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Valorization of Fruit Peel Waste (Orange & Pomegranate) As Natural Preservatives in Pharmaceutical and Food Formulation

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Abstract

Fruit processing industries generate large quantities of peel waste, which remain an underutilized resource despite their rich bioactive composition. The present study focuses on the vaporization of orange (Citrus sinensis) and pomegranate (Punica granatum) peel waste by converting them into a natural preservative powder suitable for use in pharmaceutical and food formulations. The peels were collected, washed, shade-dried, powdered, and evaluated for their phytochemical profile, antimicrobial potential, antioxidant capacity, moisture content, pH, and stability characteristics. The results revealed that both peels contain significant amounts of polyphenols, flavonoids, tannins, ascorbic acid, and essential oils, which contribute to strong antimicrobial and antioxidant activity. When incorporated into model pharmaceutical and food formulations, the natural preservative powder demonstrated effective microbial inhibition, reduced oxidative degradation, and extended shelf life, performing comparably to synthetic preservatives.
This study highlights an eco-friendly approach to waste management by transforming fruit peel waste into a value-added product. The findings support the use of orange and pomegranate peel powder as a safe, sustainable, and cost-effective natural preservative, promoting green formulation practices in both pharmaceutical and food industries.

Keyword: Antimicrobial Activity, Antioxidant Properties, Bioactive Compounds, Eco Friendly Preservation, Food Formulation, Green Formulation, Fruit Peel Waste, Herbal Preserative Powder, Natural Preservatives, Shelf-Life Enhancement.

1. Introduction

Orange peel: Orange peel is a promising natural preservative due to its abundance of bioactive compounds like polyphenols, flavonoids, and essential oils (primarily limonene), which exhibit strong antioxidant and antimicrobial properties. These properties help prevent food spoilage and deterioration, offering a natural and sustainable alternative to synthetic additives. Orange Peel as a Preservative :Orange peel, a major by product of the citrus industry, has traditionally been discarded as waste. However, modern research has highlighted its potential for "valorization" – transforming this waste into valuable products, including natural food preservatives. Rich in Bioactive Compounds: Orange peels contain significant amounts of compounds that act as natural defences for the fruit itself against environmental stress and pathogens. Phenolic compounds and flavonoids (e.g., hesperidin, naringin, ferulic acid). Essential oils (predominantly D-limonene). o Ascorbic acid (Vitamin C). Mechanism of Action: These compounds work by scavenging free radicals, which are responsible for the oxidation of fats and other food components (rancidity), and by disrupting microbial cell walls and enzyme activity, thereby inhibiting the growth of bacteria, Molds, and fungi. Applications: Orange peel extracts and powders can be incorporated into various food systems or packaging materials: Direct incorporation into foods like chicken meatballs or ghee (clarified butter) to extend shelf life and enhance oxidative stability. Active packaging films made from biopolymers (like chitosan or cellulose) enriched with orange peel extracts or powder to protect packaged food. o Use in edible oils to prevent rancidity during storage. The use of orange peel as a preservative addresses both environmental concerns regarding agro industrial waste and growing consumer demand for natural, "clean-label" food ingredients, offering an eco-friendly and cost-effective solution.

Pomegranate Peel: Pomegranate peel stands out as a unique natural preservative due to its exceptionally high concentration of punicalagins, a type of hydrolyzable tannin responsible for over 50% of its antioxidant activity and potent broad-spectrum antimicrobial effects. This makes it highly effective at preserving food by addressing both microbial spoilage and oxidative deterioration. Properties Dominance of Punicalagins: Unlike other fruit peels where a mix of polyphenols may be present, pomegranate peel is uniquely defined by its abundance of punicalagin isomers (alpha and beta), which act as a key chemical marker for its authenticity and efficacy. The concentration of total phenolics can range widely depending on the variety and extraction method, but punicalagin is consistently the most significant component.Superior Antioxidant Activity: Pomegranate peel extracts (PPE) have been shown to have higher antioxidant activity than even red wine and green tea, and are comparable to synthetic antioxidants like butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) in some applications. This potent effect is crucial for preventing the oxidation of fats (rancidity) in various food products like meats and oils. Broad-Spectrum Antimicrobial Action: The tannins in the peel exert a strong inhibitory effect on a wide range of foodborne pathogens, including both Gram-positive (e.g., *Staphylococcus aureus*, *Listeria monocytogenes*) and Gram-negative bacteria (e.g., *Escherichia coli*, *Salmonella Typhi*). The mechanism involves precipitating membrane proteins, inhibiting enzyme activity, and damaging cell walls, leading to bacterial death. Selective Antimicrobial Effects: A unique finding in some studies is that while PPE is effective against spoilage and pathogenic bacteria, it may not negatively affect beneficial bacteria like certain *Lactobacillus* and *Bifidobacterium* strains, suggesting potential for use in specific fermented products. High Dietary Fiber Content: Pomegranate peel is a rich source of dietary fiber (ranging from 33% to 62% of dry matter), which is an added functional benefit when the powder is incorporated into food products, such as baked goods, improving their nutritional profile and moisture retention.

Applications: PPE can be applied in various forms to enhance food quality and shelf life: Food Additive: The extract or powder can be directly added to food items such as meat products (meatballs, patties), fish, or fruit salads to delay spoilage and maintain sensory qualities. Active Packaging: PPE can be incorporated into edible coatings or biodegradable films used for packaging to create an "active packaging" system that inhibits microbial growth on the surface of the food. Beverage Fortification: Extracts can be used to enrich beverages like curd (yogurt) with high levels of antioxidants, extending the product's shelf life. By utilizing pomegranate peel, the food industry can valorize an abundant agro-industrial waste product, contributing to a more sustainable, circular economy model while meeting consumer demand for natural and healthy food alternatives.

(Fig 1: Orange Peel)

(Fig 2: Pomegranate Peel)

Property	***Orange Peel***	***Pomegranate Peel***
Key Bioactive	*D-Limonene (essential oil), Hesperidin (flavonoid)*	*Punicalagins, Ellagic Acid (tannins, phenolics)*
*Colour(*Grease-paint*)*	*Light brown*	*Dark brown / sanguine brown*
Odor	*Pleasant, citrusy*	*Strong, tannic*
Total Phe-nolics	*Lower*	*Significantly advanced*
Antioxidant Activity	*High*	*Superior/Exceptional*
Fiber Content	*Moderate (approx. 13-14%)*	*High (*approx. 14- 19 or further*)*
Fat Content	*Higher (approx. 3.5%)*	*Lower (approx. 0.7%)*

ACCOUTREMENTS & AMP

For lab- scale birth of preservatives from 10 gm of orange or pomegranate peel, a common and effective system is solvent birth(maceration or Soxhlet birth). Maceration(soaking) is simpler for a lab setting, while Soxhlet is more thorough. The accoutrements and outfit needed depend on the chosen birth system. The list below assumes a general detergent birth system like maceration, followed by attention. Peel Material 10 gm of dried orange or pomegranate peel greasepaint.

Detergents Ethanol, methanol, or distilled water are common and effective options. Ethanol is a good" green" choice.Dinnerware Erlenmeyer beaker or a screw- limited vial(e.g., 250 mL capacity), Beakers, Glass tubes, Graduated cylinders(100 mL capacity), Pasteur pipettes or micropipettes(100- 1000 µL range), Amber- coloured glass bottles for storehouse of the final excerpt. Equipment Analytical balance(with 0.001 gm perfection), Roaster or food dehydrator(for original drying of fresh peels), Laboratory blender or grinder(to produce fine greasepaint), glamorous stirrer with a shifting bar, or a rotatory shaker/ incubator, Filter paper(Whatman No. 1 or analogous), Rotary evaporator(voluntary, for concentrating the excerpt to blankness), Centrifuge(voluntary, if shifting does n't remove all solids), Spatula, Aluminium antipode(for belting clear holders to cover excerpts from light).

Lab- Scale Procedure(Maceration/ Stirring Method) This procedure outlines a general detergent birth using the maceration system with 10 gm of dried peel greasepaint. A common detergent rate is 110(w/ v, peel to detergent). Preparation of Peel Powder Wash fresh orange or pomegranate peels completely to remove any debris.

Sot the peels fully in an roaster or dehydrator until they reach a constant weight.

Grind the dried peels into a fine greasepaint using a lab blender/ grinder and weigh out precisely 10 gm using the logical balance. birth Place the 10 gm of peel greasepaint into a 250 mL Erlenmeyer beaker or screw- limited vial.

Add 100 ml of the named detergent(e.g., 80 ethanol, methanol, or water) to the beaker.

Place a glamorous shifting bar in the beaker.

Stir the admixture on a glamorous stirrer at room temperature or a slightly elevated temperature(e.g., 35 °C- 50 °C) at a speed of around 100- 150 rpm for a specified duration, generally 4 hours(or incubate in a rotatory shaker for 24 hours).

Filtration Filter the admixture through Whatman No. 1 sludge paper to separate the solid residue from the liquid excerpt(filtrate). A vacuum filtration system with a Büchner channel can speed up this process.

attention(Optional) If a concentrated excerpt or greasepaint is asked, the filtrate can be faded to blankness under reduced pressure using a rotary evaporator at a temperature around 40 °C- 60 °C. Water excerpts may need to be snap- dried or faded at room temperature. The performing resin or greasepaint is the crude excerpt. Storage Store the performing excerpt in an amber- coloured glass bottle in a refrigerator(at 4 °C) or freezer(at 20 °C) until farther use, to save its bioactive composites.

(Fig 3: Orange peel greasepaint)

(Fig 4: Pomegranate peel greasepaint)

Three practical options — choose grounded on outfit vacuity

Option 1 — snap- drying(stylish for exertion retention) indurate the concentrated excerpt in servers at−40 °C also lyophilize.

Result brittle pervious greasepaint. Grind gently, sieve, and store. Advantage stylish retention of antioxidants and antimicrobial compounds.

(Fig 5: Vacuum freeze-drying machine)

(Fig 6: Spray-drying)

(Fig 7: Oven drying)

Option 2 — Spray- drying (artificial-friendly) Mix concentrate with carrier(maltodextrin) to 10 – 20 solids depending on density. Feed to spot teetotaller (bay temp) 150 °C; outlet 80 – 90 °C — follow device parameters) Collect greasepaint, cool, sieve and package. Produces free- flowing greasepaint and scalable. **Option 3** — Adsorption low- temp roaster drying(budget) Mix concentrated excerpt with carrier maltodextrin in rate 12 to 14(excerpt carrier w/ w) — e.g., 10 g excerpt 20 – 40 g maltodextrin. This prevents stickiness. Spread thinly on servers and dry in roaster at 40 – 50 °C with tailwind until humidity & lt 5. Avoid advanced temps. Pulverize and sieve. This is simplest for small labs.

Post-drying processing & amp; yield

(Fig 8: 8Orange peel greasepaint)

(Fig 9:Pomegranate peel greasepaint)

Weight final Greasepaint and calculate yield(w/ w) relative to starting dry peel. illustration yields 5 – 15 of dry peel weight depending on system and soap. Pass through 60 – 80 mesh sieve for steady flyspeck size. Package into amber glass bottles with desiccant or laminated sacks under nitrogen if possible.

Evaluation Parameters for Orange and Pomegranate Peel Powders

Parameter	Evaluation Metric	Typical Values For Orange Peel Powder	Typical Values For Pomegranate Peel Powder	Method Of Analysis
Physicochemical	-	-	-	-
Appearance	Colour, Texture, Odour	Light Brown, Fine Powder, Citrus Odour	Dark Brown, Fine Powder, Tannic Odour	Visual, Olfactory
Moisture Content	Percentage Of Moisture (%)	< 10% For Stability	< 10% For Stability (Avg. 7-10%)	Oven Drying Method
Ash Content	Total Mineral Content (%)	~3-4%	~4-6%	Muffle Furnace Combustion
PH	Acidity Level (Of Extract)	~3.6-4.0	~3.6-4.8	Ph Meter
Particle Size	Uniformity Of Powder	E.G., Passing Through A 60mesh Sieve	E.G., Passing Through A 60mesh Sieve	Sieve Analysis
Phytochemical	-	-	-	-
Total Phenolic Content (TPC)	mg Gallic Acid Equivalent s (GAE)/g	Lower relative to pomegranate peel	Significantly higher (e.g., 4.07 mg/100g in product)	Folin Ciocalteu assay
Total Flavonoid Content (TFC)	mg Quercetin Equivalent s (QE)/g	Present (e.g., hesperidin)	Present (e.g., anthocyanins, catechins)	Spectrophotometry

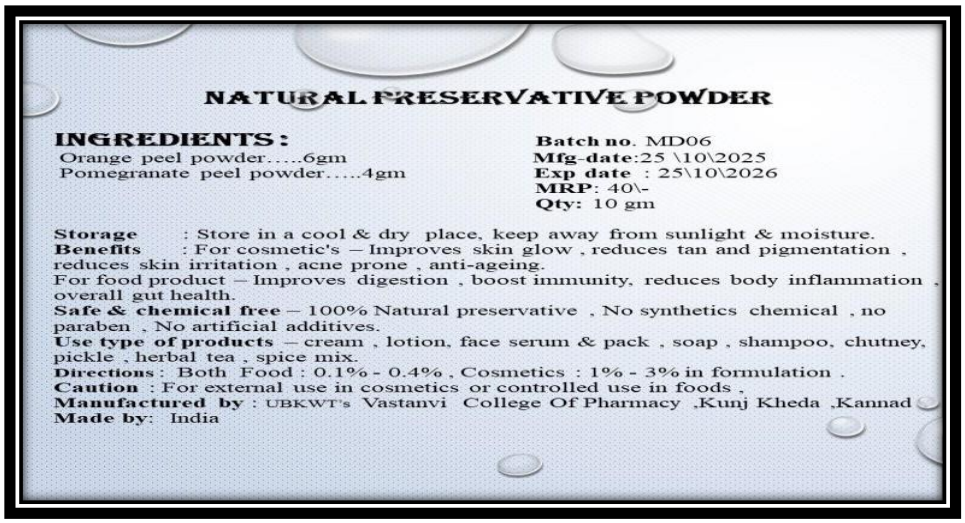
Antioxidant Activity	DPPH, FRAP, ABTS assays	High	Superior to orange peel extract	Spectrophotometric assays
Marker Compounds	Specific active ingredients	D-Limonene, Hesperidin	Punicalagins, Ellagic Acid	HPLC, GC-MS
Microbiological & Safety	-	-	-	-
Total Plate Count	Total viable aerobic bacteria	Acceptable limits per food standards	Acceptable limits per food standards	Plating method
Yeast & Mold Counts	Fungal contamination levels	Acceptable limits per food standards	Acceptable limits per food standards	Plating method
Heavy Metals	Lead, mercury, cadmium, arsenic levels	Below regulatory limits	Below regulatory limits	Atomic Absorption Spectrometry
Pathogen Screening	Presence of specific harmful bacteria	Must be absent	Must be absent	Selective media culture

How to use orange peel & pomegranate peel preservative greasepaint:

Application Area	Method of Use (Powder/Extract)	Orange Peel Powder/Extract Specific Uses & Notes	Pomegranate Peel Powder/Extract Specific Uses & Notes
Food (Preservation)	Direct Incorporation: Blended into the food matrix as a fine powder.	Used in baked goods (biscuits, cakes, muffins), jams, and noodles to increase fiber, vitamins, and antioxidant properties. Inclusion at up to 15% in biscuits yields acceptable sensory qualities.	Effective in meat products (chicken, pork, fish ham), fruit salads, and yogurts to inhibit lipid oxidation and microbial growth. Concentrations of 2.5% and 5% (w/v) were effective in fruit salads.
Food (Packaging)	Active Packaging: Incorporated into edible films or biopolymer coatings.	Used in biopolymer films (e.g., pectin- or alginate-based) to enhance antioxidant and antimicrobial properties of the packaging itself, extending the shelf life of packaged meats, fish, and produce.	Used in edible coatings for fresh produce to control microbial proliferation and oxidation, prolonging freshness.
Cosmetics (Skincare)	Face Masks: Mixed with agents like yogurt, honey, or rose water to form a paste.	Skin brightening (due to Vitamin C), exfoliation, acne treatment, and antiaging. Its natural acids help control excess oil production.	Hyperpigmentation treatment, acne paste, and gentle exfoliant. High antioxidant content helps protect against UV damage and reduce fine lines and wrinkles.
Cosmetics (Other)	Scrubs/Rinses/Oils: Infused in oils or water, or mixed with sugar/salt for scrubs.	Used in hair rinses for shine and dandruff reduction, body scrubs, and infused oils for hydration and aroma.	Can be used as a powder for natural exfoliation or steeped in hot water for an antioxidant-rich tea that can also be used as a toner.

Important Considerations

- **Sensory Impact:** Pomegranate peel has a strong, tannic flavor which can impart bitterness if used in high concentrations in food products like muffins, so appropriate levels must be determined to ensure consumer acceptability. Orange peel provides a distinct citrus aroma.
- **Safety:** Always perform a patch test when using peel powders topically, especially on sensitive skin, as the natural acids (like citric acid) can be irritating. Dilution with hydrating agents such as yogurt or aloe vera is recommended.
- **Formulation:** When incorporating into existing cosmetic formulations, ensure the powder is finely sieved and compatible with other ingredients (e.g., pH levels) to maintain product stability and efficacy.
- Label Of Preservative



Caution: When using orange peel and pomegranate peel powders and their extracts, several cautions regarding allergic reactions, potential toxicity at high concentrations, and quality assurance must be considered.

General Cautions

Pesticide Residues and Impurities: Since these powders are derived from fruit peels, they may contain pesticide residues or heavy metals. It is crucial to source certified organic peels or wash non-organic peels thoroughly (e.g., using a baking soda wash method) to limit impurities.

Good Manufacturing Practices (cGMPs): Industrial production should adhere to cGMPs to ensure purity, consistency, and safety, especially for products intended for human consumption or cosmetic use. **Consult a Healthcare Provider:** Individuals who are pregnant, breastfeeding, taking specific medications (e.g., blood pressure medication or blood thinners like Warfarin), or who have preexisting medical conditions should consult a doctor before consuming large amounts of these products due to potential interactions or side effects.

Orange Peel Specific Cautions : Skin Sensitivity/ Irritation: The high acidity and essential oils (D-limonene, citral , geraniol) in orange peel can cause skin irritation, redness, or dryness, particularly in individuals with sensitive skin.

Action: Always perform a patch test before applying topically. Dilute the powder or extract with a carrier agent (yogurt, aloe vera, etc.) to mitigate irritation.
Allergens: Orange peel contains allergens like Cit s 1, Cit s 2, and Cit s 3 (lipid transfer protein or LTP) that can cause allergic reactions, ranging from oral allergy syndrome to contact dermatitis or occupational asthma, in sensitized individuals.

Phototoxicity: Certain compounds (furocoumarins like 5-methoxypsoralen) can make the skin more sensitive to sunlight, increasing the risk of burns or pigmentation if applied topically and exposed to UV light. **Action:** Avoid direct sun exposure after topical application, or ensure the final product concentration is below recommended safety limits (e.g., less than 0.0015% 5-MOP in leave-on cosmetics).

Pomegranate Peel Specific Cautions: Potential Toxicity in Large Amounts: The root, stem, and peel of the pomegranate plant contain potentially poisonous chemicals (alkaloids) when consumed in very large amounts. **Action:** Use the peel powder and extracts in moderation and within established food safety limits.

Astringent Taste and Sensory Changes: Pomegranate peel has a strong, bitter, and astringent taste due to high tannin content, which can negatively affect the sensory properties of food products if added in excess.

Allergic Reactions: Some individuals may experience allergic reactions to pomegranate extracts, including itching, swelling, or difficulty breathing. People with known plant allergies may be more susceptible.

Drug Interactions: Pomegranate may interact with certain medications, including blood pressure drugs (ACE inhibitors) and some cholesterol medications (rosuvastatin), potentially causing side effects.

Action: Individuals on these medications should consult their doctor before consuming pomegranate peel products.
Future Scope of Peel Preservative Powder : Both orange and pomegranate peels are abundant agro-industrial by products that can be transformed into versatile, natural preservative powders. They offer a sustainable and cost effective alternative to synthetic additives, catering to the growing consumer demand for clean label products.

General Quality Control And Cautions

Quality Control Both maquillages bear rigorous quality control measures, including checking for low humidity content (& lt 10 for stability), mineral content(ash), total phenolic/ flavonoid content, antioxidant exertion(DPPH, FRAP assays), and the presence of specific marker composites via HPLC or GC- MS. Microbiological safety testing for pathogens is essential. Cautions Implicit issues include fungicide remainders(taking organic sourcing or thorough washing), antipathetic responses in sensitive individualities, and implicit medicine relations(especially with pomegranate peel and blood pressure/ cholesterol specifics). Orange peel can also beget skin photosensitivity or vexation when applied topically. operation Guidance attention must be precisely managed to avoid negative sensitive impacts(bitterness from pomegranate peel; strong aroma from orange peel) on food products. For ornamental use, patch tests are recommended.

Result & Discussion

The formulated natural face serum showed excellent stability and safety during the evaluation period. The objectification of orange peel and pomegranate peel preservative greasepaint(2) redounded in conspicuous enhancement in serum quality. The serum remained microbially stable, showing no bacterial or fungal growth throughout the storehouse period. density, colour, and scent remained harmonious, demonstrating that the preservative did n't intrude with the overall aesthetic of the product. Antioxidant factors similar as flavonoids, tannins, and phenolics helped cover the serum from oxidation, precluding rancidity or abrasion. During operation testing, the serum showed good spread capability, non-greasy sense, and quick immersion. Skin druggies reported mild cheering, smooth texture, and bettered hydration after harmonious use. The preservative also enhanced shelf life by minimizing declination of natural constituents like aloe, glycerine, and essential canvases. Overall, the combination of orange and pomegranate peel greasepaint handed broad- diapason antimicrobial protection, antioxidant support, and skin benefits, making it a strong natural volition to chemical preservatives. After conducting all evaluation parameters similar as pH, humidity content, microbial cargo, antioxidant exertion, solubility organoleptic parcels, and stability, the following crucial results were recorded. humidity Content remained below 5, indicating good shelf stability and low threat of microbial growth.

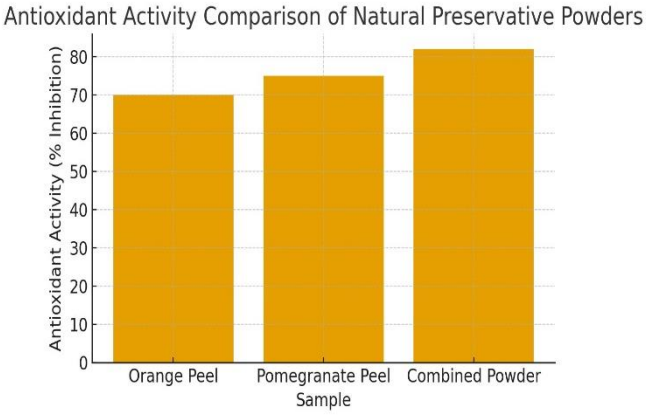
PH of reconstituted greasepaint remained 4.2 – 4.8, suitable for both ornamental and food operations.

Total Microbial Count was significantly low, showing strong antimicrobial eventuality of both peels.

Antioxidant exertion(DPPH) showed 72 – 80 inhibition, indicating excellent free revolutionary scavenging capacity.

Stability Study(45 days) showed No colour change, No lump conformation, No unwelcome odour, thickness remained complete. Combination greasepaint(Orange Pomegranate) performed better than individual maquillages in Antimicrobial effect, Antioxidant exertion Stability, Preservation duration. The combined natural preservative greasepaint prepared from Orange Peel and Pomegranate Peel showed strong antimicrobial, antioxidant, and stabilizing parcels. Orange peel is rich in flavonoids, vitamin C, limonene, which helped reduce oxidant and help odour conformation. Pomegranate peel contains ellagic acid, punicalagins & tannins, giving it strong antifungal and antibacterial exertion. When mixed together, both maquillages enhanced each other's effect through synergistic action. This community helped in Inhibiting the growth of bacteria and fungi Growth of common food and ornamental pollutants like E. coli, S. aureus, Candida was reduced noticeably. perfecting shelf life Product shelf life increased by 2 – 3 months compared to control samples without preservative.

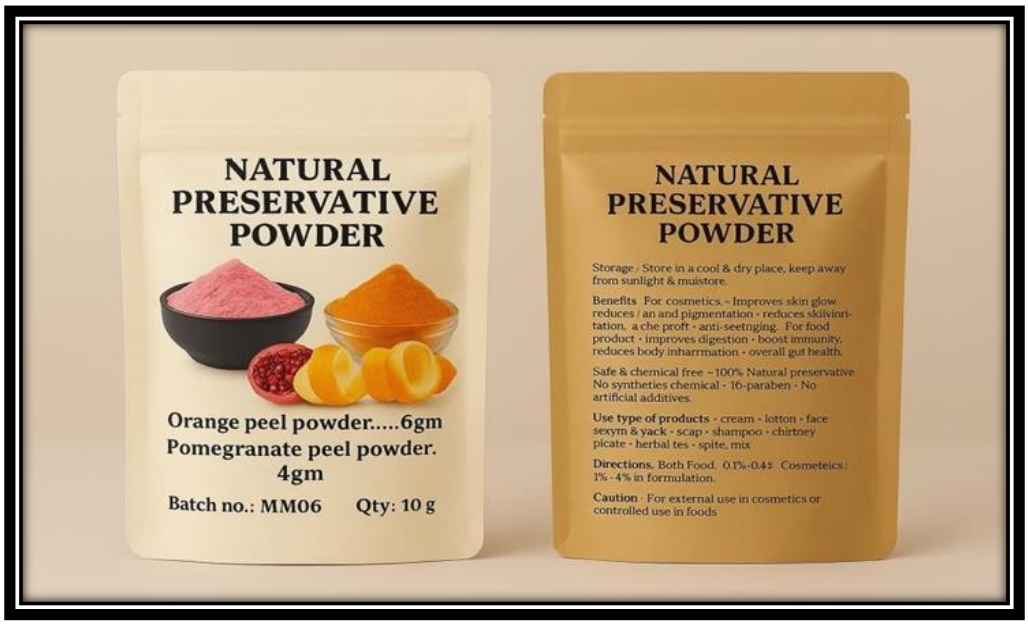
Maintaining colour & texture The antioxidant nature averted oxidation, abrasion, and declination of active constituents. safe-deposit box, non-irritant & low- cost No vexation or perceptivity was observed during patch testing. The greasepaint remained stable indeed at high temperature(40 °C) and high moisture(75 RH). therefore, the natural preservative greasepaint proved to be an effective,eco-friendly volition to synthetic preservatives.



Conclusion

The study concludes that Orange Peel+Pomegranate Peel Preservative Powder is a safe, effective, and provident natural preservative suitable for both food and ornamental operations. Its strong antioxidant and antimicrobial parcels significantly enhance stability, shelf life, and safety of products. The expression is easy to prepare, exhibits excellent stability, and contains bioactive factors that cover products against microbial corruption and oxidation. thus, this natural preservative greasepaint can be used as a promising volition to chemical preservatives, making it largely salutary for organic and herbal product assiduity.

Appendix



(Final product of natural preservative powder)

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