Scientific Research Publishing

Open Journal of Medicinal Chemistry, 2024, 14, 15-28
https://www.scirp.org/journal/ojmc
ISSN Online: 2164-313X
ISSN Print: 2164-3121

Preparation and Characterization of Vitamin-D Incorporated Marshmallow

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How to cite this paper: Ajmal, M., Bibi, R., Imran, R. and Azher, M.A.B. (2024) Preparation and Characterization of Vitamin-D Incorporated Marshmallow. *Open Journal of Medicinal Chemistry*, **14**, 15-28.
https://doi.org/10.4236/ojmc.2024.142002

Received: March 12, 2024
Accepted: June 26, 2024
Published: June 29, 2024

Abstract

This project looks at a novel way to enhance the sensory experience of vitamin D ingestion by incorporating it into marshmallows. This investigation used a human panel taste test with twelve individuals, an index of swelling, and a stability evaluation. Samples of vitamin D infused marshmallows were prepared and given to participants in the human panel taste test, which evaluated mouthfeel and flavor. By analyzing dissolving behavior, the swelling index test revealed unexpected erosion. In addition, a temperature threshold for storage conditions was found through a temperature sensitivity test. All of these techniques assessed the feasibility and palatability of vitamin D supplementation with marshmallow flavor, offering insights into both the possible advantages and difficulties. The marshmallow infusion technique effectively covered up the disagreeable taste of vitamin D pills, leading to reviews that were overwhelmingly favorable ("Moderate Sweet") and that indicated a pleasant mouthfeel. During the swelling index test, it showed erosion behavior, suggesting a certain kind of dissolution that is advantageous for nutritional absorption. Furthermore, the study discovered a temperature sensitivity threshold, highlighting how crucial proper storage conditions are.

Keywords

Vitamin D, Marshmellow Infusion, Taste Making, Supplement Adherence, Nutrient Delivery

1. Introduction

Initially classified as a vitamin in the 20th century, vitamin D is now understood to be a prohormone. Vitamin D2 (ergocalciferol) and vitamin D3 (cholecalciferol) are the two main forms of vitamin D [1]. Vitamin D's function as an immune

system regulator has been studied more lately. Enhancing innate immunity and bolstering the adaptive immune system are two major functions of vitamin D [2]. Increased antimicrobial activity of immune cells like macrophages and monocytes is a result of vitamin D3, which has been identified as a key modulator of innate immune responses [3]. As the main line of defense against unchecked inflammation and viral infection in general, vitamin D can also boost T regulatory cells [4]. Inflammatory cytokines are seen to be elevated in correlation with low vitamin D levels. Together with its immunomodulatory effects, vitamin D can also have anti-inflammatory effects. It does this by raising the levels of anti-inflammatory cytokines and decreasing those of pro-inflammatory cytokines, which cause lung lining destruction and pneumonia. The prevention of respiratory tract infections may be achieved with vitamin D [5]. Findings from the analysis suggested that vitamin D supplementation, whether weekly or daily, provided protection against acute respiratory tract infections, particularly in those who were iron deficient. Acute respiratory tract infections, especially epidemic influenza, have been linked to low serum vitamin D levels in clinical investigations. Insufficient vitamin D may impair respiratory immune function, raising the possibility of COVID-19 severity and mortality, according to certain recent reviews [6]. The absorption of calcium, bone health, and possible immune system support all depend on vitamin D, a crucial fat-soluble vitamin [7]. Supplements, specific foods, and exposure to sunlight can all provide it. Cholecalciferol, or vitamin D3, is produced in humans when solar UV-B irradiation of 7-dehydrocholesterol in the skin produces vitamin D3. This vitamin is then activated in the liver and kidney. Humans can get vitamin D from two different sources: their diet or their body's natural production [8]. A growing number of appropriate products are needed for appropriate supplementation, enabling good compliance also in specific populations at risk, such as the elderly and children, since sunlight exposure and dietary intake alone are typically insufficient for most people to maintain optimal vitamin D status [9]. Lack of it can cause diseases including rickets in kids, osteomalacia in adults, higher risk of fractures, and possible immune system impairment; too much of it can cause hypercalcemia and calcification of soft tissues [10]. Over a billion people worldwide suffer from vitamin D insufficiency (VDD), which is a pandemic [11]. The people of Pakistan are also severely deficient in Vitamin D; in Karachi, it has been estimated that deficiencies in this nutrient might reach up to 91.50% of the population [12]. Hypovitaminosis D has been linked to a number of illnesses, such as hypertension, cardiovascular disease (CVD), type-1 and type-2 diabetes mellitus (DM), obesity, dyslipidemia, congestive heart failure, multiple sclerosis, Parkinson's disease, rheumatoid arthritis, cognitive impairment, and several cancers, including colon, breast, and prostate cancers.

It has also been linked to viral and bacterial infections, chronic obstructive pulmonary diseases, autoimmune diseases, dementia, and pregnancy-related complications [13].

In pediatrics, it is more difficult to manage medication compliance because it

must address the concerns of the patient as well as those of the parent or others. Supplemental vitamin D is also linked to issues with palatability. Children who did not stick to their supplement regimen were more likely to report the palatability of vitamin D3 as unfavorable [14]. To improve palatability and facilitate ease of intake, researchers have recently investigated the possibility of adding vitamin D to innovative food matrices [14]. Vitamin D pills have been made to taste good in a variety of ways by various studies. Confectionary products based on vitamin D have been created by researchers, including films, gums, and fortified dairy sour cream desserts [15]. First created to help patients in their pediatric and geriatric years swallow conventional oral dosage forms, oral disintegrating tablets (ODT) have gained popularity recently as a novel dosage form for assuming active pharmaceutical ingredients, vitamins, and ingredients for food supplements. Alternatively, dispersible films (ODF) are also becoming more and more popular. For the administration of vitamins, food supplements, and active medicinal components, ODF is a unique dosage form. Further, orodispersible films are superior to formulations for oral disintegrating tablets, which can have harder and more costly manufacturing procedures, as well as problems with friability and hardness during production, handling, and use [9]. Chewing medicated gum releases concentrated bioactive components for the purpose of mending certain areas of the body. It is a cohesive, soft, and pleasurable confectionary product. Administering medication through chewing gum has become more common than using pharmaceuticals in pre-dose form. That being said, after chewing, gum bases are thrown away, producing non-biodegradable trash that harms both living things and the environment [16].

The most effective method for preventing vitamin D from degrading in a food matrix is to encapsulate it and add it to an emulsion. Nonetheless, an emulsion in the macro- and nano-ranges is a thermodynamically unstable system that is susceptible to stratification and destabilization over time, according to conventional theories [15].

This study uses the findings from previous research to inform our own investigation as it thoroughly examines the addition of vitamin D to marshmallows and assesses the results through different tests. The history of marshmallows dates back thousands of years; they are not a recent innovation. By mixing honey and the sap from the marshmallow plant's root, the ancient Egyptians created these. While marshmallows were given as gifts to the gods, marshmallows were only enjoyed by Egyptian nobility in the past, unlike now. When marshmallow sap was substituted with gelatin in the middle of the nineteenth century, marshmallow candy which had previously been administered to children in Western nations who had sore throats, lost its medicinal properties. Extruding machines; which became available in the middle of the 20th century as the world grew increasingly industrialized, made marshmallow production feasible in large quantities, and the delicacy spread over the globe. The end product of this project should successfully remove the unpleasant taste of vitamin D and provide an effective and delicious food supplement.

2. Materials and Procedure

2.1. Materials

Ingredients for the marshmallows included:

- Sucrose, or sugar
- Food-grade gelatin powder
- Water
- Food-grade vanilla flavor
- NaCl, or table salt
- Vitamin D

2.2. Procedure

The first step in making marshmallows was to dissolve 20 g of gelatin in 50 ml of warm water and set it aside. 200 g of sugar was then taken and mixed with 100 ml of water. Heating and stirring were employed to dissolve the sugar. The mixture was brought to a boil and began to thicken. The "Soft ball method" was employed to verify the proper temperature and consistency. Using this technique, a drop of heated sugar syrup is added to a cup of cold water. In order to be eligible for this test, the sugar syrup drop must form a "soft ball." A hard ball suggests that the temperature and consistency of the sugar syrup have reached their limit. Temperature can also be measured directly using a candy thermometer and kept at the range of 245˚F - 250˚F.

Gelatin that had been dissolved earlier, was added to sugar syrup once it had reached the proper temperature (soft ball test qualified). The entire mixture was put into a planetary mixer after being swirled once or twice. When the mixture's temperature dropped, it was first mixed at high speed for two to three minutes. Next, while mixing at a moderate speed, 5 ml of vitamin D was added drop by drop. During this period, 1 g of salt and 8 ml of vanilla flavor were also added. The mixture was then mixed at a faster speed until it took the appearance of a "cloud". Then, the mixture was placed on a baking dish and it was chilled for eight hours.

3. Characterization of Product

By providing necessary vitamin D in a more digestible and convenient form, these marshmallows offer a fresh and creative approach to the issue. Its product seeks to address the issues of taste and texture that are frequently related to standard vitamin D supplements by integrating vitamin D into the well-known and delightful medium of marshmallows. The product has the following important feature.

3.1. Physical Form

The marshmallows that were produced had a white hue, a mushy and frothy texture, were porous, and were not tacky.

3.2. Taste and Palatability

A dosage form's acceptability and adherence depends on its palatability, which is a crucial factor. Oral palatability is a reported problem for vitamin D. The marshmallows have a "Moderate Sweet" flavor that manages to cover up any possible fatty or oleogustus taste that comes with vitamin D. They appeal to a broad spectrum of consumers due to their generally well-liked and pleasant taste.

To characterize the taste and palatability of formulated marshmallows, two methods are generally employed:

- E-Tongue Evaluation
- Human Panel Method

3.2.1. E-Tongue Evaluation

"Electronic Tongue", or E-Tongue for short, is a sophisticated *in-vitro* technique used to assess the flavor of oral dosage forms, especially those containing drugs and nutraceuticals. Global selectivity is the foundation of electronic tongue, a sensing technology that has advanced quickly in the recent century. It has the advantage of measuring harmful chemicals and performing objective analysis when compared to human panelists. The e-tongue is mostly used for taste evaluation of pediatric medications, most likely because of its speed, ease of use, and lack of risk, in addition to providing less inaccurate data and causing no weariness [17]. This research does not include this method because it involves *in-vivo* testing from volunteers.

3.2.2. Human Panel Test

The human panel, with its inherent unpredictability, is more realistic way of examining taste [17]. A human panel taste test was carried out as part of an extensive research project with the goal of improving the taste of vitamin D. The purpose of this 12-person taste test was to evaluate the overall sensory experience and flavor of marshmallows that had been fortified with vitamin D. Following the presentation of the produced vitamin D-marshmallow samples, the participants were asked to score two distinct aspects: flavor and overall feel.

3.2.3. Examination of Human Panel

The human panel, with its inherent unpredictability, is more realistic way of examining taste. A human panel taste test was carried out as part of an extensive research project with the goal of improving the taste of vitamin D. The purpose of this 12-person taste test was to evaluate the overall sensory experience and flavor of marshmallows that had been fortified with vitamin D. Following the presentation of the produced vitamin D-marshmallow samples, the participants were asked to score two distinct aspects: flavor and overall feel.

1) Taste Assessment

After chewing and holding the marshmallows in their mouth for at least 30 seconds, the participants were asked to rate how the marshmallows tasted. A

rating scale of the following kind was used:

The rating of 0 (Oleogustus) indicates that the flavor is deemed to be greasy.

i) (Moderate Oleogustus): Those who selected this option reported a moderately greasy flavor.

ii) (Mild Oleogustus): Marshmallows gave this rating due to their mildly fatty flavor.

iii) Participants who chose this option (slight Sweet) reported a slight sweetness.

iv) Marshmallows classified as (Moderate Sweet) were deemed to be rather sweet.

v) The highest rating, "Sweet", signified that the marshmallows were thought to be particularly sweet.

2) Taste Assessment

The general sensation of the marshmallows in the participants' lips was the second component of the taste test to be evaluated. There was once more a rating scale used for this:

i) Unpleasant

ii) Oily Feel in the Mouth

iii) Pleasant feel

3) Swelling Index

Marshmallows should properly dissolve without leaving any residue at salivary pH. This feature guarantees effective palatability as well as nutrient delivery. This property was tested by swelling Index test.

a) Material used for Test

- Weighing balance
- pH meter
- Stirrer
- 500 ml beakers
- Watch glasses
- 100 ml volumetric flask,
- Aluminum foil
- Knife
- Measuring scale
- Metal coin
- NaOH
- KH_2PO_4
- Distilled water

b) Methodology used for Test

To begin the test, 136.086 mg of KH_2PO_4 were weighed out and dissolved in 100 ml of distilled water. A little quantity of distilled water was introduced to a volumetric flask along with 0.04 mg of NaOH. After that, more distilled water was added to reach the 100 ml threshold, creating a 0.1 Molar NaOH solution.

An essential part of the experiment was adjusting the pH. Before being sub-

merged in the KH_2PO_4 solution, which initially had a pH of 4.3, the pH meter was thoroughly cleaned. By adding NaOH solution progressively, the pH was brought to the necessary level of 6.27. This modification sought to replicate the optimal pH environment, which is similar to saliva, in order to ensure the marshmallow cube's appropriate reaction. The next step involved cutting the marshmallow into cubes with measurements of 3.5 cm by 3.5 cm by 1.5 cm. We tested its weight and found that it was 13.4 mg with a total volume of 18.38 cm^3.

To begin the test, the marshmallow cube was put into one of the ready-made beakers with the modified solution inside. A metallic coin that had been cleaned with distilled water was placed on top of the cube to guarantee complete submersion in the event that it floated instead of fully submerged. The timer was started and erosion behavior was measured.

3.3. Temperature Stability

The product shows sensitivity to temperatures higher than forty degrees Celsius, emphasizing the significance of appropriate storage circumstances. It must be stored below the threshold temperature in a dry, cool atmosphere in order to preserve stability.

4. Result and Findings

4.1. Human Panel Test

Table 1 summarizes the results of first part of test which included the taste assessment rated by volunteers 1 - 6 males and 6 - 12 females under the age group of 25 - 30. Amazingly, option 5, which indicates a "Sweet" flavor for the vitamin D-marshmallow samples, was chosen by every single participant—all 12 of them. It appears from the general agreement that the addition of vitamin D to marshmallows effectively covered up any possible oleogustus (fatty taste) and produced a delightful sweetness that the panel enjoyed as shown in Table 1.

Table 1. Volunteer rating taste.

Research Question	Voluteer's Opinion					
	0	1	2	3	4	5
How does it tastes after chewing and keeping marshmallows in oral cavity for at least 30 s?	0	0	0	0	0	12

Table 2 summarizes the second part of test which included the overall feel of the prepared marshmallows. There was also a strong unanimity in this instance, as all 12 participants continuously chose option 2, which denotes a "Pleasant Feel" after eating the vitamin D-enriched marshmallows. The fact that there was no perceived unpleasantness or oily feeling suggests that the marshmallows were well-liked not only for their taste but also for their mouthfeel. In conclusion, the twelve-person human panel taste test produced very encouraging findings.

A "Moderate Sweet" flavor and a "Pleasant Feel" in the mouth were consistently reported for the vitamin D-enriched marshmallows, indicating the effective relief of taste problems related to vitamin D administration. These results indicate that the formulation has the potential to be a palatable method of delivering vitamin D and offer important new insights into its acceptability. As shown in Table 2.

Table 2. Volunteer rating of feel of taste.

Research Question	Volunteer's Opinion		
	0	1	2
How will you rate the overall feel?	0	0	12

4.2. Swelling Index Test/Erosion Measurement Test

Intriguing results came from the Swelling Index Test, which was part of the research effort. It showed erosion instead of swelling, a feature that is advantageous in pharmacological situations. This amazing result was the result of a meticulously planned process that included the preparation of a buffer solution to approximate the ideal pH of saliva. It started through an initiation stage 1 in which erosion has not really started yet and only the surface seems to be swelled as shown in Figure 1. Due to wear and tear, the solvent has penetrated into the cube and the cube has started ripping without erosion in stage 4 as shown in Figure 2. After that erosion has started; parameter of marshmallow has blurred and diffused and the color of solvent has become turbid as well at stage 6 as shown in Figure 3. In final step, marshmallow has eroded completely at stage 8 as shown in Figure 4.

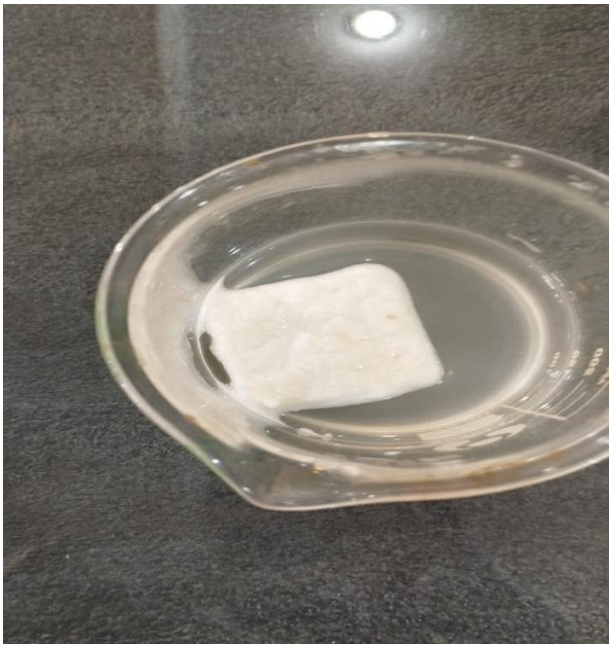

Figure 1. Initial step: Stage 01.

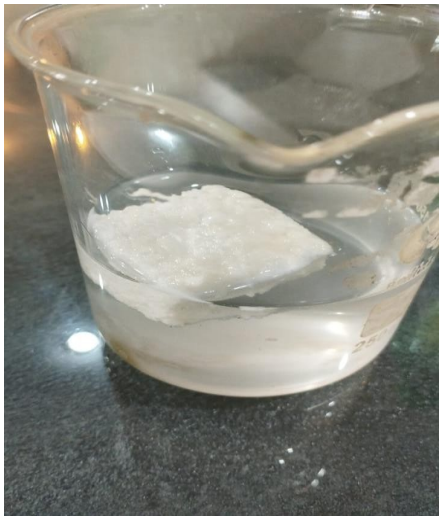

Figure 2. Stage 04: ripping.

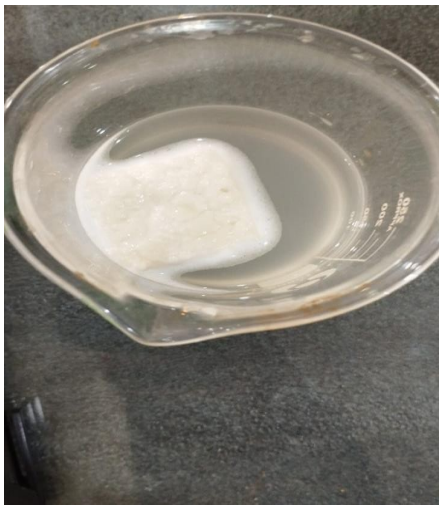

Figure 3. Stage 06: erosion initiation.

Figure 4. Stage 08: full erosion.

The marshmallow cube was eroding rather than growing during the test, as the solution progressively turned turbid. Every five minutes on average, the cube was taken out of the solution and its weight help of digital scale and volume using water displacement method were recorded. The results for swelling index are summarized in Table 3. The Graphical Representation of the Observed Volume and weight at Different Time Intervals are shown in form of vertical coordinates in Figure 5 and Figure 6 respectively.

Table 3. Summarization of swelling index.

		V (cm^3)	W (mg)
Sr. No.	Time Interval		
1	0 min	18.3	13.4
2	5 min	15.87	11.76
3	10 min	13.88	10.40
4	15 min	11.21	8.74
5	20 min	8.89	7.47
6	25 min	6.28	5.66
7	30 min	3.86	4.29
8	35 min	1.79	3.6

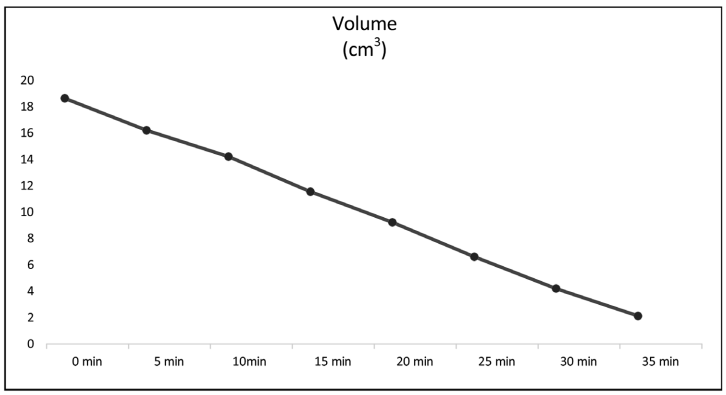

Figure 5. Graphical representation of the observed volume at different time intervals.

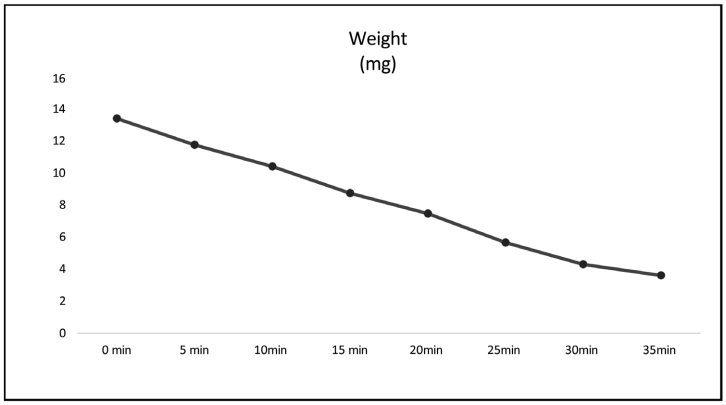

Figure 6. Graphical representation of the observed weight at different time intervals.

Important insights on the marshmallow cube's erosion behavior were obtained from the data gathered, which included weight and volume measurements. Plotting the data on a graph showed a steady declining trend with small fluctuations. According to this pattern, the marshmallow particles were evenly distributed, which led to a smooth surface erosion devoid of appreciable porosity. A small amount of non-uniformity and solution penetration at particular cube spots was shown by the graph's minor variations. The uniform deterioration of vitamin D-enriched marshmallows in a controlled setting is demonstrated by this experiment, which may have benefits for medicinal applications. Important information for additional study and development is provided by the regulated pH and well-recorded erosion behavior.

4.3. Temperature Stability Test

Our project's stability test, which is an essential step, was created to evaluate the product's capacity to endure temperature changes and hold its integrity over time. Throughout this experiment, we raised the temperatures gradually from 25˚C and higher. When the marshmallows started to change at 40˚C, an important discovery was made. This is when they began to melt, indicating that the product behaved similarly to a refrigerator element. This discovery provides important information about how to store our vitamin D-enriched marshmallows, showing that high temperatures should not be applied to them in order to keep them stable and retain their original shape and usefulness. In order to maintain the product's effectiveness and customer appeal, the stability test results offer crucial direction for handling and storage requirements.

5. Discussion

For a number of reasons, the project's extensive effort is notable. First off, by addressing the problems with vitamin D supplement palatability, it effectively addressed a major obstacle in the field of nutrient supplementation. Outstanding findings were obtained from the Human Panel Taste Test, wherein every participant consistently rated the vitamin D-enriched marshmallows as having a "Moderate Sweet" taste and a "Pleasant Feel" in the tongue. The project's ability to improve the taste of vitamin D is demonstrated by this result, which may encourage increased adherence to supplementing schedules.

Additionally, the Swelling Index Test yielded a valuable but unexpected discovery. A constant dissolving and absorption are crucial for pharmaceutical aims, and the observation of erosion rather than swelling shows that the marshmallows can dissolve consistently in the mouth.

The project gained a crucial aspect from the Stability Test, which highlighted the significance of appropriate storage conditions. The fact that the marshmallows become soft at temperatures higher than 40˚C highlights the pragmatic factors that must be taken into account to ensure the stability and quality of the product. The recommendations for product handling and storage are based on

this conclusion.

In addition, it provides a workable answer to the issue of providing vital nutrients to particular demographics, including kids and the elderly, who frequently have trouble consuming conventional supplement forms. Since marshmallows are so tasty and easy to eat, they can help patients comply with their treatment plans and continuously receive the health advantages of vitamin D. For the immune system, bone health, mood management, and other reasons, enough vitamin D intake is essential. Better health outcomes and a possible lower risk of disorders linked to vitamin D insufficiency can result from increased supplement adherence, which can be attributed to improved palatability. By tackling a typical obstacle to supplement adherence, this study advances public health initiatives. It has the ability to improve overall health outcomes by perhaps lowering the prevalence of disorders linked to vitamin D insufficiency, such as autoimmune diseases and osteoporosis.

Using marshmallows as a vehicle, this project presents a novel strategy for nutrient delivery. Due to its efficacy, this strategy can be used to address palatability issues with other vitamins and nutrients. The conclusions may persuade the supplement and pharmaceutical businesses to think of creative ways to improve the taste and usability of their products. This can therefore spur the creation of fresh, enhanced items.

In summary, the project demonstrates a novel strategy for optimizing nutrient delivery systems, with a particular emphasis on increasing the feasibility and acceptability of vitamin D supplementation. The endeavor not only offers a promising means of enhancing supplement adherence but also advances the fields of nutraceuticals and pharmaceuticals by skillfully incorporating vitamin D into marshmallows and resolving taste and solubility issues. Taste testing, erosion behavior, stability assessments, and other extensive methods used in the research highlight the breadth of its scientific investigation and possible effects on public health and welfare.

6. Limitations

Despite the encouraging results of the project on vitamin D-enriched marshmallows, it's critical to recognize its limitations.

6.1. Temperature Stability

With only 12 participants, the Human Panel Taste Test may not accurately reflect the wide range of tastes and preferences of the general public due to its small sample size. The generalizability of the results might be improved with a larger and more demographically varied sample.

6.2. Pre-Formulation

Due to time constraints, pre-formulation studies were not performed. For further exploring marshmallows as a novel dosage form, these studies can be done

along with compatibility testing with other APIs and nutraceuticals.

6.3. Assessment of Short-Term Stability

The main emphasis of the Stability Test was how the marshmallows reacted to brief temperature fluctuations. Longer-term stability evaluations that took into account variables like shelf-life and exposure to different environmental conditions were outside the purview of this study. The Stability Test evaluated the marshmallows' sensitivity to temperature; however, it did not investigate the marshmallows' possible susceptibility to other environmental conditions, which might significantly affect the stability of the product, like humidity or light exposure.

6.4. Lack of Control Group

It was difficult to make direct comparisons between the palatability improvements brought about by the marshmallow delivery mechanism and the taste test as there was no control group taking conventional vitamin D supplements.

The research effort provides a useful beginning point for addressing difficulties related to vitamin D supplement palatability, notwithstanding these limitations. The subject of nutrition delivery and supplementation could be further advanced by future research by building on these results and addressing these constraints.

Conflicts of Interest

The Authors declare no conflict of interest regarding the publication of paper.

Acknowledgements

We are collectively grateful to Dr. Nasir Abbas, Professor at College of Pharmacy, University of Punjab for his kind support and guidance during whole research journey and write-up of manuscript.

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