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Effect of maca (*Lepidium meyenii*) on some physical characteristics of cereal and root starches

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Abstract: Maca (*Lepidium meyenii*) is a plant from Peru that has long been used as a food for its nutritional value and medicinal properties linked to fertility and vitality. The aim of this study is to evaluate maca and starch interactions in order to facilitate the use of this functional food as an ingredient. Four different starches (potato, corn, tapioca and wheat) were used, with maca added at three concentrations. The effect of maca addition was then determined by measuring the Water Absorption Index (WAI) of samples heated at 50, 60, 70, 80 and 90°C. The pasting properties of samples were measured and gel compression tests were performed to evaluate the effect of maca on starch gel strength. Maca had a significant ($p \leq 0.05$) effect by decreasing the WAI of starches at temperatures close to the starch pasting temperature. The viscosity of the starches decreased significantly ($p \leq 0.05$) when maca was added. Adding maca at 10% (w/w) also significantly decreased the strength of the potato, corn and wheat starch gels. Results showed that there were no detrimental effects on the starches' physical properties at low levels of addition. Therefore, the use maca as a food ingredient is possible and should allow for a number of potential food applications.

Keywords: maca, viscosity, texture, starch interactions

Introduction

Maca (*Lepidium meyenii)* is a native plant of the Andes region growing in altitudes varying between 3700 and 4450 m. Maca is a major staple for the Andean Indians and indigenous people, and was domesticated during the pre-Inca archaic period sometime around 3800 B.C (Quiros and Cardenas, 1997).The roots can be used in many forms as juice, soup, extract, or processed food enriched with maca flour. Nevertheless, its availability in pills helped its commercialization in the international market, especially in Europe and Asia for functional and medicinal purposes (Gonzales *et al*., 2001).

Chemical research has demonstrated that maca root contains a family of biologically-active aromatic isothiocyanates (Sandoval *et al*., 2002). Particularly, p-methoxy isothiocyanate has respected aphrodisiac properties (Li *et al*., 2001). Because maca is thought to balance hormonal activity, it is believed to be useful in cases of infertility and reproductive disorders (Cicero *et al*., 2001). Furthermore, it is thought that maca possibly helps in cases of chronic fatigue syndrome and its ingestion may restore lost vitality and vigor (Rubio *et al*., 2006). Additionally, its significant iodine content (Ochoa, 2001) possibly explains why maca has been used to improve thyroidal symptoms (Meissner *et al*., 2006). Additionally, reports have indicated its beneficial impact in some cases of anemia as it is rich in iron (*Gonzales et al., 2002*).

Maca has a high nutritional value, similar to that of cereal grains. This is because it contains carbohydrates (60-75%), proteins (10-14%), fibers (8.5%) and lipids (2%) (*Muhammad et al., 2002*). Moreover, it has a high content of free basic amino acids, especially arginine and lysine, which form the basis of its capacity to regulate the fertility for both sexes. Particularly, the male reproductive cells contain a large amount of arginine (Fujii *et al*., 2003). Maca plugs the arginine in these cells and consequently it alleviates fertility problems as well as shortage of libido. Likewise, lysine helps women with fertility problems and menopausal complaints (Dini *et al*., 1994).

Several research groups have directed their concerns toward the fertility-enhancing and aphrodisiac activities of maca. Oral administration of the lipid extract decreased the latent period of erection in male rats with erectile dysfunction as well as improved the sexual function of mice and

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rats by increasing the number of intercourses and the number of sperm-positive females in normal mice (Zheng *et al*., 2000; Chung *et al*., 2005). Gonzales *et al*. (2003) reported that maca does not affect serum reproductive hormone levels in adult men but rather it improves sperm motility and sperm production in dose-dependent manner and demonstrated that the sexual desire was improved significantly after eight weeks of treatments. This effect was independent of sexual hormone levels (testosterone and estradiol). According to the same research group the oral administration of hexane extracts improved sexual performance parameters as well (Gonzales *et al*., 2003). Oral administration of an aqueous extract of maca roots resulted in an increase in the weights of testis and epididymis and the root invigorated spermatogenesis in male rats by acting on the initial portion of the seminiferous tubules where mitosis takes place (Gonzales *et al*., 2001).

In addition to all previously mentioned properties, maca has shown prominent antimicrobial and insecticidal activities. The oil of the plant was selectively toxic towards *Cyanobacterium Oscillatoria peromata* with complete growth inhibition at 100 μg/ml. Moreover, mortality of the Formosan subterranean termite, *Coptotermes formosanus* was also observed in tests conducted on filter paper treated with maca oil. At 1% (wt/wt), maca oil appeared to act as a feeding deterrent to termites. This anti-termite activity is significantly promoted by 3-methoxyphenylacetonitrile and benzyl thiocyanate (Tellez *et al*., 2002).

There are many published research papers on the health benefits of maca, while relatively little information has been reported on the properties of isolated maca starch (Rondán-Sanabria and Finardi-Filho, 2009). There is, however, no published report on quality characteristics of maca powder such as water activity and viscosity which can affect the quality of food when maca is used as an ingredient. The aim of this study is to evaluate maca and starch interactions in order to facilitate the use of this functional food as an ingredient in a range of applications used in the food industry

Materials and Methods

Materials

Maca powder was donated from Sanitarium (Cooranbong, NSW). This powder is from pure organic maca obtained from selected sun dried maca roots which were milled and shipped from Peru. Potato, corn and tapioca starches were provided from National Starch and Chemical Pty Ltd, NSW, Australia.

Starch and maca characterization

Four types of starches (wheat, potato, corn and tapioca) and maca powder have been used to understand the characteristics of each individual ingredient. Subsequently, combinations between maca and the other four starches (Table 1) were studied in order to assess their interactions.

Water absorption index

Water absorption indices were determined according to the method of Li and Yeh (2001) with some modifications. Starches and mixed samples (Table 1) (1g, dry weight basis) were weighed directly into a pre weighted screw-cap test tube, and 10 ml distilled water was added. The capped tubes were then placed on a vortex mixer for 10 s and incubated in 50, 60, 70, 80, and 90°C water bath for 30 min with mixing by vortex at 10 min intervals. The tubes were then cooled to room temperature and centrifuged at 2000 g in a Clements 2000 bench top centrifuge (Clements, Sydney, Australia) for 10 min, the material adhered to the wall of the tube was thought as sediment and weighed (Ws). The water absorption index (WAI) was calculated as follows: WAI (g/g dry material) = Ws/1.

Determination of pasting properties

Pasting properties of starches and different combinations of them are determined by using the Rapid Visco Analyser (RVA) (Newport Scientific, RVA model 4, New South Wales, Australia) controlled by Thermocline for Windows software (version 2.1, Newport Scientific). The moisture content of the starch samples was determined (Method no. 02-52, AACC, 2005) and this was used to compensate for differences in moisture content between samples by adjusting the quantities of starch and distilled water used to prepare the RVA sample (Method no. 61-02, AACC, 1995). RVA tests were performed with around 3 g of starch samples and approximately 25 g of distilled water. After the canister was fitted to the device, the operations were run based on the approved profile (Method no. 61-02, AACC, 1995). Each sample was held at 35°C for 1 min, heated to 95°C at 3°C/min, held for 2 min, cooled down to 50°C at 3°C/min, and held at 50°C for 2 min. Total elapsed time was 40 min. RVA measured Values from the pasting profile were the following:

1. Peak viscosity [cP] (maximum paste viscosity achieved in Stage 2, the heating stage of the profile);
2. Trough viscosity [cP] (minimum paste viscosity achieved after holding at the maximum temperature,

Table 1. Samples used for evaluation of maca-starch interactions

Base Flour	Samples		
	Maca 3%	Maca 5%	Maca 10%
Wheat	WM1	WM2	WM3
Potato	PM1	PM2	PM3
Corn	CM1	CM2	CM3
Tapioca	TM1	TM2	TM3

Table 2. WAI of maca and starches with and without maca addition [a]

Sample	50°C	60°C	70°C	80°C	90°C
Maca	3.8±0.04	3.7±0.06	3.7±0.22	3.8±0.015	3.8±0.2
Potato	1.8±.022	5.7±0.39	5.2±0.18	4.0±0.07	5.2±0.55
Corn	1.6±0.13	1.8±0.01	4.4±0.07	6.9±0.12	3.7±0.35
Tapioca	1.4±0.12	2.1±0.12	4.5±0.24	7.7±0.05	3.3±0.14
Wheat	2.0±0.00	3.4±0.30	5.5±0.01	6.4±0.07	8.6±0.24
PM1	1.7±0.18	2.5±0.48	5.2±0.40	4.8±0.20	4.3±0.16
PM2	2.0±0.05	1.9±0.09	5.0±0.11	4.7±0.17	4.1±0.08
PM3	2.0±0.05	2.1±0.07	4.5±0.07	4.5±0.33	3.8±0.06
CM1	0.9±0.38	1.7±0.11	4.1±0.09	6.2±0.29	4.1±0.58
CM2	1.8±0.01	1.8±0.02	4.1±0.08	5.7±0.15	3.5±0.07
CM3	1.9±0.07	1.8±0.14	3.8±0.07	5.5±0.25	3.3±0.18
TM1	1.2±0.18	1.9±0.03	3.0±0.04	3.9±0.22	2.8±0.55
TM2	0.9±0.23	1.9±0.02	3.3±0.05	3.2±0.21	2.3±0.57
TM3	1.8±0.02	2.0±0.03	3.2±0.10	2.7±0.27	3.2±0.45
WM1	2.1±0.03	3.4±0.07	5.5±0.06	5.8±0.15	7.5±0.41
WM2	2.1±0.05	3.5±0.18	5.5±0.04	5.8±0.12	7.3±0.51
WM3	2.1±0.02	3.1±0.13	5.5±0.19	5.9±0.19	7.0±0.38

[a] All the values in the table are the mean of 3 replicates

Stage 3);

3. Final viscosity [cP] (the viscosity at the end of run);

4. Pasting temperature °C (the temperature at which starch granules begin to swell and gelatinize due to water uptake and defined as an increase of 25 cP over a period of 20s);

5. Peak time [s] (the time at which peak viscosity was recorded);

6. Breakdown viscosity [cP] (difference between peak viscosity and trough).

All analyses were performed in triplicate.

Compression of starch gels

The starch samples prepared in the RVA were poured into small aluminum canisters and stored at 4°C for 24h. The gel formed in the canisters was evaluated for gelling compression by measuring the hardness of the starches using a microprocessor controlled texture analysis system in conjunction with data collection and analysis software (TMS-Pro, Food Technology Corporation, S.I. Instruments, S.A, Australia). The gels formed in the canisters were directly used in the texture analysis, and each gel was penetrated 10 mm by a cylindrical probe of 25 mm diameter and the force required was recorded. The probe speed was 25 mm/min speed, during the penetration and 400 mm/min post-test. The load cell used in this analysis was 250 N. From the texture profile curve hardness was calculated. The compression analyses were conducted in triplicate.

Statistical analysis

One way analysis of variance (ANOVA) was used to determine statistically significant differences ($p \leq 0.05$) among means, SPSS 16.0 for Windows software.

Results and Discussion

Water absorption index

Water absorption indexes (WAI) of the starches with and without maca are directly correlated to the pasting temperature of the starches (Table 2 and Figure 1). As can be seen from Figure 1, highest levels of WAI were verified at the temperature close to the starch pasting temperature. The WAI of the potato, corn, tapioca and wheat starch were between 1.8–5.7, 1.5-6.9, 1.4-7.7 and 2.0-8.5 g/g respectively.

The differences in WAI depend on several factors such as starch origin, amylose and amylopectin content, isolation procedure and thermal history (Singh and Smith, 1997). Adding maca at different concentration had significant effect ($p \leq 0.05$) in WAI of the starches at temperature close to their pasting temperatures reported by researchers (Yasumatsu *et al*., 1972; Lii and Chang, 1981). The amount of water which can be absorbed and retained by starch and insoluble fiber depends on several factors such as the chemical structure, particle size, temperature, the degree of cross linking as well as the degree of molecular association. From these findings we can say maca may have affected all these factors and resulted in decreasing the WAI in all starches.

Pasting properties

The pasting viscosities of the starches and starch mixtures are presented in Figure 2 and Table 3. Native starches displayed significantly ($p \leq 0.05$) higher peak (Fig.2) and final viscosities (Table 3) than starch mixtures. As the proportion of maca in the starch mixtures increased, the peak, trough, breakdown and final viscosities (PV, TV, BV and FV respectively) of the mixtures were decreased. This result was expected because peak and final viscosities of native starch were higher than those of maca. Unlike the peak, trough, breakdown and final viscosities, however, the peak temperature and peak time of starch mixtures did not show a linear change according the content of starches (Table 3).

The effect of maca on potato and tapioca starches however, is different than its effect on corn and wheat starch. Different concentration of maca in potato and tapioca starch mixtures shown significant effect ($p \leq 0.05$) in TV, BV and FV while there was no significant effect between corn and wheat starch and mixtures as shown in Table 3. As can be seen in Figure 2, addition of maca at 3 and 5% in the mixture with the potato starch led to peak viscosity value which was less than half of the control (7644 and 3812 cP respectively). On the other hand, for the corn 3 and 5% corn–maca mixture no such significant differences in peak viscosity were shown (Figure 2) with 3050 and 2979 cP, respectively. The crystalline and molecular orders may be in the origin of this different behavior of potato and tapioca starches compared with wheat and corn starches. According to Cooke and Gidley, (1992) wheat and corn starches crystalline order was lower than potato or tapioca starches, whereas wheat and corn starches molecular order was higher than potato or tapioca starches.

While the viscosity of a starch paste depends on the volume fraction occupied by swollen granules, other parameters such as the rigidity of swollen granules, the viscoelasticity of the continuous phase and the adhesion between the dispersed granules and continuous phase influence the pasting properties. These properties of a starch might be affected when

Table 3. Pasting characteristics of starches and starch-maca mixtures *

Sample	TV (cP)	BV (cP)	FV (cP)	Peak time (min)	Peak temperature (ºC)
Potato (P)	2120[a]	5524[a]	2540[a]	12[a]	41[a]
PM1	2008[ab]	1819[b]	2416[a]	15[a]	41[a]
PM2	1961[b]	1012[c]	2373[a]	14[a]	42[a]
PM3	1348[c]	517[d]	1710[b]	15[a]	42[a]
Tapioca (T)	1567[a]	2853[a]	2555[a]	14[a]	44[a]
T1	1199[b]	2619[b]	2187[a]	14[a]	44[a]
T2	1002[c]	2140[c]	1516[b]	15[a]	45[a]
T3	613[d]	1733[d]	1058[b]	15[a]	45[a]
Corn (C)	2198[a]	852[a]	3719[a]	20[a]	48[a]
C1	2298[ab]	681[b]	3510[a]	20[a]	49[a]
C2	2312[ab]	687[b]	3573[a]	20[a]	49[a]
C3	1999[ac]	650[b]	2972[b]	20[a]	49[a]
Wheat (W)	1910[a]	523[a]	3197[a]	22[a]	59[a]
W1	1846[ab]	499[a]	3109[ab]	22[a]	58[a]
W2	1763[b]	428[ab]	2862[b]	22[a]	58[a]
W3	1452[c]	377[b]	2442[c]	22[a]	58[a]

* All the values in the table are for the mean of 3 replicates. For each starch, within each column, means with the same letter do not differ significantly.

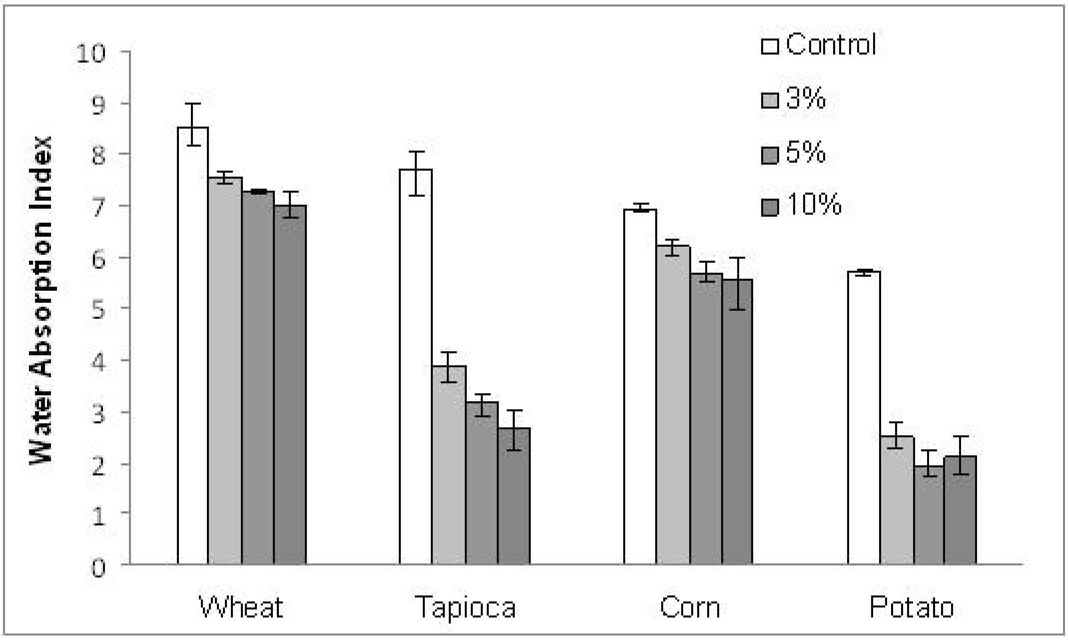

Figure 1. Effect of adding maca on the Water Absorption Index of starches at temperatures close to their gelatinization temperature (Wheat 90°C, Corn and Tapioca 80°C, Potato 60°C).All the values are the mean of 3 replicates.

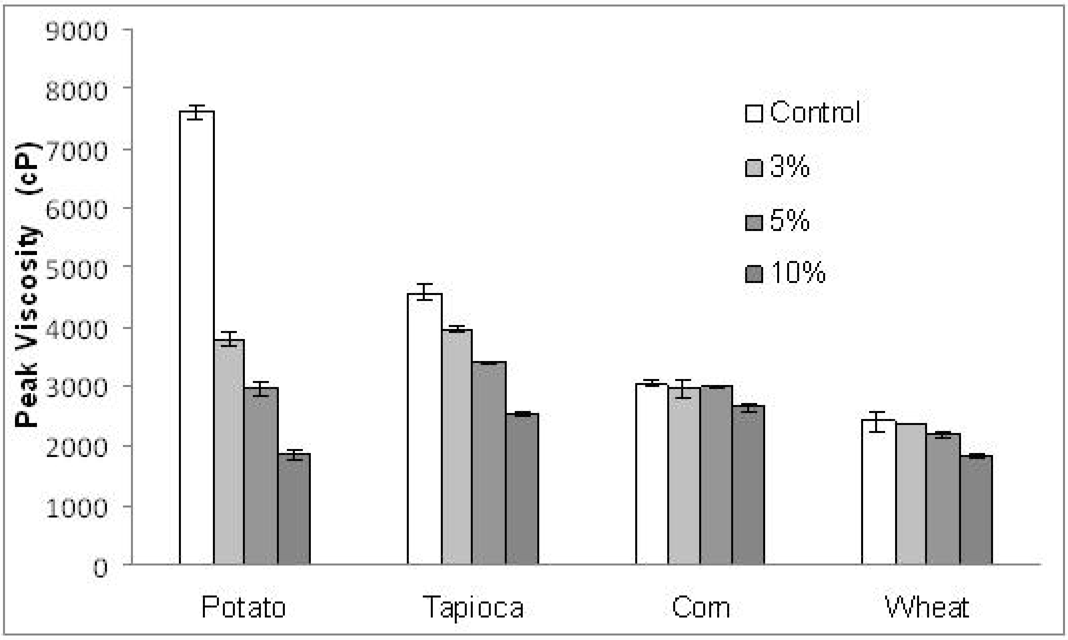

Figure 2. Effect of adding maca on peak viscosity of Potato, Tapioca, Corn and Wheat starches. All the values are the mean of 3 replicates.

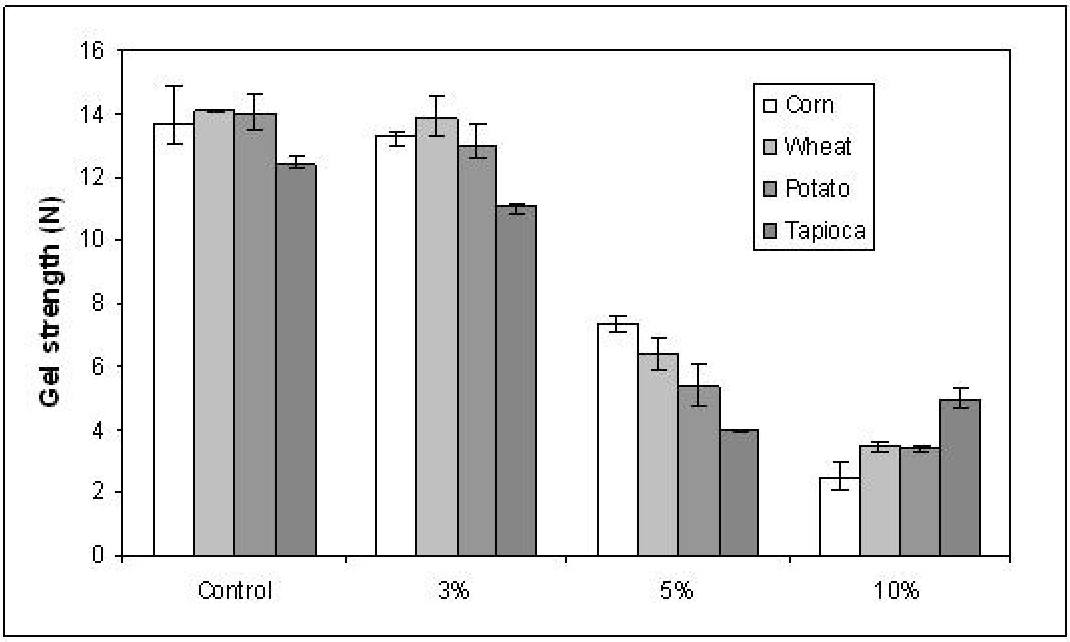

Figure 3. Effect of adding maca on the gel strength of starches. All the values are the mean of 3 replicates.

blended with another starch (Park *et al*., 2009). Adding maca would result in an overall decrease in amylose content in the mix due to the low amylose content in maca (Rondán-Sanabria and Finardi-Filho, 2009). The amylose leached from starch assists the formation of a gel network when the paste is cooled. The decrease in trough viscosity as the maca content increased (Table 3) supported the amylose effect theory.

Gel strength

Starch gels are defined as composites consisting of swollen granules filling an interpenetrating polymer network, and the major polymer in the network is amylose. However, Lindqvist (1979) indicated that not only amylose but also amylopectin of starch played important roles in the formation of starch gel. Liu and Lelievre (1992) found that other factors may affect the gel strength. In the presence of ungelatinized starch in the gel some reinforcement will happen. Liu and Lelievre (1992) explained that by saying that the corresponding dynamic viscosity remains virtually unchanged until the gelatinization occurs, whereupon the value decreases to a fixed level. This trend suggests that the gel is becoming more elastic when gelatinization takes place. Reiterating gels may become stronger when there is a strong interaction between the amylose matrix and rigid filler according to the Liu and Lelievre (1992) study. The gel strength defined as the maximum force of first compression by texture profile analysis, varied significantly among the starch types (Figure 3). Tapioca starch had the lowest gel strength with 2.24 N followed by potato, wheat and corn. These results are in totally agreement with the study of Ting-Jang *et al*. (2008). The low gel strength of the tapioca suggests the negative effect of amylopectin branching structure on gel formation. However, maca showed significant effect ($p \leq 0.05$) on gel strength at 10% w/w while there were no significant effects at low amounts (3 - 5% w/w). Maca effect on tapioca starch is different than its effect on potato, corn and wheat starches. All the starches showed a decrease in gel strength when maca was added at 10% w/w except tapioca gel strength which was increased by increasing maca in the mixture. This difference may be related to starch granule types which are type A in wheat and corn, type B in potato and type C in tapioca (Owusu-Apenten, 2005) or, as mentioned above, to the amylopectine branching difference between the starches (Liu and Lelievre, 1992).

Conclusion

Interaction of maca with a number of commonly used starches showed that there were no detrimental effects on the starches' physical properties at low levels of addition. Therefore, the incorporation of an established functional food, such as maca, as a food ingredient is possible and should allow for a number of potential applications in the food industry. Such foods would benefit from the proven properties of maca without compromising the all important texture of the final product.

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