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Development of a portable prototype: pH meter for prolonged esophageal pH monitoring with low cost materials

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***Abstract*— *Objective: to develop a prototype portable register for extended esophageal pHmetry examination with low cost materials. Materials and Methods: Preclinical research, pilot test with preliminal data to evaluate the effectiveness and accuracy of the prototype. From the product assembly and the software used for data reading and measurement. In this software are written the codes for reading the pH values and preparation of the Arduino plate for data transmission. The indicator for pH reading calculates the average value every 10 measurements and the result obtained is displayed as long as this process is necessary. In this same code, the display buttons are configured as well as the calibration mode for each buffer solution. After mounting and proper calibration of the Arduíno and Commercial instruments, both containing two channels were tested in 10 substances in cycles. First, the channels were immersed in a solution containing beer and the pH was read in the times 0 s, 30 s, 90 s, 120 s, 150 s and 180 s in both arduous and commercial for* *comparative purposes. At the end of the reading, the channels were immersed in water for 3 min for cleaning and then tested in a new solution. The same cycle was repeated for the other solutions, which are: orange juice, energy, mineral water, isotonic, vinegar, coca-cola, guava juice, grape juice and guarana. Results: The differences statistically: 180s of the energetic (p = 0.0178*); 60s Mineral Water time (p = 0.0178*); 150s and 180s of the Isotonic (p = 0.0371* and p = 0.0330* respectively); 0s Coca-Cola time (p = 0.0246*); and 150s Grape juice time (p = 0.0230*); 0s orange juice time (p = 0.0371*); 0s energy time (p = 0.0330*); 0s and 30s vinegar time (p = 0.0075* and p = 0.0216* respectively). Conclusion: The analysis, as to its performance regarding the precision in the recording of pH values (aqueous solutions) are satisfactory for presenting results very close to the measurements indicated by the commercial recorder, in simultaneous measurements during the testing phase.*

Keywords— Gastroesophageal Reflux; Esophageal pH Monitoring; Technological Development; Evidence-Based Medicine.

I. INTRODUCTION

Gastroesophageal reflux disease (GERD) is a complex disease with high prevalence worldwide, which generates a high cost in its diagnostic investigation and treatment (Henry, 2014).

Population risk factors for GERD development are recognized: age, gender, gestation, obesity, genetic factors and presence of hiatal hernia. Although GERD occurs in all age groups, the prevalence of this clinical condition, as well as its complications such as stenosis and ulcers, is higher among elderly individuals (ALMEIDA et al., 2017).

Traditionally, reflux is considered to occur when the esophageal pH drops below 4. This threshold is clinically relevant, as pyrosis occurs with a pH below 4, and peptic activity decreases rapidly above this level. The end of a reflux episode is usually considered to be the point at which the esophageal pH rises above 4 (NASI, QUEIROZ, & MICHELSOHN, 2018).

It is important to mention that there are definitions of GERD that consider not only the acid content of the reflux, coming from the stomach, but also the non-acid content, coming from the duodenum (initial portion of the small intestine), thus, it is duodenogastric reflux. In addition to esophageal symptoms, there may be manifestations of extra-oesophageal symptoms such as asthma, recurrent non-coronary chest pain and pharyngitis, for example. The symptoms may or may not be associated with esophageal tissue lesions, depending on the clinical picture (Sifrim, 2013).

In the diagnosis and subsequent follow-up of the disease, it is also possible to find different consequences that GERD may trigger, depending on some factors. Therefore, there are variations on the endoscopic conditions in each patient, from the inexistence of lesions in the mucosa to major complications, in more severe cases. In addition, GERD is one of the most recurrent diseases in medical practice, a further justification for this subject to be greatly investigated and consequently, the number of information and publications on the subject is growing (Gonçalves, Pimenta, & Neto, 2005).

As already seen, GERD has diverse clinical manifestations. The most common and unusual types of clinical manifestations may coexist, however, the inexistence of some of the most common symptoms is not a decisive factor in ruling out a positive diagnosis for GERD. The two typical clinical manifestations of GERD are heartburn and acid regurgitation: this is the burning sensation that reaches the region between the manubrium of the sternum bone to the base of the neck, and the reflux of acid or dietary content into the oral cavity, respectively(Ferreira et al., 2014; Sanchez-Lermen, Dick, Salas, & Fontes, 2007).

The anamnesis has great relevance for the diagnosis of typical GERD and is the first action of the diagnostic process. To this end, the patient is asked in detail about the characteristics of the symptoms presented, such as duration and frequency, factors that activate the symptoms and how much they influence their quality of life (Fraga & Martins, 2012).

Among the diagnostic methods presented below, High Digestive Endoscopy (HDA) and Extended Esophageal pHmetry are the methods that are effectively used for the diagnosis of GERD: it can be diagnosed by endoscopic changes suggestive of reflux, such as esophagitis and/or pathological reflux, identified by prolonged reflux monitoring (pHmetry). The other methods, although they do not perform a direct diagnosis of GERD, are present in this topic due to their importance in clinical practice, performing, for example, evaluations of specific clinical conditions of GERD carriers and identification of complications of the disease (Henry, 2014; Nasi, Moraes-Filho, & Cecconello, 2006).

In relation to the prolonged esophageal pHmetry examination, this method was introduced into clinical practice in the mid-1970s and has since provided more knowledge about gastrosophageal reflux, quantification and counting of the number of episodes during the examination period. Before the inclusion of prolonged esophageal pHmetry as a method for monitoring and diagnosis, gastrosophageal reflux was perceived only through the resulting inflammation of the esophageal mucosa (esophagitis) in patients who presented it, detected by upper digestive endoscopy (NASI et al., 2018).

Extended esophageal pHmetry is a diagnostic method for GERD and performs a monitoring of gastrosophageal reflux over about 24 hours of examination. Intraesophageal pH monitoring allows determination: the intensity of acid reflux, but does not detect the presence of "non-acid" reflux; characterize the pattern of reflux; diagnose GERD in patients who do not have esophagitis (does not allow characterizing esophagitis or its consequences); displays supra-oesophageal/laryngopharyngeal reflux if any (when acid reflux generates the atypical manifestations); in addition to acting to check the effectiveness of clinical and/or surgical treatment after it has been performed, if there are symptoms after either type of treatment (PONTE, 2015).

It was from the introduction of this prolonged monitoring method that the terms physiological reflux and pathological reflux were established: through pHmetry the reflux in healthy volunteers was quantified and this is considered normal, physiological reflux. Reflux that exceeds this limit in the quantification is said pathological reflux, therefore (NASI et al., 2018).

The exam consists of passing the pHmetry probe through the nose, which on average is two millimeters in diameter and has sensors that detect the acid pH. Probes with more than one sensor are usually used for this exam, in which the distal sensor is positioned five centimeters above the upper limit of the Lower Esophageal Sphincter (LES) (usually through esophageal manometry). The probe is connected to a portable recorder that records the pH values at each four-second interval (this period can be set on some recorder models) throughout the exam (between 18 and 24 hours in duration). The patient must record the beginning and end of his feeding, periods in which he is standing and lying down (supine), and the occurrence of symptoms (Nasi et al., 2008).

Prolonged esophageal pHmetry testing is indicated for:

- Evaluation of GERD, in cases of patients with functional dysphagia, non-cardiogenic chest pain, aerophagia and rumination, in addition to the characterization of the food esophageal transit disorder resulting from motor disorders;
- Pre and post antireflective surgery evaluation in which pathological acid reflux is suspected to persist;
- Detection of GERD in patients with chest pain of non-cardiac origin, after cardiac evaluation using a scheme (index) of symptom association;
- For study of supra-oesophageal or pharyngeal reflux, when the main symptom of the individual is a respiratory manifestation (asthma, chronic cough, microaspiration recurrent pneumonia), otorhinolaryngological (posterior laryngitis, hoarseness, burning in the oropharynx, globes, chronic hawking and pharyngeal mucus) or oral (halitosis) (Machado, Cardoso, Ribeiro, Zamin Júnior, & Eilers, 2008).

The esophageal pH monitoring is a direct in vivo measure of esophageal acid over time and generally has some recommendations to indicate monitoring, such as when in the presence of symptoms suggestive of GERD, when you want to establish the relationship between GERD and extradigestive symptoms and as a way to control the effectiveness of treatment, which can be clinical or surgical (Guimarães, Marguet, & Camargos, 2006; SBMDN, 2017).

Currently, two systems are used: catheter-based or wireless. Catheter monitoring requires the intranasal insertion of the catheter, with its measuring electrode located 5 cm above the upper edge of the LES. While the wireless is inserted 6 cm above the scamocolumnar junction (SJ) or in Barrett's esophagus above the top of the gastric folds, the data is transmitted to a radio frequency recorder and then transferred to a software (Han & Peters, 2014). Thus, due to the large apparatus required, the wireless pH sensor costs approximately 3 to 5 times more than the catheter-based pH monitor, which should be taken into consideration when choosing the type of monitoring (Carlson & Pandolfino, 2014).

Although catheter monitoring is relatively inexpensive, most patients feel that they cannot work during the test period, which somewhat raises the cost for the patient (Gawron, French, Pandolfino, & Howden, 2014). Thus, the search for a low cost and efficient pHmeter is an important ally in the diagnosis of GERD. To achieve this, catheter monitoring, which is the least expensive compared to wireless, should be improved, seeking to reduce costs as a way to optimize the diagnosis or follow-up of the disease.

We note the scarcity of information in the literature and transparency portals of the Single Health System about the financial costs of the GERD diagnosis method in question. However, it is empirically known that private clinics that perform the diagnostic examination charge high

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prices, which makes access to current diagnostic methods difficult. Therefore, there is a need for greater disclosure of these costs in future works in order to provide a basis for comparison between new low-cost diagnostic methods and the current ones.

In this context, the objective of this study was to develop a prototype portable recorder for prolonged esophageal pHmetry examination with low-cost materials.

II. METHOD

Type of study

Preclinical research, pilot testing with pre-eliminate data to evaluate the effectiveness and accuracy of the prototype.

Place and period of study

The study was carried out in two Higher Education Institutions (HEIs): Universidade do Estado do Pará (UEPA) located at Tv. Perebebuí, 2623 - Marco, Belém - PA, 66087-662 and Universidade Federal do Pará (UFPA) located at Rua Augusto Corrêa, 01, Guamá, Belém - PA, 66075-010, from May 2018 to July 2019.

Study/project phases

First, there was the stage of research and studies in scientific articles, books, content available on websites and in collaborative programming environments on the fundamental concepts for the development of this monograph, the theoretical basis concerning the assembly of the product and software used for reading and measuring data.

List of project components and materials used for testing:

Arduino Mega 2560;

• LCD display with buttons;

• Protoboard;

• Jumpers;

• pH sensor module;

• Probes for 1 and 2 channel pHmetry;

• Module Bluetooth HC-05;

• BNC to RJ45 output adapter;

• Source DC 12v 1A;

• USB cable for computer connection.

Programming

- **Arduino IDE (1.8.5)**

This software writes the codes for reading the pH values and preparation of the Arduino plate for data transmission.

The code for pH reading calculates the average value every 10 measurements and the result obtained is displayed as long as this process is necessary. In this same code, the display buttons are configured as well as the calibration mode for each buffer solution.

Assembly and Calibration

The schematic of the equipment assembly is shown below:

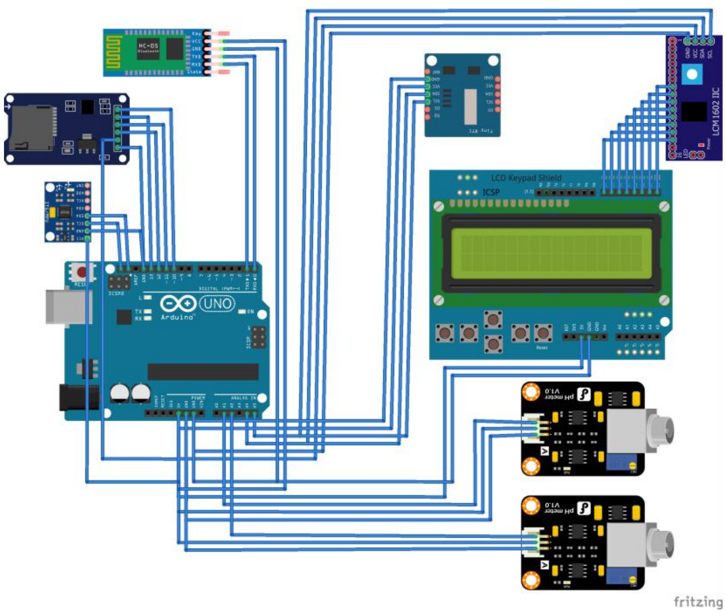

Image 3 - Schematic model of pH meter assembly.

Source - Author of research.

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For calibration of the probe, which must be carried out before each examination, a glass vessel must be provided to receive the pH 4 buffer solution, a second one to receive water and a third one for pH 7 buffer solution, in which case the calibration uses the buffer solutions.

Ready the containers and assemble the equipment, the equipment calibration mode must be selected from the display buttons. Then the probe for pHmetry must be connected to the adapter and inserted in a container containing the pH 4 buffer solution, so that all the channels of the probe are submerged in the solution if it is a probe with more than one channel. Wait about 2 minutes until the display indicates that the calibration for that pH has been completed. Then the probe should be dried with paper and placed in a container of water so that there is no interference with the calibration with buffer solution pH 7 (same procedure as pH 4).

After calibration in the two buffer solutions, the equipment is ready for examination.

Image 4 - Nox buffer solutions pH 7.00 and pH 4.00

Source - Nox Lab Solutions

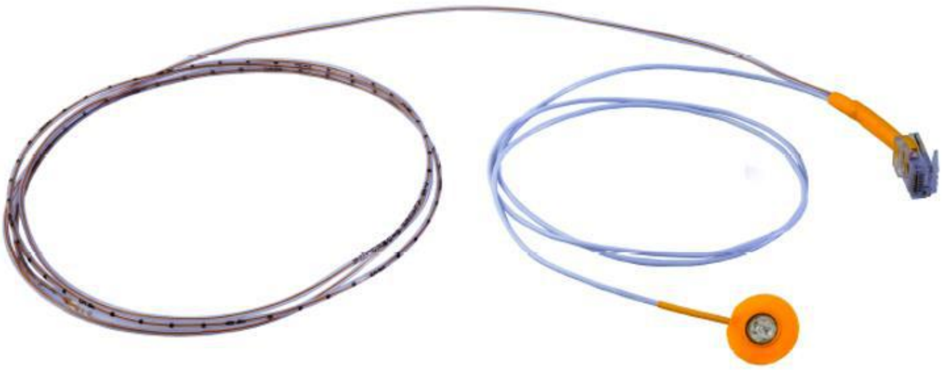

Image 5 - Two-channel pHmetry probe.

Source- Alacer Biomédica Ltda, 2019.

Image 6 - Assembled Arduino pHmeter (left) compared with commercial pHmeter (right)

Source - Author of research.

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Data Collection

After assembly and proper calibration of the Arduino and Commercial devices, both containing two channels were tested on 10 substances in cycles. First, the channels were immersed in a solution containing beer and the pH was read in the times 0 s, 30 s, 90 s, 120 s, 150 s and 180 s, both in Arduino and Commercial for comparative purposes. At the end of the reading, the channels were immersed in water for 3 min for cleaning and then tested in a new solution. The same cycle was repeated for the other solutions, which are: orange juice, energy, mineral water, isotonic, vinegar, coca-cola, guava juice, grape juice and guarana (Image 15).

		1 CERVEJA							Água	2 SUCO DE LARANJA							Água
EXPERIMENTO 7		0 seg	30 seg	60 seg	90 seg	120 seg	150 seg	180 seg	3 min	0 seg	30 seg	60 seg	90 seg	120 seg	150 seg	180 seg	3 min
ARDUINO	CANAL 1	5.1	5.1	5.1	5.0	5.1	5.2	5.1	5.9	5.1	5.0	4.9	4.9	4.8	4.6	5.0	5.8
	CANAL 2	5.2	5.3	5.2	5.1	5.1	5.2	5.1	5.8	5.2	5.0	5.0	4.9	4.9	4.9	4.9	4.7
COMERCIAL	CANAL 1	5.3	5.2	5.1	5.1	5.1	5.1	5.1	6.7	5.5	5.3	5.2	5.1	5.1	5.1	5.1	6.3
	CANAL 2	5.4	5.4	5.4	5.3	5.3	5.3	5.3	6.6	5.4	5.2	5.2	5.2	5.1	5.1	5.1	6.4
		3 ENERGÉTICO							Água	4 ÁGUA MINERAL							Água
EXPERIMENTO 7		0 seg	30 seg	60 seg	90 seg	120 seg	150 seg	180 seg	3 min	0 seg	30 seg	60 seg	90 seg	120 seg	150 seg	180 seg	3 min
ARDUINO	CANAL 1	5.8	5.6	5.5	5.4	5.6	5.4	5.5	5.6	6.2	5.7	5.9	6.9	5.8	5.9	6.1	6.0
	CANAL 2	5.9	5.7	5.7	5.6	5.7	5.7	5.7	5.6	6.3	5.7	5.8	6.3	6.9	6.3	6.5	5.7
COMERCIAL	CANAL 1	6.3	6.2	6.2	6.2	6.3	6.2	6.2	6.6	6.8	6.8	6.8	6.8	6.8	6.8	6.9	7.0
	CANAL 2	6.4	6.3	6.3	6.3	6.4	6.4	6.4	6.6	6.8	6.9	6.9	6.9	6.9	6.9	6.9	7.0
		5 ISOTÔNICO							Água	6 VINAGRE							Água
EXPERIMENTO 7		0 seg	30 seg	60 seg	90 seg	120 seg	150 seg	180 seg	3 min	0 seg	30 seg	60 seg	90 seg	120 seg	150 seg	180 seg	3 min
ARDUINO	CANAL 1	4.2	4.3	4.1	4.1	4.1	4.2	4.2	6.3	4.7	4.3	4.2	4.1	4.1	4.4	4.2	5.3
	CANAL 2	4.4	4.3	4.3	4.2	4.3	4.3	4.2	5.5	4.7	4.6	4.4	4.3	4.4	4.4	4.4	5.4
COMERCIAL	CANAL 1	4.3	4.2	4.2	4.2	4.2	4.2	4.2	6.7	4.8	4.7	4.7	4.6	4.6	4.6	4.6	6.2
	CANAL 2	4.3	4.2	4.2	4.2	4.2	4.2	4.2	6.6	4.8	4.7	4.7	4,7	4.7	4.7	4.7	6.2
		7 COCA- COLA							Água	8 SUCO DE GOIABA							Água
EXPERIMENTO 7		0 seg	30 seg	60 seg	90 seg	120 seg	150 seg	180 seg	3 min	0 seg	30 seg	60 seg	90 seg	120 seg	150 seg	180 seg	3 min
ARDUINO	CANAL 1	4.4	4.4	4.4	4.5	4.4	4.5	4.4	5.2	5.2	5.1	5.2	5.2	5.0	5.2	5.2	5.8
	CANAL 2	4.7	4.3	4.3	4.6	4.4	4.4	4.4	5.0	5.3	5.3	5.4	5.1	5.2	5.1	5.2	5.7
COMERCIAL	CANAL 1	4.7	4.7	4.7	4.7	4.7	4.7	4.7	6.6	5.8	5.7	5.7	5.6	5.6	5.6	5.6	6.4
	CANAL 2	4.9	4.7	4.7	4.7	4.7	4.7	4.7	6.6	5.7	5.6	5.5	5.5	5.5	5.5	5.5	6.4
		9 SUCO DE UVA							Água	10 GUARANÁ							Água
EXPERIMENTO 7		0 seg	30 seg	60 seg	90 seg	120 seg	150 seg	180 seg	3 min	0 seg	30 seg	60 seg	90 seg	120 seg	150 seg	180 seg	3 min
ARDUINO	CANAL 1	6.0	5.9	5.7	5.8	5.7	5.7	5.8	6.0	5.1	5.4	5.3	5.2	5.0	5.3	5.3	5.8
	CANAL 2	6.1	6.1	6.0	6.0	6.0	6.0	6.0	6.1	5.3	5.3	5.6	5.5	5.1	5.7	5.2	5.9
COMERCIAL	CANAL 1	6.5	6.1	6.1	6.1	6.1	6.1	6.1	6.2	5.7	5.6	5.6	5.6	5.6	5.6	5.6	6.8
	CANAL 2	6.4	6.3	6.2	6.2	6.2	6.2	6.2	6.2	5.8	5.6	5.6	5.6	5.5	5.5	5.6	6.9

Image 15 - Schematic of the pH check cycles through Arduino x Commercial channels per solution.

Source - Author of research.

Data Presentation and Analysis

The sample characterization information was computed in a database developed in *Microsoft® Office Excel® 2016* software.

In the application of the Descriptive Statistics, calculations were performed to identify the pairing constant, when necessary, of the results with Arduino in relation to the Commercial device. Tables and graphs were constructed to present the results and position measurements were calculated as arithmetic mean and standard deviation.

Foi realizado o teste de Normalidade de Shapiro-Wilk, onde se identificou que as amostras eram heterocedásticas, não obedecendo uma Distribuição Normal. A estatística analítica foi aplicada através do teste de Mann-Whitney para duas amostras independentes.

The descriptive and analytical statistics were performed in *BioEstat® 5.4 software*. For decision making, the significance level was adopted $\alpha = 0.05$ or 5%, signaling with an asterisk (*) the significant values.

Budget

The choice of components for the assembly of the recorder for pHmetry has undergone some modifications during the development of the Project, in order to make the hardware simpler. Therefore, the components listed above are the ones that are part of the final component selection for the prototype. In Table 1, the costs for composing the hardware of the recorder are presented.

Table 1 - Arduino Inexpensive Prototype Hardware Costs.

Componente	Custo
Arduino UNO Rev3	R$ 54,90
Módulo sensor de pH líquido para Arduino PH-4502C (2 unidades)	R$ 129,80
Display LCD 16 x 2 shield com teclado	R$ 29,90
Módulo Bluetooth RS232 HC-05	R$ 34,90
Módulo micro SDCard	R$ 9,90
Micro SDCard 8 GB	R$ 17,83
Módulo Tiny RTC DS1307	R$ 15,90
Acelerômetro e Giroscópio Módulo GY-521 MPU-6050	R$ 16,90
Módulo Serial I2C para Display LCD	R$ 9,90
Bateria de 9V	R$ 25,02
Caixa para montagem Patola	R$ 34,11
TOTAL	**R$ 379,06**

Source - Author of research.

III. RESULTS AND DISCUSSION

It is essential to make a comparison between the performance of the Arduino pHmeter prototype and the commercial device adopted as a model for the development of this prototype, in order to prove that it is performing measurements correctly, so that its reading of pH values generates results close to those of the reading performed by the commercial device.

The results of the evaluations carried out on the two devices, Arduino and commercial, when using a channel, were statistically similar. The comparisons proved no statistically significant difference (p-value <0.5) in 64 (91.4%) of the 70 performed in Table 2.

The statistically significant differences were present only in the following times and substances: in 180s of the energetic (p = 0.0178*); 60s of the Mineral Water (p = 0.0178*); 150s and 180s of the Isotonic (p = 0.0371* and p = 0.0330* respectively); 0s of the Coke (p = 0.0246*); and 150s of the Grape Juice (p = 0.0230*).

Table 2 - Comparative data of the substances tested by Arduino pHmeter and Commercial pHmeter in 1 channel, organized by evaluation period.

Substance	Rated times - Channel 1						
Appliance	**0 s**	**30 s**	**60 s**	**90 s**	**120 s**	**150 s**	**180 s**
Beer							
Arduino	5.18	5.21	5.24	5.20	5.19	5.38	5.25
Commercial	5.25	5.24	5.21	5.21	5.21	5.20	5.20
p-value	0.1723	0.1351	0.1592	0.4168	0.3683	0.0748	0.1963
Orange juice							
Arduino	5.48	5.40	5.19	5.14	5.10	5.06	5.25
Commercial	5.39	5.25	5.16	5.14	5.13	5.13	5.13
p-value	0.1038	0.1038	0.3566	----	0.2998	0.0371	0.3746

Substance	**Rated times - Channel 1**	**Substan ce**	**Rated times - Channel 1**	**Substan ce**	**Rated times - Channel 1**	**Substance**	**Rated times - Channel 1**
Energy							
Arduino	6.48	6.34	6.31	6.24	6.26	6.21	6.18
Commercial	6.45	6.36	6.34	6.30	6.33	6.31	6.30
p-value	0.3372	0.4582	0.3778	0.1436	0.1403	0.0812	**0.0178***
Mineral water							
Arduino	6.70	6.59	6.44	6.51	6.55	6.61	6.59
Commercial	6.746.796.806.816.816.806.83						
p-value	0.2311	0.1240	**0.0178***	0.0781	0.0946	0.0781	0.0707
Isotonic Arduino	4.25	4.19	4.15	4.15	4.14	4.11	4.13
Commercial	4.26	4.21	4.21	4.21	4.19	4.19	4.21
p-value	0.2643	0.2474	0.0707	0.0707	0.0707	**0.0371***	**0.0330***
Vinegar							
Arduino	4.95	4.79	4.69	4.68	4.68	4.70	4.68
Commercial	4.76	4.71	4.69	4.68	4.66	4.74	4.54
p-value	0.0781	0.0869	---	---	0.4087	0.3540	0.1055
Coca-Cola							
Arduino	5.20	4.86	4.83	4.86	4.85	4.80	4.81
Commercial	4.85	4.80	4.80	4.83	4.84	4.85	4.84
p-value	**0.0246***	0.1671	0.3183	0.3308	0.4407	0.3236	0.3983
Guava juice							
Arduino	5.93	5.58	5.61	5.59	5.55	5.60	5.56
Commercial	5.81	5.63	5.58	5.56	5.53	5.53	5.50
p-value	0.1874	0.2139	0.2474	0.2818	0.2768	0.1122	0.1300
Grape juice							
Arduino	6.28	6.06	6.09	6.06	6.00	5.99	5.99
Commercial	6.26	6.08	6.08	6.08	6.08	6.08	6.08
p-value	0.4582	0.3764	0.4582	0.3372	0.0564	**0.0230***	0.0564
Guarana							
Arduino	5.65	5.61	5.53	5.51	5.51	5.59	5.58
Commercial	5.63	5.58	5.53	5.53	5.49	5.51	5.50
p-value	0.3372	0.2154	----	0.0564	0.2311	0.2311	0.2643

Source - Author of research.

*Teste U Mann-Whitney

The measurement of the pH in beer sample in this test shows that the commercial recorder performed equal reading of the pH values for both channels at all times agreed for such value annotation during three minutes (instants 0 seconds, 30 seconds, 60 seconds, 90 seconds, 120 seconds, 150 seconds and 180 seconds).

In general, the readings taken by the commercial recorder and prototype were of pH values very close to each other and during the three minutes of measurement. These values tended to get closer and closer, until in the instant 150 seconds there was a distance from the results - pH variation of 0.18 more in the arduous prototype, returning to the initial standard of approach at 180 seconds.

About measuring the pH in Industrialized Orange Juice. The pH values read by the commercial recorder channels have been reducing over time, but have remained close to the values recorded by the prototype. The prototype also presented decreasing values, but between 150s and 180s, there was an increase in the pH value of 0.12. When compared, the instants of 0 seconds, 30 seconds and 180 seconds showed the highest different values between the two models, in these cases, always the Arduino pHmeter presenting a higher value than the commercial one.

In the Energetic analysis, the readings from the commercial recorder showed satisfactory proximity to the prototype readings, with the greatest difference being that it is statistically relevant at the moment 180 seconds with a pH of the commercial pHmeter 0.12 ($p=0.0178$) greater than the Arduino pHmeter.

The test in mineral water showed that the pH values read by the channels of the commercial recorder remained similar to each other during almost the entire three-minute period, with its highest pH difference at the time 60 seconds with a variation of 0.44 more for the Commercial pHmeter.

The values obtained from the isotonic analysis, the readings from the commercial recorder showed satisfactory proximity to the prototype readings, with the greatest difference in pH being 150 seconds and 180 seconds with a pH of the commercial pHmeter 0.8 greater than the Arduino pHmeter.

Regarding the measurement of the pH of the Vinegar, it conferred a lot of stability in the reading of both the commercial register and the Arduino register. It is observed that despite the small oscillations in the channel readings, only the instants 0 seconds and 180 seconds ran with pH values respectively higher by 0.19 and 0.14 in the measurement of Arduino pHmeter.

For the records of the Coca-cola soft drink, there is statistical variation between the data obtained by the commercial recorder and the arduino recorder in the period of 0 seconds, where its pH variation was 0.35 more in the arduino recorder. The other measurements were made with low variation, in which the 30-second period was the one with the highest pH variation (0.06) when compared to the initial variation.

Regarding the values obtained from the analysis of Guava Juice, the readings from the commercial recorder showed satisfactory proximity to the prototype readings, with the greatest difference in pH being 0 seconds with a pH of the arduous pHmeter 0.12 greater than the commercial pHmeter.

In the Grape Juice analysis, he studied with statistical equity throughout the analysis, except only the instant of 150 seconds, where the pH variation was 0.08 plus pro commercial model.

Already in the analysis of Guaraná performed in 1 channel. Statistically speaking there is no expressive difference between the values obtained in both models. The moment of greatest difference was 150 and 180 seconds, where in both, the pH variation was 0.08 more in the Arduino model.

On the other hand, the general results of the evaluations carried out on the two devices, Arduino and commercial, when using two channels, were also statistically similar. Comparisons proved no statistically significant difference ($p\text{-value} < 0.5$) in 66 (94.3%) of the 70 performed, all presented in Table 3 and graphically represented by the Graphs 11 to 20.

The statistically significant differences were only present in the following times and substances: in 0s of orange juice ($p = 0.0371^*$); 0s time of energy ($p = 0.0330^*$); 0s and 30s time of vinegar ($p = 0.0075^*$ and $p = 0.0216^*$ respectively).

Table 3 - Comparative data of the substances tested by Arduino pHmeter and commercial pHmeter in 2 channels, organized by evaluation period.

Substance	**Tempos avaliados - Canal 2**						
Appliance	**0 s**	**30 s**	**60 s**	**90 s**	**120 s**	**150 s**	**180 s**
Beer							
Arduino	5.20	5.20	5.21	5.23	5.16	5.21	5.23
Commercial	5.23	5.28	5.24	5.23	5.20	5.21	5.20
p-value	0.2311	0.3346	0.4319	----	0.3915	----	0.2474
Orange juice							
Arduino	5.55	5.44	5.31	5.24	5.19	5.18	5.33
Commercial	5.40	5.23	5.21	5.21	5.18	5.18	5.18
Substance	**Rated times - Channel 1**						
Appliance	**0 s**	**30 s**	**60 s**	**90 s**	**120 s**	**150 s**	**180 s**
p-value	**0.0371***	0.0911	0.0605	0.3307	0.2998	---	0.1240
Energy							
Arduino	6.59	6.41	6.40	6.34	6.35	6.23	6.30
Commercial	6.45	6.36	6.35	6.34	6.34	6.35	6.35
p-value	**0.0330***	0.0946	0.0781	----	0.2154	0.1468	0.2818
Mineral water							
Arduino	6.78	6.63	6.63	6.46	6.66	6.76	6.66
Commercial	6.75	6.81	6.84	6.81	6.84	6.81	6.84
p-value	0.4658	0.2573	0.2208	0.1075	0.2825	0.4369	0.2956
Isotonic							
Arduino	4.30	4.26	4.24	4.20	4.19	4.18	4.18
Commercial	4.29	4.24	4.21	4.19	4.19	4.18	4.19
p-value	0.3764	0.2004	0.2311	0.3391	----	-----	0.3756
Vinegar							
Arduino	5.08	4.86	4.81	4.78	4.80	4.80	4.75
Commercial	4.76	4.71	4.71	4.71	4.71	4.66	4.59
p-value	**0.0075***	**0.0216***	0.1189	0.1428	0.0974	0.0539	0.0522
Coca-cola							
Arduino	5.25	4.89	4.88	4.89	4.85	4.84	4.84
Commercial	5.01	4.81	4.83	4.83	4.83	4.81	4.81
p-value	0.1084	0.1752	0.2793	0.2255	0.3822	0.3841	0.4054
Guava juice							
Arduino	5.82	5.54	5.50	5.40	5.45	5.39	5.41
Commercial	5.73	5.51	5.48	5.46	5.46	5.46	5.43
p-value	0.2175	0.4168	0.4374	0.0545	0.2311	0.0929	0.2311

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Substance	Rated times - Channel 1	Substance	Rated times - Channel 1	Substanc e	Rated times - Channel 1	Substanc e	Rated times - Channel 1
Grape juice							
Arduino	6.38	6.15	6.13	6.11	6.10	6.10	6.10
Commercial	6.23	6.09	6.08	6.08	6.08	6.06	6.06
p-value	0.0587	0.1860	0.2643	0.2998	0.4168	0.2998	0.3764
Guarana							
Arduino	5.79	5.59	5.64	5.60	5.65	5.68	5.64
Commercial	5.73	5.65	5.70	5.63	5.63	5.64	5.65
p-value	0.3671	0.1038	0.3641	0.3183	0.4483	0.4194	0.4722

Source - Author of research.

*Teste U Mann-Whitney

For the measurement of the pH in beer, the pH values read by the channels of the commercial recorder and Arduino prototype were statistically similar, and there was no major disagreement between them. The longest distance period was 30 seconds, where the pH variation was 0.08 more in the commercial prototype.

On the other hand, in the analysis of the orange juice it obtained significant statistical variation only in the instant of 30 seconds, which the pH variation was 0.21 (p=0.0911) plus prototype Arduino. The other values were reduced between the variation in time, equalizing in the instant of 150 seconds and distancing again in 180 seconds with a pH variation of 0.15, although statistically not important.

The analysis of the pH obtained in the Energetic solution by the commercial pHmeter and the arduous prototype showed statistically relevant pH variation of 0.14 (p=0.0330) more for the arduous prototype in the instant of 0 seconds. The other times and measurements had quite similarity in their data.

In the values obtained from the Mineral Water analysis, and the Isotonic solution analysis. In both, both the commercial pHmeter and the arduous prototype were made with similar data, not showing important variations to the statistics.

On the other hand, in Vinegar analysis, it is performed with two statistically different moments, represented in 0 seconds with a pH variation of 0.32 (p=0.0075) and 30 seconds with a pH variation of 0.27 (p=0.0216), both with higher data in the arduous pHmeter. The other times and values of both pHmeters showed no statistically relevant divergence, being considered similar.

In the presentation of Coca-Cola pH analysis, even with the pH difference of 0.24 plus in the arduous prototype, this, as well as the other results, does not present significant statistical variation.

In relation to the analysis of guava juice, it presents statistical similarity at all analyzed moments, and no significant inconstancy or divergence is evidenced. The interval of greater distance between the data obtained by the Commercial pHmeter and Arduino pHmeter was the instant of 0 seconds, with pH variation of 0.09 more for the prototype Arduino.

For the analyses of Grape Juice and Guarana respectively, they present stability in the data collected in both with pHmeters, being noticed statistical similarity in all the analyzed moments, not being evidenced any inconstancy. Its moments of greater variation between the obtained data, were 0 seconds in Graph 19 with variation of pH of 0.15 more for the prototype Arduino, and 30 and 60 seconds in Graph 20, with variation of pH of 0.06 more for the Commercial pHmeter.

IV. CONCLUSION

The portable Arduino pHmeter was built at a low financial cost for better accessibility to pHmetry examination. Daily substances (Beer, Energetic, Mineral Water, Orange Juice, Grape Juice, Guava Juice, Isotonic, Guarana, Coca-cola and Vinegar) were tested, having their readings done and saved in SD memory card, where they were recorded for later access.

The analysis, its performance in terms of accuracy in recording pH values (aqueous solutions) is satisfactory because it presents results very close to the measurements indicated by the commercial recorder, in simultaneous measurements during the testing phase.

The calibration with the buffer solutions of pH 4.00 and 7.00 values purchased corresponded to the actual pH values of each solution, so the portable recorder showed satisfactory results with respect to the calibration procedure also.

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