Utilization Of Food Byproducts as Sustainable Raw Materials in Production of Herbal Skincare Cosmetics

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***Abstract*—This study explores the sustainable valorization of tomato and grape pomace food-industry by- products rich in carotenoids, polyphenols, flavonoids, tannins, and resveratrol for the development of an herbal gel offering protection against High-Energy Visible (HEV) light. With rising screen exposure and the associated risks of oxidative stress, pigmentation, and premature aging, the demand for HEV-protective skincare is increasing. Bioactive were recovered using a green hydro- glycerin extraction method combined with microwave-assisted extraction to preserve thermolabile antioxidants. To enhance stability, penetration, and bioavailability, the extracts were encapsulated in niosomes prepared via thin-film hydration and optimized for vesicle integrity.**

The niosomal dispersions were incorporated into a Carbopol-based gel containing hyaluronic acid, glycerin, dimethicone, tocopherol, and sodium benzoate. The final formulation demonstrated a skin- compatible pH (5.1–5.2), smooth spread ability, stable viscosity, and no phase separation during short-term stability testing. UV–Vis's analysis confirmed strong absorbance at 415 nm, indicating effective HEV-light attenuation. A 6% niosome loading provided the best balance of efficacy, stability, and sensory performance.

Overall, this work presents an eco-friendly, high-value cosmetic formulation that transforms food- processing waste into a functional, sustainable niosomal gel designed to address modern "digital aging" while supporting circular-economy principles.

***Index Terms*—Tomato pomace; Grape pomace; Niosomes; HEV protection; Digital aging; Sustainable cosmetics.**

I. INTRODUCTION

The rapid growth of the global food-processing sector has led to a substantial increase in agro- industrial waste, creating both environmental and economic concerns. Each year, millions of tons of fruit and vegetable residues particularly peels, seeds, and pomace are discarded without consideration of their inherent bioactive potential. These by-products, though often treated as waste, are naturally enriched with secondary metabolites such as carotenoids, flavonoids, phenolic acids, tannins, resveratrol, vitamins, dietary fibers, and essential fatty acids. When recovered efficiently, these compounds exhibit strong antioxidant, anti-inflammatory, anti-aging, and photoprotective properties, making them valuable candidates for use in herbal and sustainable cosmetic formulations.

In regions like Nashik India's wine capital and a major tomato-producing zone large quantities of grape and tomato pomace are generated during wine making, juice extraction, and sauce processing. These residues typically end up in landfills or near natural water bodies, where their high moisture and sugar content accelerates microbial growth, foul odor generation, and release of greenhouse gases during decomposition. This not only disrupts soil and water ecosystems but also represents a significant loss of nutritionally and functionally potent metabolites. Valorizing such materials therefore aligns with both environmental necessity and the principles of circular economy, transforming waste into renewable, high-value inputs for the cosmetic industry.

Simultaneously, modern lifestyle changes have increased daily exposure to High Energy Visible (HEV) light commonly known as blue light (400–500 nm) emitted extensively from digital screens, LED lighting, and sunlight. HEV radiation penetrates deeper into the epidermis than UV rays and induces the overproduction of reactive oxygen species (ROS).

These ROS damage lipids, proteins, and DNA, accelerate collagen breakdown, lead to pigmentation, dullness, and premature aging, and collectively contribute to the emerging phenomenon termed "digital aging." Traditional sunscreens primarily focus on UV filtration and provide limited defense against HEV-induced oxidative stress. This growing gap in photoprotection highlights the urgent need for innovative skincare solutions enriched with natural antioxidants and HEV-attenuating compounds.

Tomato and grape pomace offer strong potential in this context due to their abundance of bioactive components such as lycopene, β-carotene, quercetin, resveratrol, anthocyanins, and proanthocyanin's. These compounds are known to neutralize free radicals, reduce inflammation, and inhibit photodamage, making them ideal for formulating modern protective skincare. However, direct incorporation of raw plant extracts into topical products poses challenges including poor stability, low skin permeability, and susceptibility to light or temperature degradation. To overcome these limitations, green extraction technologies and advanced delivery systems are required to retain biological activity while enhancing efficacy.

In this study, hydro-glycerin extraction a safe, eco-friendly, and biocompatible method was employed to recover bioactive compounds from tomato and grape pomace without the use of harsh organic solvents. To further improve stability, skin penetration, and sustained release, the extracts were encapsulated in niosomes, which are non-ionic surfactant-based vesicular carriers known for their ability to transport both hydrophilic and lipophilic molecules into deeper skin layers. By combining sustainable raw materials with efficient delivery technology, this research aims to develop a clean, stable, and effective HEV-protective herbal gel. This approach not only supports eco-conscious cosmetic innovation but also demonstrates how food-industry by-products can be transformed into high-value skincare solutions that address contemporary environmental and dermatological challenges.

II. MATERIALS AND METHODS:

1. Selection of actives: Grape pomace:

Grape pomace, the residue left after winemaking, contains the skins, seeds, and stems that are normally discarded. This by-product is exceptionally rich in polyphenols such as flavonoids, anthocyanins, resveratrol, and proanthocyanins, all of which exhibit strong antioxidant and anti- inflammatory activity. These compounds help neutralize reactive oxygen species (ROS), prevent photoaging, and protect the skin from environmental stressors. Repurposing grape pomace therefore supports sustainable cosmetic development while providing a potent natural source of skin- beneficial actives.

Key Chemical Components

Polyphenols: Catechins, quercetin, resveratrol, and tannins that protect against oxidative and inflammatory damage.

Anthocyanins: Powerful antioxidants responsible for grape skin color and effective free- radical scavengers.

Dietary Fiber: Cellulose and hemicellulose offering mild structural benefits in formulations.

Lipids: Grapeseed oils rich in essential fatty acids with strong emollient and barrier- supporting properties.

Vitamins & Minerals: Small amounts of vitamin C, vitamin E, and trace elements that support skin repair and metabolism.

Figure No.1

Grape Pomace

a. Tomato Pomace:

Tomato pomace is the leftover mixture of skins, seeds, pulp, and juice remaining after tomato processing. Rich in carotenoids especially lycopene and β-carotene it provides strong antioxidant and photoprotective benefits by neutralizing reactive oxygen species generated from UV/HEV exposure, pollution, and lifestyle stressors. Its vitamin C and vitamin E content further supports collagen synthesis, prevents photoaging, and enhances skin radiance and hydration. Owing to this potent natural profile, tomato pomace is a highly valuable and sustainable ingredient for herbal skincare formulations.

Key Chemical Components
Carotenoids: Lycopene (major component) and β-carotene, responsible for strong antioxidant and HEV/UV protective activity.
Phenolic Compounds: A wide range of polyphenols, flavonoids, and phenolic acids offering antimicrobial and anti-inflammatory effects.
Dietary Fiber: Cellulose and pectin providing structural support and contributing to skin barrier benefits.
Lipids & Proteins: Moderate amounts from tomato seeds that add functional and nutritive value.
Vitamins & Minerals: High levels of vitamin C and E that enhance antioxidant defense and skin repair.

Figure No 2
Tomato Pomace

2. Extraction of bioactive compounds:
a. Solvent and Method Selection:
A green hydro-glycerin extraction method was selected to recover bioactive compounds from tomato and grape pomace. This approach uses a water–glycerin solvent system, which is non-toxic, eco-friendly, and ideal for cosmetic applications. Glycerin efficiently solubilizes polar and semi-polar phytochemicals while simultaneously stabilizing heat-sensitive components such as lycopene, anthocyanins, and polyphenols. The method involved macerating minced pomace in a 30:70 water–glycerin mixture for 24 hours under dark, controlled conditions, followed by brief microwave-assisted extraction to enhance yield without degrading thermolabile antioxidants. The final extract was filtered and stored in amber containers at low temperature. This process preserved bioactivity, improved extract stability, and ensured suitability for incorporation into topical formulations.

b. Yield and composition:
Here, combination of two techniques together provides efficient extraction from secondary metabolites after primary processing like antioxidant compounds, with average yield ranging from 10-20 percent of total carotenoids and phenolics.
Overall, this combination technique increases the concentration of lycopene from tomato and polyphenols from grapes.

3. Preparation of Niosomal Vesicles:
To overcome limitations of raw plant extracts such as poor skin permeability, instability, and rapid degradation the recovered bioactive were encapsulated in niosomes. Niosomes are non-ionic surfactant-based vesicles forming multilamellar or unilamellar bilayers capable of entrapping both hydrophilic and lipophilic molecules. This makes them highly compatible with complex botanical extracts. The thin-film hydration technique was used, where Tween 80 and stearic acid were dissolved in ethanol, evaporated to form a thin lipid film, and then hydrated with the prepared extracts at controlled temperatures. Sonication reduced vesicle size and produced uniform niosomes with stable membranes.

Niosomal delivery provided multiple advantages:
- Enhanced stability of sensitive antioxidants
- Improved penetration through the stratum corneum
- Controlled, sustained release for prolonged protection
- Reduced irritation due to non-ionic surfactants
- Greater efficacy through synergistic deposition of active compounds

This system ensured efficient delivery of grape- and tomato-derived antioxidants to deeper epidermal layers where HEV-induced oxidative damage occurs.

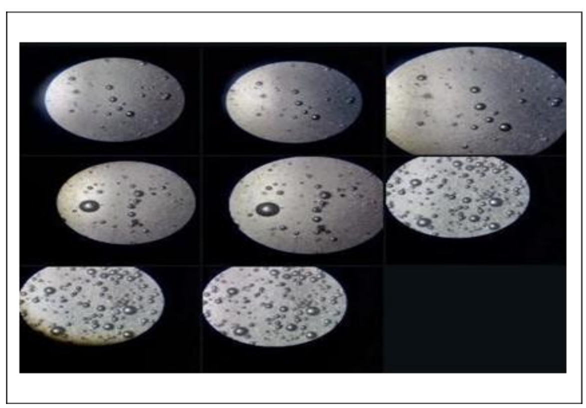

Figure No. 3
Microscopic image of niosomes

4. Formulation of Gel:
1. Formulation table:

Sr.No.	Ingredient	% w/w in 100 ml
1.	Carbopol 940	1.00%
2.	Hyaluronic Acid	1.00%
3.	Glycerin	5.00%
4.	Dimethicone	1.2%
5.	Sodium Benzoate	1.5%
6.	Tocopherol (Vit E)	1.2%
7.	Triethanolamine (TEA)	q.s.
8.	Tomato niosomal dispersion	6.00%
9.	Grape niosomal dispersion	6.00%
10.	Purified Water	78%
11.	Fragrance	q.s.
12	Water soluble color	q.s.

Table No. 1
Formulation Table

2. Formulation procedure:

PHASE A- Aqueous gel base:

i. In a clean and dry beaker measure 10 ml of purified water.
ii. Weigh Carbopol 940 and slowly sprinkle it over water surface with continues stirring to avoid lump formation.
iii. Let the mixture stand for few hours until polymers get hydrated completely to form clear gel.
iv. Measure and dissolve sodium benzoate in specific amount of water to add it into hydrated Carbopol with gentle agitation. And mix it well until forms clear uniform base.

PHASE B- Hydrating base:

i. Add glycerine (5.00%) in separate beaker with hyaluronic acid (0.55%) to form smooth and uniform premix.
ii. Once hydrated completely add premix to Phase A with continues stirring
iii. Mix until homogenous base is formed without air bubbles.

PHASE C- Addition of Additive:

i. Accurately measure Dimethicone (1.5%) and Vitamin E (1.00%).
ii. Add the blend of both into the uniform phase (A+B), keep stirring slowly to ensure uniform dispersion.

PHASE D- Neutralization and Gel Formation:

i. After determining initial pH, add triethanolamine (TEA) dropwise and keep stirring the mixture. (Ensure ph. of the base to be between 5.5-6.5) until it reaches the optimum viscosity.
ii. Be careful with over neutralization as excess TEA can harden the gel interfering with its viscosity.

PHASE E – Niosomal Dispersion:

i. Ensure the uniformity and stability of Niosomes and weigh (6) niosomes of each, grape pomace as well as tomato pomace.
ii. Add niosomes to the mixing and mix with simple folding method an avoid rigorous mixing to prevent vesicle rupture.
iii. Mix slowly until uniform blend is achieved

III. FINAL VOLUME AND DEAERATION

i. Add purified water to form 100ml volume, apparently it will adjust overall flow and consistency of the final formulation.
ii. Add required amount of water-soluble color and fragrance to enhance the aesthetic appearance.
iii. Allow the final product to stand for at least for 1 hr to release entrapped uniform.
iv. Ensure final product for any phase separation or color change before transferring it to sanitized and air tight container. And store it into cool and dry place.

IV. EVALUATION PARAMETERS:

1. Organoleptic Evaluation

The formulated niosomal gel appeared as a shiny, light-blue, translucent-to-opaque gel with a fluid, lightweight consistency. It spread easily on the skin and absorbed rapidly without leaving a greasy or occlusive residue. The fragrance exhibited a balanced blend of oceanic and woody notes, subtly complemented by the natural fruity sweetness of grape and tomato extracts, contributing to an overall refreshing sensory profile. Texturally, the gel demonstrated smooth glide, uniform application, and high user acceptability for daily skincare use.

Figure No. 4
Final formulated product

2. pH Measurement

For optimal skin compatibility, cosmetic gels must maintain a pH between 4.5 and 6.5. The pH was measured using a standardized digital pH meter calibrated with buffer solutions. A portion of the gel was diluted with distilled water, and the electrode was immersed until stabilization. The final pH ranged between 5.1–5.2, confirming excellent suitability for topical application without risk of irritation or barrier disruption.

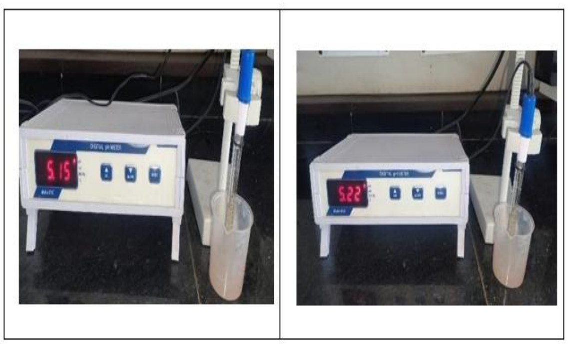

Figure No 5
pH values of final product

3. Spreadability Evaluation

Spreadability reflects application ease and uniform dosage distribution. A fixed quantity (0.5 g) of gel was placed on a clean glass plate and drawn across the surface using a second plate under constant pressure. The distance covered was recorded.

The final spread length measured was 7 cm, which falls within the standard 6–10 cm range reported for well-designed topical gels. This value indicates favourable rheology, smooth application, and good consumer usability. The spreadability (S) was computed using:

S=∑i=1nLinS = \frac{\sum_{i=1} ^{n} L_i}{n}S=n∑i=1nLi confirming reproducible ease of spreading across trials.

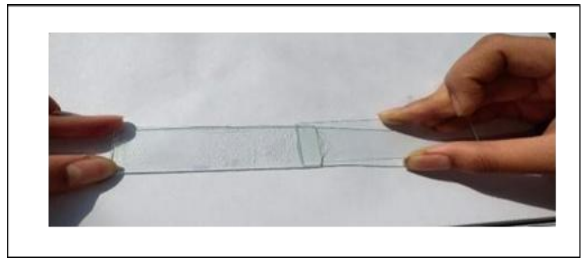

Figure No.6
Test for spreadability

4. Viscosity and Rheology Assessment

Viscosity directly influences gel flow behavior, stability and sensory experience. Measurements were performed using a rotational Brookfield viscometer fitted with an appropriate spindle (No. 6/7). Gel samples were equilibrated at 25°C and gently homogenized to eliminate trapped air.

The spindle was immersed without touching container walls, and rotational speeds were progressively increased (10, 20, 50, 100 rpm) with stabilization periods of 1–2 minutes. The optimized gel exhibited ideal viscosity at 15 rpm, consistent with Carbopol-based systems and indicative of stable, shear-thinning behavior suitable for topical application.

Figure No. 7
Measurement of viscosity using Brookfield viscometer

5. Physical and Chemical Stability Studies

Stability testing was conducted over 28 days under three conditions: room temperature, refrigerated storage (4°C), and elevated temperature (40–50°C). Samples were monitored for changes in colour, odour, phase separation, consistency and microbial spoilage.

Time interval	Final batch
8th day	Stable
15th day	Stable
24th day	Stable
30th day	Stable

Table No 2
Accelerated stability studies

6. UV–Visible Spectrophotometric Evaluation
HEV-protection efficacy was assessed via UV–Vis's spectrophotometry at 415 nm, a wavelength representative of blue-light–induced skin stress. Serial dilutions (1:10 and onward) ensured measurements remained within the linear absorbance range (0.1–1.5). The instrument was calibrated using solvent blank, and each dilution was analysed thrice for reproducibility.
The second dilution exhibited an absorbance of 1.2049, indicating strong HEV attenuation capacity and confirming the gel's potential effectiveness in mitigating blue-light-induced oxidative stress.

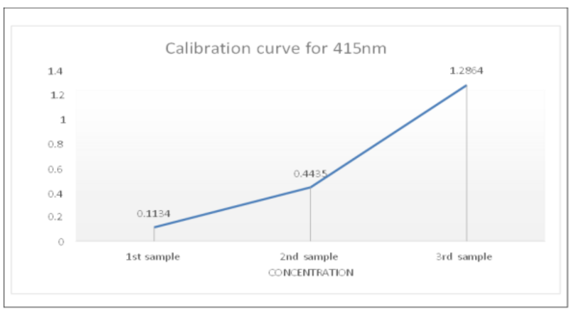

Figure No 8
UV Absorbency graph for HEV protection.

V. RESULTS AND DISCUSSION

1. Selection of Raw Materials
Tomato and grape pomace were selected as primary actives due to their local availability in Nashik one of India's major hubs for grape cultivation and tomato processing and their rich content of carotenoids, polyphenols, flavonoids, tannins and resveratrol. These by-products are typically discarded in large quantities, contributing to soil and water pollution while wasting valuable bioactive compounds. Utilizing them for cosmetic formulation not only reduces environmental burden but also aligns with circular-economy principles by converting agro-waste into safe, high-value skincare ingredients.

2. Choice of Extraction Method
Hydro-glycerin extraction was chosen as the preferred method because it is a green, non-toxic, and thermally gentle process suitable for recovering heat-sensitive antioxidants from pomace. Unlike harsh organic solvents, this method ensures biocompatibility and yields extracts appropriate for topical use. Earlier trials using higher temperatures or solvent-heavy extraction resulted in loss of color, instability, and degradation of key compounds. Hydro-glycerin extraction consistently produced stable, potent, phytochemical-rich extracts ideal for encapsulation.

3. Product Optimization and Niosome Development
Initial batches of niosomes exhibited instability weak vesicle walls, leakage, and clumping leading to cloudy, frothy gel textures. These observations revealed the need to fine-tune surfactant ratios, hydration temperature, and lipid composition. Adjustments in Tween 80 and stearic acid concentration significantly improved vesicle formation. Further trials showed gel–niosomal incompatibilities at certain extract concentrations, producing gritty or overly thick textures. By optimizing ingredient order and reducing mechanical shear during mixing, a stable and uniform gel matrix was achieved.

4. Efficacy Testing and Optimization of Niosome Concentration
Niosomal concentrations of 2% and 4% failed to deliver adequate HEV absorbance and did not produce desirable sensorial qualities. In contrast, 6% niosomal loading consistently demonstrated:

- Strong HEV absorbance at 415 nm
- Better vesicle stability
- Improved clarity and texture of the gel
- Higher consumer acceptability

Microscopic evaluation confirmed uniform vesicle distribution and structural integrity at this optimized concentration.
Overall Performance of Final Formulation
The final gel incorporated 6% grape and tomato extract-loaded niosomes along with hyaluronic acid for improved hydration and transparency. Evaluation results demonstrated:

- pH compatibility at 5.1–5.2
- Smooth spreadability (7 cm distance under standard load)

- Ideal viscosity for topical use
- No phase separation or colour degradation during stability trials
- Strong HEV-protection potential with absorbance of 1.2049 at 415 nm

Collectively, these findings confirm that the combination of green extraction and niosomal encapsulation successfully transformed agricultural waste into an effective, stable, and sensorially pleasing HEV-protective skincare gel.

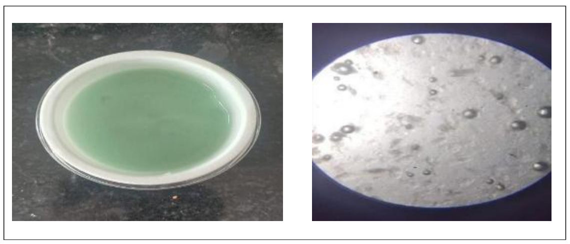

Figure No 9
Final batch of niosomal gel with microscopic image

VI. CONCLUSION

This study successfully demonstrates the sustainable valorization of tomato and grape pomace through green hydro-glycerin extraction and niosomal encapsulation to create a novel HEV- protective herbal gel. The extraction method efficiently preserved antioxidant-rich compounds, while niosomal delivery enhanced stability, penetration, and controlled release. The optimized formulation containing 6% niosomes showed high absorbance at 415 nm, confirming its potential for blue-light protection against digital aging. The final gel exhibited excellent physicochemical stability, favorable sensory properties, and consumer-friendly spreadability. Packaging in an airless pump further reduced oxidation, improved hygiene, and minimized product wastage. Beyond achieving the technical aim, the study highlights the broader potential of agro-waste as a renewable resource for future cosmeceutical development, aligning with sustainability and circular-economy goals.

VII. FUTURE PROSPECTS

1. Development of multilamellar niosomes using oil-based extracts of tomato and concentrated grape pomace to enhance encapsulation efficiency and skin bioavailability.
2. Quantitative assessment of environmental impact and waste reduction achieved through agro-waste utilization versus traditional ingredient sourcing.
3. Exploration of additional regional by-products for potential synergistic antioxidant, anti-inflammatory, or HEV-protective effects in advanced multiphase topical formulations.

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