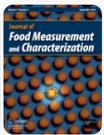


Characterization of physicochemical, tribological, and sensory properties of dark chocolate incorporated with *Nypa fruticans* as a sugar alternative

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Abstract

Dark chocolate is a popular snack, but its high sugar content raises health concerns. This study explores the potential of *Nypa fruticans* sugar (*Gula Apong*) as a natural sugar alternative to enhance the nutritional profile and quality of dark chocolate. The research evaluates its impact on physicochemical, tribological, and sensory properties. Key findings reveal that *Nypa fruticans* sugar significantly ($p < 0.05$) increases ash content (1.83–2.11%), mineral levels (notably potassium (5.57–6.81 mg/100 g) and magnesium (1.00–1.39 mg/100 g)), reducing sugar (2.03–3.04%), moisture (2.91–3.48%), hardness (6.16–6.39 kg), and spreadability, while reducing viscosity (7068.20–5578.45 cP). Microstructural analysis highlights changes in sugar crystal size, agglomeration, and amorphous phases. Thermal analysis shows variations in melting profiles, with notable shifts in enthalpy values, reflecting that more energy is required for the melting process in dark chocolate with increased substitution of *Nypa fruticans* sugar (2.60–3.00 J/g). Tribological assessments indicate a shift in the transition from static to dynamic friction, occurring at higher sliding velocities with increased substitution of *Nypa fruticans* sugar. Sensory evaluation identified NFC₅₀ as the most preferred formulation, reflecting favorable perceptions of color, aroma, flavor, texture, and taste. Notably, the sugar substitution had minimal effects on protein, fat, and carbohydrate content, ensuring overall nutritional balance. In a nutshell, this study underscores the potential of *Nypa fruticans* sugar to create healthier, locally sourced dark chocolate with enhanced sensory and nutritional attributes, paving the way for sustainable innovation in confectionery and beyond.