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Effect of ingredients and their interactions on laboratory-scale cup formation

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Abstract

The present study focused on effect of various ingredients at different levels for the development of composite cup. Various levels of ingredients like LDPE, PVA, PLA, PHA, sodium caseinate, corn starch, carrageenan, whey protein concentrate and isolate with addition of glycerol were tried either singly or in combinations. The combination LDPE (0.5%), PVA (0.5%), CS (5%), Carrageenan (1%), Mixture of WPI/WPC (2% each), glycerol (3%) resulted in a good cup formation, which had good standability, flexibility and transparency. The blending of PVA, starch and carrageenan could have led to good cup formation due to strong hydrogen bonding, while LDPE and glycerol provided plasticity. While the interaction of other ingredients with LDPE and denaturation of whey protein and increased the hydrophobicity, thus giving the cup a rigid yet flexible structure which makes this cup a good option for replacing single use plastics as packaging material.

Keywords: Ingredients, interactions, lab scale, composite, cup formation

Introduction

The global demand of plastics continues to grow and according to the Fortune Business Insights report 2026 [7], the global plastic packaging market is expected to rise to US\$ 835.88 billion by 2034. Any type of material that is utilized for containment, transfer and aids in maintaining quality of either raw or processed food type till it reaches the consumer from production point is defined as food packaging (Gopinathar *et al.*, 2016) [10]. The petroleum-based packaging is the most widely used packaging material. As these petroleum-based polymers are non-degradable, their accumulation as waste has increased leading to detrimental effects on environmental ecosystem.

Realizing the urgency due to ill impacts of plastics pollution the researcher's interest has increased towards use of biopolymers as sustainable packaging material that are potential alternatives to synthetic polymers (Gheorghita Puscaselu *et al.*, 2021) [9]. Biopolymers are renewable, biodegradable, non-toxic, biocompatible and excellent film forming properties which makes them an excellent food packaging material. The bio-based polymers are broadly derived from plants, animals, or microorganisms (Reddy *et al.*, 2021) [16] and food waste. The biopolymers like polyhydroxy alkanates (PHAs), polyhydroxy butyrate (PHBs) etc., are microorganism derived. But, because of undesirable physical, thermal, mechanical properties and high cost (production is less demand is more), these biopolymers have less use in bio-polymer blends. The plant-based ingredients (zein, gluten, soy, carrageenan, starch, cellulose etc), animal based (casein, whey etc) and carrageenans (sulfated polysaccharides obtained from red seaweed) are non-toxic, cheap, easy to blend, available in abundance, biocompatibility, biodegradable nature and also with good antimicrobial properties makes it suitable as food packaging material (Baghi *et al.*, 2022) [1]. The synthetic biopolymers like polylactic acid (PLA), polyvinyl alcohol (PVA) etc. are limited, expensive, and difficult to synthesize, making their future development difficult (Swetha *et al.*, 2023) [23]. PVA is hydrophilic and biocompatible making it an excellent blending material, but it is expensive, has slower biodegradation, to enhance its properties blending with other is suggested (Elgharabawy *et al.*, 2024) [5]. Priya *et al.*, 2014 [15], del Sol González-Forte *et al.*, 2019 [4] studied Corn/PVA blends with additives and revealed smooth miscibility of the blend having improved physico-chemical and mechanical properties.

Starch a polysaccharide, available in abundance, biodegradable and inexpensive, which makes it a suitable choice as biopolymer. It acts as a promising blending material as its functionality and structure can be modified easily. The hydrophilic nature of starch (due to presence of -OH group) is reason of poor water barrier (Ribba *et al.*, 2017) ^[17] and gas properties (Samsudin and Hani 2017) ^[19] that negatively impacts its packaging properties. The plasticiser addition tackles the problem of brittleness of starch films increases the flexibility as well as extensibility. Adding glycerol and sorbitol reduces the tensile strength, and promotes film elongation (Laohakunjit and Nookhorn 2004) ^[12]. The films prepared with addition of whey protein were transparent, soft, elastic and water-insoluble having good grease and oxygen barrier properties (Wang *et al.*, 2010) ^[25].

Blending natural and synthetic polymers has significant potential of overcoming drawbacks of both the types of polymers. Amongst synthetic polymers LDPE (Low-Density Polyethylene) is most used food packaging material. Blending these polymers will facilitate plastic waste reduction due partial degradation and moreover blending LDPE with biopolymers provides hydrophilic groups which in return decreases the surface energy, while polar hydrophilic group of biomaterials are consumed causing cracks in the polymer chain, providing access to microorganisms which breaks carbon linkages of PE (Polyethylene) resulting in polymer degradability (Rutkowska *et al.*, 2002) ^[18]. Accordingly the present study was designed to investigate impact of various ingredients in formation of a composite cup for application in solid dairy and food products.

Materials and Methods

In this study, the ingredients selected were; i.e. Corn Starch (CS), Whey Protein Concentrate (WPC), Whey Protein Isolate (WPI), Low-density polyethylene (LDPE), Polyvinyl Alcohol (PVA), Polyhydroxy alkanoate (PHA), Sodium caseinate, Polylactic acid (PLA) and glycerol. All the ingredients were obtained from reputed firm. Instruments used were hot plate-magnetic stirrer, silicone cup, dessicator, hot air oven.

For preliminary trials, selected ingredients (LDPE (0.5-5%), PVA (0.5 & 1%), PLA (0.5&1%), PHA (0.5-1%), Sodium caseinate (3-6%), Corn starch (4-6%), WPC (4-6%), WPI (4-6%), Carrageenan (0.25-2%) and glycerol (1-3%)) were

tested singly and in combinations for cup formation.

Method for composite cup formation

The combination of LDPE, PVA, CS, carrageenan, WPI, WPC resulted in good cup formation. These ingredients were dissolved in distilled water (Dw) with continuous stirring on a hot plate magnetic stirrer. For preparing the solutions, LDPE and PVA granules were heated separately at different temperatures and for different times, then starch powder was heated in water with continuous stirring till gelatinization occurred. WPI/WPC and carrageenan powders were mixed well then heated in distilled water. Afterwards all the solutions were mixed well, followed by addition of glycerol as plasticizer, to the resulting slurry and heating till the slurry mixes well. To prevent air bubble formation while pouring the slurry was cooled at room temperature. The layering technique was used for cup formation using in silicon cup which was purchased from local market. The solution was manually layered on silicon cup using brush. After application of each layer, the cup was kept in hot air oven till the layer dried up, subsequently applying 9 layers. The formed composite cups were kept in a desiccator and the procedure was followed as per (Chandla *et al.*, 2017) ^[3].

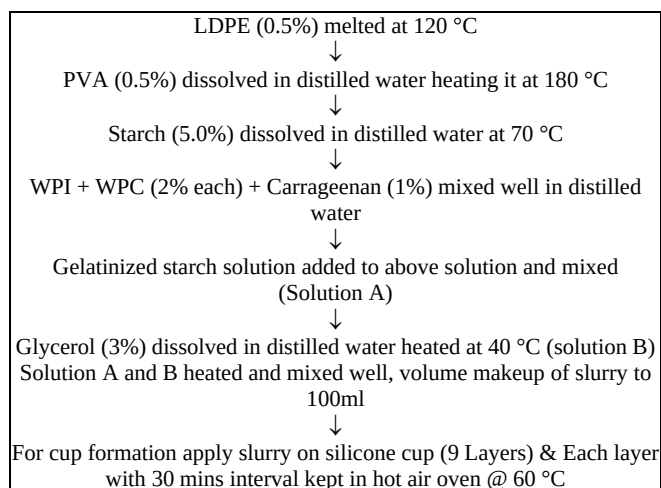


Fig 1: Flow chart for procedure of composite cup development

Results and Discussion

The different ingredients were tried for the development of laboratory scale cup formation mentioned below in Table 1

Table 1: Formulations for composite cup formation

S. No.	Formulations	Remarks	Cup formation
1	CS (5%), carrageenan (2%), Mixture of WPI/WPC (2% each), glycerol (3%)	Cup formed was fragile	
2	LDPE (0.5%), PVA (0.5%), CS (5%), Carrageenan (1%) Mixture of WPI/WPC (2% each), glycerol (3%)	Very good cup formation	

According to Table no. 1 the formulation 2 resulted in good cup formation; LDPE (0.5%), PVA (0.5%), Corn Starch (5%), Carrageenan (1%) Mixture of WPI/WPC (2% each), glycerol (3%). As observed by visual appearance cup has desirable characteristics i.e., cup was clear, standable and flexible.

In case of packaging material, appearance is an important factor. The transparency of the packaging allows visible appearance of the food packed, ease of printability, and easy reading of the print. The transparency can be attributed to homogenous slurry formation due to presence of PVA which has good film formation ability and acts as a light polarizing material (Virtanen *et al.*, 2014) ^[24]. The opacity increase can be due to corn starch induced light scattering within the matrix of composite cup. A study of Samuel *et al.*, 2026 ^[20], suggests similar results, where addition of rice starch water to PVA increased the thickness of the film and also reduced light transparency. The composite cup thickness, might have impacted the transparency which can be due to higher solid content due to presence of corn starch and carrageenan. The addition of glycerol and LDPE provides resistance to deformations, moreover they give a plasticizing effect which increases the strength of the packaging making it more flexible hence improving the mechanical properties of the cup. Glycerol addition to PVA is found to alter the arrangement of PVA chains, reducing density and makes the structure more porous increasing the flexibility. A study conducted by Jamali *et al.*, 2024 ^[11], concluded that addition of 5% glycerol to PVA increases the yield strength of film as compared to pure PVA film. Similar conclusions regarding plasticizer addition to biopolymers were confirmed by Lu *et al.*, 2009 ^[13], Ezeoha 2013 ^[6], Munde and Immanuel 2025 ^[14].

Above all, the interaction of other materials with LDPE and denaturation of whey proteins led to increased hydrophobicity. Schmid (2013) ^[21], found that, partially replacing hydrolyzed whey protein isolate with glycerol resulted into better water vapor barrier and oxygen barrier while maintaining flexibility and improved mechanical properties of film. The composite cup gave slight yellowish tinge, the reason for this can be the maillard reaction that occurs during processing of corn starch and whey protein's amino group. Sun *et al.*, 2013 ^[22], noted yellowish color in intermediate and final products and concluded that protein-aldehyde interaction due maillard reaction resulted in yellow color. As other literatures were reviewed, it was found that whey protein tends to increase the opaqueness, which could be a result of aggregates of protein-polysaccharide which are insoluble and might have formed during drying (Galus and Kadzinska 2016) ^[8].

In case of formulation 1, the cup formed but was fragile i.e. not having good standability and deformed after sometime, the reason could be the increase in moisture content of the cup. It has been found that, the water in starch is in bound state within starch molecules, but with addition of glycerol the moisture adsorption increases (Basiak *et al.*, 2018) ^[2]. The presence of hydrophilic contents increases the number of hydroxyl groups, which makes the packaging more hydrophilic thus reducing the firmness of cup. The weak mechanical strength can be due to corn starch which is reported to have high amylose content containing large crystalline structures that creates voids in the polymer matrix resulting into increased amorphousness and reduced molecular weight. This causes strength reduction of starch

film (Elgharbawy *et al.*, 2024) ^[5]. Moreover addition of glycerol (hydrophilic plasticizer) leads to formation of strong H-bonds within the polymer, which can increase the moisture content of film as more voids form in polymer matrix leading to more water absorption.

Conclusion

This research was carried out to obtain a composite cup by using partial replacement technique using materials like LDPE, PVA, PLA, PHA, sodium caseinate, corn starch, whey protein, carrageenan and glycerol. Various preliminary trials were carried out, and it was found that the composite cup with LDPE, PVA, corn starch, carrageenan, whey protein and glycerol gave good cup formation having good standability and flexibility. It can be concluded that biopolymers in combination with LDPE and glycerol as plasticizers enhance the interfacial interaction of polymer matrix providing a homogenous structure to the cup. The cup's transparency can be attributed to presence of PVA, while slight opacity was observed that can be due to addition corn starch and carrageenan. The cup was flexible and had good strength, owing to stronger hydrogen bond formation between starch and PVA, and plasticizing effect of both LDPE and glycerol.

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