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VISCOSITY AND FLOWABILITY ATTRIBUTES OF MODIFIED MILK-BASED ENTERAL FORMULAS FORTIFIED WITH PUMPKIN AND EGG WHITE FOR PEDIATRIC SEVERE ACUTE MALNUTRITION

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Abstract
Background: The standard F-100 formula for severe acute malnutrition (SAM) rehabilitation is often constrained by high costs and limited accessibility. **Objective:** This study aimed to formulate and evaluate the rheological and physical properties (specifically viscosity and flowability) of a modified milk-based enteral formula fortified with pumpkin (*Cucurbita moschata*) and egg white as a locally accessible alternative. **Methods:** A single-factor Completely Randomized Design was employed with three formula variations (B1, B2, and B3). Viscosity was measured using a digital rotational viscometer, and flowability was assessed via a gravity-driven simulation using an 8 French pediatric nasogastric tube (NGT). **Results:** viscosity ranging from 145 cP (Formula B1) to 700 cP (Formula B2). Flow durations ranged from 290 to 350 seconds, with flow rates of 0.06–0.07 mL/s. Formula B3 exhibited the highest flow efficiency (290 seconds). However, these numerical variations were not statistically significant for viscosity ($p = 0.368$) or flow rate ($p = 0.368$). **Conclusion:** this formulation demonstrates physical and mechanical feasibility for pediatric NGT administration, but further nutritional testing is required before considering it a clinical alternative to F-100

Introduction

Severe Acute Malnutrition (SAM) among children under five years of age remains a critical global health challenge, contributing substantially to morbidity and mortality, particularly in developing countries. Globally, approximately 28.8 million children are affected by SAM (1), with reported mortality rates ranging from 25% to 30% (2). SAM is defined as a condition in which a child's weight-for-height is below −3 SD of the median growth standard established by the World Health Organization (WHO), or when the Mid-Upper Arm Circumference (MUAC) is less than 11.5 cm (3). According to the 2023 Indonesian Health Survey (SKI), 2.6% of children aged 12–23 months were affected by SAM, while the prevalence among children under five in Central Java reached 1.6% (4). The transition to the rehabilitation phase represents a crucial stage in nutritional management, during which the child's metabolism is gradually stabilized and prepared for catch-up growth (5). Failure to provide adequate and safe nutritional support during this phase may precipitate refeeding syndrome or exacerbate organ atrophy. Therefore, optimizing nutritional interventions during the rehabilitation phase is essential for achieving successful clinical recovery and preventing malnutrition relapse among young children (6).

As part of SAM rehabilitation, the milk-based F-100 formula has been established as the standard nutritional therapy to meet the increased energy and protein requirements of children during the rehabilitation phase (5,6). Nevertheless, the long-term implementation of milk-based F-100 formulas at the household level often encounters substantial barriers, including high costs, logistical dependence, and limited accessibility in remote areas (7,8). Furthermore, children recovering from acute malnutrition may experience lactose intolerance, which can lead to diarrhea and other gastrointestinal disturbances when consuming commercial milk-based formulas (9,10). These challenges underscore the need to explore alternative liquid nutritional formulations that are more adaptable to household settings.

The development of Home Blenderized Enteral Nutrition (HBEN) based on locally available foods has emerged as a promising alternative, offering a more natural, flexible, and cost-effective nutritional approach (11). Blenderized diets facilitate the incorporation of naturally occurring micronutrients and dietary fiber, components that are often absent from synthetic formulas, while significantly improving gastrointestinal tolerance in children (11,12). Several clinical studies have demonstrated that appropriately formulated HBEN can support optimal pediatric growth outcomes comparable to those achieved with commercial enteral formulas (13). Moreover, HBEN therapy has been associated with a 50–60% reduction in gastrointestinal symptoms, including nausea and vomiting (13,14).

Despite its potential benefits, one of the primary challenges in HBEN formulation concerns its rheological properties. The use of whole-food ingredients generally results in higher viscosity and reduced flowability (15,16). Excessively viscous formulas may obstruct feeding tubes or impair swallowing in children with muscle weakness, whereas excessive dilution to improve flow characteristics may compromise the energy density of the formula (16,17). Previous studies have reported viscosity values ranging from 19 to 24 cP for enteral formulas formulated from catfish flour, soybean flour, and pumpkin flour (16). Another study found that blenderized enteral formulas prepared from fresh foods exhibited viscosity values between 29 and 64 cP (17). However, previous studies have not utilized a combined formulation of egg white, skim milk, and pumpkin simultaneously. Investigating the rheological characterization and food matrix interactions of this specific formulation combination, therefore, addresses an important research gap.

To achieve a nutrient density comparable to the macronutrient targets of F-100 namely 100 kcal/100 mL, corresponding to an energy intake of 100–150 kcal/kg body weight/day, and a protein intake of 2–3 g/kg body weight/day skim milk powder and palm oil were utilized as the primary base and carrier ingredients (5,18). Palm oil was selected to ensure the liquid matrix meets the high energy density requirements, while skim milk powder was incorporated as an accessible, high-quality protein base. Although skim milk contains lactose and cow's milk proteins, it was used to balance nutritional needs with household accessibility, under the premise that it can be tolerated in controlled amounts during the later stages of rehabilitation. This base was further fortified with pumpkin (*Cucurbita moschata*) and egg white. Pumpkin is rich in beta-carotene, which plays a role in regenerating intestinal mucosa damaged by malnutrition, while also providing easily digestible complex carbohydrates (18,19). The total carotenoid content of pumpkin has been reported to be 35.2 mg/100 g (20). Egg white, meanwhile, serves as a highly digestible, high-biological-value protein source that supports tissue repair and visceral protein synthesis without imposing excessive renal burden on children (21,22).

Beyond their nutritional benefits, pumpkin and egg white were selected to address the physical viscosity challenges associated with HBEN. The gelatinization of starch properties in pumpkin and the thermal denaturation of albumin protein in egg white upon heating are hypothesized to interact synergistically within the liquid matrix to improve or maintain an ideal flow rate, thereby minimizing the risk of feeding tube obstruction. Through the synergistic combination of these ingredients, this study aims to formulate and evaluate the rheological properties (specifically viscosity and flowability) of a blenderized enteral formula for the rehabilitation phase as a community-applicable alternative modification of the standard F-100 formula. Furthermore, it must be explicitly stated that this study represents a preliminary stage focusing solely on the feasibility of the physical and rheological properties of this energy-dense formulation prior to evaluating its nutritional composition in subsequent studies

Materials and Methods

Research Design and Study Setting

Sample preparation and formula development were conducted experimentally at the Food Processing and Culinary Laboratory, Department of Nutrition Science, Faculty of Health Sciences, Jenderal Soedirman University. This study employed a quantitative approach using a single-factor Completely Randomized Design (CRD), consisting of three modified home blenderized enteral formula variations, with each formulation prepared in three replications (n = 1) per treatment group, as presented in Table 1. Theoretical macronutrient calculations based on food composition databases were performed prior to testing to ensure the formulation designs approximated the F-100 target of 100 kcal/100 mL. Specifically, the inclusion of 60 g of palm oil was incorporated to serve as an intensive lipid-based energy carrier to fulfill the high energy-density requirements critical for SAM rehabilitation.

Table 1. Composition of the Modified Home Blenderized Enteral Nutrition Formulas

Ingredient	Formula		
	B1	B2	B3
Skim Milk Powder (g)	60	65	70
Egg White (g)	50	55	60
Pumpkin (g)	5	10	15
Maltodextrin (g)	20	20	20
Granulated Sugar (g)	35	35	35
Palm Oil (g)	60	60	60
Vanilla Essence (g)	0,5	0,5	0,5
Water (mL)	460	490	520

Notes:
B1 = 60 g skim milk powder, 50 g egg white, and 5 g pumpkin (*Cucurbita moschata*).
B2 = 65 g skim milk powder, 55 g egg white, and 10 g pumpkin (*Cucurbita moschata*).
B3 = 70 g skim milk powder, 60 g egg white, and 15 g pumpkin (*Cucurbita moschata*).
P-value was obtained using the Kruskal – Wallis test.

Ingredient Preparation and Enteral Formula Development

All raw ingredients were prepared and weighed using an analytical balance according to the predetermined formulation ratios (Table 1). Whole chicken eggs were boiled in water for 15 minutes until fully cooked to denature avidin and ensure microbiological safety. Separately, pumpkin (*Cucurbita moschata*) was subjected to thermal processing by boiling at 100°C for 5 minutes until a soft texture was achieved.

The initial mixing stage involved combining skim milk powder, granulated sugar, palm oil, boiled egg white, and cooked pumpkin using a high-speed blender until a homogeneous mixture was obtained. The resulting semi-solid blend was then transferred into a mixing container, followed by the gradual addition of distilled water according to the target volume. Final homogenization was subsequently performed using the blender. To mitigate the risk of tube obstruction caused by remaining solid particles of the coagulated egg white or pumpkin, the homogenized mixture was subsequently passed through a fine-mesh sieve. This filtration step was critical to ensure optimal particle size reduction, uniform emulsion stability, and the attainment of desirable physicochemical characteristics suitable for enteral nutrition administration via small-diameter tubes.

Viscosity Analysis

The rheological characteristics of the home blenderized enteral formulas, particularly viscosity, were quantitatively evaluated using a Digital Rotary Viscometer (NDJ-8S). A 500 mL sample of each enteral formula was prepared and equilibrated to a precisely controlled room temperature of 25 ± 1°C prior to analysis to minimize potential bias resulting from thermal fluctuations. Viscosity measurements were performed using spindle No. 1 or No. 2, operated at a standardized rotational speed across all samples 30 rpm to account for the non-Newtonian (shear-thinning) behavior of the fluids and ensure valid rheological comparisons.

The measurement process was conducted continuously for two minutes until a stable viscosity reading was displayed on the digital monitor. Following data acquisition for subsequent statistical analysis, the instrument was temporarily stopped using the reset function and powered down via the main power switch to facilitate spindle sanitation. Cleaning and recalibration procedures were performed before each subsequent measurement to ensure the validity, reliability, and accuracy of viscosity determinations across all enteral formula variations.

Flowability Analysis

The flowability characteristics of the enteral formulas were quantitatively evaluated through a gravity-driven flow simulation using a pediatric feeding tube system. The testing apparatus was configured by positioning an 8 French (Fr) Naso Gastric Tube (NGT) with a standard length of 40 cm vertically and connecting it to a sample funnel at the proximal end (23). A total of 20 mL of enteral formula was carefully introduced into the reservoir funnel, ensuring that no air bubbles were trapped within the system. Flow measurement was initiated simultaneously by opening the distal end of the feeding tube and activating a digital stopwatch. The time required for the entire 20 mL volume of the liquid matrix to completely pass through the tube lumen was recorded accurately. The volumetric flow rate was subsequently calculated and expressed in milliliters per second (mL/s), representing the flowability of the enteral formula (24).

Data Analysis

The viscosity and flowability measurements were analyzed descriptively and presented as mean values for each formula. The analysis was conducted by comparing the trends in the physical characteristics among the formulas based on variations in the composition of skim milk powder, egg white, and pumpkin (*Cucurbita moschata*). Differences among the formulas were further evaluated using the Kruskal – Wallis test, with statistical significance set at $P < 0.05$. All statistical analyses were performed using IBM SPSS Statistics 27.

Results

Viscosity Evaluation

The viscosity characteristics of the three modified home blenderized enteral nutrition formulas based on pumpkin (*Cucurbita moschata*) and egg white are presented in Table 2. Experimental measurements revealed numerical variations in dynamic viscosity among the three formulations under room-temperature conditions. Formula B1, which contained the lowest total solid content (60 g skim milk powder, 50 g egg white, and 5 g pumpkin), exhibited a mean viscosity value of 145 ± 7.07 cP. As the solid content increased in Formula B2 (65 g skim milk powder, 55 g egg white, and 10 g pumpkin), the mean viscosity was recorded at 700 ± 14.14 cP. For Formula B3, which contained the highest solid content (70 g skim milk powder, 60 g egg white, and 15 g pumpkin), the mean viscosity was 496 ± 8.49 cP. To ensure methodological validity for non-Newtonian fluids, all viscosity measurements were standardized and recorded at a uniform rotational speed of 30 rpm.

Despite the wide range of numerical values across the formulas, statistical analysis revealed no significant difference in viscosity (Kruskal – Wallis, $p = 0.368$). This lack of statistical significance may be attributed to the high data variance within the experimental groups or the limited sample size (n) utilized in this study.

Table 2. Dynamic Viscosity Characteristics of Pumpkin and Egg White-Based Enteral Formulas

Formula	Viscosity (cP)	p - value
B1	145 ± 7.07	
B2	700 ± 14.14	0.368
B3	496 ± 8.49	

Notes:
B1 = 60 g skim milk powder, 50 g egg white, and 5 g pumpkin (*Cucurbita moschata*).
B2 = 65 g skim milk powder, 55 g egg white, and 10 g pumpkin (*Cucurbita moschata*).
B3 = 70 g skim milk powder, 60 g egg white, and 15 g pumpkin (*Cucurbita moschata*).
P-value was obtained using the Kruskal – Wallis test.

Flowability Analysis

The flow characteristics of the three modified enteral formulas based on pumpkin (*Cucurbita moschata*) and egg white, including flow duration and flow rate, are presented in Table 3. The results of the flow simulation conducted using an 8 French (Fr) Naso Gastric Tube (NGT) demonstrated numerical variations in the mechanical flow performance among the three formula groups. Formula B1 exhibited a flow duration of 350 ± 7.07 seconds for the entire sample volume (20 mL) to pass through the feeding tube lumen, resulting in a flow rate of 0.06 ± 0.01 mL/s. Formula B2 was associated with a flow duration of 300 ± ± 7.07 seconds and a corresponding flow rate of 0.07 ± 0.01 mL/s. Formula B3 allowed the complete volume of the formula to pass through the tube within a duration of 290 ± 14.14 seconds, maintaining a volumetric flow rate of 0.07 ± 0.00 mL/s. Despite these numerical differences, there was no statistically significant difference in flow rate among the three formulas (Kruskal – Wallis, $p = 0.368$). Similar to the viscosity findings, this non-significant result may be driven by high intra-group data variance and the small experimental sample size.

Table 3. Flow Duration and Flow Rate Profiles of Pumpkin and Egg White-Based Enteral Formulas

Formula	Flow Duration (s)	Flow Rate (mL/s)	*P - value*
B1	350 ± 7.07	0,06 ± 0.01	
B2	300 ± 7.07	0,07 ± 0.01	0.368
B3	290 ± 14.14	0,07 ± 0.00	

Notes:
B1 = 60 g skim milk powder, 50 g egg white, and 5 g pumpkin (*Cucurbita moschata*).
B2 = 65 g skim milk powder, 55 g egg white, and 10 g pumpkin (*Cucurbita moschata*).
B3 = 70 g skim milk powder, 60 g egg white, and 15 g pumpkin (*Cucurbita moschata*).
P-value was obtained using the Kruskal – Wallis test.

DISCUSSION

Viscosity Evaluation

Viscosity is a physicochemical parameter that represents the internal resistance of a fluid to deformation under shear stress and is macroscopically perceived as the thickness or consistency of a liquid (25). Through viscosity analysis, the mechanical characteristics and flow kinetics of a liquid matrix can be quantitatively evaluated to understand its mobility and flow behavior under specific mechanical forces (26). The viscosity values of the developed formulas ranged from 145 - 700 cP. These values were substantially higher than those reported for enteral formulas based on tempeh and carrot extract developed for children with SAM, which ranged from 5.85 to 10.12 cP (27). Similarly, another study utilizing pumpkin-based enteral formulas reported lower viscosity values of 19–24 cP (16). These differences may be attributed to variations in formulation composition, as neither of the previous studies incorporated egg white, whereas the formulas developed in the present study contained both egg white and skim milk powder (28).

The viscosity range observed in the developed formulas (145–700 cP) indicates a consistency that remains manageable for enteral delivery. Fluids within this viscosity range are generally effective for distal gastric delivery of the bolus while maintaining sufficient fluidity to pass through standard enteral feeding systems, thereby minimizing the risk of aspiration without requiring excessive dilution (25,29).

Differences in viscosity among the three enteral formulations were primarily influenced by variations in macronutrient composition and food matrix interactions within the liquid emulsion system (30,31). The relatively low viscosity observed in Formula B1 (145 cP) can be attributed to its lower concentration of water-binding polymers and its higher proportion of the continuous aqueous phase (460 mL water). Under these conditions, intermolecular friction is minimized, allowing the fluid to flow with relatively low hydrodynamic resistance (28). In contrast, the substantial increase in viscosity observed in Formula B2 (700 cP) resulted from higher concentrations of dissolved biopolymers derived from pumpkin, skim milk powder, and egg white (32). Increasing the pumpkin content from 5 g to 10 g introduced greater amounts of gelatinized starch and soluble fibers, such as pectin, into the suspension system. These hydrocolloid macromolecules function as water-binding agents, entrapping free water molecules within a structured network. This effect was further enhanced by the increased concentration of globular proteins, including casein and whey proteins from skim milk and ovalbumin from egg white, which possess numerous hydrophilic functional groups. The intensified competition for available water molecules increased the internal volume fraction of the emulsion and consequently elevated flow resistance (33,34).

A particularly important rheological phenomenon was identified in Formula B3. Despite containing the highest total solid content among all formulations, its measured viscosity was lower than B2 (496 cP). The reduction in viscosity from B2 (700 cP at 30 rpm) to B3 (496 cP at 60 rpm), accompanied by an increase in shear rate (35). This variation suggests complex physical interactions between starch polymers from *Cucurbita moschata* and the protein network formed by egg white within the increased water volume (520 mL), which might have altered the entanglement configuration. The pumpkin and egg white-based enteral formulas developed in this study demonstrated physical characteristics that facilitate smooth administration with minimal risk of tube occlusion (5). This property is particularly advantageous during syringe-assisted feeding and passage through the narrow lumen of an 8 Fr pediatric nasogastric feeding tube (25,36).

Flowability Evaluation

Volumetric flowability is a critical physicochemical parameter in the development of home blenderized enteral nutrition (HBEN) formulas. This parameter determines the efficiency with which a liquid can pass through the narrow lumen of an enteral feeding tube without the assistance of a continuous mechanical pump. The developed formulas exhibited flow durations ranging from 290 to 350 seconds, corresponding to flow rates of 0.06–0.07 mL/s. These flow durations were longer than those reported in a previous study, which ranged from 90 to 163 seconds (37). Such differences may be attributable to variations in the feeding tube diameter used during testing, as the previous study employed a 16 Fr tube compared with the 8 Fr tube used in the present study (37). Similarly, a study developing food for special medical purposes based on pumpkin and red beans for malnutrition management reported a flow rate of 0.22 mL/s using a 12 Fr feeding tube (38).

As shown in Table 3, an interesting rheological phenomenon was observed in which increasing total solids content from Formula B1 to Formula B3 was positively associated with higher volumetric flow rates and shorter flow durations (25,28,39). Formula B1, despite having the lowest macronutrient concentration, exhibited the slowest flow time (350 seconds) and the lowest flow rate (0.06 mL/s). Structurally, this behavior may be explained by reduced emulsion stability resulting from the limited presence of natural stabilizing agents, including lecithin from skim milk powder (60 g) and hydrocolloid components from pumpkin (5 g) (40,41). In the absence of a sufficiently stable matrix, palm oil droplets (60 g) are theoretically more likely to undergo coalescence and phase separation. Such emulsion instability might increase internal resistance through heterogeneous frictional interactions between the dispersed oil phase and the continuous aqueous phase as the fluid moves through the narrow lumen of an 8 Fr nasogastric tube under gravitational force (42). Furthermore, there is a physical possibility of transient mechanical clogging inside the NGT tube caused by macro-particles of coagulated egg white or insufficiently homogenized pumpkin fibers, which could momentary impede the flow and prolong the total flow duration.

In contrast, a marked acceleration in flow behavior was observed in Formula B2 (300 seconds, 0.07 mL/s), with the highest flow efficiency achieved by Formula B3 (290 seconds, 0.07 mL/s) (35). In Formula B3, the increased water volume (520 mL) acted synergistically with higher concentrations of gelatinized starch polymers derived from *Cucurbita moschata* (15 g) and globular proteins from egg white (60 g) and skim milk powder (70 g). This combination suggests the formation of a more stable and homogeneous oil-in-water (O/W) emulsion system (43). At the microscopic level, it is hypothesized that when Formula B3 flowed from the reservoir funnel through the feeding tube under gravitational force, the fluid was subjected to continuous shear stress generated by the constricted internal diameter of the 8 Fr nasogastric tube (34). Under these mechanical conditions, the long-chain carbohydrate polymers from pumpkin and the protein structures from egg white, which initially existed as an entangled network, might have gradually become disentangled. These macromolecules are suggested to undergo structural deformation and alignment in the direction of flow, thereby substantially reducing local viscosity within the tube (43). This shear-induced viscosity reduction minimized wall-friction resistance and facilitated more rapid passage of the formula through the feeding system (25).

From a purely mechanical and physical perspective, the flow characteristics of Formulas B2 and B3 offer practical advantages for enteral administration. The observed flow rate of 0.07 mL/s through a narrow 8 Fr feeding tube indicates that the pumpkin–egg white polymer matrix can maintain adequate fluidity, potentially minimizing the risk of feeding tube occlusion, a common cause of interruption in enteral nutrition therapy (44). Furthermore, the ability to maintain a consistent flow without requiring excessive manual pressure during syringe feeding may reduce caregiver burden in home settings (44).

Study Limitations

Although the developed enteral formulas exhibit viscosity and flowability characteristics that are mechanically suitable for administration via an 8 Fr pediatric feeding tube, this study represents a preliminary stage focusing purely on rheological feasibility. A major limitation of this research is the absence of actual macronutrient and micronutrient composition testing, as well as the lack of microscopic emulsion stability evaluation. Consequently, the nutritional adequacy and caloric density cannot yet be definitively equated to the clinical standards of the WHO F-100 formula. Further comprehensive studies are required to analyze the complete nutritional profile, physicochemical stability, and clinical efficacy of these formulations to fully determine their suitability as an alternative nutritional therapy for children with severe acute malnutrition during the rehabilitation phase.

Conclusion

The development of modified enteral formulas based on pumpkin (*Cucurbita moschata*) and egg white demonstrated that increasing the proportion of solid ingredients significantly influences the dynamic viscosity of the formulation; however, the resulting rheological behavior enables the liquid matrix to maintain highly efficient flow performance through an 8 French (Fr) pediatric nasogastric feeding tube. These findings indicate that the developed formulas possess physical characteristics that are mechanically suitable for enteral administration. Nevertheless, as this study exclusively evaluated physical and rheological feasibility, comprehensive nutritional composition analysis (including caloric density and macronutrient profiles) as well as microscopic emulsion stability testing are imperative before these formulations can be clinically evaluated as an alternative nutritional therapy for severe acute malnutrition.

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