

**In vitro evaluation of flexural strength, surface hardness and tensile strength of Date seed powder and Curcumin powder reinforced polymethyl methacrylate denture base resin**

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**Abstract**

**Introduction:** Dentures are prosthetic replacements designed to replace missing teeth and are supported by oral tissues. Polymethyl methacrylate (PMMA) is widely used for denture base fabrication due to its favorable properties, although it exhibits certain mechanical limitations. This in vitro study investigates the effect of natural additives, specifically Curcumin and Date seed extract on the tensile strength, flexural strength and surface hardness of heat-polymerized PMMA.

The objectives of this study was to measure the flexural strength, tensile strength and surface hardness of two different concentrations of Date seed extract and Curcumin extract.

**Materials and Methods:** A total of 120 heat-cured PMMA specimens were prepared and divided into control and experimental groups reinforced with 3 wt.% and 5 wt.% Date seed and Curcumin extracts. Flexural strength and tensile strength was measured using Universal testing machine and surface hardness was measured using Vickers hardness tester.

**Results:** Statistical Package for Social Sciences [SPSS] for Windows Version 22.0 Released 2013. Armonk, NY: IBM Corp was used. The data was statistically analyzed using Tukey’s post hoc test to assess intergroup differences. The results showed that incorporation of Date seed and Curcumin extracts significantly affected the mechanical properties of PMMA. The highest flexural strength, surface hardness, and tensile strength

was observed in the 5 wt.% Date seed extract group. Curcumin extract showed comparatively lower flexural and tensile strength, especially at 3 wt.% and 5 wt.% concentrations. The control group exhibited the least surface hardness.

**Conclusion:** The study concluded that natural filler reinforcement with 5 wt.% Date seed extract significantly improved the mechanical properties of PMMA. This concentration demonstrated optimal properties, indicating its potential for clinical application.

**Keywords:** PMMA Denture base resins, Date seed extract, Curcumin extract, Flexural Strength, Surface Hardness, Tensile Strength.

### Introduction

Dentures are prosthetic replacements used to replace missing teeth, supported by the surrounding oral tissues<sup>1</sup>. The denture base, which rests on these tissues and holds artificial teeth, requires materials with good aesthetics, strength, stiffness, and surface hardness<sup>2</sup>. Among available materials, polymethyl methacrylate (PMMA), introduced by Dr. Walter Wright in 1937, remains the material of choice due to its ease of processing, biocompatibility, stability, and favourable aesthetic properties<sup>3</sup>.

PMMA is a thermoplastic polymer widely used in dentistry because of its strength, colour stability, and compatibility with oral tissues<sup>4</sup>. Despite its advantages, PMMA exhibits limitations such as low tensile strength and susceptibility to fracture under functional stresses, increased surface indentations often caused by fatigue, stress concentration, or structural irregularities in the denture base<sup>3</sup>.

To overcome these limitations, various reinforcement strategies have been explored, such as the incorporation of metal reinforcements, fibre reinforcements, nanoparticles, rubber modifications, natural additives,

fillers and hybrid reinforcements (combination of fibres + nanoparticles)<sup>1,7,3</sup>.

Different metal reinforcements include stainless steel mesh/woven type, wrought metal wires have been used to improve the

Different fibres used are glass fibres, carbon fibres, aramid fibres, polyethylene fibres, nylon fibres, polypropylene fibres have been used to improve the mechanical properties of PMMA<sup>3</sup>.

Different nanoparticles used in PPMA include Zirconium oxide (ZrO<sub>2</sub>), Titanium dioxide (TiO<sub>2</sub>), Silicon dioxide (SiO<sub>2</sub>), Aluminium oxide (Al<sub>2</sub>O<sub>3</sub>), Silver nanoparticles (AgNPs), Hydroxyapatite nanoparticles (HA), Zinc oxide (ZnO) nanoparticles, Nanodiamonds, Copper oxide (CuO) nanoparticles, Graphene oxide nanoparticles<sup>14</sup>.

Various natural fillers used are Date seed extract, Curcumin extract, Chitosan, Cellulose fibres, Coconut fibres, Bamboo fibres, Sisal fibres, Jute fibres, Flax fibres, Rice husk ash, Eggshell powder, Aloe vera extract<sup>1,11,12</sup>.

However, these reinforcements have certain limitations. Fiber reinforcements may exhibit poor bonding with the PMMA matrix, reducing their effectiveness and potentially causing surface roughness and plaque accumulation. Nanoparticles can decrease translucency, compromise aesthetics, and increase material cost. Metal reinforcements may add weight to the denture and are susceptible to corrosion over time. Elastomer modifications can increase water absorption, while hybrid reinforcements are often costly and may present compatibility issues between different additives<sup>10</sup>.

Recently, natural fillers have gained attention due to their biocompatibility, cost-effectiveness, ease of incorporation, and eco-friendly nature<sup>6,7</sup>.

Among these Date seed powder has shown promising improvements in mechanical properties across dental and

polymer applications, while Curcumin, a bioactive compound from turmeric, offers additional antioxidant and antimicrobial benefits. However, studies evaluating curcumin as a reinforcing agent in denture base resins remain limited<sup>10,11</sup>.

High flexural strength helps the denture withstand repeated occlusal and functional loads, reducing the risk of midline fractures and accidental breakage. Similarly, surface hardness of PMMA is an important mechanical property that determines the resistance of the denture surface to indentation, scratching, abrasion, and wear during clinical use. The tensile strength of PMMA is an important mechanical property that indicates the ability of the denture base material to resist forces that attempt to pull or stretch it apart without breaking<sup>3</sup>.

Hence, this in vitro study was undertaken to evaluate and compare the effect of incorporating Date seed powder and Curcumin powder as natural reinforcing agents on the tensile strength, flexural strength, and surface hardness of heat-polymerised PMMA denture base resin.

**Materials and Methods**

This in-vitro study was conducted in Department of Prosthodontics & Crown Bridge & Implantology, Vydehi Institute of Dental Sciences & Research Centre after obtaining the institutional ethical clearance (VIDS-IEC/UG/APP/2024/124).

The sample size for the present study was calculated as N =120 using G Power software (latest ver. 3.1.9.7; Heinrich-Heine-Universi-tät Du'sseldorf, Du'sseldorf, Germany).

The 120 samples were divided into 5 groups of 24 samples each. Of the five groups, one was control group (C) and 4 were experimental groups (E1- 3wt.% date seed powder, E2- 5wt.% date seed powder, E3- 3wt% curcumin powder, E4- with 5wt% curcumin powder).

Each of the five groups were further divided into 3 sub-groups of 8 samples each to test tensile strength, flexural strength and surface hardness respectively. The sample distribution is depicted in table 1.

Sn.	Group	N	Description
1	Control group C	24	Heat cure PMMA
2	Experiment group E1	24	Heat cure PMMA reinforced with 3wt.% date seed powder
3	Experiment group E2	24	Heat cure PMMA reinforced with 5wt.% date seed powder
4	Experiment group E3	24	Heat cure PMMA reinforced with 3wt% curcumin powder
5	Experiment group E4	24	Heat cure PMMA reinforced with 5wt% curcumin powder

Table 1: Grouping of samples

Hundred and twenty wax strips (DPI Modelling wax) were fabricated using a two-way metallic mould of 60mm x 10 mm x 2.5 mm (Fig 1) as per the International Organization for Standardization (ISO) 1567 standard<sup>2</sup> by pouring molten wax into the metal mould which was placed on a flat surface after the application of petroleum jelly to the mould space. The wax patterns were retrieved by pressing from one side of the two-way mould once it was set. Only the patterns which were devoid of voids and inaccuracies were selected.



Figure 1; Metal mold



Figure 2: Flasking of wax strips

The selected wax patterns were then invested in a dental flask (Fig 2) using dental plaster (Kalabhai Kaldent) which was mixed following the manufacturer's instructions. Mechanical vibrator was used to prevent air trapping during flasking and the flask was clamped and kept aside for setting before dewaxing. Dewaxing was done in a dewaxing unit at 100° Celsius for 5 mins. The residual wax was flushed away with boiling water. The flask was allowed to dry and cool at room temperature (Fig 3). Then separating media (cold mould seal; DPI) was applied with the help of a no.2 camel hair brush on all surfaces and allowed to dry.



Figure 3: Flasks after dewaxing

#### **Preparation of PMMA (DPI HEAT CURE) control and experimental specimens**

**For the control group PMMA:** 20 gms of polymer was mixed with 10ml monomer (2:1 ratio by weight) and packed in the flask at the dough stage. Trial closure was done and flasks were clamped under a hydraulic press (fig 4) and left for bench curing for 1hour. Processing was done with the short curing cycle at 74°C for 2 hrs,

followed by 1 hr of terminal boiling. After processing, the flasks were bench cooled and then de-flasking was done, and control group PMMA specimens were retrieved.



Figure 4: Packed flask under hydraulic bench

#### **For the experimental group E1 & E2 - Date seed extract reinforced PMMA specimens:**

E1- 0.6gm (3% by weight) of Date seed extract (Simply Herbal brand) was measured on a measuring scale and mixed with 19.4gm of PMMA polymer (to make it to 20gms of polymer)

E2 - 2gm (5% by weight) of Date seed extract was measured on a measuring scale and mixed with 18gm of PMMA polymer (to make it to 20gms of polymer)

#### **Experimental group- For Fabrication Curcumin reinforced specimens:**

E3- 0.6gm (3% by weight) of Curcumin extract (Simply Herbal brand) was measured on a measuring scale and mixed with 19.4gm of PMMA polymer (to make it to 20gms of polymer)

E4 - 2gm (5% by weight) of Curcumin extract was measured on a measuring scale and mixed with 18gm of PMMA polymer (to make it to 20gms of polymer)

Flasking, dewaxing and packing of the experimental groups was done following the same protocol as the control group.

### Post retrieval specimen preparation

The excess resin on the specimens was trimmed with acrylic trimmers. Specimens were finished with various grits of sand paper, followed by polishing with pumice. Thickness, length and width of each specimen was verified using Vernier calliper.

Specimens were kept in distilled water at 37°C for 1 week prior to testing to ensure the release of unreacted monomer.

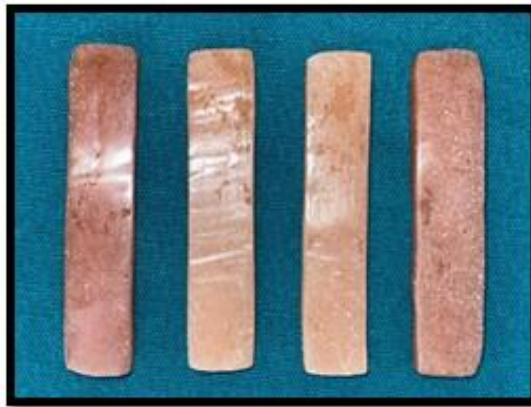


Figure 8: PMMA reinforced with Date seed



Figure 9: PMMA reinforced with Curcumin

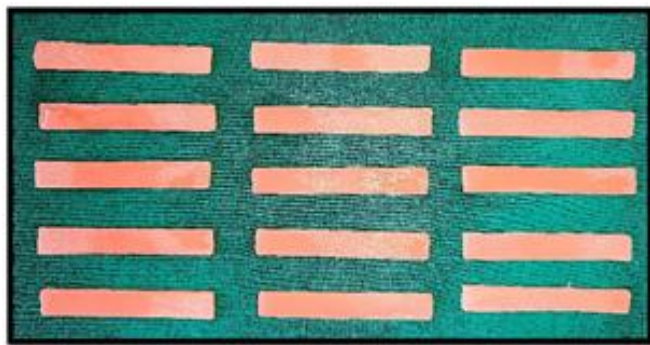


Figure 5: Control group specimens



Figure 6: Date seed extract



Figure 7: Curcumin extract

### Testing of Flexural Strength

Flexural strength was determined using a bench 3-point bend test using a universal testing machine with a span length of 60 mm and a crosshead speed of 5 mm/min (as per ISO 20795-1) guidelines for denture base polymer. 8 specimens of each group was tested. The midline was marked on the specimens that corresponded to the spot where the testing machine's striker would make contact with the samples. The rectangular specimens were used to test the fracture strength. Each specimen was positioned on the support beams. A load cell was applied to the centre of the specimens using the upper anvil assembly of a universal testing machine at a crosshead speed of 5 mm/min until fracture. The maximum load before fracture which was displayed on the screen was

recorded as fracture load in Newton's(P) and was used in the formula to determine the flexural strength.

$$\text{Flexural strength (MPa)} = \frac{3PL}{2bd^2}$$

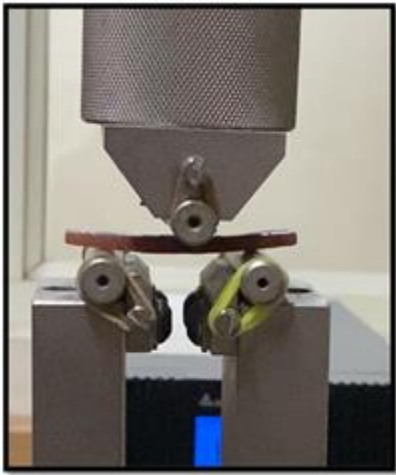


Figure 10: Flexural testing using UTM

where P=maximum fracture load in Newtons, b=specimen width (10 mm), L=specimen span length (60 mm), d=specimen thickness (3 mm)

#### Testing of Surface Hardness

Prepared specimens were measured for surface hardness (SH) using a digital Vickers microhardness tester. 8 specimens of each group were tested. A 50gf load was applied by the diamond pyramid for 5 seconds indentation time and VHN was obtained digitally.

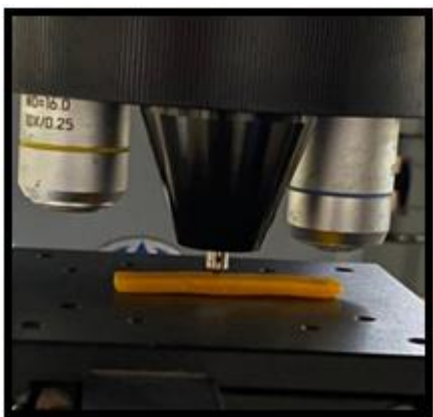


Figure 11: Surface hardness testing using Vickers microhardness tester

#### Testing of Tensile Strength

Tensile strength was determined using Universal testing machine (UTM). Specimens from each group were inserted in relative jigs and were tightened. 8 specimens from each group were tested. A tensile force of 5mm/min until the specimen fractures and the load at that time was recorded.

Tensile bond strength was calculated using the formula  
Tensile bond strength = Maximum force/ Cross sectional area of the strained specimen.



Figure 12: Tensile strength using UTM

#### Results

The mean value of the Flexural strength, Surface hardness and Tensile strength of all the groups was computed. Statistical Package for Social Sciences [SPSS] for Windows Version 22.0 Released 2013. Armonk, NY: IBM Corp., was used to perform statistical analyses.

One-way ANOVA test followed by Tukey's Post Hoc Test was used to compare the mean flexural strength, surface hardness & tensile strength between 5 groups.

The level of significance was set at  $p < 0.05$ .

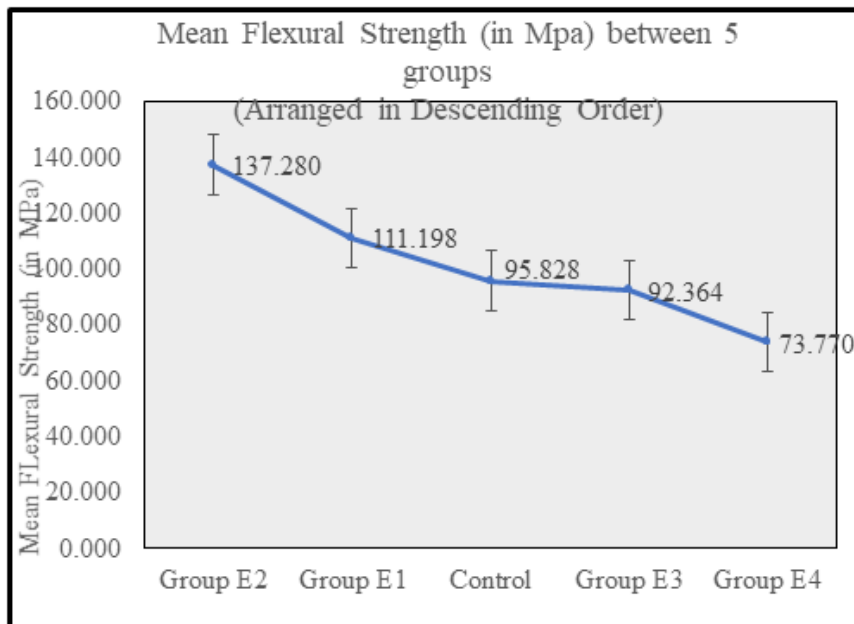
**Flexural Strength**

Comparison of mean Flexural Strength (in Mpa) between 5 groups using One-way ANOVA Test							
Distance	Groups	N	Mean	SD	Min	Max	p-value
Flexural Strength (in Mpa)	Control	8	95.828	5.206	89.54	103.96	<0.001*
	Group E1	8	111.198	9.686	98.62	128.26	
	Group E2	8	137.280	14.495	123.10	158.80	
	Group E3	8	92.364	3.697	87.53	98.60	
	Group E4	8	73.770	11.516	60.25	89.32	

Table 2: Flexural strength

One-way ANOVA showed a statistically significant difference in flexural strength among the groups. The highest mean value was observed in 5% Date seed extract (137.28MPa), followed by 3% Date seed extract (111.19 MPa), Control group(95.82Mpa), 3% Curcumin extract (92.36 MPa), 5% Curcumin extract (73.77 MPa).

Post hoc analysis confirmed that Date seed reinforced groups had substantially higher flexural strength than PMMA (p = 0.0001), with the most pronounced improvement seen in 5% Date seed extract (mean difference = -26.08 MPa). Among reinforced groups, Date seed extract consistently outperformed others, and its effect was concentration-dependent. Flexural strength differed significantly among groups (p < 0.001), with Group E2 showing the highest values and Group E4 the lowest; most pairwise comparisons were statistically significant. Group E3 showed values comparable to the control (no significant difference), while Group E1 demonstrated moderate improvement over the control.



Line Graph 1: of mean flexural strength between 5 groups

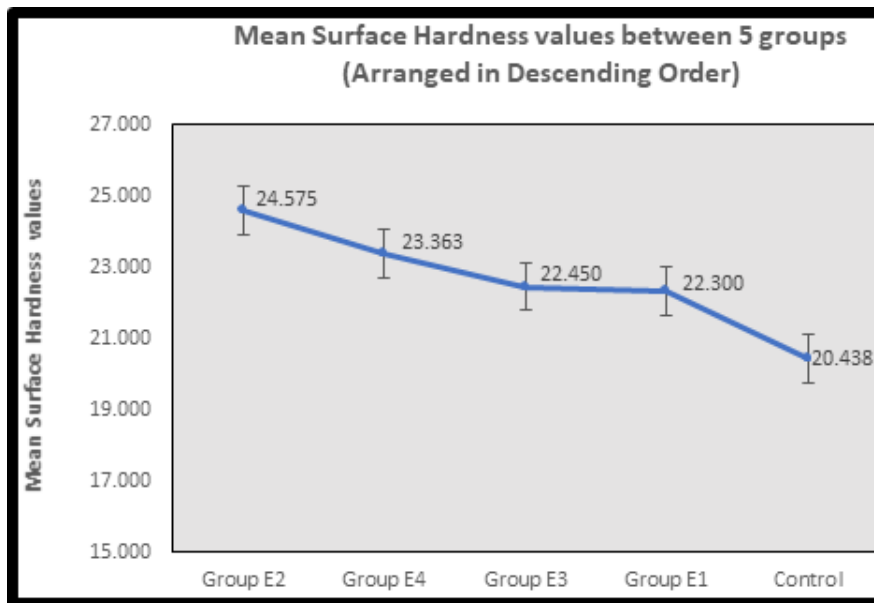
### Surface Hardness

One-way ANOVA showed a statistically significant difference in surface hardness among groups. Mean values in ascending order were: PMMA (20.43), 3% Date seed extract (22.30), 3% Curcumin extract (22.45), 5% Curcumin (23.36), 5% Date seed extract (24.57).

Comparison of mean Surface Hardness values between 5 groups using One-way ANOVA Test							
Distance	Groups	N	Mean	SD	Min	Max	p-value
Surface Hardness values	Control	8	20.438	2.236	17.20	23.00	<0.001*
	Group E1	8	22.300	1.034	20.80	23.70	
	Group E2	8	24.575	1.244	23.20	26.80	
	Group E3	8	22.450	1.308	20.50	23.90	
	Group E4	8	23.363	1.474	20.70	25.70	

Table 3: Surface hardness

Post hoc analysis showed all group differences were statistically significant (p = 0.51). The greatest improvement was seen in 5% Date seed extract (mean difference from PMMA -4.14). At this comparison, Group E2 demonstrated superior surface hardness, while the control group retained the lowest values. Group E1, Group E3, and Group E4 showed intermediate hardness values, with Group E2 consistently outperforming the others.



Line Graph 2: of mean surface hardness between 5 groups

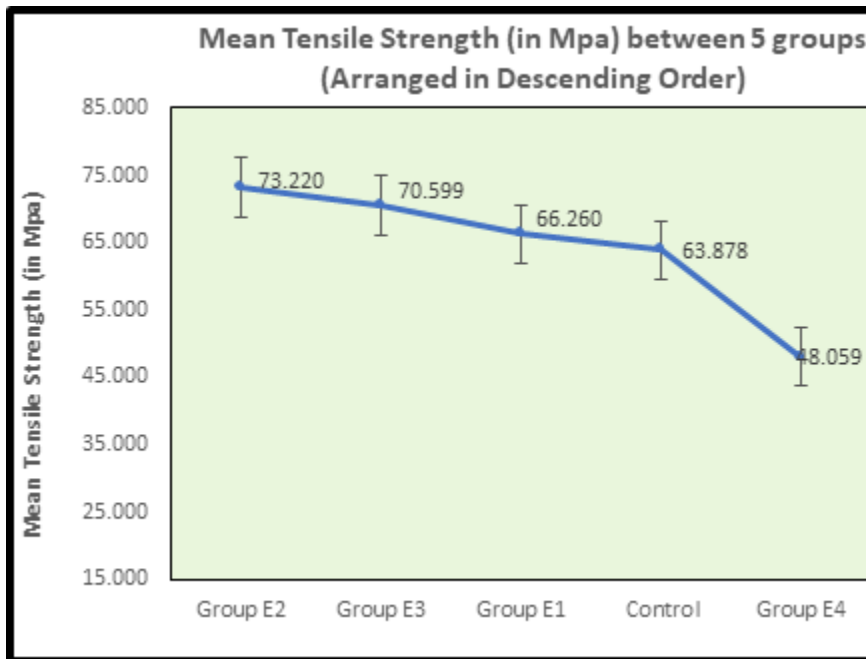
### Tensile Strength

One-way ANOVA showed a statistically significant difference in tensile strength among groups. Mean tensile strength values in ascending order were: 5% Curcumin extract (48.05), PMMA (63.87), 3% Date seed extract (66.26), 3% Curcumin extract (70.59), 5% Date seed extract (73.22).

Comparison of mean Surface Hardness values between 5 groups using One-way ANOVA Test							
Distance	Groups	N	Mean	SD	Min	Max	p-value
SS Surface Hardness values	Control	8	20.438	2.236	17.20	23.00	<0.001*
	Group E1	8	22.300	1.034	20.80	23.70	
	Group E2	8	24.575	1.244	23.20	26.80	
	Group E3	8	22.450	1.308	20.50	23.90	
	Group E4	8	23.363	1.474	20.70	25.70	

Table 4: Tensile strength

Post hoc analysis showed that Tensile strength differed significantly among groups ( $p < 0.001$ ), with Group E2 showing the highest values and Group E4 the lowest; most significant differences involved Group E4. Groups E1 and E3 showed intermediate values with mostly non-significant differences, while the control group remained moderately lower than the reinforced groups.



Line Graph 3: Mean tensile strength values between 5 groups

**Discussion**

The results of this study showed that flexural strength was significantly improved in all natural fillers-reinforced groups with Date Seed extract showing the most pronounced effect, especially at 5% concentration (137.280 MPa). The 5% Date seed group outperformed all others, while 3% Curcumin extract demonstrated better strength than 5% Curcumin.

These results highlight that both filler type and concentration are crucial for improving flexural strength, as higher amounts of Date seed improve polymer chain interaction, increasing fracture resistance which may be referred to the uniform distribution of the natural filler used in this study, which enabled them to fill spaces between linear chains of polymer matrix, resulting in restricting the segmental motion of macromolecular

chains which increased the fracture resistance with enhanced flexural strength.

To support this, similar results were shown given by Mahajan et al supporting these findings, noting that specific concentrations of natural extracts enhance strength, while higher curcumin concentrations may reduce strength due to agglomeration that creates stress concentration areas<sup>10</sup>.

Studies by Badran et al. found that incorporating Date seed extract at varying concentrations (0.2 wt%, 1.2wt%) significantly improved flexural strength, with the 1.2wt% concentration showing the most pronounced enhancement compared to the other levels<sup>11</sup>.

With respect to surface hardness, incorporating natural fillers significantly enhanced the surface hardness of PMMA, with Date Seed extract at 5% concentration providing the most substantial improvement. Both the type and percentage of the extract play critical roles in affecting surface hardness.

This enhancement is attributed to the presence of natural fillers on the specimen surface and their strong bonding with the resin matrix, requiring more energy to break the bond<sup>13</sup>. These findings align with previous studies showing that various natural fillers improve the surface hardness of PMMA resin<sup>4,8</sup>.

The outcome of tensile strength has given a significant variation in the incorporated groups, emphasizing the effects of both the type and concentration of additives. The tensile strength peaked at 73.220 MPa for the 5% Date seed extract group, followed by 70.599 MPa for the 3% Curcumin extract group, while PMMA with 5wt% Curcumin showed the lowest strength at 48.059 MPa.

The control group, lacking natural fillers, exhibited lower tensile strength due to insufficient structural reinforcement and cohesion.

Increasing concentrations of Curcumin led to decreased tensile strength, attributed to poor adhesion between the filler and matrix, resulting in local stress and cracking. This finding is consistent with studies conducted by Khan et al<sup>11</sup>, who noted that excessive filler concentrations could compromise mechanical properties. Overall, both the 5% Date seed extract and the 3% Curcumin extract groups significantly outperformed the control group, with the 5% Date seed group achieving the highest tensile strength<sup>14</sup>.

### Conclusion

To conclude this study 5% Date seed extract had the highest Flexural strength, Surface hardness and Tensile strength. This innovative formulation enhances both the strength and hardness of the material. This enhancement may translate into greater durability of dentures, reduced risk of fracture, and improved longevity of prostheses in patients, thereby addressing one of the common limitations of conventional acrylic resin bases. Reinforcement with date seed extract, can be considered a reliable and cost-effective additive for clinical use.

Consequently, it serves as an ideal solution for improving the mechanical performance of heat cure acrylic resin, making it a valuable advancement in applications where mechanical integrity is essential.

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