ISSN: 3060-4737 Volume 3, Issue 2 IF(Impact Factor) 10.98 / 2025

A-KETOGLUTARATE- AND SODIUM MALATE-INCORPORATED BIOACTIVE FILMS BASED ON POLY(VINYL ALCOHOL): PREPARATION AND CHARACTERIZATION.

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Abstract. This article presents the preparation of bioactive films based on poly(vinyl alcohol) (PVA/PVS) incorporating A-ketoglutarate (α-ketoglutarate) and sodium malate, and evaluates their physicochemical and functional properties. PVA is a water-soluble, biocompatible, film-forming polymer that can develop network-like structures through hydrogen bonding and, under suitable conditions, esterification/crosslinking when combined with organic acids and their salts. In the proposed system, sodium malate is considered as a component that can act as a plasticizer and regulate the hydrophilic–hydrophobic balance within the PVA matrix, whereas α-ketoglutarate is viewed as a bioactive metabolite and, through its carbonyl/carboxylate groups, a modifier capable of strengthening interchain interactions in the polymer. The films are prepared by the solution-casting technique and characterized using FTIR spectroscopy, mechanical testing, moisture uptake/swelling analysis, water-vapor transmission measurements, thermal stability assessment, and, when necessary, bioactivity tests. It is expected that the additives will compact the PVA structure, tune hydrophilic behavior, optimize mechanical and barrier performance, and provide a platform for bioactive functionality.

Keywords: poly(vinyl alcohol) (PVA/PVS), α-ketoglutarate, sodium malate, bioactive film, solution casting, FTIR, mechanical properties, water-vapor transmission, biodegradation.

Introduction. Bioactive films are increasingly important in food packaging, wound care, drug delivery, and environmentally friendly materials. Key requirements for such films include mechanical stability, controllable permeability to moisture and gases, safety/biocompatibility, and enrichment with functional additives (antimicrobial, antioxidant, or metabolically bioactive components). PVA is among the polymers that closely meet these requirements due to its excellent film-forming ability, favorable interactions with water, and ease of modification. However, the high hydrophilicity of PVA can cause practical limitations related to barrier performance and moisture resistance. Therefore, PVA is frequently modified using organic acids/salts,

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multifunctional additives, or crosslinking agents. Literature reports indicate that introducing organic acids (including malate/malic-acid derivatives) into PVA can significantly affect surface wettability (e.g., contact angle) and water resistance; moreover, when combined with thermal treatment, crosslinking and plasticization effects may occur simultaneously. α-Ketoglutarate (A-ketoglutarate), a biologically relevant metabolite, has attracted attention in processes associated with immunity and tissue regeneration, suggesting that polymer systems containing α-ketoglutarate may serve as bioactive platforms for applications such as wound healing.

Literature Review. Recent review studies on PVA-based films and composites emphasize PVA's film-forming performance, biocompatibility, and compatibility with various blend components. In particular, strengthening interchain interactions (hydrogen bonding, ion pairing, esterification/crosslinking) is frequently highlighted as a principal strategy to regulate barrier and mechanical properties in "active" packaging and biomaterials. Organic acids such as malate/malic acid can reduce PVA's excessive hydrophilicity and, under heat treatment, may intensify crosslinking-related effects, leading to improved mechanical strength and barrier behavior. In parallel, α-ketoglutarate is increasingly considered a "functional" component in biomaterials due to its metabolic bioactivity (e.g., in wound-healing contexts). Hence, incorporating α-ketoglutarate into a PVA matrix may enhance the likelihood of creating a film that functions as a bioactive platform.

Methodology. Film preparation (solution casting).

1. Preparation of PVA solution: PVA (typically 5–10% w/v) is dissolved in distilled water at 80–90°C with stirring until fully solubilized, then cooled to 40–50°C.
2. Incorporation of additives:

– Sodium malate is dissolved separately in a small amount of water and then added to the PVA solution.
– α-Ketoglutarate (in acid or salt form) is dissolved and added.

Compositional variants are selected in three groups within the experimental design: (i) control PVA, (ii) PVA + sodium malate, (iii) PVA + sodium malate + α-ketoglutarate.

3. pH/ionic strength control: if the films become excessively hydrophilic or turbidity appears, maintaining pH near neutral (buffering) and optimizing additive content is recommended.

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4. Casting and drying: the solution is poured onto a flat substrate and dried at 25–40°C under dust-free conditions. If required, a short thermal treatment at 80–120°C is applied to densify the structure (this step may be particularly important for malate-containing systems).

Characterization and testing.
A) FTIR spectroscopy: interactions are assessed by monitoring PVA –OH bands and the $–COO^-$/C=O signals of α-ketoglutarate/malate and their band shifts.
B) Mechanical testing: tensile strength, elongation at break, and Young's modulus.
C) Water uptake/swelling: mass changes over defined time intervals and swelling coefficient determination.
D) Water-vapor transmission rate (WVTR) or moisture resistance: barrier properties are quantified.
E) Thermal analysis (TGA/DSC) and morphology (SEM): thermal stability and microstructure assessment.
F) Bioactivity (application-dependent): for example, antimicrobial screening (for packaging or wound care) and cytotoxicity/biocompatibility testing (for biomedical use).

Results. Structural and spectral signatures: FTIR is expected to show band shifts associated with carboxylate and carbonyl vibrations and broadening of the –OH region, indicating strengthened hydrogen bonding/ion-pair interactions between the additives and PVA chains. Such changes are commonly associated with matrix "densification." Literature on PVA–organic acid systems also notes that malate and related organic acids can regulate hydrophilic behavior and, when combined with thermal treatment, produce crosslinking/plasticization effects. Mechanical properties: sodium malate may increase ductility through plasticization, although excessive amounts can reduce tensile strength. When combined with α-ketoglutarate, depending on formulation and drying/curing conditions, tensile strength may be balanced and film integrity may improve due to enhanced interchain interactions. Moisture and barrier performance: because PVA's primary limitation is water sensitivity, partially network-forming the structure using malate/organic acid systems and reducing water-vapor transmission is practically significant; thermal treatment can further strengthen this effect. Bioactivity: as a metabolite, α-ketoglutarate may serve as a bioactive component in biomaterials (e.g., wound-healing contexts). Within the film, both "bound" and diffusion-released fractions may exist, supporting a controlled (sustained-release) functional concept.

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Discussion. The scientific rationale of this system is grounded in multipoint interactions between PVA –OH groups and the additives' $–COO^-$/C=O functional groups. Due to its ionic nature, sodium malate can intensify ion–dipole and hydrogen-bond interactions in the PVA matrix, while simultaneously plasticizing the film and reducing brittleness. α-Ketoglutarate, through its carbonyl and carboxylate functionalities, may introduce additional "anchoring sites," thereby influencing morphology and structural ordering. If applied, thermal treatment can intensify crosslinking effects in the presence of organic acids and improve water resistance, as emphasized in studies of PVA–organic acid systems. From an application perspective, the most critical step is composition optimization. Excessive malate may yield overly soft films or rapid swelling in water, whereas excessive α-ketoglutarate may increase turbidity/crystallization, brittleness, or ionic-strength effects. Therefore, a design-of-experiments approach (e.g., a 3×3 concentration matrix) and rubric-based selection of an optimal point (mechanical performance + WVTR + swelling + bioactivity) is recommended.

Conclusion. Preparing bioactive films based on PVA incorporating α-ketoglutarate and sodium malate via solution casting is technologically simple and offers broad opportunities for modification. Sodium malate can regulate mechanical flexibility and moisture response of PVA films, while α-ketoglutarate can add functional value as a bioactive metabolite. Comprehensive evaluation using FTIR, mechanical testing, water uptake/swelling, and barrier measurements enables identification of an optimal formulation. Future work should include deeper investigation of cytotoxicity, biodegradation kinetics, and, depending on the target application, antimicrobial activity and sustained-release profiles.

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