Unveiling Skincare Ingredient Networks

FRANK H.[1]

[1]NPA, Rockville MD 20855, USA

Corresponding author: Frank H.
email: frankh.nov14@gmail.com

The cosmetic industry has experienced substantial growth, driven by consumers' increasing demand for effective and innovative skincare products. This study examines the relative importance of various cosmetic ingredients across five product categories: cleansers, eye creams, face masks, moisturizers, and sun protection products. Using the PageRank algorithm, we analyze ingredient significance by considering their occurrence and co-occurrence in a dataset of 1,472 cosmetic products sourced from Sephora. Our findings reveal key multifunctional ingredients such as water, oils, and plant extracts, which are frequently used across different categories due to their moisturizing, antioxidant, and soothing properties. Additionally, specialized ingredients like zinc oxide in sun protection products highlight the industry's focus on targeted skincare needs. The results provide valuable insights for formulators, researchers, and consumers, aiding in the development and selection of high-performance skincare products.

Keywords: Cosmetics, PageRank, association, skincare, ingredients.

1. INTRODUCTION

The cosmetic industry has seen significant growth over the past few decades, driven by increasing consumer demand for innovative and effective products. With the rise of skincare awareness and the desire for personalized beauty solutions, understanding the composition and efficacy of cosmetic ingredients has become crucial. This study aims to analyze the importance of various cosmetic ingredients across different product categories using the PageRank algorithm.

Cosmetic products are formulated with a wide range of ingredients, each serving specific functions such as moisturizing, cleansing, exfoliating, and protecting the skin. The selection of ingredients is often based on their efficacy, safety, and consumer preferences. However, the relative importance of these ingredients in different product categories has not been extensively studied *(Figure 1)*.

2. INVESTIGATIONS & DATA

To address this gap, we utilized a dataset (1,472 cosmetics on Sephora) from Kaggle, which contains detailed information on cosmetic ingredients, their ranks, prices, and effects on the skin [1].

The association map visualizes the relationships between various cosmetic ingredients based on their co-occurrence in different products. Each node represents an ingredient, with the size of the node indicating how frequently the ingredient appears across the dataset. The edges connecting the nodes show the strength of associations between ingredients, with thicker edges representing stronger associations.

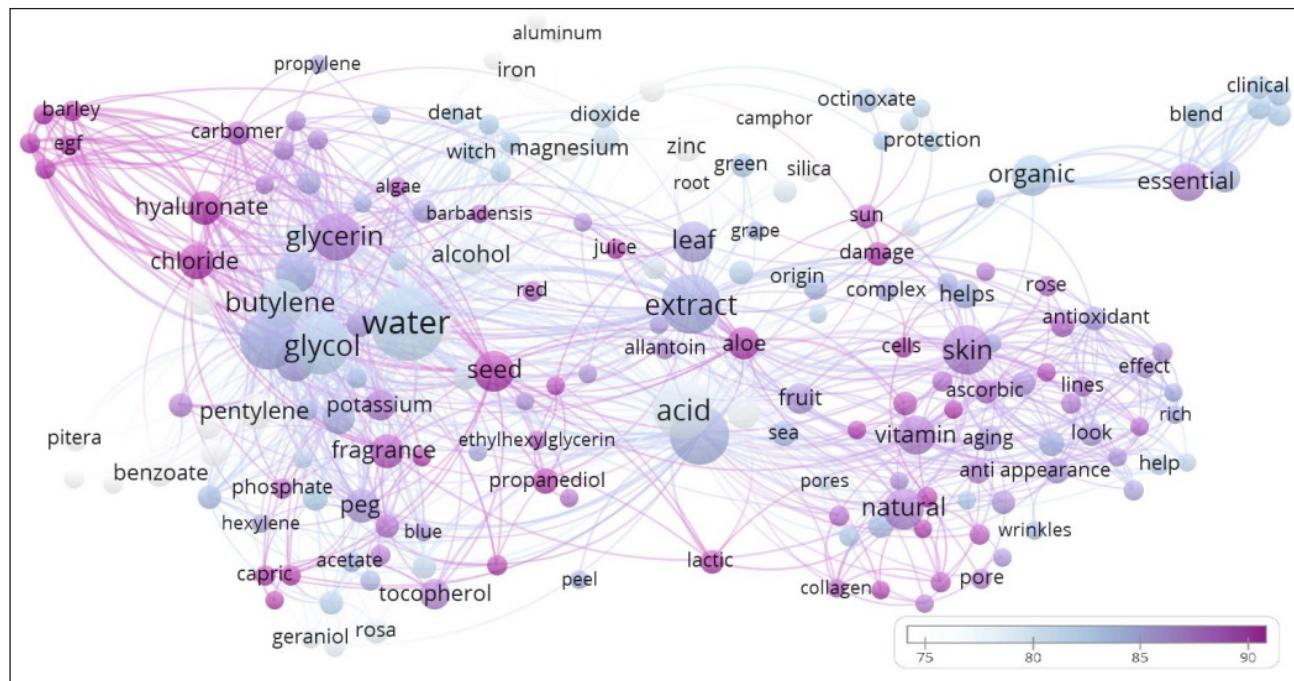**Figure 1.** *Wordcloud of brands and productions.*

Figure 2. *Association word map of all ingredients (occurrence ≥ 3).*

The color of the nodes reflects the average user ratings for products containing those ingredients, converted from a five-star scale to percentage scores. This allows us to see which ingredients are associated with higher user satisfaction. For example, words with larger, more colorful nodes are both frequently shown in ingredient fields and highly rated by users *(Figure 2)*.

This visualization helps identify key ingredients that contribute to product effectiveness and consumer satisfaction, providing insights for cosmetic formulators and marketers. (Additionally, the regression analysis reveals that products with lower prices tend to have higher customer satisfaction scores.)

3. METHODS

To rank the importance of cosmetic ingredients, the PageRank algorithm was employed. PageRank is a link analysis algorithm originally used by Google to rank web pages in their search engine results. In this study, the algorithm was adapted to rank cosmetic ingredients based on their occurrence and co-occurrence in different products:

3.1 Graph Construction

A bipartite graph was constructed where one set of nodes represented cosmetic products and the other set represented ingredients. An edge was drawn between a product and an ingredient if the ingredient was present in the product.

3.2 Matrix Representation

The bipartite graph was converted into an adjacency matrix, which was then used to calculate the transition probabilities between nodes.

3.3 PageRank Calculation

The PageRank scores were computed iteratively until convergence. The scores represented the relative importance of each ingredient within the network of cosmetic products.

4. RESULTS

4.1 Cleansers

Water: Solvent that helps dissolve other ingredients and aids in application.
Sodium: Helps with cleansing and foaming.
Glycol: Humectant that retains moisture in the skin.
Acid: Used for exfoliation and pH balance (e.g., salicylic acid).
Oil: Dissolves sebum and makeup for a thorough cleanse.
Glycerin: Humectant that attracts moisture to the skin.
Butylene: Solvent and conditioning agent.

4.2 Eye Creams

Water: Aids in dissolving other ingredients and application.

Oil: Moisturizes and nourishes the delicate skin around the eyes.

Extract: Plant extracts with soothing and antioxidant benefits.

Glycerin: Humectant that retains moisture.

Palmitate: Helps reduce wrinkles and fine lines.

Vitamins: Protects and repairs skin.

Table I. *Words of ingredient: top 17 pageranks*

	cleanser	eye cream	face mask
1	water	water	skin
2	sodium	oil	extract
3	glycol	sodium	vitamin
4	acid	extract	effect
5	skin	glycol	soothing
6	oil	circles	provide
7	butylene	dark	tone
8	peg	palmitate	powder
9	chloride	appearance	oils
10	edta	butylene	water
11	alcohol	carbomer	help
12	disodium	glycerin	glycol
13	glycerin	phenoxyethanol	brighten
14	isopropyl	leaf	fruit
15	extract	origin	look
16	natural	plant	rich
17	phenoxyethanol	aging	antioxidant
	moisturizer	**sun protect**	**treatment**
1	oil	extract	acid
2	water	oil	extract
3	glycol	skin	water
4	sodium	leaf	oil
5	seed	protection	skin
6	skin	fruit	seed
7	peg	alcohol	sodium
8	butylene	organic	glycol
9	pentylene	silica	reduces
10	rosa	damage	salicylic
11	glycerin	broad	anti
12	phenoxyethanol	spectrum	vitamin
13	acid	raspberry	helps
14	vitamin	seed	natural
15	ferment	dihydroabietate	zinc
16	filtrate	methyl	glycolic
17	benzoate	acrylates	supports

4.3 Face Masks

Extract: Plant-based extracts provide antioxidant and soothing effects.

Vitamins: Brighten and protect the skin.

Oils: Moisturize and nourish the skin.

Fruit Extracts: Provide antioxidants that benefit skin health.

4.4 Moisturizers

Oil: Moisturizes and locks in moisture.

Glycerin: Attracts moisture and keeps skin hydrated.

Acid: Such as hyaluronic acid, boosts hydration and balances pH.

Vitamins: Nourish and protect the skin.

4. 5 Sun Protection Products

Extract: Antioxidant and soothing plant-based extracts.

Oil: Moisturizes and forms a barrier against UV rays.

Broad Spectrum Ingredients: Provide UVA and UVB protection.

Zinc Oxide: Commonly used for UV protection.

5. DISCUSSION

While certain ingredients perform similar functions across different types of cosmetics *(Table I)*, they are tailored for specific product purposes:

5.1 Common Ingredients & Functions

Water and oil are essential across all categories. Water acts as a solvent, helping with application, while oils provide moisturizing and nourishing benefits, especially important in moisturizers and sun protection products.

Glycerin and glycols are widely used as humectants in cleansers, eye creams, face masks, and moisturizers, indicating their importance in maintaining skin hydration.

Plant extracts are used in masks, sun protection, and eye creams for their antioxidant and soothing properties, highlighting the growing consumer preference for natural ingredients.

5.2 Differences Across Categories

Acid-based ingredients (e.g., salicylic acid, hyal-

uronic acid) are primarily found in cleansers and moisturizers, where they are used for exfoliation and pH balance, but are less common in eye creams and face masks.

Sun protection products focus on specific protective ingredients like zinc oxide and broad-spectrum UV filters, which are unique to this category and reflect its specialized function.

Face masks use fruit extracts and powders (e.g., clay, charcoal) to enhance cleansing effects, which differentiates them from the more nourishing and protective roles of moisturizers and eye creams.

6. CONCLUSION

Core cosmetic ingredients provide similar basic functions such as moisturizing, nourishing, and antioxidant protection, but are adapted for specific products based on their purpose. The rising demand for natural and safe ingredients has driven the widespread use of plant extracts and natural oils across categories. Additionally, specialized ingredients like UV protection in sun care products show the market's increasing focus on product segmentation and targeted skincare needs.

7. ACKNOWLEDGMENT

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