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Effect of corncob powder concentration on properties of inlay waxes

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ABSTRACT

Background: *Corncob powder is a promising filler that needs to be assessed when it is incorporated into inlay waxes to modified its properties.* ***Purpose:*** *This study aims to investigate the effect of different concentrations of corncob powder filler on physical and mechanical properties of inlay waxes.* ***Methods:*** *Five groups of inlay waxes were prepared from paraffin, corncob powder, carnauba wax, and beeswax in varying proportions (w/w%), namely, group I (70:0:25:5), II (65:5:25:5), III (60:10:25: 5), IV (55:15:25:5), and V (50:20:25:5). The wax mixture was heated at 80°C, filtered, added with corncob powder, and stirred until homogeneous then poured into mold for melting point, residue on ignition, flow, hardness, and trimming samples. They were based on ANSI/ADA specification no.122 and ASTM D 1321. The data were analyzed through one-way ANOVA, post-hoc LSD, and Tamhane tests (p = 0.05), except trimming test data.* ***Results:*** *One-way ANOVA revealed that the concentration of corncob filler influenced all inlay waxes properties (p<0.05). LSD and Tamhane post-hoc test, showed significant different among mostly between groups of tests. Addition corncob powder increased the melting point, hardness, and residue of inlay waxes but decreased the flow of inlay waxes. Addition corncob did not influence the trimming property of inlay waxes.* ***Conclusion:*** *The concentration of corncob filler added in inlay wax compositions influenced the melting point, flow, hardness and residue properties but did not influence trimming properties. Inlay wax containing 10% corncob filler potential as a local inlay wax, but further research should be done to overcome the residue on ignition property that higher than standards.*

Keywords: *corncob powder; concentration; inlay wax, mechanical properties; physical properties*
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INTRODUCTION

The Indonesian Health Survey 2023 reports that 43.6% of the Indonesian population has tooth damage or cavities problem and 21% among this population have lost their teeth.[1] Patients with dental problems require dental treatment either with direct or indirect restorations through a minimally invasive technique.[2] Dental waxes play a crucial role in clinical and laboratory aspects in the production of dental indirect restorations.[3] Dental pattern waxes, exemplified by inlay wax, are important for fabricating wax patterns in the construction of inlays, crowns, or bridge restorations for tooth restoration or rehabilitation and maxillofacial prothesis.[3–5] The increasing awareness of dental care will increase the need for inlay waxes, especially for indirect dental restorations.

Most inlay waxes in Indonesia are imported products that have good quality, but are quite expensive and sometimes difficult to obtain. On the other hand, Indonesia produces polymer materials, such as paraffin and beeswax as components of dental waxes. Those raw materials can be used in producing dental waxes as local dental material products. Dental waxes are primarily a blend of natural and synthetic waxes along with other components.[6] Typically, dental inlay waxes consist of 60% paraffin, 25% carnauba, 10% ceresin, and 5% beeswax.[7] Natural paraffin and beeswax, as components of inlay waxes, are produced locally in Indonesia. Paraffin is produced by Pertamina in Cepu, Cilacap, and Balikpapan.[8] whereas beeswax is harvested from local bee farms in some Indonesian provinces.[9,10] Numerous studies have been conducted on the use of Indonesian paraffin and beeswax as components

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of modeling, inlay, and carving waxes. Studies have shown that these waxes have promising physical and mechanical properties and are similar to commercial dental waxes.[8,11–13] However, the final composition of inlay waxes containing local waxes, fillers, and other additions has to be formulated by considering its stability and its effects on several wax properties.[13]

Fillers are incorporated into dental waxes to modified its properties, such as enhance hardness, reduce plastic properties, and minimize thermal expansion.[14] Fillers consist of organic and inorganic materials.[15] Numerous studies have investigated dental waxes based on local natural waxes; some of the investigated dental waxes incorporate various organic and inorganic fillers, such as silica powder, Ca-bentonite powder, starch powder, and flaxseed oils.[8,15–18]

Organic material, such as corn (*Zea mays* L) powder, has been utilized as filler in polymers; the main component of corncob powder includes fiber, which comprises lignocellulose.[15] Corncob powder exhibits thermal stability because lignin degradation occurs at 200–500°C and has a density of 300–330 kg/m^3.[19,20] This relatively low density causes corncob powder to float in liquids.[13] Corncob powder, which has a particle size of 150 µm, has also been explored as a filler for polypropylene polymers at concentrations of 0–25%.[21] Corncob powder, as a promising filler, needs to be assessed when it is incorporated into inlay waxes from the aspects of dental wax's important properties. For example, its effect on melting point, flow property, hardness, trimming properties, and residue in ignition must be investigated. The pattern wax needs to match the size, shape, and contour of the device being constructed precisely.[22]

Dental inlay waxes should have important properties, such as suitable hardness to be carved without flaking or chipping upon solidification and complete burnout without leaving residues.[23] Furthermore, inlay waxes must have suitable melting points and the capacity to flow into cavities without distortion.[3] The latest ANSI/ADA specification states that the solid residue values of inlay wax should not exceed 0.1% and that the wax should be trimmable without chipping, flaking, or tearing.[24]

This research aimed to investigate the effect of the concentration of corncob powder filler on the physical and mechanical properties of inlay waxes. This study explores the hypothesis that the addition of corncob powder filler at varying concentrations will influence the melting point, flow, hardness, residue on ignition, and trimming properties of inlay waxes. The study identifies the inlay wax composition containing local waxes and fillers with physical and mechanical properties that meet standards.

MATERIALS AND METHODS

The research protocol was approved by the Ethics Committee of the Faculty of Dentistry, Universitas Gadjah Mada (Approval No. 00462/KKEP/FKG-UGM/EC/2020). Inlay waxes were formulated by combining paraffin, carnauba wax, beeswax, and corncob powder as fillers in five distinct compositions (Table 1). The primary materials employed in this research included fully refined paraffin wax (FRW52, Kirana Mitra Abadi, Jakarta, Indonesia), carnauba wax (Batch J1171/4 PT. Brataco Chemicals, Bandung, Indonesia), beeswax (code June 2019; Pramuka, Yogyakarta, Indonesia), corncob powder (PT. Pagoh Selaker, Tanah Karo Sumatera Utara Indonesia), and dental inlay wax soft type (Lot 1208091 GC, Japan).

Flow, residue in ignition, and trimming tests of samples were conducted by following ANSI/ADA specification No. 122 for dental casting and baseplate waxes.[24] The hardness or penetration depth test done based on American Standard Testing Material/ASTM D 1321.[25] The melting point test was done based on the research by Irnawati et al.[11,13] Each test group consisted of six samples, except for the hardness test consisted of four samples. A commercial inlay wax product soft type (GC, Japan) was included as a reference group.

Corncob powder was prepared by drying at 70–100°C for 2 hours in oven (Memmert, Germany) and sieved to get particle size 0.149 mm or less using a 100-mesh siever (Fisher Scientific Company, USA). The waxes were cut into small pieces, weighed in accordance with their respective compositions. The waxes were melted using double stainless pan (Bima, Surabaya Indonesia). The waxes were put into the upper pan and the bottom pan was filled with vegetable oil. The waxes were heated at 80°C on digital hot plate magnetic stirrer (As One, Japan) until melted, then the wax mixture was stirred using magnetic stirrer bar (Bel-art products, USA) for 5 minutes. The wax mixture was filtered using a stainless-steel strainer 2 mm in diameter size (Tanica, Indonesia) that covered with two pieces of gauze to remove impurities in the wax, then the mixture poured back into the pan. Corncob flour is gradually added to wax mixture and stirred using a magnetic stirrer for 5 minute to get homogeneous mixture.[11,13]

The inlay wax mixture was poured into metal molds for making samples. Melting point and residue on ignition

Table 1. Composition of inlay waxes

Group	Paraffin (%)	Corncob powder (%)	Carnauba wax (%)	Beeswax (%)	Total amount (%)
I	70	0	25	5	100
II	65	5	25	5	100
III	60	10	25	5	100
IV	55	15	25	5	100
V	50	20	25	5	100

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samples were molded using 10x10x2 mm aluminum mold, flow samples were molded using 6 mm height and 10 mm in diameter aluminum mold, and trimming properties samples were made by 6x6x20 mm aluminum mould.[24] Hardness samples were made by pouring wax mixture into aluminum tubes 55 mm in diameter and 35 mm in height.[25] All samples are allowed to harden at room temperature for 24 hours.

The melting point of inlay waxes was determined upon the initial melting of the samples. The samples were placed on the melting point apparatus (Fisher John, England), and the light and temperature controllers were activated. The samples were observed until complete wax melting occurred, as indicated by the presence of liquid wax at the sample edges. Temperature was recorded with a precision of 0.1°C.[11,13]

The initial height of flow test samples (L1) was measured using digital sliding caliper with an accuracy of 0.01 mm (Mitutoyo, Japan) at room temperature (23±2°C). The flow instrument (Mechanical Engineering UGM, Yogyakarta) to be used and the wax samples to be tested are placed in a water bath (Eyela, Japan) at a temperature of 30°C for 20 minutes. The samples were placed on the flow instrument table and a constant axial load of 19.6 N is applied to the sample for 10 minutes. After that, the samples were cooled to room temperature. The height of the samples was measured again (L2). The flow rate of samples can be determined by calculating the percentage change in the initial height of the sample before and after test. The same procedure was applied on samples to be tested at temperature 40°C and 45°C.[24]

The inlay wax samples in the mold were immersed in a water bath at temperature of 25°C for 1.5 hours. The sample was placed in the testing bath and positioned directly under the needle of penetrometer (Setamatic, England). Needle with a load weight of 100 grams was applied onto the sample surface for 5 seconds. The penetration value indicated on the scale with an accuracy of 0.1 mm is recorded. Measurements are taken 4 times at different locations, 1 cm apart from the starting point then the average penetration value of the inlay wax is calculated.[25]

One gram of inlay wax specimens for the residue test were weighing by digital scales with accuracy 0.0002 g (Sartorius, Germany). Porcelain crucibles (Gooch, China) were heated to 700°C in a furnace (Naber D-2804, England) allowed to cool to room temperature, and weighed with a precision of 0.0002 g. The specimens were placed in the crucibles and heated in the furnace at 700°C for 1 hour. The crucibles were reweighed after cooling. Residue values were calculated as weight percentages with an accuracy of 0.02%.[24]

Trimming tests were performed by cutting the samples with a dental carver and visually inspecting them for chipping, flaking, and tearing on their cut surfaces.[24] Data were subjected to statistical analysis by one-way ANOVA, post hoc LSD, and Tamhane tests at a significance level of 0.05, using IBM SPSS Statistic software version 23 (IBM SPSS Inc., New York USA).

RESULTS

The melting point test results of the inlay waxes and their raw materials are presented in Figures 1. One-way ANOVA indicated that variations in the concentration of corncob powder filler had a significant effect on the melting point values of the inlay waxes ($p < 0.05$). The addition of corncob increases the melting point of the inlay waxes. The LSD post hoc test revealed significant differences between groups, except between the 0% and 5% groups (Group I and II, respectively; Table 2).

Table 2. Summary of the LSD post hoc test results for the melting points of inlay waxes

Groups	I	II	III	IV	V
I	-	0.375	1.458*	2.250*	3.625*
II	-	-	1.083*	1.875*	3.250*
III	-	-	-	0.792*	2.167*
IV	-	-	-	-	1.375*
V	-	-	-	-	-

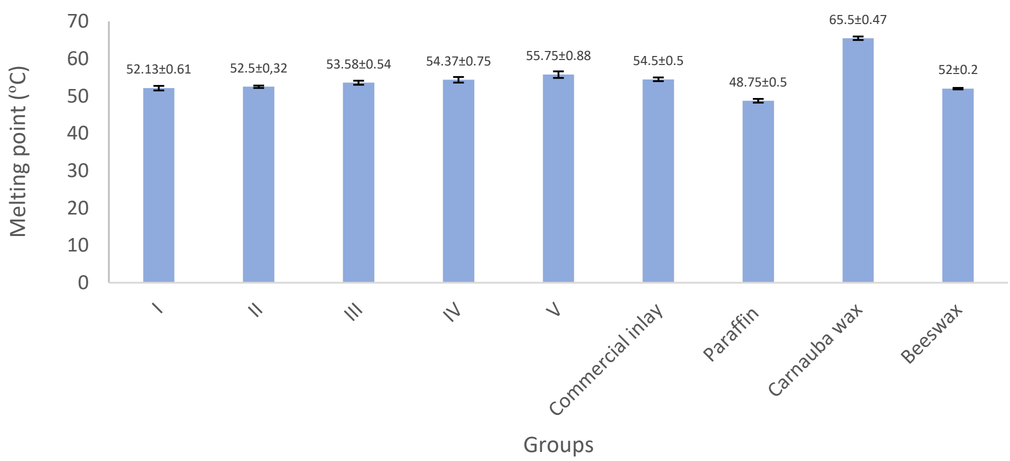

Figure 1. Mean and standard deviation of the melting points of inlay waxes and their components.

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Mean and standard deviation of inlay waxes flow can be seen in Table 3. One-way ANOVA results showed that filler concentration affects inlay wax flow at temperatures of 30°C, 40°C, and 45°C (p<0.05). Increasing filler concentration leads to decreased inlay wax flow. LSD post hoc test at 0.5 significance level indicates significant differences in flow rate (p<0.05) between groups, except between the 0% and 5% groups at all temperatures, and between the 5% and 10% groups at temperatures of 40°C and 45°C (p>0.05).

The penetration depth test results showed in Table 4. One way ANOVA results indicate that filler concentration influences the depth of inlay wax penetration (p<0.05). The higher filler concentrations can reduce the depth of inlay wax penetration, indicating increased hardness of the inlay wax. Tamhane's post hoc test results showed differences in penetration depth among groups (p<0.05), except between the 0% and 5% groups and between the 5% and 10% groups (p>0.05). The trimming test results demonstrated that the inlay waxes in all treatment groups did not exhibit any chipping, flaking, or tearing during cutting and carving with a dental carver (Table 5).

The residue test results of the inlay waxes and their raw materials are presented in Figures 2. One-way ANOVA indicated that variations in the concentration of corncob powder filler had a significant effect on the residue values of the inlay waxes (p< 0.05). The residue values of the inlay waxes tended to increase with the increase in concentration of fillers. Post hoc tests with Tamhane revealed significant differences among various groups (p<0.05). The differences were statistically significant, except between the 5% and 10% groups (Group II and III) for residue values (Table 6).

Table 3. Mean value and standard deviations of inlay wax flow (%)

Group (% Filler)	30°C	40°C	45°C
I (0%)	1.69 ± 0.19 a	69.78 ± 3.12 b	83.63 ± 1.43 d
II (5%)	1.65 ± 0.14 a	64.54 ± 4.67 b,c	81.89 ± 1.15 d,e
III (10%)	0.98 ± 0.16	59.09 ± 5.10 c	80.46 ± 0.45 e
IV (15%)	0.67 ± 0.15	43.96 ± 5.48	77.51 ± 0.93
V (20%)	0.35 ± 0.11	22.69 ± 4.82	71.82 ± 2.97
Commercial inlay wax	0.29 ± 0.05	51.74 ± 2.22	77.78 ± 1.83

Table 4. Mean and standard deviations of penetration depth of inlay waxes

Group (% corncob flour)	Mean ± SD (mm)
I (0%)	5.28±0.16 a
II (5%)	4.81±0.52 a,b
III (10%)	3.56±0.58 b
IV (15%)	3.47±0.15
V (20%)	2.56±0.66
Commercial inlay wax	3.65±0.15

Table 5. Trimming test results of inlay waxes

Groups	Chipping	Flaking	Tearing	Compared with standards
I	0*	0*	0*	Acceptable
II	0*	0*	0*	Acceptable
III	0*	0*	0*	Acceptable
IV	0*	0*	0*	Acceptable
V	0*	0*	0*	Acceptable

*Score 0 = no chipping/flaking/tearing

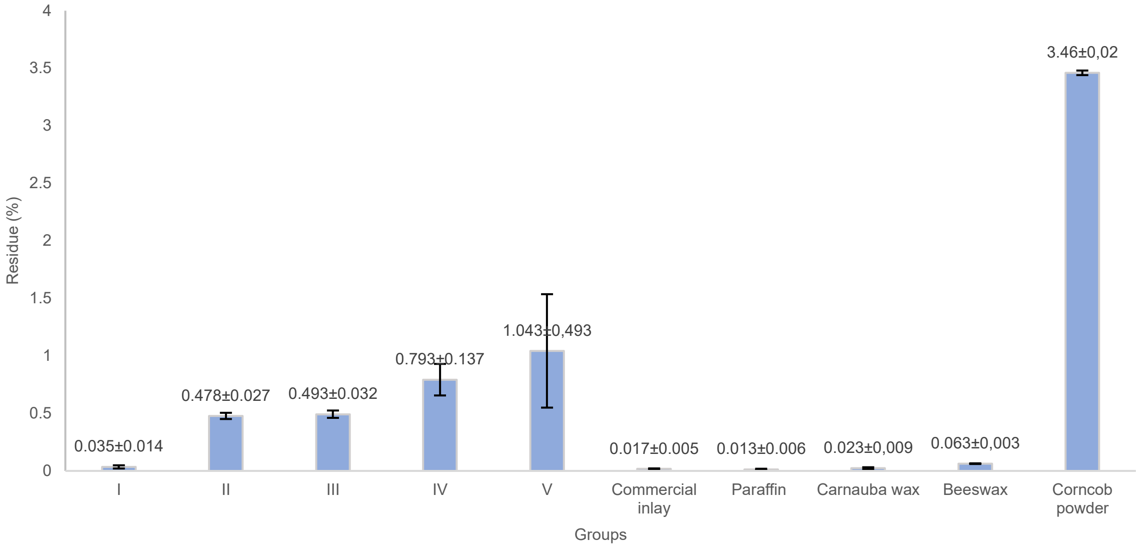

Figure 2. Mean and standard deviation of the residue values of inlay waxes and their components.

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Table 6. Summary of the Tamhane post hoc test results for the residue values of inlay waxes

Groups	I	II	III	IV	V
I	-	0.463*	0.473*	0.717*	0.950*
II	-	-	0.010	0.253*	0.487*
III	-	-	-	0.243*	0.477*
IV	-	-	-	-	0.233*
V	-	-	-	-	-

*Significant difference

DISCUSSION

Inlay waxes present variations in their physical and mechanical properties due to their natural waxes and various additive ingredients composition.[26] One such property is melting point, which varies due to the diverse components present in natural waxes. Natural waxes exhibit melting ranges rather than precise melting points because they consist of mixtures of different compounds with different melting behaviors. As temperatures rise within the melting range, wax components progressively melt, transitioning from solid into liquid states.[3,26]

In this study, inlay waxes were formulated by using a combination of paraffin wax, carnauba wax, and beeswax, each with its distinct melting range. Among these, paraffin wax has the lowest melting point, followed by beeswax and carnauba wax. The concentration of paraffin wax in the mixture varied due to the addition of corncob powder filler, resulting in changes in the melting point of the inlay waxes. The trend of increasing melting points with decreasing paraffin wax concentration was observed confirming the influence of filler concentration on the melting point of inlay waxes. Notably, the melting point of inlay waxes containing 15% corncob powder filler was nearly equivalent to that of commercial inlay wax. These results support with prior findings that the addition of certain fillers, such as flaxseed extract, affect the softening point of inlay waxes.[19,20]

Addition of corncob powder as a filler in the composition of inlay waxes will decrease the flow property of inlay waxes. Flow is the change in shape under an applied force, caused by the slippage of the long-chained wax molecules over each other.[3] Corncob as a filler in inlay waxes increase the viscosity of wax mixture and change the slippage among wax molecules that decrease flow of inlay waxes. The flow of dental waxes influences by temperature of the wax, force applied to the wax, and the time force applied.[7] Flow requirements for inlay waxes class 1 (casting wax) type 1 (soft wax) at 30°C maximum 1%, at 40°C minimum 50%, and at 45°C 70% to 90%.[24] The results showed that only inlay waxes with 10% corncob filler met the requirement at all temperature and similar to commercial products.

The hardness of inlay wax is influenced by the wax components.[3] The composition of inlay waxes in this study varied in the concentration of paraffin and corncob filler. The structure of paraffin is a non-polar coordinating covalent valence bond. The interaction of non-polar bonds with other molecules is weak so the molecules will move easily. The more paraffin used in the wax inlay mixture, the weaker the intermolecular bonds will be, so the hardness will also be lower.[12] The addition of fillers can modify the physical properties of a material.[15] Materials with added fillers such as wax can reduce the plasticity of the matrix and lead to increase the hardness.[16] The addition of corncob causes the hardness of the inlay wax increases. Inlay waxes with corncob powder concentrations of 10% and 15% showed hardness that was close to the commercial inlay wax.

Wax patterns should have suitable melting points and hardness so that can be carved properly to obtain wax patterns with the appropriate sizes, shapes, and contours. The addition of corncob powder filler at concentrations ranging from 0% to 20% did not affect the trimming properties, including chipping, flaking, and tearing of inlay waxes. All inlay wax compositions met the trimming property requirements outlined in ANSI/ADA No. 122.[24] The compositions produced inlay waxes with appropriate melting points, rendering them sufficiently hard at room temperature. Engraving inlay wax blocks did not lead to chipping, flaking, or tearing because the filler material increased the wax's hardness without making it brittle.

In the lost-wax casting technique, the wax pattern should be completely removed from the mold without leaving any residue. During casting, the residue retained in the mold can result in defects, increased surface roughness, and surface contamination that can complicate polishing or lead to corrosion issues.[26] Therefore, filler materials should be thoroughly mixed and leave no residue upon combustion.[27]

Waxes undergo oxidation during heating, and some of their components may evaporate over time.[23] As temperature increases, some wax components may volatilize, whereas others begin to decompose, depositing carbon within mold pores. The removal of this carbon residue relies on the diffusion of oxygen from the mold's free surfaces. Dental waxes must have low inorganic content to prevent undesirable casting properties. Fillers cannot be used to modify casting wax properties unless they are entirely combustible.[27]

The results of the residue on ignition test revealed that all inlay wax groups with fillers left residues of 0.035% to 1.043%. Statistical analysis using one-way ANOVA

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indicated that the addition of corncob powder filler led to an increase in inlay wax residues. The $Tamhane_{0.05}$ post hoc test showed significant differences in residues among groups, except between the 5% and 10% groups (Group II and III). The increase in the residues of dental waxes can be attributed to the burning of waxes and corncob powder filler. Natural waxes, including paraffin wax, carnauba wax, and beeswax, often contain contaminants that contribute to residues in the resulting inlay waxes, even though they are present in a relatively small percentage.[13]

Corncob powder contains lignocellulose and is composed of approximately 37% hemicellulose, 33% cellulose, 5% lignin, 2.5% protein, 6% starch, and 3.5% powder.[15,19,20] It exhibits thermal stability due to lignin degradation over the temperature range of 200°C–500°C due to variations in the thermal stability of oxygen groups within its structure.[19] The ash contents of corncob charcoal and corncob briquettes are 11.29% and 0.14%, respectively.[27,28] In this study, the solid residue of corncob powder was 3.46% which significantly affected the overall residue of inlay waxes. Corncob powder left high amounts of residues likely due to its high natural fiber content and large particle size (approximately 0.149 mm [100 mesh]). The residue level exceeded ANSI/ADA standards, which require residues of < 0.1%. These results align with prior findings on inlay waxes with starch powder as fillers that also left residue on acrylic teeth after wax removal.[16]

The addition of corncob powder as a filler in concentration ranging from 5% to 20% generally impacts the physical and mechanical properties of inlay waxes. Increasing the concentration of corncob powder tends to raise the melting point and hardness, as well as increase ignition residue, while reducing flow properties. However, it does not significantly affect trimming properties. At a concentration of 10%, corncob powder shows promise as a filler for inlay wax, exhibiting melting point and hardness properties comparable to commercial inlay wax, and meeting flow and trimming standards set by ANSI/ADA. Unfortunately, the ignition residue exceeds the 0.1% limit specified by ANSI/ADA standards. To address this limitation, future research should focus on methods to reduce ignition residue to acceptable levels. Investigating corncob powder with a particle size smaller than 0.149 mm could determine if it burns more efficiently, potentially producing smaller residues.

Based on the results of this research, it can be concluded that: First, addition corncob powder increased the melting point, hardness, and residue of inlay waxes. Second, addition corncob powder decreased the flow of inlay waxes. Third, the addition corncob did not influence the trimming property of inlay waxes. Inlay wax containing 10% corncob filler shows promise for development as a local inlay wax, as it exhibits physical and mechanical properties similar to commercial inlay wax and meets ANSI/ADA standards, with the exception of residue on ignition property. Further research is needed to explore methods to reduced inlay wax residue to meet the standard.

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