IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 21, Issue 10 Ser.1 (October. 2022), PP 50-56
www.iosrjournals.org

Evaluation of Water Absorption and Linear Dimensional Changes of Acrylic Resin Denture Base Reinforced with Ramie and Banana Stem Fibers

Endang Prawesthi[1*], Marzia M. Tetelepta[1], Heldayani[1]
[1]*Dept. of Dental Technology, Health Polytechnic Ministry of Health Jakarta II Jakarta, Indonesia*

Abstract:
Background: *Heat polymerized acrylic resin is one of the most commonly used denture base materials. In addition to having several advantages, this material also has several disadvantages, one of which is hydrophilic.Acrylic resin can absorb water which can cause dimensional changes. This condition results in pressure in the material so that the acrylic resin is easy to crack and fracture.Various attempts have been made to strengthen the mechanical properties of acrylic denture base materials, including the addition of reinforcing materials such as fibers.There are two types of known fibers, namely synthetic and natural fibers. Synthetic fibers are relatively expensive, so an alternative is needed, namely the use of natural fibers (ramie and banana stem).This study aims to determine the effect of adding ramie and banana stem fibers on water absorption and dimensional changes of the acrylic denture base.*
Materials and Methods: *This study aims to determine the effect of adding ramie and banana stem fibers on water absorption and linear dimensional changes of the acrylic denture base.The shape of the specimen for the water absorption test is an acrylic disk with a diameter of (50±1) mm and a thickness of (0.5±0.1) mm according to ISO 20795-1: 2013, and the specimen for the linear dimensional change test is an acrylic plate with a size of 64 x10 x 3.3 ± 0.1 mm according to ISO 20795-1: 2013. The fibers used are ramie and banana stem fibers, and an alkalization process is carried out before use.The fiber concentration added was 1.6% of the sample weight. The specimen consisted of three groups, namely control, the addition of ramie fiber, and banana stem fiber.*
Results: *In the mean value of water absorption and linear dimensional changes, the largest value was seen in the addition of banana stem fiber, followed by the ramie fiber group, and the smallest value in the free fiber/control group. One-way ANOVA analysis - LSD test on the water absorption and linear dimensional changes there is a significant difference ($p < 0.05$). The Pearson correlation test showed a significant positive correlation between the two tests.*
Conclusion:*Water absorption and linear dimensional changes with the addition of natural fiber showed a significant increase compared to the free fiber/control group, even though the value was still within tolerable limits in the oral cavity. The greater the water absorption, the greater the linear dimensional changes of the acrylic denture base.*
Key Word*:Water Absorption;LinearDimensional Change;Acrylic Resin Denture Base;RamieFiber; Banana Stem Fiber.*

Date of Submission: 20-09-2022 Date of Acceptance: 05-10-2022

I. Introduction

Heat-cured acrylic resin is a dental material that is often used for a denture base. This material contains polymethyl methacrylate and polymerization using heating. First, this acrylic resin was introduced by Walter Wright in 1937 and is still the first choice as a denture base.[1,2]The wide use of this acrylic resin base is because the color is close to the oral tissue so that it looks better aesthetically, it is easy to process and repair, easy to clean, biologically safe, the price is relatively cheaper, and easy to polish so that the surface smoothness can last for a long time.[3,4]However, this denture has the disadvantage that it is easy to damage after being used for a long time. The lack of physical and mechanical properties of acrylic material, especially on impact, tensile and flexural strength at the time of use is one of the things that often causes damage.[1,5,6]

The weakness of acrylic resin denture bases can be improved by several methods, including the use of reinforced materials such as fibers. Fibers are pieces or components that form a fully stretched network, consisting of two groups, natural and synthetic.The price of synthetic fiber is relatively more expensive, so innovation is needed to utilize a new material as an alternative. Natural fibers can be a solution to replace synthetic fibers.[7]Natural fibers can be a solution to replace synthetic fibers. This fiber is one of the promising biomaterials because it is environmentally friendly, biodegradable, cheaper, biocompatibility, Young's modulus and tensile strength are higher, and its use in dentistry is still low.[8]

Heat-cured acrylic resins are also hydrophilic. One of the chemical properties of acrylic resin that must be considered is the water absorption property, which can affect dimensional changes, causing stress in the material which can cause the acrylic resin to crack and fracture. Takashi et al. (1998), stated that acrylic resin macromolecules containing water molecules can cause macromolecules to separate in the material. Ideally, the polymer bonds are insoluble in strong chemicals and also have good thermal stability, but most of the monomers used in the manufacture of dentures can absorb water and chemicals, and also release them back. Generally, denture bases require 17 days to become saturated with water.[3]

Many successful studies on the use of reinforcement added to heat polymerized acrylic bases to improve the mechanical properties of these denture bases, for example, studies on the effect of ramie and banana stem fibers on flexural and impact strengths on acrylic denture bases were carried out by previous authors.[9]However, it is necessary to consider its effect on dimensional accuracy, dimensional stability, and the influence of water absorption. This study aims to determine the influence of adding ramie and banana stem fibers on water absorption and linear dimensional changes of heat polymerized acrylic denture base.

II. Material and Methods

This research is an experimental laboratory with a post-test-only design with a control group design. The total number of specimens was 60 specimens of acrylic resin, divided into two test groups, namely 30 specimens for water absorption and 30 samples for linear dimensional changes. Each test group was divided into three groups: free fiber/control samples, added with ramie fiber and banana stem fiber (figure 1).

Fiber material and alkalization process

The fibers used in this study were ramie and banana stem fibers. Ramie fiber (*Boehmeria Nivea*) is taken from the bark which has a very hard consistency and a glossy white color. Banana stem fiber is taken from the midrib of the kapok banana (*Musa Paradisiaca L*).All fibers are dried until the moisture content is reduced and looks dry. Drying is processed for 12 days by keeping the fiber from getting moldy because it will reduce the quality of the fiber.The use of natural fibers requires an alkalization process with a 5% NaOH solution which aims to increase the adhesion process between the polymer matrix material and the fiber, increase the roughness of the fiber surface layer, and to reduce water absorption in the fiber.[10]The volume of fiber used is 1.6% of the weight of the acrylic plate with the formula: fiber volume (%) = fiber weight (gr)/sample weight (gr) X 100%.[11]

Materials and specimens preparation

The specimen is an acrylic plate made from a master model of metal, then planted in a flask with the dental gips (Plaster of Paris).Linear dimensional change testing: The size of the master model of metal to be used is based on ISO 20795-1: 2013 which is 64 x10 x 3.3 ± 0.1 mm and for water absorption testing: the size of the master model of metal to be used is based on ISO 20795-1: 2013, namely diameter (50±1) mm and thickness (0.5±0.1)mm.[12]

The specimens were made from heat-cured acrylic resin (*BasiQ20, Vertex, Netherlands*®), and the fibers used were cut according to the length and width of the specimen plate shape, then weighed to meet the fiber weight criteria, then the fibers were immersed in a monomer solution until all wetted.Polymers and monomers with a ratio of 2.4 gr: 1 ml were mixed in a mixing jar. Before the mixture reaches the dough stage, the mixture is put into a model mould as high as 1/3 part, then the prepared fibers are impregnated and placed in the middle 1/3 of the mould. After reaching the dough stage, the mixture was added in 2/3 parts, closed the antagonist flask which was previously coated with cellophane, and pressed gently with a hand press.The flask is reopened, then the excess acrylic is cut off. The antagonist flask was reclosed, then the pressure was applied using a table press with a pressure of 2200 psi or 50 kg/cm2. The next process is curing by putting the flask in boiling water (100℃) for 20 minutes.After curing is complete, remove the flask and put it in the water for 10 minutes to cool (according to the manufacturer's rules). After processing, the specimen was removed from the flask and the acrylic surface was smoothed with abrasive paper numbers 360, 600, and 1000, then the specimen was cleaned with water spray.

Specimen Grouping and Research Workflow

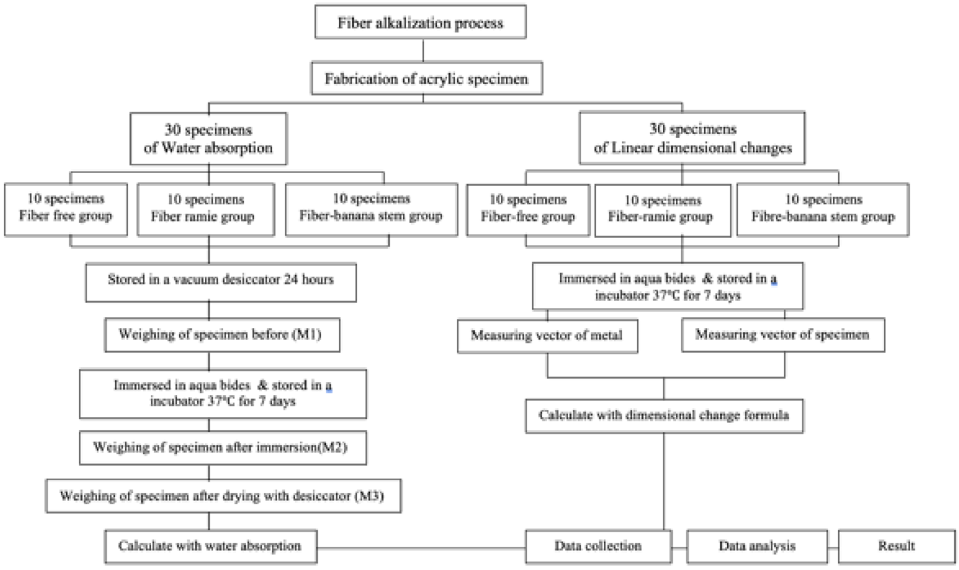

Figure 1. Research workflow diagram

Testing for sample

Testing for water absorption using the formula Water sorption (μg/mm^3) = M2 -M3/V. M2 is the weight of the specimen after immersion (μg), and M3 is the weight of the specimens after immersion and after drying with a vacuum desiccator (μg). V- Surface area of the disc in cubic millimetres. The surface area is mm^3. V=πr2xt, r- radius of the disc in mm; t- a height in mm.[12] The tool used for measurement is an electronic digital balance (*digilife*®) with an accuracy of 0.001gr. Testing for linear dimensional changes using marking on the specimen in the form of four intersections at the four corners of the specimen determined as reference points (A, B, C, and D). A traveling microscope (*Shimadzu®, Japan*) with an accuracy of 0.01 mm was used to measure, then the measurement of dimensional changes can be made using the vector method formula, V = $\sqrt{AB^2 + BC^2 + CD^2 + DA^2 + AC^2 + BD^2}$. Measurements are made at the distance between the interior angles of the intersection of each reference point; AB, BC, CD, and DA (where AB is the distance from A to B and so on). Then, AC and BD measurements are calculated.[13]

Statistical analysis

Data were analyzed using SPSS version 26 (SPSS Inc., Chicago, IL). After data collection, normality, homogeneity, and calculation of the average of each group were conducted to test for water absorption and linear dimensional changes. To determine the significance, analysis was carried out using the One-way ANOVA test with a significance value of $p < 0.05$, and further testing was carried out with the Post Hoc LSD test. Pearson correlation test was used to see the correlation between the water absorption test and dimensional changes.

III. Result

The data in this research, after the normality test was carried out through the Shapiro-Wilk test and based on the significance value ($p < 0.05$) obtained normal data distribution results because all groups (water absorption and dimensional changes) had a p value> 0.05, then continued with Lavene homogeneity test obtained p value > 0.05, so the data in both groups were considered homogeneous.

Water Absorption

Table 1 and Figure 2 show that the mean value of water absorption for the group with the addition of banana stem fiber had the largest average value (34.14 ± 1.102 µg /mm^3), followed by the mean value of the flax fiber group (30.67 ± 1.687 µg /mm^3).) and the smallest mean value was found in the control group (22.62 ± 1.254 µg/mm^3).

Table 1: Mean water absorption value of heat polymerized acrylic resin plate in the free-fiber group (control), with the addition of ramie fiber and banana stem fiber (N=30).

Group	N	Water absorption minimum	Water absorption maximum	Mean Water absorption µg/mm^3 ± SD
Free fiber	10	20.38	2.46	22.62 ± 1.254
Ramie fiber	10	28.53	33.63	30.67 ± 1.687
Banana stem fiber	10	32.61	35.67	34.14 ± 1.102

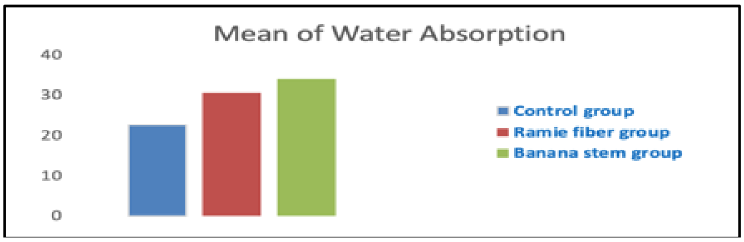

Figure 2. Graph of Mean Water Absorption

Table 2 shows the significance of the difference in the mean value of the water absorption test (µg/mm^3) in the group free fiber (control), the group with the addition of ramie fiber, and the addition of banana stemfiber. The analysis was carried out using a one-way ANOVA with a significance value of $p< 0.05$, and because the p obtained was 0.000 (Ho was rejected), a further test was carried out with the Post-Hoc LSD (Least Significant Different) test to determine the difference in significance between the groups. It can be seen from table 2, that the significance (p) between each group (control, addition of ramie fiber, and banana stem fiber) in the water absorption test was found to have a significant difference ($p< 0.05$), $p = 0.000$.

Table 2: LSD Test - One Way ANOVA, Significance between groups of heat-polymerized acrylic resin plates without fiber (control), with the addition of ramie fiber and banana stem fiber in the water absorption Test (N= 30).

Group		*Mean difference*	*p*
Free fiber/control	**Ramie fiber**	-8.048	0.000*
	Banana stem fiber	-11.516	0.000*
Ramie fiber	**Free fiber/control**	8.048	0.000*
	Banana stem fiber	-3.468	0.000*
Banana stem fiber	**Free fiber/control**	11.516	0.000*
	Ramie fiber	3.468	0.000*

Description: *Significant

Linear Dimensional Changes

Table 3 and Figure 3 show the value of the linear dimensional changes, each group has a different mean value. The mean value of linear dimension changes of the banana stem fiber addition group had the largest mean value (0.546 ± 0.029 mm), followed by the mean value of the ramie fiber group (0.488 ± 0.033 mm) and the smallest mean value of the control group (0.385 ± 0.034 mm).

Table 3: The mean value of the change in dimensions of the hot polymerized acrylic resin plate in the free-fiber group (control), with the addition of ramie fiber and banana stem (N=30).

Group	N	Linear dimensional changes minimum	Linear dimensional changes maximum	Mean Linear dimensional changes (mm) ± SD
Control/Free fiber	10	0.31	0.43	0.385 ± 0.034
Ramie fiber	10	0.43	0.54	0.488 ± 0.033
Banana stem fiber	10	0.51	0.60	0.546 ± 0.029

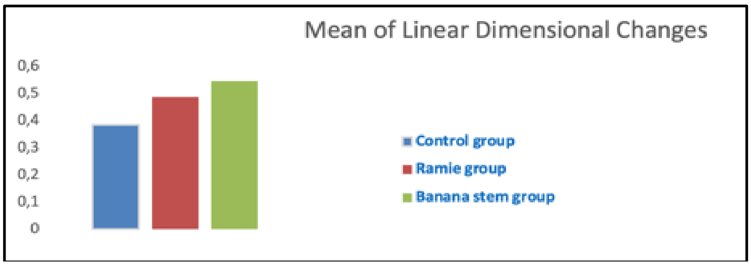

Figure 3. Graph of Mean Linear dimensional changes

Table 4 shows the significance of the difference in the mean value of the Linear dimensional changes Test (mm) in the group free fiber (control), the group with the addition of ramie fiber, and the addition of banana stem fiber.Analysis of the significance value used the one-way ANOVA $p < 0.05$, and because the $p = 0.000$ (Ho was rejected), a further test was carried out with the Post Hoc LSD (Least Significant Different) test to determine the difference in meaning between the groups.The results of the significance (p) between each group (free fiber, addition of ramie fiber, and banana stem fiber) in the linear dimensional changes test found that there was a significant difference ($p < 0.05$), $p = 0.000$.

Table 4: LSD Test - One Way ANOVA, Significance between groups of heat-polymerized acrylic resin plates free fiber (control), with the addition of ramie fiber and banana stem fiber in the linear dimensional change Test (mm) (N= 30).

Group		*Mean difference*	*p*
Free fiber/control	**Rami fiber**	-0.103	0.000*
	Banana stem fiber	-0.161	0.000*
Ramifiber	**Free fiber/control**	0.103	0.000*
	Banana stem fiber	-0.058	0.000*
Banana stem fiber	**Free fiber/control**	0.161	0.000*
	Rami fiber	0.058	0.000*

Description: *Significant

Correlation between Water Absorption and Linear Dimensional Changes

Table 5 shows the correlation between the water absorption and thelinear dimensional changes. In the Pearson correlation test, it was found that there was a significant positive relationship between water absorption and linear dimensions changes of the heat-polymerizedacrylic resin in the ramie fiber addition group, p (2-tailed) = 0.000 and r = 0.852 and in the banana stem fiber group, p (2-tailed) = 0.000 and r = 0.903 (Table 6). From these results, it can be seen that the two groups, namely the addition of ramie fiber and banana stem fiber, have a very strong correlation between the water absorption test and linear dimensionschanges.

Table 5: Correlation between water absorption and linear dimensional changes of heat-polymerized acrylic resin plate with the addition of ramie fiber and banana stem fiber.

Group	Correlation Water absorption and Linear dimensional changes	
	r	***Sig. (2-tailed)***
Ramie fiber	0.852	0.000*
Banana stem fiber	0.903	0.000*

Description: *Significant

IV. Discussion

Water absorption in acrylic resin is the ability to absorb water at a certain time. All polymer resins will absorb water when exposed to humid air or when the polymer is immersed in water.This water absorption process slowly goes through a diffusion process and reaches an equilibrium point of about 2% after a few days depending on the thickness of the denture base. Diffusion is the movement of a substance through a cavity that can cause resin expansion or through a substance that can affect the strength of the polymer chain. Clinical results show that excessive water absorption can cause discoloration and dimensional changes in the denture base.[3,14]

In this study, the mean water absorption value of the heat-polymerized acrylic resin in the group free fiber was 22.62 $\mu g/mm^3$, this value was greater than the previous study conducted by Tuna et al. (2008), which was 19.60 $\mu g/mm^3$, which is 16.26$\mu g/mm^3$.[2,15]However, the water absorption mean value in this study, both the group free fiber and with the addition of ramie fiber (30.67 μg /mm3) was still below the recommended water absorption value based on ISO 1567:1999 specifications, which should not be greater than 32 μg/mm^3.[16,17,18]Meanwhile, for the banana stem fiber addition group, the value was slightly larger (34.14 μg /mm^3). Water absorption in the denture base of heat-polymerized acrylic resin can be influenced by several factors, including diffusion, the amount of absorption of the material, surface area, and surface roughness.[19,20]

The difference in the water absorption value of the free fiber group between this study and that of Tuna et al. (2008) and Felicya et al. (2021) may be due to differences in the denture base material of heat polymerized acrylic resin used and the size of the specimens. In this study, the heat-polymerized acrylic resin used was *BasiQ20 Vertex®* with cylindrical specimens and sizes based on ISO 20795-1: 2013, namely diameter (50±1) mm and thickness (0.5±0.1) mm. While in the research conducted by Tuna et al. (2008), the acrylic resin used was *Meliodent®* with a test rod specimen size of 20 x 20 x 1.5 mm, and Felicya et al. (2021) used *Acron MC®* with a test rod specimen size of 65 x 10 x 2.5 mm.The difference in size and surface area of these specimens allows for differences in water absorption capacity.[2,15]Craig et al. (2000) states that water absorption in acrylic resin is influenced by the amount of water absorption and the surface area of the materials.[20]

The use of ramie fiber and banana stem fiber on an acrylic base in this study had a greater value than the value in the free fiber group, this was probably because ramie and banana stem fibers were hydrophilic as well as the acrylic base also had hydrophilic properties, so water absorption on the base acrylic resin denture with the addition of fiber is increasing. Natural fibers have hydrophilic characteristics that easily absorb water.This condition is caused by natural fibers having a semi-crystalline structure that contains parts that are amorphous and crystalline domains. This part of the amorphous domain causes the fiber to be hydrophilic.[21]Ramie fiber and banana stem fiber are natural fibers that have a fairly high cellulose composition. Ramie fiber contains 80-85% cellulose and banana stem fiber contains 63-64% cellulose. The polar hydroxyl groups in cellulose make natural fibers hydrophilic so that they have a low interface between the fiber and the polymer matrix. In contrast to glass fibers where water absorption occurs only on the surface, cellulose fibers such as ramie and banana stems interact with water throughout the fiber.[22,23]In acrylic resin with natural fiber reinforcement, the absorption process begins with water molecules spreading to the polymer matrix because the diameter of the water molecules is less than 0.28 nm smaller than the distance of the polymer chains in the polymer matrix. The water seeps into the polymer through unsaturated chains or an imbalance of intermolecular forces in the polymer.[6,24] Water absorption in the banana stem absorption group had the highest value compared to ramie fiber and free fiber, this was probably because the composition of banana stem fiber had the highest hemicellulose content of 20%.Hemicellulose is one of the compositions of tool fiber that has a short chain and is not straight so it is easy for solvents to enter. Hemicellulose is like cellulose but is more soluble in alkaline solution (NaOH), so this banana stem fiber will lose its hemicellulose after the alkalization process, which begins with oxidation and degradation processes. This condition causes holes between the fibers and makes it easier for solvents to enter the area.[25]

Linear dimensional changes in this study indicate that the heat-polymerized acrylic resin denture base added with ramie fiber and banana stems affects increasing linear dimensional changes. In this study, the mean value of the linear dimensional change of the heat polymerized acrylic resin in the group without the addition of fiber was 0.385 mm, this value is greater than the previous study conducted by Somchai et al. (2008) which was 0.0761.[13]This condition may be caused by differences in the denture base material of heat-polymerized acrylic resin used and the size of the specimen. This study uses *BasiQ20 Vertex* ® acrylic resin with a plate-shaped specimen and size based on ISO 20795-1: 2013 which are 64 x10 x 3.3 ± 0.1 mm, while Somchai et al. (2008) uses *Meliodent*® acrylic resin with a specimen test rods size of 24x16x3 mm.[12,13]This difference in acrylic resin brands allows for differences in the ratio of polymers and monomers to heat-polymerized acrylic resins, polymerization processes, water absorption, and invisible internal porosity.[14]

Research by Rimple et al. (2011) concluded that changes in the linear dimensions of heat-polymerized acrylic resins can be affected by water absorption.[26]Meanwhile, Polat et al. (2013) stated that the dimensional change was caused by the process of water diffusion that occurred between macromolecules, so the bonds between acrylic resin macromolecules were disrupted, resulting in the expansion of acrylic resin macromolecules. This condition is due to the small molecular diameter of water, which is less than 0.280 nm so the water molecules can diffuse between acrylic resin macromolecules.[3,24]

In this study, the acrylic base with the addition of ramie and banana stem fibers had a higher dimensional change value than the group free fiber. The group with fibers has a dimension change value ranging from 0.488 to 0.546 mm. This value does not significantly affect the adaptation of the denture base in the oral cavity, so it can still be tolerated by the compressibility of the mucosa. This compressibility cannot compensate if the discrepancy that occurs exceeds 1 mm, especially if it occurs in the posterior palatal area because it can create a gap between the denture base and the supporting tissues in the oral cavity and reduce the stabilization of the denture. The stability of the denture is influenced by the tight adaptation between the denture base and the supporting tissues of the oral cavity.[27]

V. Conclusion

Water absorption and linear dimensional changes of acrylic denture base with the addition of ramie and banana stem fibers showed a significant increase compared to without the addition of fiber, although the value was still within the limits that could be tolerated by the compressibility of the oral mucosa.The high value of water absorption and linear dimensional changes of acrylic denture bases is because the acrylic resin is hydrophilic, and natural fibers have high cellulose and semi-cellulose content and are also hydrophilic. Water absorption has an effect on linear dimensional changes. The greater the water absorption, the greater the linear dimensional changes of acrylic denture base with reinforced ramie and banana stem fibers.

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Endang Prawesthi, et. al. "Evaluation of Water Absorption and Linear Dimensional Changes of Acrylic Resin Denture Base Reinforced with Ramie and Banana Stem Fibers." *IOSR Journal of Dental and Medical Sciences (IOSR-JDMS),* 21(10), 2022, pp. 50-56.