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# The influence of kava and carbonated soft drink on the mechanical properties of denture base resins

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## Abstract

*Background:* Edentulism remains a widespread disease in the Pacific Island Countries and Territories where consumption of kava and carbonated soft drinks is popular. This research investigates the effect of kava and carbonated soft drink on the mechanical properties of heat-cure and self-cure denture base resins.

*Methodology:* Samples (n=30) were subjected to aging via thermocycling (10,000) when immersed in artificial saliva, carbonated soft drink and kava. 3-Point bend test and nano-indentation were performed to establish the flexural strength, flexural modulus, hardness, elastic modulus and Weibull modulus. Fourier-transform infrared spectroscopy was performed to establish degree of polymer breakdown and scanning electron microscopy was used to characterise the effects of ageing on the surface and establish the origin of fracture. Data were statistically analysed using ANOVA.

*Results:* There was a significant decrease in flexural strength compared to the control for self-cured but no significant difference in the heat-cured group. There was no significant difference in hardness compared to their controls and a significant decrease in the elastic modulus for self-cured but no significant difference in the heat-cured group.

*Conclusions:* Carbonated soft drink and kava does not reduce mechanical properties enough to fail the minimum ISO 20795-1 standards for testing denture based polymers.

## Introduction

Tooth loss due to periodontal disease and severe caries is a significant global health problem (Peres et al. 2019; Watt et al. 2019). Edentulism is related to various health consequences such as obesity, hypertension and malnutrition (Peres et al. 2012; De Marchi et al. 2012; Nascimento et al. 2016). Partial or complete tooth loss leads to an adverse impact on patient's quality of life, such as physical and mental health (Haag et al. 2017). According to global statistical data, tooth loss was 4.3% in 1990, and this percentage decreased to 4.1% in 2015. However, due to the population rise, the overall number has increased from 157 to 276 million people (Kassebaum et al. 2017). Recent data from the Australian National Study of Adult Oral Health survey, for the period 2017-2018 showed that complete tooth loss, observed in age groups from 33-54 years was 1.1% with an increase in the 55-74 age group to 8.1% and 21% in those who are aged 75 years and more (Do & Luzzi, 2019). A similar projection was observed in a 2018 New Zealand survey revealing 15.8% of the population aged 65 and over were edentulous (New Zealand 2018 Census of Populations and Dwelling, 2018).

In order to restore the facial profile and dental arch, polymethylmethacrylate (PMMA) resins are used as a cost effective material to manufacture partial and complete dentures. The longevity of denture base materials is important so that limitations of strength and design can meet functional demands in the oral cavity. Consequently, the long-term performance of the denture may be compromised and may not be adequate due to the effects caused by poor design including fit and occlusion, problems during manufacture, low strength of repair material and inherent stress on the denture base that occurs over time (Darbar et al. 1994). Furthermore, damage to the denture base over time in the form of various notches and cracks requires the material to withstand and meet the performance criteria as per ISO 20795-1 (Standardization 2013a). Literature on the longevity of complete dentures was found to be scarce. According to a survey by Murtomaa et al (1992) 45% of the upper and 40% of lower dentures were over 10 years old in the Finish population. In contrast, Zarb et al (1997) stated that complete dentures can be expected to last between 5 and 10 years. A more recent study by Dorner et al (2010) reported the survival rate of acrylic resin prostheses was 15.8 years for the mandible and 19.4 years for the maxilla. They further reported that dentures usually do not require relining for the first five years and are event-free for 69.7% of maxillary and 80.5% of complete mandibular dentures (Dorner et al. 2010). In summary, the range reported for denture longevity is between 5 to 19.4 years.

Recently, anecdotal reports by dental technicians in Fiji and other Pacific Islands have been concerned about the consumption of the kava beverage and its possible effects on mechanical properties of acrylic resins. Kava, also known as *Yaqona (Fiji)* or Ava, is a recreational beverage that is produced from the plant of *Piper methysticum* (Piperaceae or intoxicating pepper) and is widely used as a social and ceremonial drink in the South Pacific islands for many centuries. It is known for its pharmaceuticals properties, such as muscle relaxation and its depressant action on the central nervous system (Garner and Klinger 1985). Intake of kava beverage in Arnhem Land in 2003 showed that average daily intake is 44.3–62.9g of powder per person (with the ratio of 25g of powder to 250 mL of water) (Clough 2003). A similar study conducted in Hawaii in 2006 reported that the

Tongan population's average intake of the kava beverage was equal to three drinks a day (Brown et al. 2007). According to Vartanian (2011), in the 2000s, the average daily intake of kava was 240 mL per person (Vartanian et al. 2007). Anecdotally it has been suggested that daily average ceremonial kava drinking in Fiji takes up to 4 hours. Moreover, another common beverage among other ethnic groups is carbonated drinks such as Coca-Cola. According to the Australian health survey, up to 50% of Aboriginal and 37% of other Australian population has one carbonated drink daily (Australian Health Survey, 2012).

To date, there has been no published literature on the effect of kava beverage on mechanical properties of denture base materials. Furthermore, to the authors knowledge, there are no studies which have investigated the influence of kava and carbonated drink on PMMA denture base resins. Therefore the aim of this study is to evaluate the influence of kava and carbonated soft drink on the mechanical properties of denture base resins. The null hypothesis was that there would be no significant difference in mechanical properties between control groups, artificial saliva, carbonated soft drink and kava.

## Materials and Methods

Materials used in this study are listed in Table 1.

### *Design and Specimen Preparation*

120 Heat-cure (Vertex Rapid Simplified, Vertex, Netherlands ) and 120 cold-cure (Vertex Castapress, Vertex, Netherlands) PMMA resin specimens were fabricated following the ISO 20795-1 specification with the following dimensions: H: 3.3±0.2 mm, L: 64±0.2 mm, W: 10±0.2 mm as per manufacturer's recommendations. After processing, all specimens were sequentially polished using grit paper P-400, P-1000, P-1200 (Riken Corundum Ltd., Japan) to achieve an even surface and required dimensions. Each group was further divided into four sub-groups (*n=30)*:, control, artificial saliva, carbonated soft drink , and kava.

### *Beverage Exposure*

According to "ISO 20795-1:2013 Dentistry — Base polymers — Part 1: Denture base polymers", it is required that samples are submerged in distilled water at 37C for 24 hours prior to testing. This was applied to our control samples to produce base line data for later comparison to the experimental groups which were thermal cycled (Standardization 2013b). The heat cure and cold cure acrylic resin samples for two of the three test groups (artificial saliva and carbonated soft drink ) were placed in plastic sealable sachets (6-8 pieces in each sachet) with the ability to be fully exposed to the stimulus liquids. For the third test group, samples were placed in plastic sealable sachets (6-8 pieces in each sachet) containing 25 g kava powder mixed with 250 mL of distilled water at 40 °C. All samples were subjected to thermocycling procedure (10,000 cycles equivalent to 12 months in vivo for saliva and six years for kava based on typical four hours per day exposure) (Gale and Darvell, 1999) , with temperature range 5-55 °C (Proto Tech, USA) and dwell time of 30 seconds. For each stimulus liquid, pH was measured (Jenco Instruments, Inc. USA) before and after

**Table 1.** Acrylic denture base materials and stimulus condition liquids included in this study identified by product name, composition and manufacturer as per the manufacturer's specification information sheet.

| | Product Name | Composition | Manufacturer |
|---|---|---|---|
| Stimulus conditions | Artificial Saliva | Water, Carboxymethyllecellulose (CMC) | (Gale and Darvell, 1999. The development of an artificial saliva for in vitro amalgam corrosion studies. J Oral Rehabil. 1978 Jan;5(1):41-9. doi: 10.1111/j.1365-2842.1978.tb00390.x. PMID: 272442) |
| | Carbonated soft drink (Coca-Cola) | Water >90%, $CO_2$, Sugar, Caffeine, Phosphoric Acid (E150d), Natural Flavouring | Coca-Cola, Amatil, NZ |
| | Kava (Lami Kava) | Information supplied by the manufacturer.<br>*Piper methysticum* shrub.<br>Individual Lactones:<br>Desmethoxyyangonin 0.9%<br>Dihydrokawain 1.6%<br>Yangonin 1.6%<br>Kawain 2.6%<br>Dihydromethysticin 0.8%<br>Methysticin 1.7%<br><br>Chemotype–463215 | Lami Kava, Fiji |
| Denture Base Acrylics | Vertex Rapid Simplified | Methyl methacrylate > 95%, crosslinker <5%, accelerator <1% | Vertex-Dental B.V. (Zeist, The Netherlands) |
| | Vertex Castapress | Methyl methacrylate > 95%, crosslinker <5%, accelerator <1%, UV absorber <<1% | |

24 hours of thermocycling. The liquids were changed every 24 hours. The pH of the stimulus liquids was recorded before and after the thermocycling procedure.

### *Specimen Testing*

The flexural strength of the specimens was measured under three-point bending with a distance of 50 mm between the lower support rollers on a universal testing machine (Instron 3369 Instron, USA) equipped with a 500N load cell with a crosshead speed of 5 mm/min. Fourier Transform Infrared Spectroscopy (FTIR) (Platinum-ATR Alpha II, Bruker, USA) was used to obtain infrared spectra and quantify the changes in chemical bonds in the material. Approximately 10mg were finely scraped from the surface of each tested material and placed on the diamond crystal to record the spectrum. All spectra were obtained from 24 scans at a resolution of 4 $cm^{-1}$.

Nano-indentations (UMIS2000, Semi-Labs, Hungary) using a Berkovich indenter were conducted on specimens sliced to an approximate dimension of 10×10×3 mm. Specimens that exhibited the lowest and highest flexural strength were chosen for nano-indentation. 25 indents were made per specimen across the surface at a static load of 60 mN and held for one second. Compliance of the load frame for the nano-indentation unit was 0.25 nm/mN. Data analysis of hardness and elastic modulus were performed on IBIS2 software (Semi-Labs, Hungary) using the Oliver and Pharr method (Oliver and Pharr 1992). For each group, a representative specimen was selected for SEM analysis for the point of initiation failure surface fractographic analysis.

Flexural strength was calculated using the formula:

$$\sigma = \frac{3FL}{2bh^2}$$

where F – is force at the fracture point, L – is the length of the support span, b – is width and h – height of the specimen.

Flexural modulus was calculated using:

$$E = \frac{L^3F}{4bh^2y}$$

where L – is the length of span; y – distance covered by load F, that is measured from initial position; F – load (N); b – width of bar (mm); h – thickness of bar (mm).

Weibull analysis was performed to obtain the Weibull modulus and normalising strength of the material. The following formula was used:

$$P_f = 1- exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right]$$

Where $P_f$ – is probability of failure, $\sigma$ – is the fracture strength, $\sigma_0$ – a normalising strength, m is the Weibull modulus.

The data sets were analysed with statistical software (IBM SPSS Version 26) and MatLab (R2020a). Descriptive statistics with mean, standard deviation for all tests and groups were computed. The statistical differences between the tested materials were assessed with normality test, one-way ANOVA (analysis of variance) and a posthoc Tukey's test.

## Results

### *pH measurements*

High acidity was observed in the carbonated soft drink with a pH of 2.62; there were minimal changes between pre-test and post-test. Kava was slightly acidic after 24 hours, reaching a pH value of 5.61, whereas artificial saliva became more alkaline, reaching pH value of 8.23 (Table 2).

**Table 2.** Mean pH of the stimulus liquids before and after thermocycling.

| Temp (25°C) | Before Thermocycling | After Thermocycling |
|---|---|---|
| Carbonated soft drink | 2.65 | 2.62 |
| Kava | 6.26 | 5.61 |
| A. Saliva | 6.8 | 8.23 |

### *Flexural strength*

Both heat-cure and self-cure materials showed a decrease in flexural strength compared to the control group. A statistically significant difference was observed in heat-cured specimens between control and artificial saliva groups ($p<0.0001$). However, no statistically significant difference was observed between control groups and carbonated soft drink ($p>0.679$) or kava ($p>0.583$). A significant decrease in flexural strength was observed in the heat-cured specimens in artificial saliva (76.59 ± 12.16 MPa) in comparison to the carbonated soft drink (89.05 ± 14.46 MPa) and Kava (88.41 ± 10.55 MPa). For self-cured specimens, the control group (110.03 ± 8.21 MPa) had a statistically significant difference compared to artificial saliva (96.62 ± 14.07 MPa), carbonated soft drink (92.04 ± 16.61 MPa) and Kava (90.63 ± 13.13 MPa) ($p<0.001$) (Figure 1).

### *Flexural modulus*

Statistically significant difference were observed in heat-cured samples in artificial saliva (1.731 ± 0.125 GPa) and with higher results in carbonated soft drink (1.899 ± 0.174 GPa ) ($p < 0.007$) group. No statistical difference was observed between kava (1.700 ± 0.411 GPa) and artificial saliva ($p > 0.29$) groups in heat-cured samples. The self-cured group showed a statistical difference between control group (1.668 ± 0.155 GPa) and artificial saliva (1.520 ± 0.154 GPa) ($p < 0.032$), as well between artificial saliva and kava (1.686 ± 0.149 GPa) ($p < 0.0007$) where a slight increase was observed. Moreover, the self-cured group had a statistically significant difference between carbonated soft drink (1.568 ± 0.179 GPa) and kava ($p > 0.0286$). Meanwhile, there was no significant difference between artificial saliva and Carbonated soft drink ($p > 0.6566$), (Figure 2).

*Fourier Transform Infrared Spectroscopy (FTIR)*

FTIR spectra of PMMA (Figures 3a and b) were similar between the groups and sub-groups. The peaks observed between 3025 $cm^{-1}$, 2950 $cm^{-1}$ and 2845 $cm^{-1}$ were associated to the vibrational modes of C-H bonding. The dual-band between 2400 $cm^{-1}$ and 2350 $cm^{-1}$ was attributed to $CO_2$ due to inherit porosity in the denture acrylic and spacing between particles. Each group showed an intense peak at 1731 $cm^{-1}$, which was the attribute to the C=O stretching that represents resin groups. Another noticeable band that ranged from 1260 $cm^{-1}$ to 1000 $cm^{-1}$ was due to C-O (ester bond) stretching vibrations. Meanwhile, looking at the band of 1731 $cm^{-1}$ there was no statistically significant difference observed between sub-groups in heat-cured and self-cured samples with a difference in transmittance of 0.007 between artificial saliva and carbonated soft drink groups. As a result, it can be confirmed that the post-thermocycle PMMA denture resin with kava had $CO_2$ stretching when compared to other sample groups. However, this reaction did not cause any subsequent change in the molecular structure of PMMA material, due to the absence of vertical or horizontal peak shifts.

*Nano-indentation*

For the heat-cured and self-cured specimens, there was no statistically significant difference in its hardness in control groups in comparison to artificial saliva ($p > 0.958$ and $p > 1.000$) (Figure 4). While the heat-cured group did not have a significant decrease and statistically significant difference in hardness in carbonated soft drink (0.281 ± 0.0329 GPa) samples

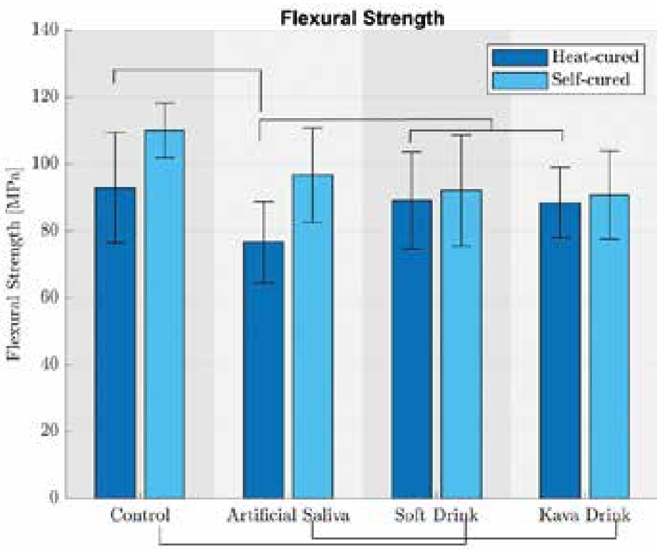


**Figure 1.** Summary of mean flexural strength at maximum load (MPa) of four sub-groups: control, artificial saliva, carbonated soft drink and kava drink. The connection arrays represent groups that had a statistically significant difference between each other; the error bars represent the standard deviation of each group.

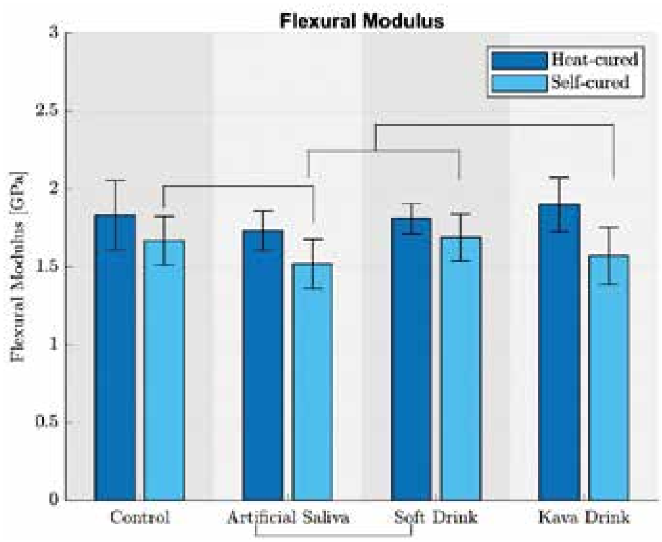


**Figure 2.** Summary of mean flexural modulus (GPa) (that was calculated as stress/strain) of four sub-groups: control, artificial saliva, carbonated soft drink and kava drink. The connection arrays represent groups that had a statistically significant difference between each other; the error bars represent the standard deviation of each group.

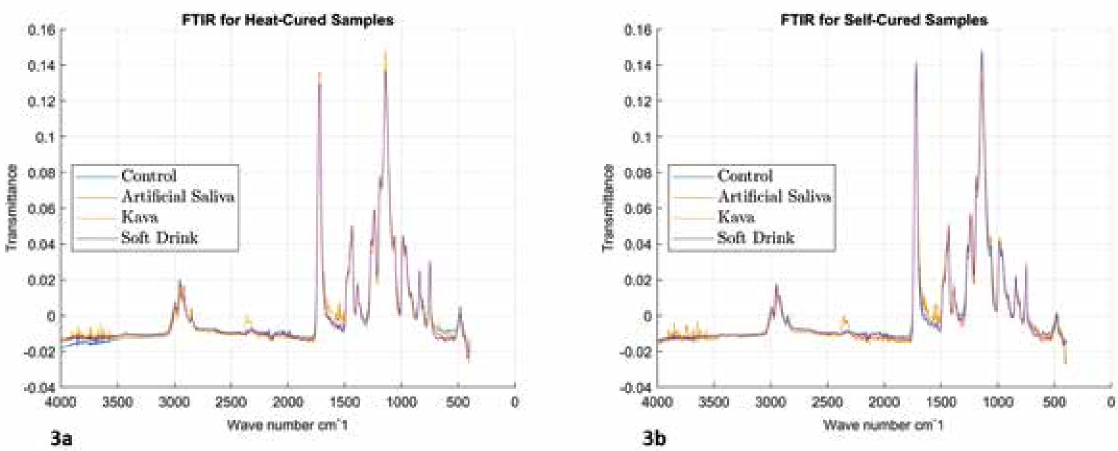


**Figure 3.** Shows summary FTIR spectre of (a) heat-cured samples and (b) self-cured samples. All data were normalised before graph plotting.

in comparison to artificial saliva ($p > 0.978$) (0.281 ± 0.031 GPa), both had a statistically significant difference in the kava group ($p < 0.001$) (0.246 GPa ± 0.041 GPa). Self-cured samples of carbonated soft drink (0.223 ± 0.020 GPa) and kava (0.229 ± 0.04 GPa) had a significant drop in elastic modulus in comparison to the artificial saliva ($p < 0.001$) (0.279 ± 0.048 GPa). The elastic modulus of heat-cured samples after kava thermocycling (3.809 ± 0.349 GPa) has significantly decreased (Figure 5), and the difference in hardness between artificial saliva (4.939 ± 0.278 GPa) and carbonated soft drink (4.835 ± 0.349 GPa) was also statistically significant ($p < 0.002$). Self-cured samples had a significant decrease in elastic modulus in kava (4.557 ± 0.470 GPa) and carbonated soft drink (4.586 ± 0.226 GPa) groups in comparison to artificial saliva ($p < 0.001$) (5.118 ± 0.435 GPa).

Control group had no statistically significant difference between any of the groups.

### *SEM analysis*

A representative SEM image of the heat-cured and self-cured groups are presented in Figure 6. Analysis of the fractography of the fracture surface identified the primary mode of failure in PMMA materials occurred mostly due to the presence of the red vein filaments found at the surface of the tension side in both the heat-cured and self-cured samples (Figure 6 a and b). The less discernible fracture mirror indicates high energy upon fracture. No observable evidence of liquid penetration was observed.

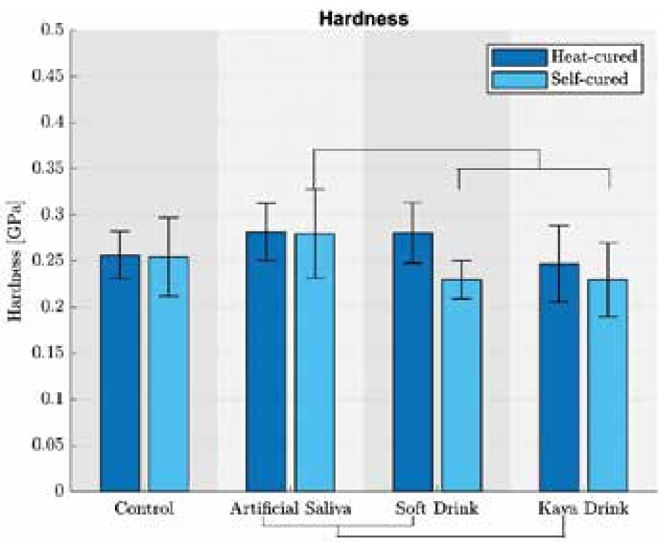


**Figure 4.** Graphs showing the mean hardness (GPa) in heat-cured and self-cured samples. The connection arrays represent groups that had a statistically significant difference between each other; the error bars represent the standard deviation of each group.

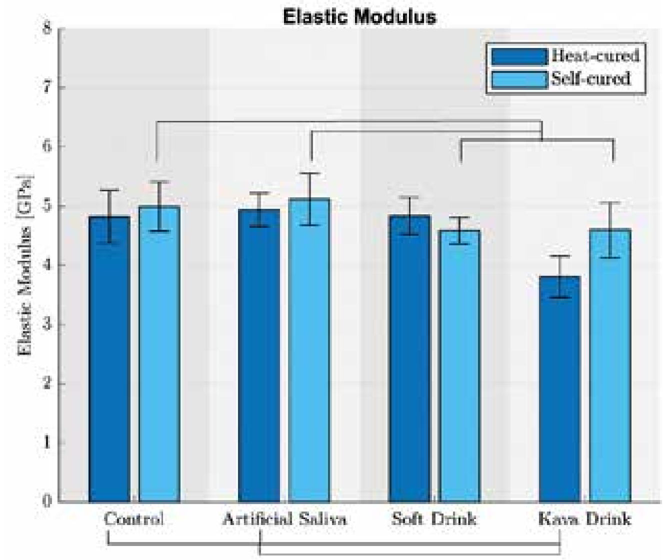


**Figure 5.** Graphs showing the mean elastic modulus (GPa) in heat-cured and self-cured samples. The connection arrays represent groups that had a statistically significant difference between each other; the error bars represent the standard deviation of each group.

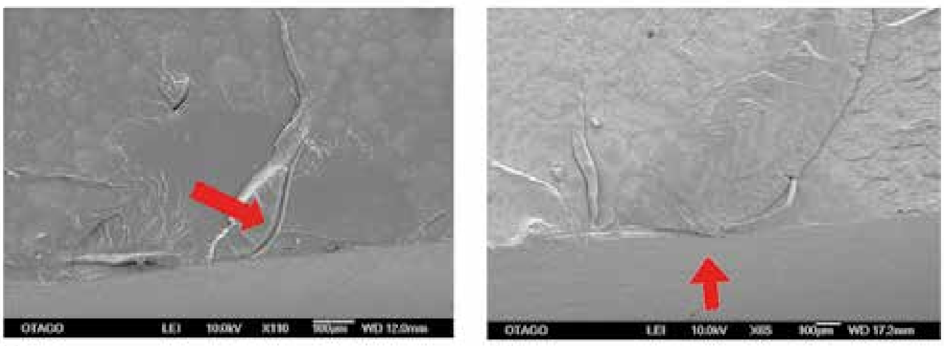

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**Figure 6.** SEM images (a) of the heat-cured specimen that underwent thermocycling in kava stimulus conditions, red arrow represent vein filament as the point of fracture initiation, (b) a self-cured specimen that underwent thermocycling in a carbonated soft drink , red arrow represent porosity of the material.

**Table 3.** Represents Weibull modulus and normalising strength

| | | Weibull Modulus | Normalising Strength (MPa) |
|---|---|---|---|
| Self-Cured | Control | 15.951 | 113.69 |
| | Saliva | 7.5955 | 102.92 |
| | Carbonated soft drink | 6.8073 | 98.50 |
| | Kava | 8.2839 | 96.04 |
| Heat-Cured | Control | 6.6507 | 99.53 |
| | Saliva | 7.6049 | 81.55 |
| | Carbonated soft drink | 7.2117 | 95.04 |
| | Kava | 10.233 | 92.81 |

### *Weibull Analysis*

Weibull analysis confirms the reliability of the previous experiments (Figure 7) by showing that Weibull modulus readings are above 5 to meet the threshold (Anusavice et al. 2012). Among the heat-cured samples, the control group has the highest normalising strength (99.53 MPa), followed by carbonated soft drink (95.04 MPa) and kava (92.81 MPa), while artificial saliva had the lowest normalising strength (81.55 MPa) in heat-cured samples. However, kava had the highest Weibull modulus among the heat-cured group 10.233, followed by artificial saliva 7.605, carbonated soft drink 7.212 and control group 6.651.

Similar to heat-cured groups, self-cured samples had Weibull modulus above 5. Control samples had the highest normalising strength (113.69 MPa), followed by artificial saliva (102.92 MPa), carbonated soft drink (98.50 MPa) and kava (96.04 MPa). Weibull modulus was highest in the control sample group 15.951, followed by kava 8.284, artificial saliva 7.6 and carbonated soft drink 6.807. The scale parameter or normalizing strength, $\sigma_0$, is stress configuration, specimen size dependent, and determines the strength value ($\sigma$) at probability of failure (Pf = 63.2%), which is indicated along the 0 value of the y-axis in the Figure 7 graphs. The highest normalising strength value from heat-cured samples groups is control group, which is expected due to lack of chemical interface, and lowest normalising strength is saliva group. Similarly, self-cured sample group's highest normalising strength was observed in control group, whereas lowest value was in the samples that were artificially aged in kava.

## Discussion

In this study, the effects of artificial saliva, carbonated soft drink and kava on the flexural strength, flexural modulus, hardness, elastic modulus, Weibull modulus and normalising strength, and degree of polymerisation at the surface of heat-cured and self-cured denture base resin was measured and compared.

Results that were obtained for flexural properties in the control groups showed that heat-cured and self-cured PMMA exhibited highest flexural strength of 92.88±16.54 and 110.03±8.21 MPa respectively and flexural modulus 1.831 and 1.668 GPa respectively. However, the difference was insignificant (*p>0.077*) and were higher than quoted by the manufacturer for acrylic resins for flexural strength, 85.2 and 75 MPa respectively, but significantly lower for flexural modulus, 2.316 and 2.367 GPa respectively. Even though results were lower than the manufacturer reported, it did meet the ISO 20795-1 requirements for the flexural strength but not flexural modulus which requires a flexural modulus for Type 1, 3, 4, 5 denture base materials above 2 GPa (2000 MPa) and ultimate flexural strength that is above 65 MPa. After thermocycling, all groups experienced

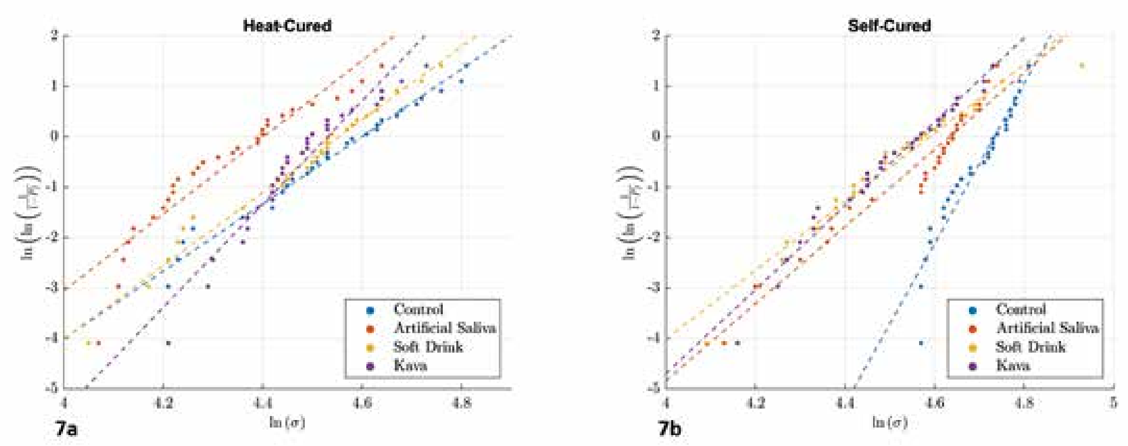


**Figure 7.** Represents scattered data of Weibull analysis in heat-cured and self-cured samples. Probability of failure ($P_f$ = 63.2%) which indicated along the Y-axis (zero value).

a decrease in flexural modulus and flexural strength in comparison to control groups except the flexural modulus of the heat-cured carbonated soft drink group specimens which exhibited slightly higher results which were not statistically different (*p>0.9*). This may have been caused by further polymerization of the material during thermocycling, while the controls which were not thermocycled were kept in distilled water at 37 C° prior to testing as per the ISO requirements. A previous study reported that long polymerization cycles produce better flexural property values (Gad et al. 2019), however, with our results we cannot confirm whether further polymerisation has occurred since the FTIR results did not show significant changes. The SEM images (Figure 6) and fractographic analysis suggested that the primary cause for the failure of the heat-cured PMMA 3-point bend test was due to defects caused by imbedded red vein fibres at the tension surface, which was confirmed by the facture mirror and facture propagation lines indicating this as the origin of the failure.

The hardness test in particular can indicate not only how the surface properties were affected but also infer abrasive resistance of the material (Harrison et al. 1978), since denture base materials require sufficient abrasion resistance to prevent excessive wear by food and cleaners that are regularly applied. The present study has shown that overall self-cured PMMA had a lower surface hardness after they underwent thermocycling than heat-cured PMMA, consistent with findings from previous studies (Al-Mulla et al. 1988; Ali et al. 2008). In terms of the elastic modulus results from nanoindentation, previous studies report that depending on the testing method, three-point bend test or nano-indentation, the elastic modulus can vary despite the same material being tested (Iijima et al. 2011). The results from our study have confirmed this variation between these two tests. This type of variation could be induced due to the specific area that was tested, the surface subjected to various liquids on the nano scale being different to the bulk material. The SEM results showed no evidence of surface penetration by the various test liquids. However, kava heat-cured samples have exhibited a statistically significant decrease in hardness and elastic modulus in both heat-cured and self-cured groups.

Weibull distribution is a useful parameter that allows parameters to compare greater shape flexibility and to predict failure of the brittle material (Quinn and Quinn 2010). Normalising strength has shown a decreasing trend between the control and the tested groups for self-cure samples, which was expected since the aging process is expected to decrease the expected strength of the material. Heat-cure specimens on the other hand observed a wider scatter as shown from the lower Weibull modulus in general compared to the self-cured specimens. This may be attributed to fast curing and fast cooling during manufacturing, influencing shrinking of material, on average 2% (Frazer et al. 2005). Although self-cured samples had a higher reliability than the heat-cured samples, the Weibull modulus and normalising strength also displayed a diminishing trend from control, artificial saliva, carbonated soft, and kava (113.69, 102.92, 98.50, and 96.04, respectively). A similar trend can be identified within the elastic modulus obtained from nanoindentation, where PMMA exposed to both kava and carbonated drink had significant decrease in elastic modulus when compared to control and artificial saliva. This implies that self-cured PMMA material is more vulnerable post-thermocycle with kava and carbonated drink in comparison to heat-cured PMMA.

FTIR was used as an analytical technique to characterise and identify PMMA polymeric chemical properties post exposure to various selected liquids. Upon analysis, no quantifiable difference was observed within the detected spectral peaks and no horizontal shift in peaks suggest no bond breakage or forming occurred in the polymer chains. The reliability of the FTIR analysis is supported in the literature (Spasojevic et al. 2015) thus signifying the selected solutions did not alter the chemical properties of both heat-cured and self-cured PMMA.

A limitation of our study was it's *in vitro* nature and that the experiment was limited to an *in vivo* simulation of 10,000 cycles being equivalent to 12 months. However, due to the nature of kava drinking (4 hours daily), the duration of the thermocycling, 10,000 cycles would be equal to 6 years consumption. While the artificial saliva was tested for the same amount of cycles, it could be suggested that for achieving more accurate results, the artificial saliva group should have undergone 60,000 cycles to simulate the equivalent 6 years *in vivo* of the kava. However, in order to standardise all the testing parameters and limit the number of variables, it was decided to subject all the groups to the same number of cycles. Future research could extend the *in vitro* simulation time to allow time for any effect to become more apparent. Another limitation of our study was that we only tested using one brand of kava. As there are different cultivars of kava, the composition of these varieties and their chemotype profile may have

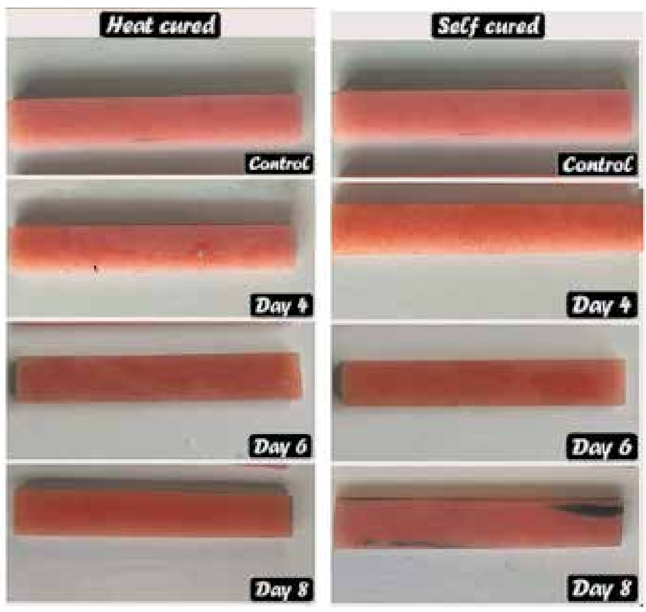


**Figure 8.** Shows the progressive discolouration of the heat-cured and self-cured samples that were subjected to thermocycling in kava in vitro for 12 month

influenced the outcome of our study and the results can not necessarily be applied to other varieties of kava. Although colour change was not part of our study, we observed that the kava exposed denture based resin specimens, both heat-cured and self-cured, progressively discoloured as the thermocycling progressed (Figure 8). The measurement of colour change in future research would be recommended.

The null hypothesis can be rejected as the surface nanoindentation hardness and elastic modulus showed a significant drop in both heat-cure and self-cure groups that underwent thermocycling in kava. Likewise, there was a significant decrease in strength in the bulk flexural modulus results between the self-cure control and the artificial saliva group.

## Conclusion

Within the limitations of the study,

- Exposure to carbonated soft drink and kava resulted in a significant decrease in flexural strength compared to the control group for self-cured PMMA. There was no significant difference in the heat-cured group between carbonated soft drink, kava and the control. The overall trend showed a decrease in flexural strength as a result of both heat-cure and self-cure groups being thermocycled in saliva, carbonated soft drink and kava. However, these values were still above the minimum requirements of the ISO 20795-1.
- Exposure to carbonated soft drink and kava produced no significant difference in hardness of the surface in both heat-cure and self-cure groups compared to their controls.
- Exposure to carbonated soft drink and kava produced a significant decrease in the elastic modulus on the surface of the PMMA self-cured denture base materials compared to the control group but no significant difference in the heat-cured group. In terms of the bulk flexural modulus, there was no significant difference between the carbonated soft drink and kava heat-cured and self-cured groups and their controls.

### *Clinical implications*

According to ISO 20795-1.12, the flexural strength of resins employed as denture base materials should not be less than 65 MPa. Subjecting heat-cured and self-cured PMMA denture material to artificial saliva, carbonated soft drinks and kava does not alter their mechanical properties sufficiently that they would fail the minimum flexural strength standards set by this standard. However, clinicians and dental technicians should be aware of the effects of kava on self-curing denture based resins when selecting appropriate materials for their treatment plan.

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