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ASSESSMENT OF THE PHYSICAL AND CHEMICAL PROPERTIES OF *Colocasia esculenta* (TARO) CORM GEL AND ITS USE IN ULTRASOUND IMAGING: VISIBILITY METRIC FOR AN ALTERNATIVE SONOGRAPHIC GEL

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Abstract: The high cost and unavailability of consumable supplies such as ultrasound gel affect the number and quality of ultrasound procedures in low-resource healthcare settings. This study evaluates the chemical properties of taro corm gel and its potential use as an alternative sonographic gel to produce quality ultrasound images. Spreadability, viscosity, and pH evaluation tests were done to identify the chemical properties of taro corm gel. The ultrasound images obtained from the gelatin-based ultrasound phantom were evaluated using the 10-cm Visual Analogue Scale (VAS) and a 5-point Likert scale to assess the spatial resolution and image sharpness. Seven radiology residents who were blinded to the type of gel used were asked to evaluate the 26 ultrasound images obtained using each gel type. A pilot study was undertaken to determine the interrater agreement of the researcher-made research tool for evaluating the quality of the ultrasound images. The statistical analysis of the data gathered from the tests for chemical properties and evaluation of the ultrasound image quality revealed that the taro corm gel exhibited a significantly higher spreading ability, greater alkalinity, and less viscosity than the commercial ultrasound gel (CUG). In addition, the spatial resolution and sharpness of the ultrasound images obtained from using the taro corm gel and the CUG were not significantly different, showing that the images obtained using taro corm gel were at par with the images obtained using CUG.

Keywords: Physical and chemical properties, taro corm, ultrasound gel, ultrasound image quality

I. INTRODUCTION

With limited access to healthcare, ultrasonography has desirable clinical choices for in-patients and out-patients requiring an imaging procedure due to its portability, affordability, and absence of ionizing radiation exposure. This imaging procedure can speed up diagnosis, which in turn results in quality delivery of patient care and management of diseases (Stewart et al., 2020; Bierig & Jones, 2009). The inaccessibility of commercial ultrasound gels in rural areas and small healthcare systems and its high cost make some healthcare providers and patients resort to handed-down ultrasound gel (Riguzzi et al., 2017), which potentially increases the risk of cross-contamination. Moreover, its use has been linked to the development of several skin reactions after having an ultrasound procedure. These include allergic contact dermatitis, episodes of eczematous lesions, acute urticaria, and other adverse skin reactions and nosocomial infections (Chasset et al., 2015; Moreno et al., 2009; Cacciapuoti et al., 2018; Mueller & Theoharis, 2013). In medical ultrasonography, the main objective is the reception and detection of the reflected echoes from numerous body interfaces to produce images with precise and accurate diagnostic information (Bhargava, 2010). Bhargava (2010) claims that the transmission and detection of ultrasound pulses and echoes can be achieved by integrating an ultrasound gel and a transducer. Ultrasound gel application eliminates the air gap between the transducer and the skin surface of the anatomical region of interest, establishing an increased intensity of the sound waves delivered from the transducer to the patient's body and contributing to a production of a quality ultrasound image (Bhargava, 2010). The similar acoustic properties of the ultrasound gel to the soft tissues of the body and the ability of the ultrasound gel to accommodate irregular borders and shapes of the transducer and body surface, which excludes air bubbles, are a few of the foundations of the continuous application of the ultrasound gel (Hussey, 1985). According to Alipio (2021), the primary feature of an ideal plant-based ultrasound gel alternative is the presence of mucilaginous materials. This mucilaginous material consequently influences an ultrasound gel's chemical and physical properties that are considered relevant to the ultrasound application. Philippine plants and synthetic-made gel formulations introduced alternatives to commercial ultrasound gel. These plants are commonly found in most provinces with low maintenance conditions**.** From all these ultrasound gel alternatives, a standard recommendation is to find another alternative that contains a rich amount of mucilage, which exhibits an optimized viscosity during the application of ultrasound gel. Gawai et al. (2017) highlighted that mucilage contains hydrophilic materials that can be dissolved and dispersed when mixed with water. The viscosity effect makes it possible for the mucilage to be utilized as the main component in food formulation to improve the viscosity, gel-like properties, texture, and shelf-life of the food.

Wang and Higa (1983) stressed that similar mucilaginous substances found in these ultrasound gel alternatives are present in the taro root crop, which is also one of the predominant food crops in the Philippines. Taro is abundantly grown and serves as a backyard crop in the country. It is also known for its edible corms and leaves, making taro one of the major staple foods (Villanueva & Tupas, 1982). The corms of the taro plant are underground and starchy plant stems that internally contain high amounts of mucilage that contribute to the slimy property of the surfaces of the peeled corms when cut (Strauss, 1983).

With the high demand for ultrasonography examinations and its accompanying consumable supplies, including but not limited to the ultrasound coupling gel in low-resource settings (Salmon et al., 2015), several studies have been conducted that address the need for an ultrasound coupling gel alternative. Most studies show no statistical differences in the ultrasound images' quality when applying the formulated acoustic gel alternatives. However, a few ultrasound gel alternatives demonstrated inconsistent results with the alternative ultrasound gel's physical and chemical properties, which can affect the efficiency of the ultrasonography procedure and production of the ultrasound image. Feasibility studies on the Philippine succulent extracts and okra pod gel as ultrasonography acoustic gel alternatives revealed that the formulated coupling medium had a higher spreadability. However, it showed lower viscosity compared to the commercial reference ultrasound gel and exhibited lower volatility than the alcohol-based ultrasound gel (Alipio et al., 2021; Alipio et al., 2020). These results demonstrate that the ultrasound coupling agent prepared from the Philippine succulents and okra pods does not easily evaporate when applied to the skin and is not as thick as the commercial ultrasound gel. Several studies recommend finding alternative ingredients for the ultrasound gel because of the existing ultrasound gels' physical and clinical quality concerns. With this, the researchers studied the possibility of taro corm gel as an alternative ultrasound gel. Generally, the study aims to determine and establish a statistical difference between the taro corm and the commercial ultrasound gel in terms of pH level, viscosity, and spreadability, and to identify differences in the quality of the images produced when applied to an ultrasound phantom in terms of the spatial resolution and sharpness of the ultrasound images.

II. METHODOLOGY

A descriptive-comparative research design was used to determine the physical and chemical properties of the taro corm gel. For the identification of the chemical properties, the taro corm gel was used for the experimental group, and the commercial ultrasound gel served as the control. The statistical comparison was conducted for the spreadability test, pH determination, and viscosity test.

A study by Richardson et al. (2015) assessed the quality of the ultrasound images produced from applying taro corm gel on a gelatin-based phantom. The taro corm gel was used for the experimental group and the commercial ultrasound gel as control. The ultrasound images produced using the taro corm gel and those produced using the commercial ultrasound gel were evaluated blindly as to the type of gel utilized.

The taro corms were washed, peeled, and sliced into one-inch cubes. Two hundred grams were blenderized with 800 mL of water for 3 minutes. Then, the mixture was separated using a piece of cloth and a strainer. The pH evaluation and spreadability test for the taro corm gel and the commercial ultrasound gel were conducted at the Chemistry Laboratory of Cebu Doctors' University. On the other hand, the viscosity test was done by the Biomedical Physics Groups of the University of San Carlos Department of Physics at their laboratory. The ultrasound images were obtained at Oasis Diagnostic and Laboratory Center. The viewing and assessment of the quality of the ultrasound images produced using the taro corm gel and the commercial ultrasound gel were done at the respective viewing stations of the radiologists and radiology residents who participated in the study.

The pilot study required acquiring three images using Tru-Gel, a commercial ultrasound gel, and three images using the taro corm gel. Three certified radiologists based in Cebu, Philippines, evaluated each of the six images. These radiologists were chosen using purposive sampling. The evaluation tool was based on the Benfield 10-cm scale modified by the researchers and evaluated by certified radiologists for reliability. The data from this pilot study underwent statistical analysis to determine the reliability and validity indices. For the actual study, seven radiology residents-in-training were chosen using purposive sampling to become the research respondents who would evaluate the quality of the ultrasound images obtained on a homemade gelatin-based ultrasound phantom. Twenty-six images–13 images obtained using the taro corm gel and 13 images obtained using the commercial ultrasound gel–were evaluated by the residents-in-training, who were blinded as to the type of gel used.

To determine the chemical properties of the taro corm gel and the commercial ultrasound gel and assess the quality of the ultrasound images produced using the taro corm gel and those produced using the commercial ultrasound gel, the following were conducted: (a) for evaluating the ability of the taro corm gel and commercial ultrasound gel to spread, a glass beaker filled with enough sand to make it weigh 100 grams was used to press down on two glass plates with gel in between, as described in the published studies of Alipio (2021), Estanqueiro et al. (2015), and Deuschle et al. (2015); (b) in determining the pH value of the taro corm gel and the commercial ultrasound gel, a digital pH meter was used; (c) to measure the viscosity of the taro corm gel and the commercial ultrasound gel, samples were sent to the University of San Carlos, where a rheometry technique was used; and (d) for the analysis of the ultrasound images, the ultrasound image pairs were evaluated by competent radiologists and radiology residents using the 10-cm visual analogue scale partly adapted from Aziz et al. (2018), Riguzzi et al. (2014) and Riguzzi et al. (2017) and a 5-point Likert scale. The evaluators were blinded as to the type of gel used to obtain the ultrasound images. For this assessment, the ultrasound images were evaluated with respect to the following parameters: sharpness of the image and spatial resolution.

Authorization letters to conduct the study were submitted to the Chairman of the Department of Radiologic Technology, the Dean of the College of Allied and Medical Sciences and the Dean of the College of Arts and Sciences of Cebu Doctors' University, the Chair of the Department of Radiology of Cebu Doctors University Hospital, and the proprietors of Oasis Diagnostic and Laboratory Center. Moreover, the research tool used to evaluate the ultrasound images produced using the taro corm gel and the commercial ultrasound gel was submitted to a statistician and a psychometrician for research tool evaluation. Once approval was given to use the research tool, the researchers conducted the pilot study using the hybrid 10-cm visual analogue scale and 5-point Likert scale partly adapted from the study of Aziz et al. (2018) for the assessment of the ultrasound image quality. The researchers then continued with the actual data gathering by first preparing the taro corm gel and procuring the commercial ultrasound gel. The taro corm gel and procurement of the commercial ultrasound gel were subjected to tests for chemical properties including the viscosity test, pH evaluation, and the spreadability test. The commercial ultrasound gel and taro corm gel were utilized to obtain ultrasound images from a gelatin-based phantom as described by Richardson et al. (2015). The ultrasound procedure on the gelatin-based phantom using the taro corm gel and the commercial ultrasound gel was done 13 times for each type of gel. The quality of the 26 ultrasound images generated was evaluated by seven radiology residents using the 10-cm visual analogue scale (VAS) and 5-point Likert scale in terms of the sharpness of the image and spatial resolution (Aziz et al., 2018; Riguzzi et al., 2017; Binkowski et al., 2014). The evaluators were blinded as to the type of gel used to obtain the ultrasound images. The method of extraction and preparation of the taro corms was derived from Arora et al. (2011) with some modifications. The use of a gelatin-based ultrasound phantom to assess the sonographic images was described by Richardson et al. (2015).

The mean and standard deviation were obtained from the data gathered. An independent sample *t*-Test was used to establish the statistical comparison of the values obtained from the tests conducted for the chemical properties of the taro corm gel and the commercial ultrasound gel and the quality of the corresponding ultrasound images produced from the sample gels. A *p* value ≤ 0.05 was used to determine whether there is a statistically significant difference between the chemical properties and the ultrasound image qualities of both ultrasound gel types. Meanwhile, the Mann-Whitney *U* Test was used to compare whether the distribution of the dependent variable is the same for the taro corm gel and the commercial ultrasound gel.

III. RESULTS AND DISCUSSIONS

Table 1. Chemical Properties of Taro (Colocasia esculenta) Corm Gel and Commercial Ultrasound Gel With Their Corresponding *p* Values

Chemical Properties	TARO (*Colocasia esculenta*) CORM GEL	COMMERCIAL ULTRASOUND GEL
	MEAN ± STANDARD DEVIATION	MEAN ± STANDARD DEVIATION
SPREADABILITY (*in centimeters*)	5.450 ± 0.4093	3.917 ± 0.0289
Mean Difference	1.533	
df	4	
t	6.473	
p value	0.003	
pH EVALUATION	7.758 ± 0.0641	6.271 ± 0.0222
Mean Difference	1.487	
df	4	
t	37.981	
p value	**< .001***	
VISCOSITY (*in Pa·s*)	0.113 ± 0.0058	8.373 ± 0.194

Chemical Properties	TARO (*Colocasia esculenta*) CORM GEL	COMMERCIAL ULTRASOUND GEL
	MEAN ± STANDARD DEVIATION	MEAN ± STANDARD DEVIATION
Mean Difference	- 8.26	
df	2.004	
t	- 73.716	
p value	**< .001***	

***p value < .001 is significant**

Table 1 shows the spreading ability, pH value and viscosity of the taro corm gel and the commercial ultrasound gel. Both sample groups underwent three trials. For the spreadability test, the statistical mean of the taro corm gel was 5.450 cm with a standard deviation of 0.4093. On the other hand, the commercial ultrasound gel had a mean of 3.917 cm and a standard deviation of 0.0289. According to Nurman et al. (2019), good spreadability implies that a gel is evenly distributed over a distance of 5 to 7 centimeters when applied to the skin surface. The spreadability test resulted in taro corm gel having a spreading ability falling between 5.1 cm to 5.9 cm, which indicates that the taro corm gel has excellent spreading ability. The results of the independent samples *t*-Test, as shown in Table 1 above, showed that there is a statistically significant difference between the spreading ability of the taro corm gel (5.450 ± 0.4093) and the spreading ability of the commercial ultrasound gel (3.917 ± 0.0289), with $t(4)=6.473$ and $p=0.003$. This suggests that the taro corm gel can spread more than the commercial ultrasound gel. Moreover, a large effect size was also calculated for the difference in the spreading diameter between the two types of gels, $d=5.284$, demonstrating that the spreading diameter of the taro corm gel is greater than the spreading diameter when using the commercial ultrasound gel. Logically, the wider the spreading diameter, the greater the surface area the gel can cover. The larger diameter, demonstrating the greater spreadability of the taro corm gel, confirms that the taro corm gel can cover a greater surface area when applied to the skin surface. Hence, a lesser amount of the taro corm gel is needed to carry out a specific medical imaging scan. This also addresses the economic research gap concerning the commercial ultrasound gel's high cost.

For the pH determination, the statistical mean obtained from taro corm gel was 7.758 with a standard deviation of 0.0641. In contrast, commercial ultrasound gel had a statistical mean of 6.271 and a standard deviation of 0.0222. This demonstrates that the taro corm gel has a basic pH in contrast to the commercial ultrasound gel. The results of the independent samples *t*-Test showed a statistically significant difference between the pH values of the taro corm gel (7.758 ± 0.0641) and those of the commercial ultrasound gel (6.271 ± 0.0222) with $t(4)=37.981$ and $p < .001$). This shows that taro corm gel is significantly less acidic compared to the commercial ultrasound gel.

The test for viscosity demonstrated that the taro corm gel has a lower mean viscosity of 0.113 ± 0.0058 Pa•s compared to the commercial ultrasound gel of 8.373 ± 0.1940 Pa•s. This indicates that for the three trials done on each sample, the commercial ultrasound gel exhibited greater viscosity when compared to the taro corm gel. The commercial ultrasound gel has a decreasing viscosity behavior as the shear rate increases. This means that the commercial ultrasound gel becomes solid under static conditions and when a certain amount of stress is applied to the commercial ultrasound gel, a smooth flow of the commercial ultrasound gel is seen. Correspondingly, despite the taro corm gel exhibiting less viscosity than the commercial ultrasound gel, the shear-thinning property of the taro corm gel also generates beneficial features. These features include the drip resistance behavior of the gel when at rest and the ease of application on a surface when external pressure or stress is applied. Similar to the commercial ultrasound gel, the taro corm gel is considered a non-Newtonian fluid. The difference in spread between the two types of gels, *d*=60.187, indicates that the taro corm gel is less viscous than the commercial ultrasound gel.

Table 2. Mean and Standard Deviation of the Quality of the Ultrasound Images in a 10-cm Visual Analogue Scale and a 5-point Likert Scale

Type of Scale	IMAGE QUALITY PROPERTY	TYPE OF ULTRASOUND GEL	*n*	MEAN ± STANDARD DEVIATION	*p* value
10-cm Visual Analogue Scale	Image Sharpness	Taro (*Colocasia esculenta*) Corm Gel	13	7.273 ± 0.8495	.787
		Commercial Ultrasound Gel	13	7.164 ± 0.7160	
	Spatial Resolution	Taro (*Colocasia esculenta*) Corm Gel	13	7.240 ± 0.8134	
		Commercial Ultrasound Gel	13	7.166 ± 0.5330	

Type of Scale	IMAGE QUALITY PROPERTY	TYPE OF ULTRASOUND GEL	*n*	MEDIAN VALUE	INTERPRETATION	*p* value
5-point Likert Scale	Image Sharpness	Taro (*Colocasia esculenta*) Corm Gel	13	4	Apparently Clear	.787
		Commercial Ultrasound Gel	13	4	Apparently Clear	

	Spatial Resolution	Taro (*Colocasia esculenta*) Corm Gel	13	4	Apparently Clear	
		Commercial Ultrasound Gel	13	4	Apparently Clear	

p value > 0.05 is considered not significant

The table above illustrates the sharpness of the image and spatial resolution of the ultrasound images produced from taro corm gel and the commercial ultrasound gel when applied on the gelatin-based phantom.

Using the 10-cm VAS for image sharpness, the mean and standard deviation for the taro corm gel was 7.273 ± 0.8495 cm while those for the commercial ultrasound gel were 7.164 ± 0.7160 cm. This means that the ultrasound images produced using the taro corm gel are slightly sharper than the images produced using the commercial ultrasound gel. An ultrasound image is described as sharp when the tissue boundaries of the anatomical part being imaged are accurately displayed on the display monitor of the ultrasound machine (Simpson, 2009). With these results, the ultrasound images produced using the taro corm gel are slightly more accurately displayed compared to those produced using the commercial ultrasound gel in terms of the boundaries of the anatomical area of interest of the homemade gelatin-based phantom. The results obtained from the independent samples *t*-Test suggest that there is no statistically significant difference between the sharpness of the images produced using the taro corm gel and those produced using the commercial ultrasound gel, with $t(24)=0.356$ and $p = .725$. This means that based on the 10-cm Visual Analogue Scale, the sharpness of the images produced are identical for both the taro corm gel and the commercial ultrasound gel, with the image sharpness for both types of ultrasound gels at around 7 out of 10 cm on the 10-cm VAS. Using the 5-point Likert scale, the ultrasound images generated using the taro corm gel and the commercial ultrasound gel are “Apparently Clear.”

Additionally, the results of the Mann-Whitney *U* Test suggest that there is no statistically significant difference between the sharpness of the ultrasound images generated using the taro corm gel (MR=14.00) and that of the images produced using the commercial ultrasound gel (MR=13.00), with U=78.000 and p = .762. This implies that the sharpness of the images produced using either the taro corm gel or the commercial ultrasound gel was identical, with the sharpness of the images for both ultrasound gel types rated ‘Apparently Clear’ on the 5-point Likert Scale. For Carlton and Adler (2013), image sharpness refers to the accuracy of the structural lines being reflected in the ultrasound image. With the images rated as “Apparently Clear” and nearing the “Very Sharp” category, the ultrasound images produced using either the taro corm gel or the commercial ultrasound gel demonstrate accurately the lines of the structures being examined. Therefore, the image sharpness of the ultrasound images generated from both types of gels is at par with each other.

Utilizing the 10-cm VAS to determine the spatial resolution, the ultrasound images produced using the taro corm gel were rated as slightly more well-defined (7.240 ± 0.8134 cm) than those of the commercial ultrasound gel (7.166 ± 0.5330 cm).

According to Simpson (2019), images that have good spatial resolution accurately display two distinct parts that are being scanned. This implies that the ultrasound images produced using the taro corm gel exhibit more distinction in imaging two distinct parts that are close to each other in the homemade gelatin-based ultrasound phantom. Correspondingly, the results of the independent samples *t*-Test suggest that there is no statistically significant difference between the spatial resolution of images produced using the taro corm gel (7.240 ± 0.8134 cm) and the commercial ultrasound gel (7.166 ± 0.5330 cm) with $t(24)=0.274$ and p = .787. This means that the spatial resolution of the ultrasound images produced using both the taro corm gel and the commercial ultrasound gel is identical with a rating at around 7 out of 10 on the 10-cm Visual Analogue Scale. When using the 5-point Likert scale for the assessment of the ultrasound images, the spatial resolution of the ultrasound images acquired using the taro corm gel and the commercial ultrasound gel are both "Apparently Clear". These results show that the quality of the ultrasound images produced using both types of gels is of high quality. Furthermore, the outcome from the Mann-Whitney *U* Test suggests that there is no statistically significant difference between the spatial resolution of the ultrasound images produced using the taro corm gel (MR=13.00) and the commercial ultrasound gel (MR=14.00), with U=78.000 and p = .762. This infers that the spatial resolution of the ultrasound images produced using both ultrasound gel types is identical, with the ultrasound images assessed as 'Apparently Clear' on the 5-point Likert scale. With the results indicating no statistically significant difference between the spatial resolution of the ultrasound images produced using both types of gels being used, the ultrasound image is accurate in demonstrating two distinct objects that are close to each other.

IV. CONCLUSION

In summary, the taro corm gel exhibits a significantly higher spreading ability, greater alkalinity, and less viscosity compared to the commercial ultrasound gel. The statistical analysis of the quality of the images did not show a statistically significant difference between those obtained using the taro corm gel and those obtained using the commercial ultrasound gel. The chemical properties and the quality of the ultrasound images produced using the taro corm gel are comparable to those of the commercial ultrasound gel. Therefore, the taro corm gel is a viable alternative to the commercial ultrasound gel.

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