Plant Archives Vol. 25, No. 2, 2025 pp. 1477-1485 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.213

INNOVATIVE 3D-PRINTED FAST DISSOLVING ORAL DISINTEGRATING FILMS FROM ALTERNANTHERA: A STEP TOWARDS PERSONALIZED MEDICINE

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(Date of Receiving-24-07-2025; Date of Acceptance-25-09-2025)

ABSTRACT

Fast-dissolving oral disintegrating films (ODFs) offer an innovative route for nutrient delivery, especially for populations with swallowing difficulties. Leveraging plant-based matrices such as *Alternanthera sessilis* enhances both bioactivity and sustainability. This study aimed to develop and evaluate a multi-component, plant-derived ODF for personalized micronutrient supplementation. ODFs were formulated using *A. sessilis* leaf powder, HPMC K4M/E5, pullulan, moringa gum, ghatti gum, glycerol, roselle calyx powder and monk fruit syrup. Fabrication was achieved via extrusion-based 3D printing. Physicochemical and mechanical properties were assessed, including disintegration time, tensile strength, moisture content, transparency, swelling index and surface pH. SEM, FTIR and ICP-MS were employed for structural, chemical and elemental characterization. The films exhibited uniform thickness (0.228/ ±/ 0.008/ mm), rapid disintegration (15.23/ ±/ 0.53/ s) and high organoleptic scores (92.4/ ±/ 1.60/100). Moisture content (7.50/ ±/ 0.13%) and swelling index (40.40/ ±/ 2.80%) supported ambient stability and mucosal compatibility. SEM revealed a uniform matrix with fine cracks; FTIR confirmed functional groups such as C–O–C, phenolic O–H and carbonyls. ICP-MS detected essential macro elements (K: 568.21, Na: 222.92, Mg: 7223, Ca: 19.74/ mg/100g) and trace microelements (Fe, Zn, Cu, Se, Mn, Cr, Co). The *A. sessilis*-based ODFs demonstrated excellent physicochemical properties and mineral content, validating their potential as sustainable, bioactive platforms for personalized nutrient delivery.

Alternanthera sessile-based 3D-printed oral films exhibited rapid disintegration, high organoleptic acceptance and rich elemental content, confirming their suitability for sustainable, personalized nutrient delivery. Structural and chemical analyses validated the films' stability, bioactivity and compatibility with mucosal administration.

***Key words*:** Antioxidant properties, Disintegration time, FTIR, ICP-MS, Phytochemicals, SEM.

Introduction

Oral disintegrating films (ODFs) have emerged as a promising drug delivery system, particularly suited for populations with swallowing difficulties such as children and the elderly. These thin, flexible films dissolve rapidly upon contact with saliva, offering ease of administration, improved patient compliance and potential for personalized dosing (Mahboob *et al.*, 2016; Bala *et al.*, 2013). Traditionally, ODFs have relied on synthetic polymers for film formation; however, the growing emphasis on sustainability and natural excipients has increased interest in plant-based matrices (Mahboob *et al.*, 2016; Hoffmann *et al*., 2011)

Alternanthera sessilis, a leafy vegetable widely consumed in tropical regions, is known for its rich micronutrient profile and ethnomedicinal properties, including antioxidant, anti-inflammatory and hepatoprotective effects (Ragavan *et al.*, 2023; Warkade *et al*., 2024). Its incorporation into ODFs provides structural support and contributes to nutritional enhancement and therapeutic potential (Umate and Marathe, 2017). In parallel, natural gums such as moringa and ghatti gums offer excellent film-forming, emulsifying and mucoadhesive properties, making them suitable alternatives to synthetic excipients (Bahadur *et al.*, 2017; Abhita, 2015). Pullulan and hydroxypropyl methylcellulose (HPMC) variants further enhance mechanical strength and disintegration behaviour, supporting rapid dissolution and patient acceptability (Mahboob *et al.*, 2016; Gunda *et al*., 2022).

The addition of roselle calyx powder, rich in anthocyanins and vitamin C and monk fruit syrup, a natural non-caloric sweetener, enhances the antioxidant capacity and palatability of the films, aligning with the principles of functional food design (Jamini *et al.*, 2019; Riaz *et al*., 2021). Advanced fabrication techniques such as 3D food printing allow for precise control over film geometry and composition, enabling reproducibility and customization for personalized nutrition and drug delivery (Febriyenti *et al.*, 2025). To validate the structural and nutritional attributes of these films, scanning electron microscopy (SEM) provides insights into surface morphology, while inductively coupled plasma mass spectrometry (ICP-MS) enables accurate quantification of essential minerals (Umate and Marathe, 2017; Riaz *et al*., 2021). This study aims to develop and characterize a multi-component, plant-based ODF using *Alternanthera sessilis* and natural excipients, with a focus on physicochemical properties, structural integrity and mineral content.

Material and Methods

Material

Fast-dissolving oral disintegrating films were fabricated by using alternanthera leaves powder, polymers such as HPMC grades, Pullulan, natural gums such as moringa gum and ghatti gum, alongside glycerol as plasticizer, roselle (*Hibiscus sabdariffa*) calyx powder as saliva stimulant and monk fruit syrup as sweetener. Alternanthera and roselle calyces were collected from the field. All these chemicals were procured from Alpha Chemika Company, India.

Table 1: Formulation of Alternanthera-based fast-dissolving oral disintegrating films.

Ingredients	Formulation
Alternanthera (mg)	350
Moringa gum (ml)	10
Ghatti gum (ml)	10
HPMC K4M (ml)	10
Pullulan (ml)	10
HPMC E5 (ml)	5
Glycerol (ml)	1.5
Roselle (mg)	2
Monk fruit syrup (3ml)	3
Distilled water	quantitative satis

Methods

The detailed composition of the formulation is presented in Table 1. The entire mixture was homogenized and loaded into a desktop 3D food printer. Films were printed in rectangular strips (2 cm × 3 cm), dried at 40°C for 12 hours and stored in aluminium pouches until further analysis.

Evaluation of Fast-Dissolving Oral Disintegrating Films

Thickness of the Film

Film thickness was measured at five points: center and four corners on three 2×2 cm² samples using a micrometer screw gauge. The average thickness ensured uniformity across batches. Consistent thickness is essential for accurate drug dosing in ODFs (Nair *et al*., 2013).

Weight of the film

Three mouth dissolving films (2×2 cm²) from each batch were weighed using a Wesner PGB600 Precision Gold Balance. The average weight and standard deviation were then computed to assess batch uniformity (Mansoori *et al*., 2017).

Disintegration time

Disintegration time indicates when an oral film starts fragmenting upon contact with saliva or water, typically within 5–30 seconds for fast-dissolving types. It can be assessed using a USP apparatus or visually in a pH 6.8 buffer with periodic swirling (Nautiyal *et al*., 2023; Tirunagari *et al*., 2014).

Visual characteristics

The prepared oral films were visually examined to evaluate their morphological characteristics, including uniformity, colour, transparency and surface texture (Mishra and Amin, 2009).

Organoleptic properties

Oral dissolving films were evaluated by ten healthy volunteers with normal taste perception after obtaining informed consent. The assessment focused on taste, flavour and texture, emphasizing smoothness and the absence of grittiness, which are essential for rapid disintegration (Daud *et al.*, 2011).

Moisture uptake (%)

Moisture absorption was assessed by placing pre-weighed films in a desiccator containing potassium chloride solution at 80 percent relative humidity for 24 hours. Films were then reweighed and the absorption percentage was calculated using a gravimetric method (Irfan *et al.*, 2016).

$$\text{Moisture (\%)} = \frac{\text{final weight - initial weight}}{\text{initial weight}} \times 100$$

Moisture content (%)

Film samples (2 × 2 cm²) were weighed before and after 72 hours in desiccators with anhydrous calcium chloride to determine moisture loss using gravimetric analysis. This test assesses the film's stability and resistance to dehydration (Kumawat and Bharkatiya, 2025).

$$\text{\% Moisture content} = \frac{\text{final weight - initial weight}}{\text{initial weight}} \times 100$$

Opacity (%)

Opacity was measured using 1 cm × 2 cm film specimens placed inside a HITACHI UH 5300 UV-Visible spectrophotometer. Absorbance at 600 nm was recorded to evaluate film transparency (Apriliyani *et al.*, 2020).

$$\text{Opacity} = \frac{Abs600}{d\,(mm)}$$

Note:

Abs 600 = Absorbance value at 600 nm

d = Film thickness (mm)

Swelling property (%)

The prepared films were first weighed and then placed on a 2 % agar plate, where their weight gradually increased until stabilizing at equilibrium (Samvelyan *et al.*, 2021).

$$\text{\% Swelling Degree} = \frac{\text{final weight - initial weight}}{\text{initial weight}} \times 100$$

Surface pH

The surface pH of the films was measured to assess potential mucosal irritation, aiming for neutrality to avoid adverse effects. A 2×2 cm² film was dissolved in distilled water and a glass electrode was placed on the surface for one minute; readings were taken in triplicate and averaged (Raju *et al.*, 2013).

Table 2: Physico-chemical properties of alternanthera-based fast-disintegrating oral films.

Properties	Observations
Thickness (mm)	0.228 ± 0.008
Weight of the film (mg)	94.000 ± 4.31
Disintegration time (sec.)	15.230 ± 0.53
Visual characteristics	Smooth, Homogeneous, olive-green, semi-transparent
Organoleptic properties	92.4 ± 1.60
Moisture absorption (%)	4.317 ± 0.20
Moisture content (%)	7.500 ± 0.13
Opacity (%)	2.396 ± 0.11
Swelling property (%)	40.40 ± 2.80
Surface pH	6.17 ± 0.28

Scanning electron microscopy (SEM)

Surface morphology of optimized films was examined via SEM (Carl Zeiss EVO18, USA) at 10 kV using samples with acceptable drug release and physical traits. Micrographs at magnifications ranging from 200× to 15000× captured detailed topological features (Mashru *et al.*, 2005; Reddy and Karpagam, 2017).

Fourier transform infrared (FTIR) spectroscopy

FTIR spectroscopy was used to assess compatibility between active ingredients and the polymer matrix, employing the KBr disc method on a Shimadzu 160A instrument. Spectra were recorded from 400 to 4000 cm^{-1} with 100 scans at 4 cm^{-1} resolution to identify functional group interactions (Sri *et al.*, 2012).

Proximate mineral profiling

Mineral quantification was conducted using the Perkin Elmer NexION 350x ICP-MS in KED mode with helium to minimize interferences. Samples (0.25 g) were digested with suprapure nitric acid and hydrogen peroxide via microwave-assisted digestion, then diluted to 50 mL and filtered through 0.22 µm paper. The system operated with 18 L/min plasma gas, 0.82 L/min nebulizer flow and 1600 W RF power, ensuring stable ionization. Each sample was flushed for 35 seconds and read for 15 seconds, with all steps performed in triplicate with little modifications (Chudzinska *et al.*, 2012).

Statistical analysis

All data were expressed as mean ± standard deviation (SD) and statistical significance was determined using one-way ANOVA followed by Tukey's post hoc test ($p < 0.05$).

Results

Physico-Chemical Properties

The developed oral dissolving films (ODFs) displayed a uniform thickness of 0.228 ± 0.008 mm and an average weight of 94.000 ± 4.31 mg. The disintegration time was notably fast, averaging 15.230 ± 0.53 seconds, consistent with the performance expectations for rapid-release formulations. Visually, the films presented a smooth and homogeneous surface texture with an olive-green hue and semi-transparent appearance. Sensory evaluation revealed a pleasant taste profile, smooth or slightly creamy mouthfeel and acceptable sweetness, with no bitterness detected. Organoleptic assessment yielded high acceptability scores, with an overall ranking of 92.4 ± 1.60 out of 100, indicating favourable initial and residual taste impressions.

Moisture absorption was recorded at 4.317 ± 0.20%, while the total moisture content was measured at 7.500 ± 0.13%, reflecting the films' ability to retain water under ambient conditions. Transparency analysis showed absorbance values below 0.575 at 600 nm, corresponding to an opacity of 2.396 ± 0.11%, confirming the semi-transparent nature of the films. The swelling index reached 40.40 ± 2.80%, demonstrating sufficient hydration capacity while maintaining structural integrity. Surface pH analysis of Alternanthera-based films revealed a neutral pH of 6.17 ± 0.28, indicating suitability for contact with oral mucosal surfaces.

Scanning Electron Microscopy (SEM)

SEM image, captured at 1000× magnification with a 10/ µm scale bar and an accelerating voltage of 10/ kV, reveals the surface morphology of an oral dissolving film (ODF) as shown in Fig. 1. The micrograph shows a relatively uniform texture interspersed with fine cracks and linear features, which may indicate polymeric alignment or stress-induced microfractures during film formation or drying (Alam *et al.*, 2017).

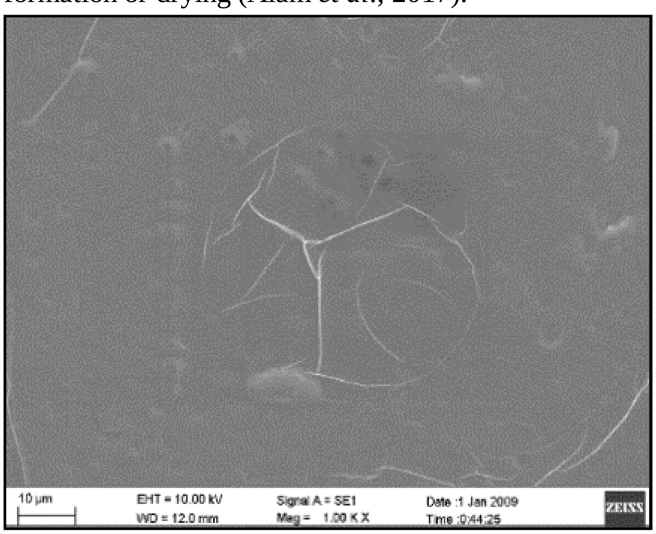

Fig. 1: SEM micrograph of the alternanthera-based fast-disintegrating oral films.

Table 3: FTIR spectra representing functional groups.

S.	Peak	Functional groups
1	1035.77	C-O-C vibration (stretch)
2	1340.53	In-plane phenolic O–H bending
3	1492.9	Aromatic skeletal vibrations
4	1624.06	Aromatic skeletal vibrations
5	1639.49	Aromatic skeletal vibrations
6	1720.5	C=O stretching
7	2094.69	Ca"N or Ca"C group
8	2908.65	Aliphatic C-H stretching
9	3363.86	O-H stretching

Fourier Transform Infrared (FTIR) Spectroscopy

The spectral data and corresponding bond assignments are detailed in Table 3 and visually illustrated in Figure 2. FTIR analysis of the oral dissolving film matrix revealed distinct absorption peaks associated with characteristic functional groups. A pronounced peak at 1035.77/ cm^{-1} corresponds to C–O–C stretching vibrations, while the band at 1340.53/ cm^{-1} is attributed to in-plane bending of phenolic O–H groups. Aromatic skeletal vibrations were evident at 1492.9, 1624.06 and 1639.49 cm^{-1}, indicating the presence of aromatic structures. The sharp peak at 1720.5 cm^{-1} signifies C=O stretching, characteristic of carbonyl groups. A signal in 2094.69cm^{-1} may be associated with C≡N or C≡C functionalities. Aliphatic C–H stretching was observed at 2908.65cm^{-1} and a broad absorption at 3363.86cm^{-1} confirmed O–H stretching, indicative of hydroxyl group presence. Collectively, these functional groups affirm the chemical compatibility and structural coherence within the films.

Proximate Mineral Profiling

As presented in Table 4, the ICP-MS analysis of the oral dissolving film matrix demonstrated the quantifiable presence of both macro and micro minerals. The macro elements, including calcium at 19.74 milligrams per 100 grams, magnesium at 72.23 milligrams per 100 grams, along with sodium and potassium, were detected in substantial concentrations and contribute significantly to the overall mineral content of the formulation. In contrast, the microelements identified were iron, zinc, copper, selenium, manganese, chromium and cobalt, which appeared in trace amounts. This diverse mineral profile reflects the comprehensive elemental composition of the oral films and highlights their potential in delivering a broad spectrum of essential nutrients.

Discussion

Alternanthera sessilis powder has a finer particle size and disperses uniformly in aqueous media. This leads to lower viscosity and enhanced levelling during casting,

Table 4: Mineral composition in alternanthera-based fast-disintegrating oral films.

Name of the mineral	Classification	mg/100g
Calcium (Ca)	Macro	19.74
Magnesium (Mg)	Macro	72.23
Sodium (Na)	Macro	222.92
Potassium (K)	Macro	568.21
Iron (Fe)	Micro	9.81
Zinc (Zn)	Micro	5.93
Copper (Cu)	Micro	1.86
Selenium (Se)	Micro	0.01
Manganese (Mn)	Micro	0.76
Chromium (Cr)	Micro	0.92
Cobalt (Co)	Micro	0.02

resulting in thinner films. Turkovic *et al*., (2022) also observed that differences in mixing homogeneity and botanical dispersion strongly influence final film thickness in plant-based ODFs, particularly when casting conditions are controlled. Supporting data reported by Kanani *et al*., (2017) suggest that the thickness of the formulated ODFs was affected by the unique nature of colloidal compounds as thickeners and the interaction between the components of oral disintegrating films.

Alternanthera's finer powder disperses more evenly, creates a less viscous suspension and facilitates better film levelling, resulting in lighter films with reduced solid load per unit area. Similar trends were reported by Choudhary *et al*., (2012), who noted that fine herbal powders incorporated into pullulan-based fast-dissolving films produced thinner, lower-weight films with rapid disintegration.

Alternanthera-based oral disintegrating films (ODFs) demonstrated rapid disintegration, primarily due to reduced thickness, lower matrix density and efficient dispersion of plant-derived components. Disintegration kinetics were further influenced by polymer type, plasticizer concentration and particle size distribution. Vuddanda *et al*., (2017) reported that nanocrystalline drug particles ($\leq$ 200 nm) enhance clarity and disintegration, whereas larger aggregates (>10 µm) hinder uniform breakdown. Hydrophilic polymers such as HPMC and pullulan facilitate faster disintegration, often achieving complete breakdown within 20–60 seconds, depending on formulation variables (Rezaee and Ganji, 2018). Regulatory standards emphasize the importance of rapid disintegration, with Dhadwad and Shelke (2023) suggesting that oral films should ideally dissolve within 30 seconds to be considered fast-dissolving (Rezaee and Ganji, 2018). The optimized matrix composition of Alternanthera-based films aligns with these expectations, delivering efficient disintegration and functional integrity.

Visually, the films exhibited olive green coloration and semi-transparency, attributed to the proportion and integration of plant powders, which also contributed to uniformity and aesthetic appeal.

Films demonstrated high organoleptic acceptability (92.4 ± 1.60/100), primarily due to consistent use of monk fruit syrup and roselle calyx powder. Monk fruit syrup, rich in mogrosides, offers a clean sweetness without bitterness, ideal for paediatric and geriatric formulations. Roselle calyx adds mild tartness and aromatic depth, enhancing flavour complexity and stimulating salivary flow, which improves mouthfeel and accelerates disintegration. Their balanced incorporation minimized sensory variation across plant-based formulations. Scott *et al*., (2025) confirmed monk fruit's sensory benefits in patient-centred systems, while Zhao *et al*., (2024) noted its compatibility with starch-based ODFs. Jacob *et al*., (2023) highlighted roselle's role in enhancing mouthfeel and salivation, reinforcing its utility in orodispersible dosage forms.

According to the United States Pharmacopoeia (USP) and industry standards, moisture uptake in fast-dissolving oral films should remain below 5% under controlled conditions (40°C, 75% RH for 7 days) to ensure mechanical integrity, performance and microbial safety. In this study, several formulations met this benchmark, confirming their stability for product development. Variations in moisture uptake were primarily linked to the hydrophilic nature of polymers such as pullulan, HPMC variants and natural gums, which readily absorb environmental moisture. Once absorbed, moisture acts as a plasticizer, softening the polymer matrix and accelerating disintegration. Films with higher moisture uptake disintegrated more rapidly, while those with lower uptake retained rigidity and delayed breakdown. This behaviour aligns with Cerqueira *et al*., (2012), who attributed glycerol's water-attractiveness to its hydroxyl groups, enabling hydrogen bonding and internal moisture retention. Tamer *et al*., (2018) further supported these findings, noting that elevated moisture levels enhance hydration kinetics, reduce disintegration time and promote faster drug release.

According to USP guidelines and Nair *et al*., (2013), oral films should maintain moisture content below 5% to ensure stability and prevent microbial growth. Several formulations met this criterion, confirming their suitability for development. Tamer *et al*., (2018) reported low moisture levels (0.7 ± 0.5% to 2.03 ± 0.4%), indicating minimal water retention. Excess moisture can weaken mechanical properties and degrade APIs, while insufficient moisture tightens polymer chains, reducing swelling and disintegration, as described by Zhao *et al.*, (2024). Kanani *et al.*, (2017) emphasized low water content in edible films for packaging to prevent moisture transfer, which may compromise product integrity and shelf life. These findings support moisture control in ODF design.

The semi-transparent nature of *Alternanthera sessilis*-based oral films is attributed to the plant's intrinsic phytochemical profile and physicochemical behaviour. As noted by Umate and Marathe (2017) and Sree and Vijayalakshmi (2018), *A. sessilis* contains moderate levels of flavonoids, phenolics and terpenoids, which exhibit minimal light scattering near 600 nm, resulting in low absorbance (<0.575) and opacity (2.396 ± 0.11%). Fine particle size and uniform dispersion within HPMC or PVA matrices enhance clarity by reducing turbidity. Gopinath *et al.*, (2018) and Srikanth *et al.*, (2022) confirmed polymer compatibility, preventing aggregation. With no opacifying agents used, the observed transparency in films is primarily due to favourable physicochemical interactions and the low pigment density of the Alternanthera matrix. Devineni *et al.*, (2024) similarly emphasized phytochemical and polymer synergy in edible film transparency.

The swelling behaviour of oral films incorporating *Alternanthera sessilis* is mechanistically linked to its hydration-responsive phytochemical profile. Studies by Sree and Vijayalakshmi (2018) highlight the plant's high moisture content, crude fiber and soluble carbohydrates, which promote water absorption and matrix expansion. Warkade *et al.*, (2024) further identified saponins, lupeol, â-sitosterol and campesterol compounds known for their hydrophilicity and gel-forming behaviour upon hydration. Ecologically, *A. sessilis* thrives in wet habitats, reinforcing its suitability as a hydration-promoting matrix. When blended with hydrophilic polymers like HPMC or PVA, these attributes facilitate synergistic water uptake and controlled swelling, enhancing disintegration and functional performance. The plant's compatibility with polymer systems positions it as a sustainable and bioactive candidate for advanced oral film design.

The slightly lower surface pH observed in films may be attributed to the presence of organic acids, particularly oxalic acid and a diverse array of phenolic compounds in alternanthera. Recent studies have confirmed that oxalic acid is present in high concentrations in alternanthera leaf powder and is known to mildly acidify aqueous matrices (Pamidighantam, 2018). Additionally, comparative profiling of red and green cultivars of alternanthera revealed significant levels of ferulic acid, vanillic acid and catechins, which are phenolic constituents capable of influencing pH due to their acidic hydroxyl groups (Azizah *et al.*, 2014; Nunez-Estevez *et al.*, 2021).

Such morphological traits are critical for evaluating the mechanical integrity and dissolution behaviour of ODFs. According to Mashru *et al.*, (2005), smoother surfaces with minimal porosity and uniform texture contribute to consistent drug release and improved patient acceptability. Similarly, Reddy and Karpagam (2017) emphasized that microstructural uniformity supports rapid disintegration and enhances film performance. The absence of large pores or irregularities in this image suggests a well-formed matrix, likely contributing to the favourable disintegration and swelling properties observed in the formulation.

The FTIR spectrum of formulation films (Fig. 2) shows a broad band at 3363.86/ cm^{-1}, indicating O–H stretching from moisture-rich constituents in alternanthera and roselle, with extensive hydrogen bonding enhancing elasticity (Yin *et al.*, 2024; Srivastava *et al.*, 2024). A prominent peak at 2908.65 cm^{-1} corresponds to aliphatic C–H stretching from HPMC, Pullulan and glycerol, contributing to matrix flexibility (Zhang *et al.*, 2019). The 1720.50 cm^{-1} band reflects C=O stretching from mogrosides or ester-like plasticizer–polymer interactions (Santana *et al.*, 2022). Aromatic C=C vibrations at 1639.49, 1624.06 and 1492.90 cm^{-1} confirm flavonoids and anthocyanins from plant extracts (Keong *et al.*, 2019). The 1340.53 cm^{-1} peak indicates in-plane phenolic O–H bending, supporting antioxidant incorporation. A strong band at 1035.77 cm^{-1} corresponds to C–O–C stretching in glycosidic linkages from HPMC and Pullulan (Zhang *et al.*, 2019). A weak signal at 2094.69/ cm^{-1} may suggest trace alkynyl or nitrile groups from alternanthera phytochemicals (Mani *et al.*, 2011).

Films with 350 mg of *Alternanthera sessilis* were notably high in sodium (222.92 mg/100 g) and potassium (568.21 mg/100 g), which are in line with the

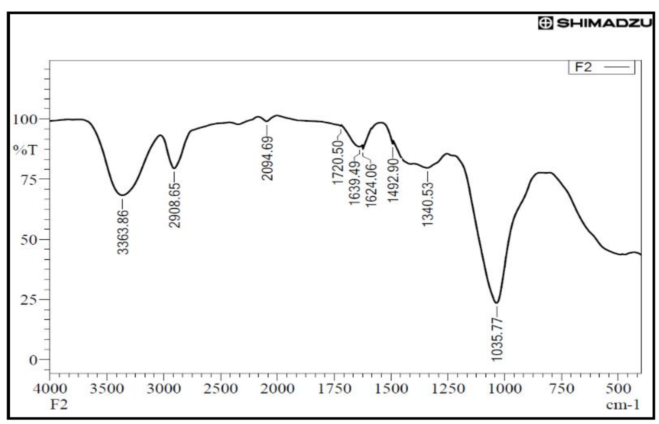

Fig. 2: FTIR spectra of the alternanthera-based fast-disintegrating oral films.

recommended dietary allowances documented by Sree and Vijayalakshmi (2018). *Alternanthera* is reported to possess a high concentration of electrolytes, particularly K and Na, making it a significant contributor to these values (Umate and Marathe, 2017). Its iron and manganese values were moderate, consistent with its known nutrient density. The quantified mineral composition reflects the formulation's potential to support systemic micronutrient balance and metabolic efficiency. Elevated levels of potassium (568.21 µg/g) and sodium (222.92 µg/g) underscore its suitability for maintaining electrochemical gradients critical for neuromuscular function, aligning with findings from Osko *et al.*, (2022), which emphasize the nutritional impact of these electrolytes in green tea-based supplements. Magnesium (72.23 µg/g) and calcium (19.74 µg/g), acting as key cofactors, contribute to enzymatic activation and bone health, as demonstrated by Adluri *et al*., (2010), who showed that plant-based calcium derived from marine algae significantly enhances osteoblast proliferation and mineralization compared to inorganic salts. Iron (9.81 µg/g), zinc (5.93 µg/g) and copper (1.86 µg/g) enhance the formulation's nutritional value through their roles in haematopoiesis, immune modulation and redox balance, consistent with mineral profiles reported in *Alternanthera sessilis* leaves (Sree and Vijayalaxmi, 2018). Trace levels of selenium (0.01 µg/g), manganese (0.76 µg/g) and chromium (0.92 µg/g) contribute additional metabolic benefits, such as glucose regulation and antioxidant activity, as emphasized in the reference framework outlined by Kuszak *et al*., (2025). Collectively, this mineral-rich profile validates the formulation's potential as a plant-based oral supplement designed for personalized and sustainable micronutrient delivery.

Conclusion

This study establishes *Alternanthera sessilis*-based oral disintegrating films as a promising platform for sustainable and personalized micronutrient delivery. The incorporation of multifunctional plant-derived gums such as moringa and ghatti, along with biocompatible synthetic polymers including hydroxypropyl methylcellulose and pullulan, led to films exhibiting favourable mechanical robustness and rapid disintegration, thereby enhancing patient compliance. Nutritional enhancement was achieved through a mineral-rich profile comprising potassium, magnesium and iron and bioactive constituents extracted from roselle calyx and monk fruit syrup contributed substantial antioxidant properties and improved sensory attributes. The application of 3D-printing technology ensured high reproducibility, precise control over film thickness and uniform distribution of active ingredients, which are essential for scalability and industrial translation. These findings suggest that such formulations can be effective alternatives to conventional dosage forms, particularly in populations affected by micronutrient deficiencies. Future research should prioritize the development of multilayered film architectures, conduct comprehensive bioavailability assessments and pursue clinical validation to establish their full therapeutic potential.

Acknowledgements

Conflicts of Interest: The authors declare no conflict of interest**.**

References

Abhita, M.H. (2015). Natural polymers in pharmaceutical formulation. *International Journal of Institutional Pharmacy and Life Sciences*. **5(1)**, 205-231.

Adluri, R.S, Zhan L., Bagchi M., Maulik N. and Maulik G. (2010). Comparative effects of a novel plant-based calcium supplement with two common calcium salts on proliferation and mineralization in human osteoblast cells. *Molecular and cellular biochemistry*. **340(1)**, 73-80.

Alam, S.N., Sharma N. and Kumar L. (2017). Synthesis of graphene oxide (GO) by modified Hummers method and its thermal reduction to obtain reduced graphene oxide (rGO). *Graphene*. **6(01)**, 1.

Apriliyani, M.W., Purwadi P., Manab A., Apriliyanti W.M. and Ikhwan D.A. (2020). Characteristics of moisture content, swelling, opacity and transparency with the addition of chitosan as edible films/coating based on casein. *Advance Journal of Food Science and Technology*. **18(1)**, 9-14.

Azizah, O., Amin I. and Fouad A.R. (2014). Antioxidant properties of *Alternanthera sessilis* red and green. In *XXIX International Horticultural Congress on Horticulture, Sustaining Lives, Livelihoods and Landscapes (IHC2014)*, **VI 1106**, 131-136.

Bahadur, S., Sahu U.K., Sahu D., Sahu G. and Roy A. (2017). Review on natural gums and mucilage and their application as excipients. *Journal of Applied Pharmaceutical Research*. **5(4)**, 13-21.

Bala, R., Pawar P., Khanna S. and Arora S. (2013). Orally dissolving strips, A new approach to oral drug delivery systems. *International journal of pharmaceutical investigation*. **3(2)**, 67.

Cerqueira, M.A., Souza B.W., Teixeira J.A. and Vicente A.A. (2012). Effect of glycerol and corn oil on physicochemical properties of polysaccharide films–A comparative study. *Food hydrocolloids*. **27(1)**, 175-184.

Choudhary, D.R., Patel V.A., Chhalotiya U.K., Patel H.V. and Kundawala A.J. (2012). Development and characterization of pharmacokinetic parameters of fast-dissolving films containing levocetirizine. *Scientia Pharmaceutica*. **80(3)**, 779.

Chudzinska, M., Debska A. and Baralkiewicz D. (2012). Method validation for the determination of 13 elements in honey samples by ICP-MS. *Accreditation and Quality Assurance*. **17(1)**, 65-73.

Daud, A.S., Sapkal N.P. and Bonde M.N. (2011). Development of *Zingiber officinale* in oral dissolving films, Effect of polymers on in vitro, in vivo parameters and clinical efficacy. *Asian Journal of Pharmaceutics (AJP)*. **5(3)**.

Devineni, J., Varicola K., Kowsar S.K., Devarakonda P., Udayasree H., Bhavana A. and Devi R.N. (2024). Evaluating the biological potential of *Alternanthera sessilis* methanolic extract, Antioxidant, anti-inflammatory and neurodegenerative disease management. *Asian Journal of Biological and Biomedical Sciences*. **6(6)**, 2349-2359

Dhadwad, N. S and Shelke, S. J (2023). Fast dissolving oral films, a review. *International Journal of Creative Research Thoughts.* **11(5)**, 422- 439.

Febriyenti, Aisyah R.S., Intan R., Azizah M., Syahyuning K.C. and Meri S. (2025). Orally Disintegrating Film formulation of standardized extract of red ginger (*Zingiber officinale* var. Rubrum). *Drug Discovery*. **19**, 1-9.

Gopinath, L.R., Kala K., Jeevitha S., Jeevitha S. and Archaya S. (2018). Identification of biologically active compounds from the leaf extract of Alternanthera sessilis and its antimicrobial activity and anticancer property. *International Journal of Pharmacy and Biological Sciences*. **8(3)**, 1169-1176.

Gunda, R.K., Kumar J.S., Priyanaka C., Sravani L., Naveena B., Yamini B. and Ali S.M. (2022). Formulation development and evaluation of oral dissolving films—a review. *J. Anal. Pharm. Res*. **11(3)**, 131-134.

Hoffmann, E.M., Breitenbach A. and Breitkreutz J. (2011). Advances in orodispersible films for drug delivery. *Expert opinion on drug delivery*. **8(3)**, 299-316.

Irfan, M., Rabel S., Bukhtar Q., Qadir M.I., Jabeen F. and Khan A. (2016). Orally disintegrating films, A modern expansion in drug delivery systems. *Saudi Pharmaceutical Journal*. **24(5)**, 537-546.

Jacob, S., Boddu S.H., Bhandare R., Ahmad S.S. and Nair A.B. (2023). Orodispersible films, current innovations and emerging trends. *Pharmaceutics*. **15(12)**, 2753.

Jamini, T.S., Islam A.A., Mohi-Ud-Din M. and Saikat M.H. (2018). Phytochemical composition of calyx extract of roselle (*Hibiscus sabdariffa* L.) genotypes. *Journal of Agriculture and Food Sciences*. **16(1**), 13-23.

Kanani, N., Wardalia W., Wardhoyo E. and Rusdi R. (2017). Effect of drying temperature on swelling and tensile strength of edible film results of utilization of cassava skin waste star. *Conversion Journal*. **6(2)**.

Keong, C.Y., Yousof N.S.A.M., Jamal J.A. and Wasiman M.I. (2019). Establishment of FTIR Database of Roselle Raw Material Originated From Western Coastline in Peninsular Malaysia. In *Fourier Transforms-Century of Digitalization and Increasing Expectations*. Intech Open.

Kumawat, R.M. and Bharkatiya M.K. (2025). Current and future advancement of fast-dissolving oral thin films. *International Journal of Pharmaceutical Sciences and Research*. **16(3)**, 634-643.

Kuszak, A.J., Hosbas Coskun S. and Wise S.A. (2025). A new database to guide reference material selection for dietary supplements and nutrition science. *Analytical and Bioanalytical Chemistry*. **417(12)**, 2379-2386.

Mahboob, M.B.H., Riaz T., Jamshaid M., Bashir I. and Zulfiqar S. (2016). Oral films, A comprehensive review. *International Current Pharmaceutical Journal*. **5(12)**, 111-117.

Mani, J., Sudheer Mohammed M.M. and Narayanasamy A. (2011). Secondary metabolite profiling of *Indigofera viscosa* Lam. Stem bark. *International Journal of Current Research.* **3(8)**, 116-122.

Mansoori, S., Patel M.K. and Chatterjee D.P. (2017). Formulation and characterization of oral thin film containing domperidone HCl. *Panacea. J. Pharm. Pharm. Sci*. **6**, 121-144.

Mashru, R.C., Sutariya V.B., Sankalia M.G. and Parikh P.P. (2005). Development and evaluation of a fast-dissolving film of salbutamol sulphate. *Drug development and industrial pharmacy*. **31(1)**, 25-34.

Mishra, R. and Amin A. (2009). Formulation development of taste-masked rapidly dissolving films of cetirizine hydrochloride. *Pharmaceutical Technology*. **33(2)**, 48-56.

Nair, A.B., Kumria R., Harsha S., Attimarad M., Al-Dhubiab B.E. and Alhaider I.A. (2013). In vitro techniques to evaluate buccal films. *Journal of Controlled Release*. **166(1)**, 10-21.

Nautiyal, U. and Saini M. (2023). Fast dissolving Buccal film, A comprehensive Review. *Asian Pacific Journal of Nursing and Health Sciences*, **6(1)**, 11-22.

Nuñez-Estevez, B., Finimundy T.C., Carpena M., Barral-Martinez M., Calhelha R., Pires T.C., Otero P., Garcia-Perez P., Simal-Gandara J., Ferreira I.C., Prieto M.A. and Barros L. (2021). Bioactive compound profiling and nutritional composition of three species from the Amaranthaceae family. *Chemistry Proceedings*. **5(1)**, 20.

Osko, J., Szewczyk A., Berk P., Prokopowicz M. and Grembecka M. (2022). Assessment of the mineral composition and the selected physicochemical parameters of dietary supplements containing green tea extracts. *Foods*. **11(22)**, 3580.

Pamidighantam, P.R. (2018). Chemical Characterisation, Organic Acids by HPLC, Fatty Acids by GC-GCMS and Antioxidant Activity of Commonly Consumed Leafy Vegetables in India. *Journal of Food and Pharmaceutical Sciences*. **6(3)**, 35-43.

Ragavan, O., Chan S.C., Goh Y.E., Lim V. and Yong Y.K. (2023). *Alternanthera sessilis*, a review of literature on the phytoconstituents, traditional usage and pharmacological activities of green and red cultivars. *Pharmacognosy Research*. **15(4)**, 636-652.

Raju, P.N., Kumar M.S., Reddy C.M. and Ravishankar K. (2013). Formulation and evaluation of fast-dissolving films of loratidine by the solvent casting method. *The pharma innovation*. **2(2)**.

Reddy, K.A and Karpagam S. (2018). Cellulose orodispersible films of donepezil, Film characterization and drug release. *Pharmaceutical Chemistry Journal*. **51(8)**, 707-715.

Rezaee, F. and Ganji F. (2018). Formulation, characterization and optimization of captopril fast-dissolving oral films. *AAPS Pharm. Sci. Tech*., **19(5)**, 2203-2212.

Riaz, G., Naik S.N., Garg M. and Chopra R. (2021). Phytochemical composition of an underutilized plant sorrel/roselle (*Hibiscus Sabdariffa* L.) cultivated in India. *Lett Appl NanoBioScience*. **10(2)**, 2138-2147.

Samvelyan, H.J., Hughes D., Stevens C. and Staines K.A. (2021). Models of osteoarthritis, relevance and new insights. *Calcified tissue international*. **109(3)**, 243-256.

Santana, N.D.S., Mothe C.G., de Souza M.N. and Mothe M.G. (2022). An investigation by thermal analysis of glycosidic natural sweeteners. *Journal of Thermal Analysis and Calorimetry*. **147(23)**, 13275-13287.

Scott, C.E., Stamataki N., Harrold J.A., Raben A. and Halford J.C. (2025). Health Impact Database Development for Sweeteners and Sweetness Enhancers, The SWEET Project. *Nutrition bulletin*.

Sree, L. and Vijayalakshmi K. (2018). Proximate composition, nutritional evaluation and mineral analysis in the leaves of an indigenous medicinal plant *Alternanthera sessilis*. *Int. J. Health Sci*. **8**, 55-62.

Sri, K.V., Rohini P. and Reddy G.K. (2012). Montelukast sodium oral thin films, formulation and *in vitro* evaluation. *Asian J. Pharm. Clin. Res*. **5(4)**, 266-270.

Srikanth, N., Veeresh B., Vijaya Lakshmi V., Ravi Kumar P. and Rathnakar P. (2022). GC-MS analysis for bioactive compounds and phytochemical evaluation of ethanolic extraction of *Alternanthera sessilis*. *YMER*. **21(11)**, 1989-1990.

Srivastava, A., Verma P., Mukherjee D., Moza B., Saha A., Ujjainia P., Dhondiyal P. and Jain P. (2024). A green approach to fingerprint enhancement, The potential of alternanthera dentata leaf powder. *IP International Journal of Forensic Medicine and Toxicological Sciences*. **9(1)**, 18-27.

Tamer, M.A., Hammid S.N.A. and Ahmed B.A.L.Q.I.S. (2018). Formulation and in vitro evaluation of bromocriptine mesylate as a fast-dissolving oral film. *International Journal of Applied Pharmaceutics*. **10(1)**, 7-20.

Tirunagari, M., Ahmed S. and Nandagopal A. (2014). Development, formulation and evaluation of atomoxetine oral films. *Int. J. Drug Dev. and Res*. **6(2)**, 0975-9344.

Turkovic, E., Vasiljevic I., Draskovic M. and Parojcic J. (2022). Orodispersible films—Pharmaceutical development for improved performance, A review. *Journal of Drug Delivery Science and Technology*. **75**, 103708.

Umate, S.K. and Marathe V.R. (2017). Proximate and phytochemical screening of *Alternanthera sessilis* (L.) R. Br. ex DC. (Amaranthaceae)-an underutilised leafy vegetable. *Int. J. Life Sci*. **5**, 703-705.

Vuddanda, P.R., Montenegro-Nicolini M., Morales J.O. and Velaga S. (2017). Effect of plasticizers on the physico-mechanical properties of pullulan-based pharmaceutical oral films. *European Journal of Pharmaceutical Sciences*. **96,** 290-298.

Warkade, T., Bondre A., Bihone P., Mujariya R. and Singh M. (2024). Pharmacognostic and therapeutic aspects of *Alternanthera sessilis* in the management of various disorders. *World j. pharm. life sci*. **10(6)**, 147-152.

Yin, H., Jin W., Wang J., Ke J., Zhang W., Liu C. and Wang W. (2024). Oral fast-dissolving films for co-administration of breviscapine and matrine, Formulation optimization and in vitro characterization. *Journal of Drug Delivery Science and Technology*. **95**, 105548.

Zhang, L.R., Zhang A.L., Zhang H.Z., Liu J. and Tang K.Y. (2019). Preparation and application of dialdehyde pullulan for the construction of gelatin hydrogels. In *IOP Conference Series, Materials Science and Engineering*, **504(1)**, P-012029. IOP Publishing.

Zhao, Y., Feng Y., Ren X., Hou Y., Wang F., Wang R. and Guo M. (2024). Preparation and properties characterization of composite modified starch-based orodispersible films. *Journal of Applied Pharmaceutical Science*. **14(1)**, 080-090.