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Rachna Akhand Giri
HOD, Department of Pharmacy, Barkatullah University, Bhopal, India

Udit Das Udasi
Student, Department of Pharmacy, Barkatullah University, Bhopal, India

Ayushi Tyagi
Student, Department of Pharmacy, Barkatullah University, Bhopal, India.

Naazia Firdous Ansari
Student, Department of Pharmacy, Barkatullah University, Bhopal, India.

Madhu Lodhi Thakur
Student, Department of Pharmacy, Barkatullah University, Bhopal, India.

Devendra Bansal
Student, Department of Pharmacy, Barkatullah University, Bhopal, India

Corresponding Author:
Rachna Akhand Giri
HOD, Department of Pharmacy, Barkatullah University, Bhopal, India

Development and evaluation of antioxidant-rich herbal tea formulations using fruit peel by-products

Rachna Akhand Giri, Udit Das Udasi, Ayushi Tyagi, Naazia Firdous Ansari, Madhu Lodhi Thakur and Devendra Bansal

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Abstract
Fruit peels are often discarded as agro-industrial waste despite being rich in bioactive compounds. The present study aimed to develop functional instant infusion teas using orange, banana, pomegranate, apple peels, and lemongrass, evaluating their phytochemical content, antioxidant activity, and sensory acceptability. Standardized peel powders were formulated into tea blends, optimized for brewing conditions, and tested for total phenolic content, antioxidant activity, and consumer preference. Results demonstrated that fruit peel-based teas possess significant antioxidant potential and acceptable sensory properties, highlighting their potential as sustainable nutraceutical beverages.

Keywords: Fruit peels, herbal tea, antioxidants, phytochemicals, instant infusion, functional foods

Introduction
Herbal teas are gaining popularity as functional beverages owing to their rich phytochemical composition, therapeutic properties, and consumer acceptability. Fruit processing industries generate substantial quantities of peels, which are often discarded as waste, leading to environmental and economic concerns. However, these peels are recognized as valuable sources of polyphenols, flavonoids, dietary fiber, and essential oils, all of which contribute to antioxidant, antimicrobial, and anti-inflammatory properties.
Previous studies have highlighted the nutraceutical potential of peels from orange, banana, pomegranate, and apple, as well as aromatic herbs such as lemongrass, which are widely consumed in traditional medicine and as culinary ingredients. Despite their bioactive richness, these resources remain underutilized in functional beverage development.
The present study was undertaken with the following objectives:

- To formulate herbal infusion teas using selected fruit peels and complementary spices.
- To optimize brewing conditions for maximum phytochemical and antioxidant release.
- To evaluate antioxidant activity, physicochemical characteristics, and consumer acceptability.
- To explore the potential of fruit peel utilization as a sustainable approach to waste valorization.

2. Materials and Methods
2.1 Raw Materials and Chemicals
The raw materials and excipients employed in this study were selected on the basis of availability, cost-effectiveness, and reported phytochemical content, particularly antioxidant potential.

2.1.1 Fruit Peels
Fresh peels of orange (*Citrus sinensis*), banana (*Musa paradisiaca*), lemongrass (*Cymbopogon citratus*), pomegranate (*Punica granatum*), and apple (*Malus domestica*) were collected, cleaned thoroughly, and processed as per standard drying protocols to prevent microbial contamination and degradation of active compounds.

- **Orange Peel:** Rich in flavonoids (hesperidin, narirutin), essential oils (limonene, linalool), phenolic compounds, vitamin C, and pectin. Known for antioxidant, antimicrobial, anti-inflammatory, and digestive health benefits.

Fig 1: Orange peel

Fig 2: Orange peel powder

Banana Peel: Contains polyphenols, catechins, dopamine, vitamin B6, and dietary fiber. Exhibits strong antioxidant, antibacterial, and anti-inflammatory activities while contributing to sustainable agro-waste utilization.

Fig 3: Banana peels

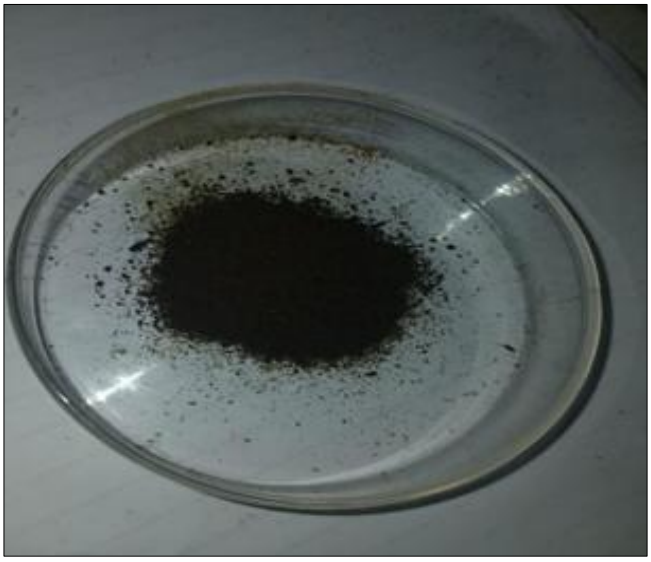

Fig 4: Banana peel powder

- **Lemongrass:** Characterized by high citral content, imparting lemon-like aroma. Possesses antioxidant, antimicrobial, and anti-inflammatory properties, along with vitamins A and C and minerals such as potassium and magnesium.

Fig 5: Lemongrass

Fig 6: Lemongrass powder

- **Pomegranate Peel:** Rich in punicalagin, ellagic acid, gallic acid, tannins, and flavonoids. Demonstrates potent antioxidant, antimicrobial, hepatoprotective, and anticancer activities.

Fig 7: Pomegranate peel

Fig 8: Pomegranate peel powder

- **Apple Peel:** Contains dietary fiber, quercetin, and polyphenols. Provides antioxidant, cardioprotective, anti-inflammatory, and antimicrobial benefits, while imparting sweet, fruity flavor.

Fig 9: Apple peels

Fig 10: Apple peel powder

The dried peels were ground into fine powders and stored in airtight containers under light-protected conditions until further use.

2.1.2 Excipients and Other Ingredients

Cardamom powder, clove powder, and dried ginger powder were incorporated into formulations to enhance flavor, aroma, and therapeutic value.

2.1.3 Chemicals and Reagents

Analytical-grade chemicals were used, including Folin–Ciocalteu reagent, DPPH (2,2-diphenyl-1-picrylhydrazyl), and other standard reagents required for phytochemical and antioxidant assays.

2.1.4 Packaging Materials

Formulated tea powders were packaged in bleach-free tea bags (1 g each) or stored in airtight glass bottles/poly-pouches. Aluminum foil wrapping was employed to protect samples from light and moisture.

2.2 Study Design and Experimental Framework

The experimental design followed a systematic sequence to achieve the research objectives.

2.2.1 Formulation Development

Standardized fruit peel powders were blended individually and in selected combinations to prepare instant infusion tea formulations. Excipients were incorporated in optimized ratios to improve palatability and functional properties.

2.2.2 Optimization of Brewing Conditions

Brewing conditions were optimized by infusing tea samples in distilled water at different temperatures (60–100 °C) and time intervals (2–10 min). The aim was to maximize antioxidant release while preserving sensory acceptability.

2.2.3 Evaluation of Bioactive Properties

- **Total Phenolic Content (TPC):** Determined using Folin–Ciocalteu method.
- **Antioxidant Activity:** Measured using DPPH radical scavenging assay and Total Antioxidant Capacity (TAC).
- **Physicochemical Parameters:** pH, solubility, and color (visual and instrumental evaluation) were recorded.

2.2.4 Sensory and Consumer Acceptability
A semi-trained panel (n = XX) evaluated the teas under controlled laboratory conditions. Color, aroma, taste, mouthfeel, and overall acceptability were scored using a 9-point hedonic scale.

2.2.5 Comparative and Correlation Analysis
Data from different temperature–time combinations were statistically analyzed to determine the correlation between brewing parameters, phytochemical content, and sensory quality, thus establishing the most effective formulation conditions.

3. Preparation of Fruit Peel-Based Tea Blends
Fruit wastes including banana, pomegranate, orange, apple peels, and lemongrass were processed for the preparation of instant infusion teabags. The raw materials were thoroughly washed, peeled, and cut into small pieces. To prevent enzymatic browning, banana and apple peels were pre-treated by immersion in 3% citric acid solution (24 °C, 1 min) prior to drying. These were subsequently dried in a vacuum oven at 40 °C for 24 h. In contrast, orange and pomegranate peels, along with lemongrass, were dried in a hot-air oven at 70 °C for 24 h, while cardamom, clove, and dried ginger were subjected to oven drying at 70 °C for 1 h.

Following dehydration, all dried materials were finely ground and homogenized using a mixer. Predetermined proportions of these powdered ingredients were weighed to obtain a total of 3 g per teabag, optimized for sensory suitability. Three distinct tea blends were then formulated for further evaluation.

3.1 Formulation of Tea Blends
Three categories of functional teas were formulated:
- Citrus Glow Tea (Orange peel + Lemongrass ±Spices)
- Antioxidant Shield Tea (Pomegranate + Apple ±Spices)
- Apple Spice Elixir (Banana + Apple ±Spices)

Table 1: Formulations of 1gm tea bags.

Tea Type	Ingredients Composition
Type A	Orange peel (0.5 g) + Lemongrass (0.5 g)
Type B	Orange peel (0.4 g) + Lemongrass (0.3 g) + Cardamom (0.1 g) + Clove (0.1 g) + Ginger (0.1 g)
Type C	Pomegranate (0.5 g) + Apple (0.5 g)
Type D	Pomegranate (0.4 g) + Apple (0.3 g) + Cardamom (0.1 g) + Clove (0.1 g) + Ginger (0.1 g)
Type E	Banana (0.5 g) + Apple (0.5 g)
Type F	Banana (0.4 g) + Apple (0.3 g) + Cardamom (0.1 g) + Clove (0.1 g) + Ginger (0.1 g)

Table 2: Preformulation parameters and their purpose in formulation and evaluation of instant infusion tea samples

Parameter	Purpose in Formulation and Evaluation
Moisture Content	To assess stability during storage and prevent microbial growth.
pH	To determine acidity/alkalinity, which influences flavor, stability, and compatibility of ingredients.
Solubility	To evaluate dissolution properties of powdered peels and ensure proper infusion.
Color	To assess visual appeal and consumer acceptability of the brewed tea.
Aroma/Flavor	To evaluate sensory quality and overall consumer satisfaction.
Phytochemical Screening (Phenolics, Flavonoids, Tannins)	To confirm presence of bioactive compounds with antioxidant and health-promoting properties.
Antioxidant Activity (DPPH, TAC assays)	To validate functional potential of peel extracts and their contribution to health benefits.
Bulk Density & Flow Properties	To determine handling, packaging suitability, and uniform filling of teabags.
Compatibility Studies	To ensure stability of combined fruit peels and spices without degradation of actives.

4. Methods Used
4.1 Drying Technique
Fruit peels were subjected to drying in a hot-air oven maintained at 50–60 °C until a constant weight was achieved, ensuring complete removal of moisture.

4.2 Grinding
The dried materials were pulverized into coarse or fine powder using a mechanical grinder for uniform particle size suitable for tea formulation.

4.3 Moisture Analysis
Moisture content was determined using a digital moisture balance and confirmed through the oven-drying method to ensure accuracy.

4.4 pH Measurement
The pH of the aqueous infusions prepared from fruit peel powders was measured using a calibrated digital pH meter.

4.5 Antioxidant Evaluation
The total antioxidant capacity (TAC) of the samples was evaluated using a colorimetric assay with a colorimeter to quantify free radical scavenging potential.

4.6 Total Phenolic Content (TPC)
Phenolic content was determined through a colorimetric method, employing gallic acid as the standard reference compound.

5. Evaluation of Formulations
The prepared instant infusion tea formulations from fruit peels were evaluated through a series of physicochemical, infusion, antioxidant, and sensory tests to assess their quality, stability, and consumer acceptability.

5.1 Physicochemical Evaluation
Color and appearance were visually observed to ensure uniformity across samples, while aroma was analyzed by a semi-trained panel (5–10 members) using a 9-point hedonic scale to capture consumer preference. The texture of powdered formulations was characterized in terms of flow properties, including angle of repose, bulk and tapped density, Carr's Index, and Hausner's Ratio, which provide insights into powder handling, mixing, and packaging behavior. Moisture content was determined using a hot-air oven or digital moisture analyzer, as it is a critical factor for predicting hygroscopicity and shelf stability.

5.2 Infusion Characteristics
Solubility and dispersibility were assessed by infusing tea powders in hot water at two temperatures (70 °C and 100 °C) and recording infusion times ranging from 3–5 minutes. Observations were made for clarity, residue, and sedimentation to determine consumer ease-of-use and product quality. The pH of the infusions, measured after 5 minutes of steeping using a calibrated pH meter, was noted since acidity

not only influences taste but also contributes to microbial stability. Water-soluble extractive values were determined and expressed as % w/w to indicate the proportion of active constituents released during brewing.

5.3 Antioxidant Evaluation

The antioxidant potential of the formulations was studied by two complementary assays. Total Antioxidant Capacity (TAC) was determined by the phosphomolybdenum method, where antioxidants in the sample reduce Mo^{6+} to Mo^{5+}, producing a green complex measurable at 517 nm. The intensity of absorbance was compared with a standard curve prepared using ascorbic acid, and results expressed as % inhibition and IC_{50} values. Total Phenolic Content (TPC) was estimated using the Folin–Ciocalteu assay, in which phenolic compounds reduce phosphomolybdic–phosphotungstic acid reagents to yield a blue chromophore measurable at 680–725 nm. Results were calculated against a gallic acid calibration curve and expressed as mg gallic acid equivalents (GAE) per gram of dry sample, reflecting the phenolic richness of the teas.

5.4 Sensory Evaluation

A structured sensory analysis was performed by a panel to evaluate the consumer-oriented attributes of the formulations, including color, aroma, taste, aftertaste, and overall acceptability. These parameters provided an integrated understanding of product appeal and guided the correlation between physicochemical quality and consumer preference.

6. Results

Table 3: Comparative Organoleptic Properties of Fruit Peel-Based Instant Infusion Teas

S. No.	Tea Name	Ingredients	pH (±0.1)	Texture	Colour (Dry)	Colour (Infusion)	Odour/Aroma
1	Citrus Glow Tea (Plain)	Orange + Lemongrass	3.5	Fine and dry	Pale orange	Bright golden yellow	Refreshing citrus and lemongrass scent
2	Citrus Glow Tea (Spiced)	Orange + Lemongrass + Cardamom + Clove + Dried Ginger	3.6	Fine and aromatic	Orange-yellow with spice flakes	Golden yellow	Strong citrusy with warm spicy aroma
3	Antioxidant Shield Tea (Plain)	Pomegranate + Apple	4.2	Slightly coarse	Reddish-pink	Rosy pink	Mild fruity with tangy apple tone
4	Antioxidant Shield Tea (Spiced)	Pomegranate + Apple + Cardamom + Clove + Dried Ginger	4.1	Slightly coarse	Reddish-brown	Deep pink to reddish-brown	Sweet, fruity with warm spicy notes
5	Apple Spice Elixir (Plain)	Apple + Banana	4.1	Slightly sticky	Pale brown	Light brownish amber	Mild fruity, dominated by apple–banana aroma
6	Apple Spice Elixir (Spiced)	Apple + Banana + Cardamom + Clove + Dried Ginger	4.0	Slightly fine texture	Pale brown with spice flakes	Light amber	Sweet and warm apple–banana–spice blend

Table 4: Comparative brewing characteristics of Fruit Peel-Based Instant Infusion Teas

S. No.	Tea Name	Infusion Time	Solubility	Clarity	Residue (After Filtration)
1	Citrus Glow Tea (Plain)	3 min	Excelle nt	Clear	Very minimal
2	Citrus Glow Tea (Spiced)	3–4 min	Excellent	Clear	Minimal
3	Antioxidant Shield Tea (Plain)	4 min	Good	Clear	Low
4	Antioxidant Shield Tea (Spiced)	4–5 min	Good	Slight haze due to spices	Moderate
5	Apple Spice Elixir (Plain)	4 min	Moderate	Clear	Slightly moderate
6	Apple Spice Elixir (Spiced)	4–5 min	Moderate	Slightly cloudy	Moderate

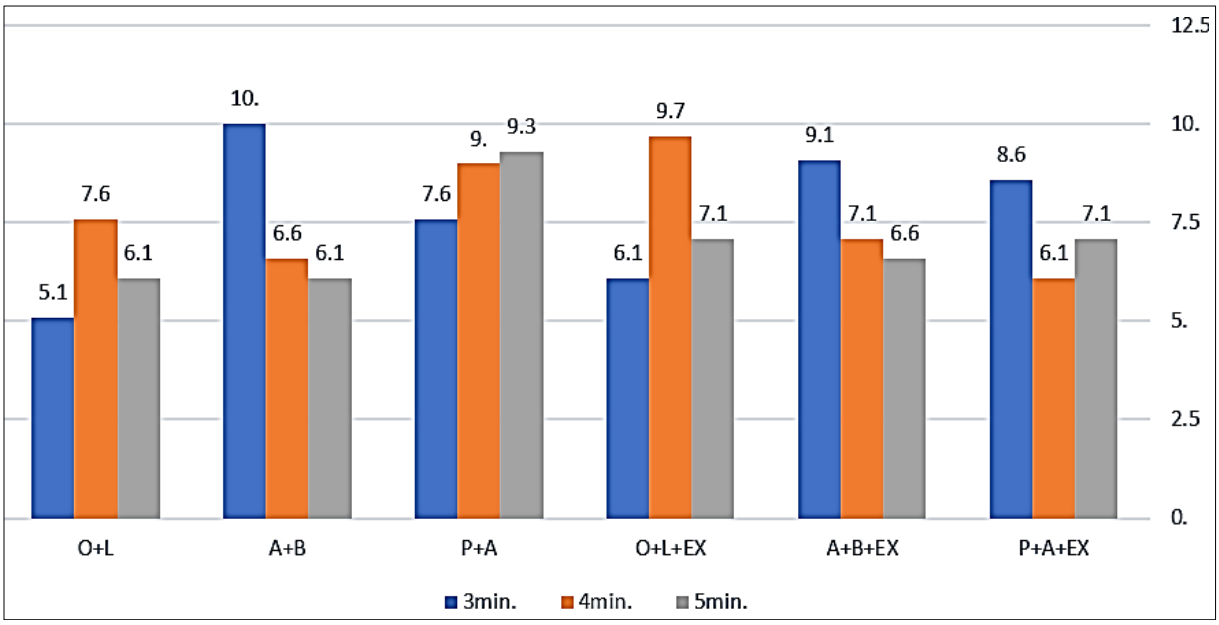

Fig 11: TPC graph of different tea sample at 100 °C

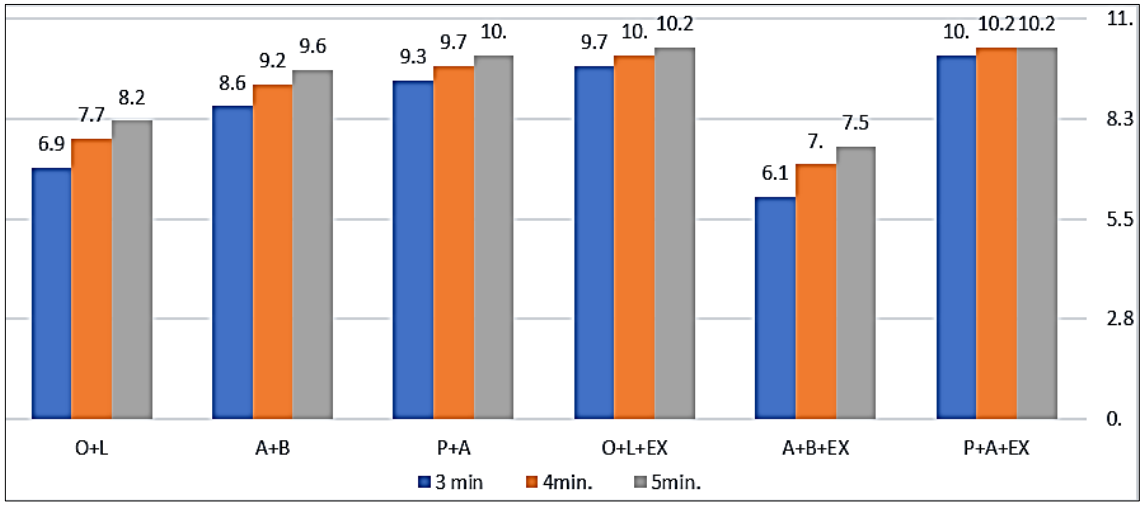

Fig 12: TPC graph of different tea sample at 70 °C

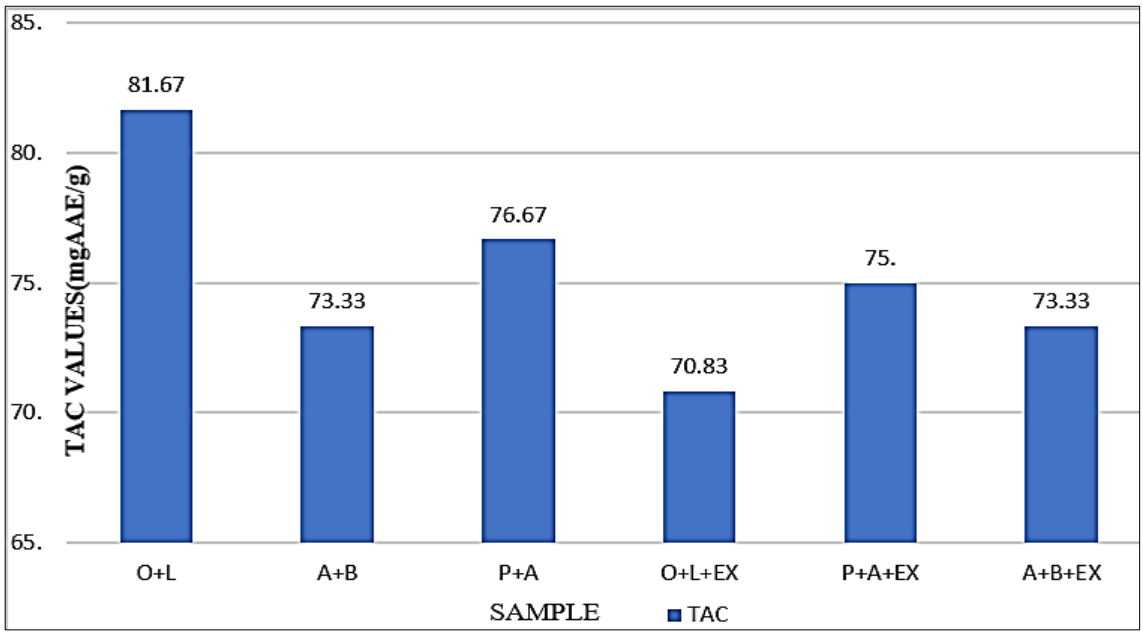

Fig 13: TAC graph for different tea sample

7. Discussion

The comparative assessment of plain and spiced fruit peel tea formulations revealed marked differences in both organoleptic and biochemical characteristics. Spiced versions demonstrated a stronger aroma profile and deeper infusion color, which can be attributed to the presence of clove, cardamom, and ginger. These spices are known to release volatile oils and phenolic compounds that enhance sensory intensity but also induce slight turbidity, consistent with the mild cloudiness observed in spiced samples. In contrast, plain formulations retained the intrinsic fruit and herb attributes, yielding lighter infusions with milder flavor intensity and greater clarity.

Among the formulations, Citrus Glow (Spiced) exhibited the lowest pH, indicating greater acidity and suggesting a more refreshing infusion profile. This finding aligns with the high water solubility of citrus bioactives, which also contributed to faster infusion rates and superior color brightness in citrus-based samples. In contrast, Antioxidant Shield formulations, particularly in their plain versions, displayed vibrant coloration due to anthocyanin release from pomegranate, highlighting their potential functional benefits as antioxidant-rich beverages. Apple Spice Elixir demonstrated a thicker mouthfeel and mellow infusion color, likely due to the release of natural sugars and fibers from apple and banana, making it more suitable as a warming, soothing blend rather than a refreshing beverage.

The evaluation of Total Phenolic Content (TPC) confirmed that both temperature and infusion duration were critical factors in determining phenolic yield. At 70 °C, TPC showed a gradual increase with infusion time across all formulations. The highest TPC values (10.2 mg GAE/g) were recorded for Pomegranate + Apple + Spices (P + A + EX) and Orange + Lemongrass + Spices (O + L + EX) at 4–5 minutes, underscoring the synergistic role of spices in enhancing polyphenol extraction. Conversely, Apple + Banana + Spices (A + B + EX) demonstrated the lowest phenolic release (6.1 mg GAE/g at 3 minutes), though a modest increase was observed with prolonged infusion. Interestingly, P + A + EX maintained consistently high TPC (10–10.2 mg GAE/g) over time, suggesting rapid extraction and early saturation of phenolic compounds.

At 100 °C, extraction efficiency increased markedly, with sharper rises in TPC across most formulations. Maximum values (10 mg GAE/g) were observed in Apple + Banana (4 min) and O + L + EX (5 min), indicating that elevated temperature accelerates polyphenol release even in formulations with initially moderate content. This suggests

that high-temperature infusion may overcome matrix-related diffusion barriers, particularly in fruit-based blends with higher sugar or fiber content.

Overall, the results suggest that spiced formulations not only enhance sensory qualities but also improve polyphenolic extraction, making them more suitable for functional beverage development. Citrus-based teas exhibited superior clarity and solubility, while pomegranate-based teas contributed strongly to anthocyanin-driven color and antioxidant potential. Apple–banana blends, while less phenolic-rich, may appeal as soothing, texturally unique infusions. Importantly, an infusion period of 4–5 minutes at 70–100 °C emerged as optimal, as longer steeping provided minimal additional benefit in phenolic yield.

8. Conclusion

The findings of this study demonstrate that both temperature and infusion time play a significant role in determining the phenolic yield of fruit peel tea formulations. Infusion at 100 °C consistently enhanced total phenolic content (TPC) compared to lower extraction temperatures, confirming the influence of heat on polyphenol release. An infusion duration of 4–5 minutes emerged as optimal across most samples, providing maximal extraction without notable further gains at prolonged steeping. Spice-enriched formulations (EX) not only improved sensory complexity but also exhibited superior antioxidant potential, suggesting a synergistic role of spices in enhancing polyphenol availability. Among all combinations, Pomegranate + Apple + Spices (P + A + EX) demonstrated consistently high TPC at both tested temperatures, establishing it as the most promising candidate for functional tea development.

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