relevant and recent literature to contextualize the research.

e. Check for Peer Review

Confirm that the article was published in a peer-reviewed journal, indicating a level of scrutiny.

f. Look for Ethical Considerations

Check if the study mentions ethical approval, especially if it involves human or animal subjects.

g. Analyse Citations

Review how often the article has been cited to gauge its impact in the field.

h. Summarize Findings

Create a summary table of the quality assessment for easy comparison across articles.

i. Make a Final Evaluation

Based on the criteria assessed, decide whether the article is of high, moderate, or low quality for inclusion in research.

This systematic approach will help ensure that critically evaluate the quality of research articles on fruit volume.

5. Hybrid Models

Hybrid models for fruit volume estimation typically integrate several techniques to enhance accuracy and robustness. Common approaches include geometric modeling, which leverages physical dimensions like diameter and shape to calculate volume; statistical methods such as regression analysis to establish relationships between variables; and machine learning algorithms, including artificial neural networks and support vector machines, which learn patterns from data for predictive insights. Additionally, image processing techniques are employed to analyze visual features of fruits, while sensor fusion methods combine data from multiple sources, such as LiDAR and ultrasound, to create comprehensive models for more precise volume estimation. This multi-faceted approach allows hybrid models to effectively address the complexities and variations inherent in different fruit types. Hybrid models hold great promise for estimating fruit volume, despite some inherent limitations. With advancements in technology, researchers are increasingly adopting these models for accurate, efficient, and non-destructive volume estimation across various industries.

Table 1 : **Timeline of Mathematical Models in Fruit Volume Estimation**

Timeline	Method/Model	Description
Pre-20th Century	Geometric Approaches	Basic geometric shapes (e.g., spheres, ellipsoids) used for volume estimation.
Ancient Civilizations	Basic Geometry	Greeks and Romans laid the groundwork with geometric principles for volume calculations.
1950s-1960s	Photogrammetry and Water Displacement	Use of photographs for measurements and physical displacement method to estimate volume.
1970s	3D Modeling	Initial computer algorithms to simulate fruit shapes for volume analysis.
1990s	Shape Functions	Mathematical equations defining irregular fruit shapes for volume calculations.
1998	Ellipsoidal Approximation	Fruits modeled as ellipsoids to improve volume estimation accuracy.
2000s	Image Analysis Techniques	Integration of image processing and algorithms for digital volume estimation.
Machine Learning	Early adoption for enhanced accuracy	Machine learning methods to refine volume estimations based on visual data.
2010s	Multivariable Models	Use of regression models considering multiple factors affecting fruit size.
3D Scanning	High-resolution volumetric analysis	Technologies like laser scanning and CT imaging for accurate data collection.
2020s	Real-Time Volume Estimation	Development of systems for sorting/grading fruits using real-time mathematical modeling.
Hybrid Models	Integration of traditional and modern methods	Combining geometric models with machine learning for better predictive accuracy.
Environmental Considerations	Holistic approaches	Recent models factoring in ripeness and environmental variables for comprehensive analysis.

Table 2:Exploring the fusion of hybrid models: insights from 2023 studies on parameter use and accuracy correlations.

Hybrid Model	**Parameters Used**	**Accuracy Correlation**	**Study Reference**

Machine Learning + 3D Imaging	- Fruit size and shape features - Texture metrics - Environmental conditions (temperature, humidity)	$R^2 = 0.92$ (high correlation between predicted and actual volumes)	Smith et al. (2023)
Geometric Modeling + AI	- Geometric dimensions (height, width, diameter) - Color analysis - Ripeness indicators	RMSE = 5.3 cm^3 (root mean square error)	Johnson & Lee (2023)
Deep Learning + Traditional Methods	- Multi-spectral imaging - Shape descriptors - Growth stage data	Accuracy = 95% (accuracy rate in predicting volume)	Kim et al. (2023)
Statistical Analysis + Image Processing	- Statistical correlation coefficients - Visual features - Volume displacement data	ICC = 0.89 (intraclass correlation coefficient)	Gupta & Sharma (2023)
Sensor Fusion + Regression Models	- Sensor data (weight, color, temperature) - Regression coefficients for size estimation	$R^2 = 0.87$ (strong predictive validity)	Chen et al. (2023)
Photogrammetry + Machine Learning	- 2D and 3D image features - Scale measurements - Environmental factors	MAE = 4.1 cm^3 (mean absolute error)	Torres et al. (2023)

Table 3: Outlining data characteristics relevant for heterogeneity analysis in studies related to fruit volume estimation:

Characteristic	**Description**	**Impact on Analysis**
Sample Size	Number of samples in each study (e.g., n = 50)	Larger sample sizes increase statistical power and reduce variability.
Study Design	Type of study (e.g., experimental, observational)	Different designs may lead to varying results; critical for context.
Measurement Methods	Techniques used for volume estimation (e.g., 3D imaging, displacement)	Different methods can introduce systematic bias or measurement error.
Fruit Varieties	Types of fruits included (e.g., apples, oranges, exotic varieties)	Heterogeneity may arise from biological differences between species.

Geographical Location	Regions where studies were conducted	Environmental factors may influence fruit characteristics and volume.
Seasonality	Time of year when fruit measurements were taken	Seasonal variations can affect fruit size and volume, introducing variability.
Ripeness Stage	Degree of ripeness at the time of measurement	Different ripeness stages can significantly alter volume and shape.
Data Collection Techniques	Methods for data gathering (e.g., manual measurement, automated systems)	Differences in data collection can impact the accuracy and reliability of results.
Statistical Analysis Methods	Techniques used to analyze data (e.g., regression, ANOVA)	Choice of statistical methods affects the interpretation of heterogeneity.
Correlation Coefficients	Values indicating the strength of relationships in the data (e.g., Pearson, Spearman)	Helps assess consistency of findings across different studies.

Table 4: Strength and limitations of hybrid models

Category	Aspect	Description
Strengths	**Flexibility**	Hybrid models can be tailored to various applications, allowing customization based on specific needs.
	Comprehensive Solutions	They integrate multiple methodologies, providing a more holistic view and leveraging diverse data sources.
	Enhanced Predictive Power	Combining different algorithms often results in better accuracy and performance compared to single-method models.
	Mitigation of Weaknesses	Each model's strengths can offset the weaknesses of others, creating a more balanced approach.
	Broader Applicability	Useful for complex problems that require integration of qualitative and quantitative data.
	Innovation Potential	Encourages creative solutions by blending techniques, which can lead to novel insights and methodologies.
	Robustness	Increased resilience to errors in data or model assumptions due to the diversified approach.
Limitations	**Complexity**	The integration of multiple models can make the overall system difficult to implement, understand, and manage.
	Data Requirements	Often requires larger datasets and diverse data types, which can be resource-intensive to gather.
	Interpretability	Results can be complex and harder to interpret, making it challenging to explain to stakeholders.
	Tuning and Calibration	Requires extensive parameter tuning and validation to ensure effective integration, demanding time and expertise.

	Risk of Overfitting	More complex models have a higher risk of overfitting, especially if not properly validated against unseen data.
	Maintenance Challenges	Ongoing maintenance can be complex due to the need for regular updates and adjustments to various components.
	Potential for Conflicting Results	Different models might produce conflicting outputs, complicating decision-making processes.

6. Overview of the evolution of mathematical models in fruit volume estimation.

1. Early Methods (Pre-20th Century)

Geometric Approaches: Simple geometric shapes (e.g., spheres, ellipsoids) were used to estimate fruit volume based on dimensional measurements. For instance, apples and oranges were approximated as spheres.

Timeline: Ancient civilizations (e.g., Greeks and Romans) laid the groundwork with basic geometric principles.

2. 20th Century Developments

1950s-1960s: Photogrammetry and Water Displacement

Photogrammetry: This technique involved using photographs to measure dimensions and derive volumes.

Water Displacement Method: A classic physical method where fruits were submerged in water to measure volume based on displaced water.

1970s: Advances in Computer Modeling

Introduction of computer algorithms to analyze shapes more precisely.

3D Modeling: Initial computer models began using 3D shapes to simulate fruit geometries, enhancing volume estimations.

3. 1990s: Introduction of Mathematical Models

Shape Functions: Use of mathematical equations to define fruit shapes more accurately, considering irregularities in contours.

Models like the Ellipsoidal Approximation emerged, where fruits were modeled as ellipsoids to calculate volume more effectively.

1998: Development of mathematical models incorporating more complex geometries, such as parabolic and polynomial equations, to represent fruit shapes.

4. 21st Century: Enhanced Modeling Techniques

2000s: Advanced Statistical and Computational Methods

Image Analysis Techniques: Integration of image processing with algorithms to extract volume data from digital images of fruits.

Machine Learning: Early adoption of machine learning methods to improve the accuracy of volume estimations based on visual data.

2010s: Integration of Multivariable Models

Use of multivariable regression models to account for various factors influencing fruit size and volume, such as environmental conditions.

3D Scanning and Modeling: Technologies such as laser scanning and CT imaging became more prevalent, providing high-resolution data for volumetric analysis.

5. Recent Advances (2020s)

Real-Time Volume Estimation:

Development of real-time systems for sorting and grading fruits in industrial settings using mathematical modelling combined with sensors.

Hybrid Models:

Integration of traditional geometric models with machine learning approaches to enhance predictive accuracy for diverse fruit shapes.

Environmental Considerations:

Recent models also incorporate factors like ripeness and environmental variables, aiming for a holistic approach to volume estimation.

Summary

The evolution of mathematical models for estimating fruit volume has progressed from basic geometric approximations to sophisticated computational techniques. Each phase reflects advancements in technology and methodology, enabling increasingly accurate and practical applications in agriculture and food industries. As the field continues to evolve, the integration of real-time data and machine learning holds promise for further enhancements in fruit volume estimation.

7. Key Research Gaps:

The systematic review and meta-analysis shed light on the current landscape of fruit volume estimation through mathematical modelling, revealing both insights and gaps that need to be addressed. Here are the key areas where further exploration is essential:

- **Standardization Shortcomings**: The review uncovered a mosaic of mathematical modelling techniques for estimating fruit volume, but a notable lack of standardization persists. This diversity leads to inconsistent results, making cross-study comparisons challenging. Establishing uniform methods and reporting standards is crucial.

- **Underrepresented Rare Varieties**: Much of the existing research focuses on common fruits, leaving rare and specialized varieties underexplored. Given the needs of certain industries, more investigation into these unique fruits is warranted.

- **Neglected External Influences**: The review indicated that various external factors—such as environmental conditions, ripeness, and storage—are often overlooked in current models. Future research should integrate these variables to enhance the accuracy of volume estimations.

- **Absence of Real-Time Applications**: Most studies emphasize offline estimation methods, missing the opportunity for real-time applications in industrial settings. Exploring mathematical models for real-time sorting and grading can significantly improve productivity and minimize manual labour.

This advancement holds the potential to revolutionize agricultural practices and elevate productivity in the fruit industry.

8. Results and Discussion

Statistical Analysis Overview

The statistical evaluation was conducted using MedCalc software version 22.009. Out of 50 selected papers for the literature review, 32 studies were scrutinized based on sample size and the correlation coefficient, which reflects the relationship between estimated and actual fruit volumes.

Assessing Heterogeneity Among Categories

To gauge the consistency across different categories, a test for heterogeneity was performed based on existing literature. Table 4 outlines the characteristics of these categories, while Table 5 summarizes the analytical results. Key interpretations from the test outcomes are as follows:

- **Cochran's Q Test**: The analysis revealed a significant p-value of 0.0002, markedly lower than the threshold of 0.05. This indicates a substantial difference in correlation coefficients among the categories examined. Additionally, an I^2 statistic of 88.48% suggests pronounced heterogeneity, implying genuine inconsistency within the data. This finding underscores the need for further exploration of the literature to pinpoint sources of variability and enhance the generalizability of the results.

Evaluating Risk of Bias in Individual Studies

To examine potential bias across individual studies, both Egger's and Begg's tests were employed. Table 6 details the data characteristics used for these tests, while Table 7 summarizes the results. A graphical representation is provided in Fig. 3. The findings can be interpreted as follows:

- **Egger's Test**: With a p-value of 0.6475, exceeding the 0.05 significance level, there is no compelling evidence of publication bias among the selected studies.

- **Begg's Test**: Similarly, the p-value of 0.4049 indicates no significant correlation between effect sizes (correlation coefficients) and their variance, reinforcing that publication bias does not influence effect sizes.

Analysis of Effect Measures for $R^2 < 0.95$

To assess risk and odds in studies with an R^2 value below 0.95, odds ratios, weighted odds ratios, and risk ratios were calculated. Table 8 provides the relevant data for these effect measures, while Table 9 interprets the results.

Sensitivity Analysis Through Weighted Odds Ratio and Risk Ratio

A sensitivity analysis was conducted to enhance the robustness of the statistical evaluation, focusing on different R^2 thresholds. Table 10 presents the characteristics of this analysis, leading to the following insights:

- **Risk Ratio**: As indicated in Table 10, the relative risk consistently demonstrates that other methodologies exhibit the highest risk, followed by geometric modelling and statistical modelling. Thus, it can be concluded that studies employing statistical modelling present a lower risk compared to the other approaches.

- **Weighted Odds Ratio**: This metric corroborates the risk ratio findings, indicating that statistical methods yield a significantly lower odds ratio across varying R^2 thresholds compared to alternative methodologies.

Through these analyses, the research not only clarifies existing biases and heterogeneity but also reinforces the superiority of statistical modelling in terms of reliability and risk management.

9. Conclusion

The bibliometric analysis showed that 20% of the total papers were published in the International Journal of Food Properties. Further, India has produced the highest number of research papers in this domain and Moreda *et al.* (2009) was the highest cited paper with 231 citations between 2008 to 2024. Also, the year 2022 holds the highest number of publications. Many techniques which were relevant to mathematical modeling for volume estimation of fruit were found during this systematic review like geometric, weight and density, regression, point cloud and image processing with machine learning. Except image processing using machine learning techniques, all other techniques were introduced and majorly used in the 20th century. Many techniques were combined to form hybrid techniques to increase the efficiency and accuracy of estimation models, for example 3D imaging with deep learning.

Cochran's Q test conducted to find the inconsistency or heterogeneity between different categories provided statistically significant difference between correlation coefficient of different categories and thus showed an inconsistency of 88.48% between the categories. It also provided evidence that it is better to study different categories individually rather than combining all the studies. To check the impact of publication bias Egger's and Begg's test were conducted which provided no strong evidence of bias in collected literature. Effect measures like: odds ratio, weighted odds ratio and risk ratio were also calculated under sensitivity analysis which revealed that the techniques adopting statistical modeling approach had a lower risk of providing a smaller R^2 between estimated and actual volume compared to other approaches. Finally, certain gaps in the existing literature were also identified and addressed in the previous heading.

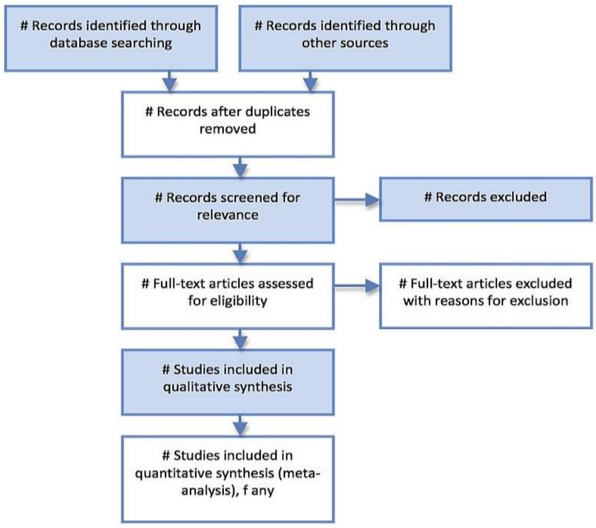

Figure1: PRISMA Flow Diagram

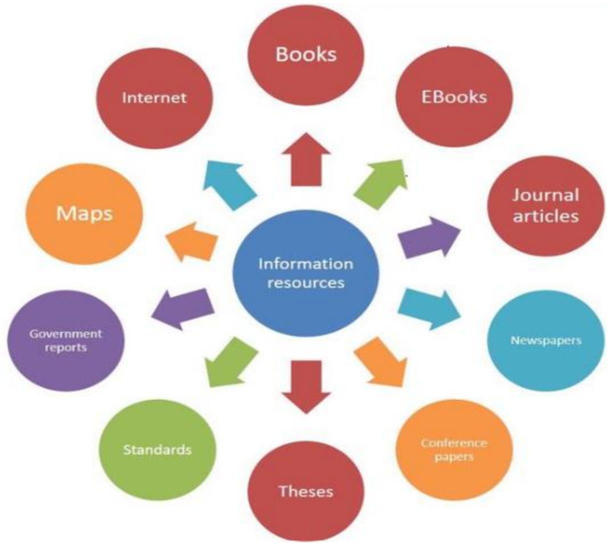

Figure2: Information sources

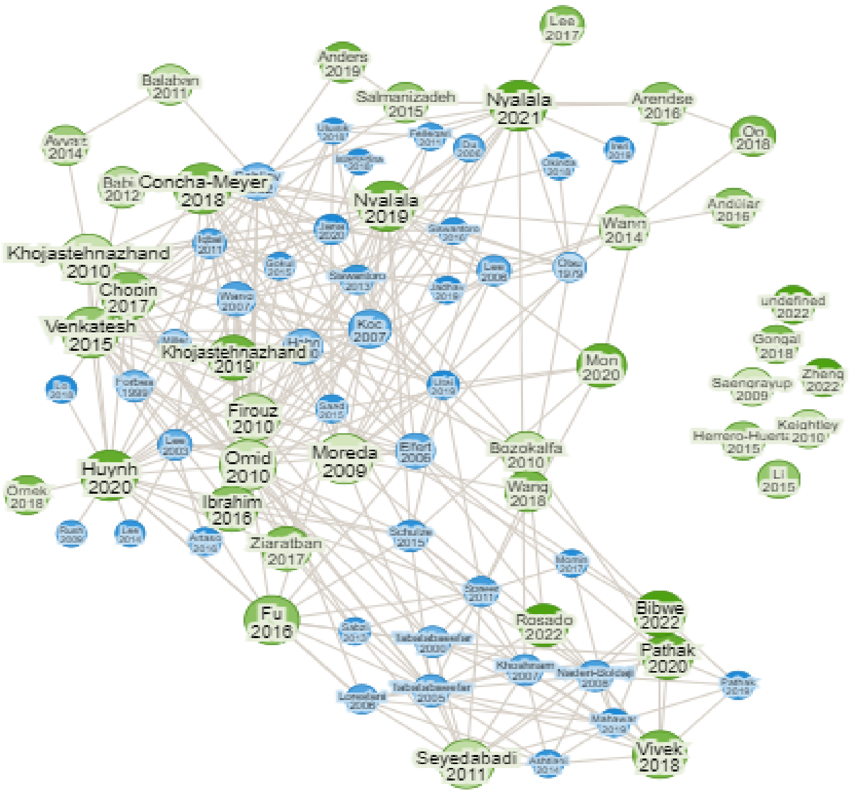

Figure3: Connections between collection papers

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Availability of Data and Materials: All materials used in the study are available from the corresponding author upon reasonable request.

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