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Original Research Article

Performance Evaluation of Refractometer Devices for Brix Determination in Rock Melons

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Abstract: Rock melon (*Cucumis melo Linn*), one of the most popular and delicious fruits of Malaysia has great potential for commercial development. This study aimed to determine the performance evaluation of refractometer devices for brix determination in rock melons in a greenhouse. A Brix meter, also referred to as a refractometer, is an essential instrument used for measuring the sugar content, or Brix level. One of the main reasons for growing rock melons in greenhouses is to mitigate pest and disease attacks. The experiment comprised the following soilless media: T1 = 100% Coconut Peat, T2 = 100% Burnt Rice Husk, T3 = 50% Coconut Peat + 50 % Burnt Rice Husk, T4 = 70 % Coconut Peat + 30 % Burnt Rice Husk, T5 = 30% Coconut Peat + 70% Burnt Rice Husk. This experiment was conducted at the Institute of Sustainable Agrotechnology (INSAT), the University of Malaysia Perlis (UniMAP) at Sungai Chuchuh, Padang Besar, Perlis, Malaysia. This study evaluated the accuracy and precision of three refractometer types, which are Reichert TS Meter-D (benchtop standard), Atago PR-201α (digital handheld), and a Extech RF15 Portable Brix Refractometer, to measure Brix in rock-melon juice. The Reichert TS Meter-D demonstrated laboratory-grade precision (refractive index accuracy ±0.0001 nD, ~±0.10 °Bx). Compared to this reference, the Atago PR-201α had minimal mean bias (–0.02 °Bx) and narrow 95% limits of agreement (LoA: –0.26 to +0.23 °Bx), meeting practical interchangeability thresholds (±0.30 °Bx). The manual model showed similar average bias (–0.03 °Bx) but wider variability (LoA: –0.49 to +0.43 °Bx), exceeding acceptable error margins. Paired *t*-tests confirmed biases were not statistically significant ($p > 0.75$). These findings indicate that the Atago PR-201α offers a reliable, high-throughput alternative to lab equipment for Brix grading whilst the Extech RF15 Portable Brix Refractometer remains useful for everyday field checks where rapid portability is essential.

Keywords: Cucumis Melo L.; Refractometer; Brix; Soilless Media

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1. Introduction

The "brix" of a fruit refers to its sugar content, usually measured as a percentage of sucrose by weight. High levels of Brix are often associated with high-quality fruit. Fruits with higher sugar content tend to have better texture, aroma, and flavour. 1 degree Brix corresponds to 1 gram of sucrose dissolved in 100 grams of solution (1 °Brix = 1% sugar) (Jaywant *et al.*, 2022). By measuring brix, growers and sellers can assess the quality of their produce and make decisions about handling, storage, and pricing accordingly. The U.S. Department of Agriculture (USDA) establishes a minimum standard of 9 °Bx for cantaloupes that are classified as "good quality." However, numerous premium cultivars consistently achieve or surpass 10 °Bx by the time they are harvested (Bumgarner, 2006) In Malaysia, locally recognized rock-melon varieties commonly reach around 11 °Bx at harvest. In contrast, measurements below approximately 9 °Bx are generally considered as underripe, lacking in flavour, or insufficiently sweet for premium markets (Németh *et al.*, 2020). From the experiment conducted by Mohd Noor (2019), the maximum fruit weight observed was 1350 grams, with a corresponding total soluble solids content of 14.25 °Brix.

A Brix meter, also referred to as a refractometer, is an essential instrument used for measuring the sugar content, or Brix level, of liquids, particularly fruit juices or other beverages. Refractometers gauge Brix levels, crucial for assessing the flavour and quality of fruits and vegetables (Ugwu *et al.*, 2018). The refractive index (RI) is a comparison of the speed of light in a vacuum to its speed in a particular medium. This value changes based on both the wavelength of light and the temperature of the liquid being measured (Jaywant *et al.*, 2022). Different types of refractometers exist primarily because various industries, especially fruit cultivation and processing, require precise measurement of sugar content. The two primary types of refractometers are analog (traditional handheld) and digital. Analog models are compact and affordable, but they require manual focus, calibration (usually with distilled water), and user interpretation of the shadow line (Ugwu *et al.*, 2018). Handheld refractometers are commonly used in the field for quick assessments, while digital models offer accuracy and convenience in laboratory settings. By offering a range of refractometer options, manufacturers cater to the specific requirements of fruit growers, ensuring they can effectively monitor and optimize fruit quality and sweetness throughout the production process.

There are three different types of refractometers used in this study: Extech RF15 Portable Brix Refractometer, Atago PR-201α Digital Refractometer, and Reichert TS Meter-D Refractometer. The brix of rock melon can be determined using these three refractometers. However, the most appropriate is determined by its precision and accuracy. Extech RF15 Portable Brix Refractometer typically features a prism or sample well, a viewing lens, and a scale for reading Brix, refractive index, or other relevant measurements. It is portable and easy to use, making them suitable for fieldwork and routine testing (Wyness *et al.*, 2016). Atago PR-201α Digital Refractometer, and Reichert TS Meter-D Refractometer are Digital Refractometers. Digital refractometers offer the advantage of digital readouts, providing more precise and accurate measurements compared to manual models (Jeffery Heileson & Julianna Jayne, 2019). Digital refractometers offer automatic temperature compensation. However, quick readings taken before temperature equilibrium is achieved may lead to errors in the results displayed (Jaywant *et al.*, 2022). It often has built-in temperature compensation and may offer additional features such as data storage and analysis capabilities. Digital refractometers are commonly used in quality control laboratories and research settings where high accuracy is required.

This study aims to analyse and assess the performance of different refractometers in determining the Brix levels of rock melons. Although manual Brix refractometers are widely used for field-level operations due to their affordability and portability, it did not suit laboratory-grade measurements, particularly where high precision and reproducibility are essential. Bland–Altman analysis will be implemented to assess agreement, with TS Meter-D serving as the "gold standard”, will determine whether the alternatives exhibit acceptable precision and systematic bias by calculating the mean difference (bias) and the 95% limits of agreement (mean ± 1.96 × SD) for each sample pair (Extech RF15 Portable Brix Refractometer vs. Reichert TS Meter-D Refractometer) and Atago PR-201α Refractometer vs. Reichert TS Meter-D Refractometer). Specifically, it will determine whether most paired values fall within ± 0.05–0.10 ° Bx of the reference (Kalra, 2017). According to Martin Bland & Altman (1986), when comparing two clinical measurement methods, one should assess agreement using mean bias and limits of agreement, as simple correlation can be misleading in determining whether the two methods are interchangeable. In recent methodological reviews, it has been emphasized that Bland–Altman plots remain widely used to compare continuous measurements (Shieh, 2018)

2. Methods

This study was conducted at the Institute of Sustainable Agrotechnology (INSAT), University of Malaysia Perlis (UniMAP), situated in Sungai Chuchuh, Padang Besar, Perlis, Malaysia. The greenhouse, positioned at GPS coordinates N6.65203, E100.260908, stands at an elevation of 53 meters above mean sea level. This location is in Zone 1 of Malaysia's agro-climate zone, known for dry weather from January to March and rainy periods from September to December. Rock melons were planted during the dry season, from January to March. There are three refractometer (Figure 1) Extech RF15 Portable Brix Refractometer (R1), Atago PR-201α Digital Refractometer (R2) and Reichert TS Meter-D Refractometer (R3).

a) Extech RF15 Portable Brix Refractometer

b) Atago PR-201α Digital Refractometer

c) Reichert TS Meter-D Refractometer

Figure 1. Type of Refractometer

In this paper, brix level of rock melon was determined using 3 different models of refractometers. The Reichert TS Meter-D has been extensively referenced in clinical and veterinary research for its ability to provide laboratory-grade precision in a compact, handheld format (Katsoulos *et al.*, 2017). Barry *et al.* (1960) characterize its reproducibility and accuracy as comparable to benchtop Abbe units, a hallmark of class-standard laboratory instrumentation. Table 1 displays the specifications for the refractometers. According to the RF15 manual, the Extech RF15 Portable Brix Refractometer features automatic temperature compensation (ATC) for sample temperatures between 10°C and 30°C, measures 0–32% Brix with a resolution of 0.2% and delivers an accuracy of ±0.2% Brix. Based on the official PAL-22S instruction manual published by Atago Malaysia (Atago Co., Ltd., 2022) measurement time is approximately 3 seconds. The accuracy of this refractometer is ± 0.1%. The Reichert Technologies (n.d.) describes the Reichert TS Meter-D Digital Hand-held Refractometer (catalog number 13960000) offers a full Brix scale measurement compliant with ICUMSA standards, achieving an accuracy of ±0.1% Brix when measuring sugar content, which is comparable to laboratory-grade devices. The readings delivered in approximately 3 seconds to its fully automatic, touch-button operation.

Table 1. Specification data for the refractometers

Refractometer	R1	R2	R3
	Extech RF15 Portable Brix Refractometer	**Atago PR-201α**	**Reichert TS Meter-D**
Brix Range	0–40	0–60	0–95
Temperature composition (°C)	10–30	10–40	10–40
Measurement Time (seconds)	10	3	3
Accuracy (%)	± 0.2	± 0.1	± 0.1

The experiment utilized five growth-media treatments composed of varying proportions of coconut peat and burnt rice husk. Table 2 presents the different types of soilless media. Modern soilless cultivation offers numerous benefits, such as increased yields and reduced risk of soil-borne diseases, but it also comes with drawbacks like higher labour requirements. Despite the initial investment costs for both varieties, soilless cultivation is generally recommended (Birkás *et al.*, 2016).

Table 2. Soilless media composition

Type of media	Soilless formulation	% Component composition
SM1	Burnt Rice Husk	100
SM2	Coconut Peat	100
SM3	Coconut Peat, Burnt Rice Husk	50:50
SM4	Coconut Peat, Burnt Rice Husk	30:70
SM5	Coconut Peat, Burnt Rice Husk	70:30

2.1. Sample Preparation

For each treatment (media mixtures SM1–SM5), five distinct rock melons were employed. The rock melons were harvested in a consistent manner upon reaching harvest maturity. In this experiment, liquid samples were measured using all three refractometers, the Atago PR-201α digital, Reichert-TS Meter-D, and Extech RF15 Portable Brix Refractometer. Figure 2 showing the sampling location within each rock melon. A small cube of flesh was taken 0.5 cm beneath the surface rind to standardize Brix measurements across all five fruits in each treatment. To ensure precision and repeatability, each sample reading was performed in rapid succession three times per instrument. Following standard practice in Brix and refractometry testing, the average of these three rapid measurements was used for each instrument per sample, minimizing random error and improving measurement reliability (Jaywant *et al.*, 2022).

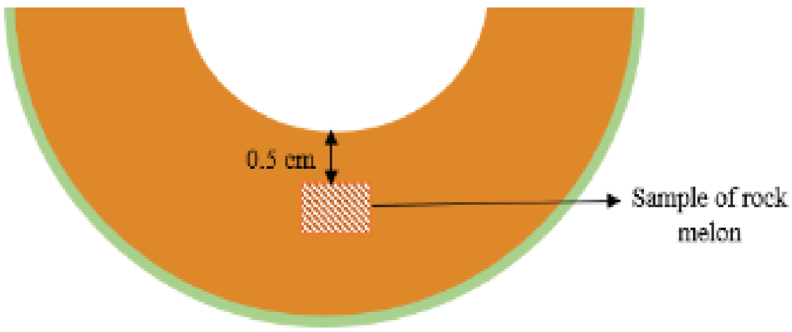

Figure 2. Sampling location within each rock melon

2.2. Brix Measurement Procedure

Prior to testing, all three refractometers were cleaned and calibrated using distilled water according to the manufacturer's instructions. For digital models, a zero reading was verified. Calibration was repeated periodically between measurements to ensure accuracy. Before starting using the refractometer, make sure to calibrate it following the manufacturer's instructions. Figure 3 depicts the Flow Diagram of the Brix Value Measurement. First, calibration ensures accurate reading by setting the instrument to zero using distilled water (Vasquez & Mueller, 2007) or a calibration solution. Then, put a few drops of rock melon juice onto the prism or sample well of the refractometer. The juice was collected at the flesh of the rock melon. For Extech RF15 Portable Brix Refractometer, close the cover to spread the sample evenly, and take the brix value. Therefore, for Atago PR-201α Digital Refractometer and Reichert TS Meter-D Refractometer, the data appeared in just 3 seconds.

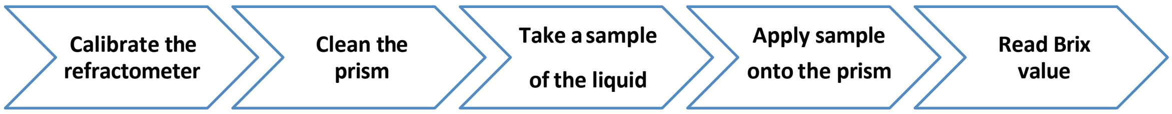

Figure 3. Flow Diagram of Brix Value Measurement

2.3. Data Collection and Organization

Data were entered into a structured Excel spreadsheet, and for each sample– instrument combination, the mean Brix value and standard deviation were calculated to assess precision. The dataset, including both raw and processed measurements, was further used to evaluate accuracy (via comparison to the reference instrument) and repeatability (via variability across triplicate readings per sample and refractometer). Such descriptive statistics provide a clear snapshot of device performance in terms of both systematic bias and random errors (Kwak & Kim, 2021).

2.4. Statistical Analysis

Statistical analysis of the Brix measurements was conducted using Microsoft Excel. To characterize central tendency and variability across the replicate measurements, descriptive statistics, such as means and standard deviations, were initially computed for each refractometer. Following this, a one-way Analysis of Variance (ANOVA) was performed to test whether the mean Brix readings from the three refractometers differed significantly, using a significance threshold of $p < 0.05$. ANOVA is appropriate when comparing more than two group means and prevents the inflated error risk associated with multiple tests (Ranganathan, 2021).

Bland–Altman analysis was conducted to further evaluate the agreement between devices by comparing the Extech RF15 Portable Brix Refractometer and Atago PR-201α instruments to the Reichert TS Meter-D reference. This method involves plotting the differences in readings against their averages, calculating the mean bias and the 95% limits of agreement (bias ± 1.96 × SD) to visually and quantitatively evaluate systematic and random errors between methods (Giavarina, 2015).

3. Results

Figure 4 presents a clustered bar chart comparing the average Brix readings for each rock melon sample across the three refractometers. The three refractometers are Refractometer 1 (Extech RF115 Portable BrBrix Refractometer Refractometer 2 (Atago PR-201α), and Refractometer 3 (Reichert TS Meter-D) as reference instrument. In this graph, the x-axis represents the treatments of the soilless media, while the y-axis displays the corresponding mean Brix values observed for each device. Based on the results, Soilless Media 3 (SM3, comprising 50% coconut peat and 50% burnt rice husk) produced the highest average °Brix values compared to all other substrate mixtures.

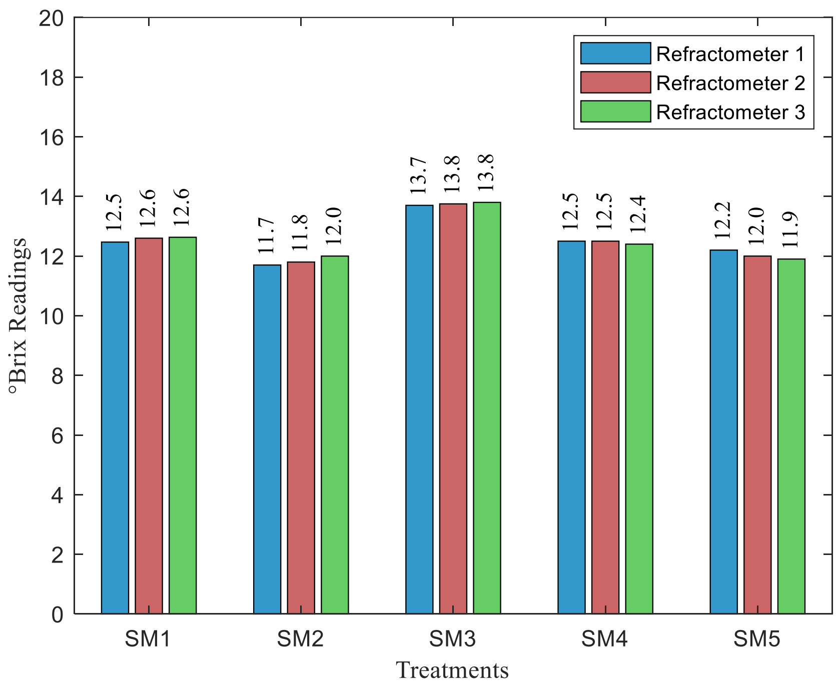

Figure 4. Comparison of Brix Reading by Three Refractometers

A repeated measures ANOVA was conducted on the five rock-melon samples (n=5) and revealed that there was no statistically significant difference in brix readings among the three refractometers (R_1, R_2, R_3). The F (2, 8) statistics were 0.085 and the p-value was approximately 0.92, indicating that the three instruments do not differ on average. However, ANOVA only tests for systematic differences in means, not method *agreement* at the individual sample level (Dendumrongsup *et al.*, 2014). To enhance this, Bland–Altman analysis was implemented pairwise with R_3 as the reference. This method initially computes the mean difference (bias) and subsequently calculates the 95% limits of agreement (LoA = bias ± 1.96 × SD of differences). Table 3 shows the comparison of brix measurements across refractometers: mean, median & standard deviation.

Table 3. Comparison of Brix Measurements Across Refractometers: Mean, Median & Standard Deviation

Media	Refractometer	Number of Sample	Mean	Median	Minimum	Maximum	Standard Deviation
SM1	R1	3	12.47	12.40	12.40	12.60	0.0943
	R2	3	12.57	12.60	12.40	12.70	0.1247
	R3	3	12.60	12.60	12.50	12.70	0.0816
SM2	R1	3	11.67	11.70	11.50	11.80	0.1247
	R2	3	11.77	11.80	11.60	11.90	0.1247
	R3	3	12.00	12.00	11.90	12.10	0.0816
SM3	R1	3	13.67	13.70	13.50	13.80	0.1247
	R2	3	13.80	13.80	13.70	13.90	0.0816
	R3	3	13.77	13.70	13.60	14.00	0.1700
SM4	R1	3	12.53	12.50	12.50	12.60	0.0471
	R2	3	12.47	12.40	12.30	12.70	0.1700
	R3	3	12.40	12.40	12.30	12.50	0.0816
SM5	R1	3	12.23	12.30	12.10	12.30	0.0943
	R2	3	12.07	12.10	11.90	12.20	0.1247
	R3	3	11.90	11.90	11.80	12.00	0.0816

Bland–Altman analysis (Figure 5) was undertaken to evaluate the agreement between each test refractometer and the benchtop laboratory reference (Reichert TS Meter-D Refractometer). For the Extech RF15 Portable Brix Refractometer (R_1) vs. R_3 comparison, the mean bias was –0.03 °Bx with a standard deviation (SD) of approximately 0.24 °Bx, yielding 95% limits of agreement (LoA) from –0.49 to +0.43 °Bx. This indicates that although there was no significant systematic offset, individual measurements from R_1 could deviate by up to ±0.5 °Bx when compared with R_3. In comparison, the Atago PR-201α Digital Refractometer (R_2) vs. R_3 exhibited a mean bias of –0.02 °Bx and SD of about 0.13 °Bx, with LoA from –0.26 to +0.23 °Bx, indicating a tighter agreement.

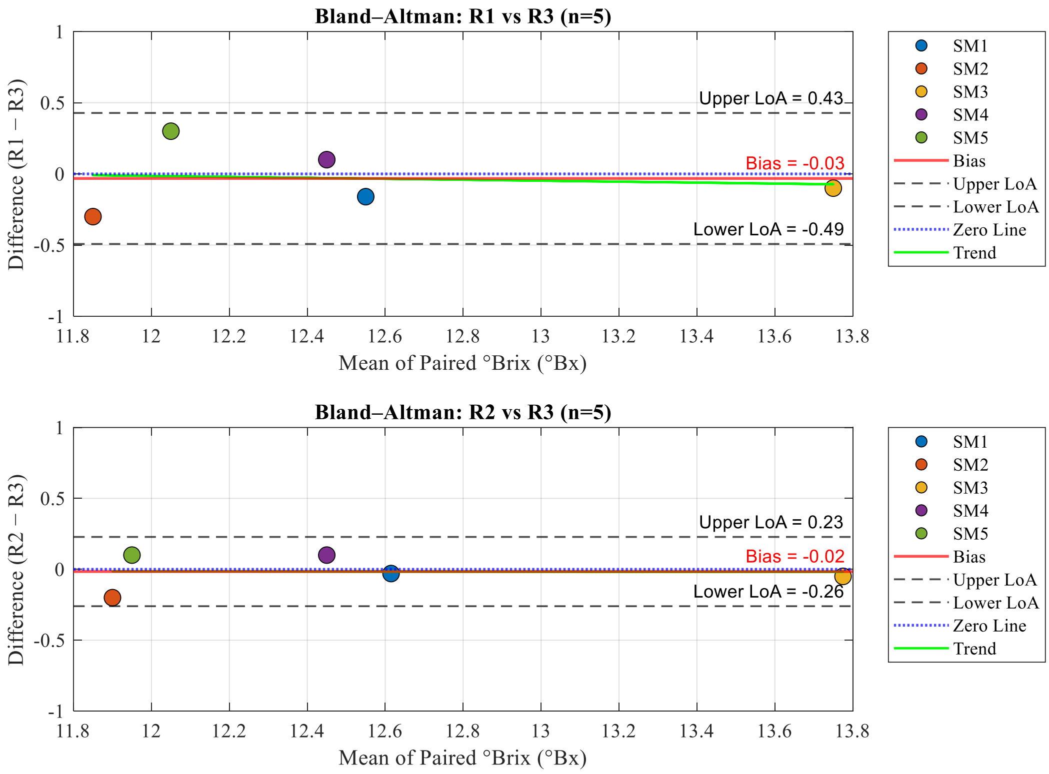

Figure 5. Bland–Altman analysis

Since method interchangeability depends not only on equivalence in mean readings but also on whether individual differences fall within predefined error tolerances, only Refractometer 2 meets this criterion. Its ±0.23 °Bx to +0.26 °Bx limits of agreement lie well within the ±0.30 °Bx threshold, indicating that individual readings are reliably consistent with the benchtop standard. In contrast, Refractometer 1 demonstrates wider limits (±0.49 °Bx), which exceed acceptable error margins—suggesting that, despite a small average bias, some readings may diverge beyond tolerable limits.

Extech RF15 Portable Brix Refractometer (R_1) tend to have wider limits of agreement because they rely on manual interpretation of a shadow line through an eyepiece, which introduces subjective error due to differences in lighting, eye positioning, or operator experience. However, Refractometer 1 (Extech RF15 Portable Brix Refractometer) remains widely used in routine field or laboratory settings due to its simplicity, portability, and speed.

It requires no power source, produces instantaneous results with minimal sample volume, and is robust under varying outdoor conditions. These practical advantages make it suitable for daily Brix inspections, especially in contexts where rapid assessments by trained operators are essential and absolute precision within lab-grade tolerance is not critical.

4. Discussion

Brix measurement aids in harvest management decisions. By tracking Brix levels over time, growers can optimize harvest timing to maximize fruit quality and yield. Harvesting fruits with optimal Brix levels ensures better marketability and longer shelf life, reducing post-harvest losses. In this experiment, the Reichert TS Meter-D, a benchtop reference instrument, exhibited laboratory-grade accuracy with a refractive index precision of ±0.0001 nD, which is equivalent to approximately ±0.1 °Bx on the complete Brix scale. Its sapphire prism optimizes measurement consistency and minimizes operator error by improving thermal conductivity and providing a more rapid and consistent temperature compensation in comparison to glass prisms. As the benchmark device in this study, it provided a reliable standard for evaluating the performance of portable refractometers.

By comparison, the Atago PR-201α digital refractometer exhibited exceptional usability and consistency, making it well-suited for both field and laboratory applications. It covers a Brix range of 0.0 to 60.0% with a resolution of 0.1% Brix and an accuracy of ±0.1% Brix within its automatic temperature compensation range of 10 to 40 °C. In this study, the Atago device demonstrated a minimal mean bias of –0.02 °Bx and tight limits of agreement (LoA) (± about 0.23–0.26 °Bx), comfortably within the commonly accepted ±0.30 °Bx tolerance for Brix grading. This illustrates its strong interchangeability with the benchtop reference while offering the practical advantages of portability and speed.

In contrast, the Extech RF15 Portable Brix Refractometer (R_1) showed wider variation in readings, with limits of agreement spanning approximately ±0.49 °Bx compared to the reference. These bigger differences were probably because analog models have some built-in flaws, like the fact that shadow lines are subjective to read, scale resolution is smaller, and mechanical parts that adjust to temperature more slowly or more quickly can change. However, Refractometer 1 (Extech RF15 Portable Brix Refractometer) is still widely used in the field and lab because it is easy to use, portable, and quick. It works well in a wide range of outdoor situations and does not need a power source. Results are shown instantly with a small sample volume. Because of these useful features, it can be used for daily Brix checks, especially when quick checks by trained workers are needed and lab-grade accuracy is not very important.

5. Conclusions

In this experiment, the Reichert TS Meter-D, a benchtop reference instrument, exhibited laboratory-grade accuracy with a refractive index precision of ±0.0001 nD, which is equivalent to approximately ±0.1 °Bx on the complete Brix scale. Among the test instruments, the Atago PR-201α digital refractometer delivered the strongest overall performance. It offers a Brix measurement range of 0.0–60.0%, a resolution of 0.1 °Bx, and an accuracy of ±0.1 °Bx within an ATC temperature window of 10–40 °C. In this study it exhibited a negligible bias (–0.02 °Bx) and tight limits of agreement (± ~0.23–0.26 °Bx), affirming its interchangeability with the TS Meter-D for most practical purposes.

The Extech RF15 Portable Brix Refractometer (R_1), on the other hand, was cheaper and easier to use, but the results were less consistent. The limits of agreement were as low as 0.49% Bx. These bigger differences are probably caused by the fact that analog devices have limits like shadow-line interpretation being subjective, lower scale resolution, and temperature adaptation mechanisms that work more slowly. Even so, R_1 is still commonly used in the field because it is portable, does not need power, is cheap, and can give answers right away with a small sample volume.

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