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Skin Hydration Potential of a Fluid Gel-Based Formulation of *Kappaphycus alvarezii* (Rhodophyta, Gigartinales)

Laiara Torres [1], Bianca Aparecida Martin [2], Laura de Martin Coletti [1], Bruna de Souza Altoé Adorno [3], Juliana da Silva Coppede [1], Renata Fonseca Vianna Lopez [2], Suzelei de Castro França [1], Ana Lucia Fachin [1] and Mozart Marins [1,4,*]

[1] Unidade de Biotecnologia, Universidade de Ribeirão Preto-UNAERP, Ribeirão Preto 14096-900, SP, Brazil; laiara.torres@sou.unaerp.edu.br (L.T.); jcoppede@unaerp.br (J.d.S.C.)
[2] Faculdade de Ciências Farmacêuticas de Ribeirão Preto, Universidade de São Paulo-USP, Ribeirão Preto 14040-903, SP, Brazil
[3] Curso de Ciências Farmacêuticas, Universidade de Ribeirão Preto-UNAERP, Ribeirão Preto 14096-900, SP, Brazil
[4] Algastech Aquiculture, Research and Development, Ubatuba 11695-722, SP, Brazil
* Correspondence: mmarins@unaerp.br

Abstract

The red alga *Kappaphycus alvarezii* is a rich source of bioactive compounds with potential applications in the cosmetic industry. This study aimed to characterize a cosmetic serum containing *K. alvarezii* and evaluate its immediate moisturizing effect on the skin. A randomized, triple-blind, parallel-group clinical trial was conducted with 28 healthy participants, allocated 1:1 to receive either a control formulation with hyaluronic acid or a test formulation with *K. alvarezii*. The formulations were assessed for stability over 60 days using organoleptic, microbiological, pH, and rheological analyses. Mechanical and bioadhesive properties were assessed using a texture analyzer, while the water content of the stratum corneum on the palms and backs of the hands was measured in vivo using a Corneometer® CM 825 (Courage & Khazaka Electronic GmbH). Both formulations showed similar stability and rheological behavior. Texture analysis indicated comparable compressibility and elasticity, with a slight reduction in bioadhesive strength for the test formulation. In vivo results demonstrated a moisturizing effect for both formulations, with a significant increase in palmar hydration 60 min after application of the *K. alvarezii* serum. These findings indicate that the formulation containing *K. alvarezii* can improve short term skin surface hydration; potential contributions of film formation and barrier modulation remain hypothetical and were not directly assessed in this study.

Keywords: hydration; skin barrier; cosmetics; polymers; seaweed; *Kappaphycus alvarezii*

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1. Introduction

The main function of the skin is to provide a protective barrier against external agents and water loss [1]. Skin health is influenced by the balance between the renewal of skin cells and adequate hydration levels. The amount of water in the stratum corneum, together with lipids on the surface, maintains a balance that is essential for the appearance and function of the skin [2]. Considering these aspects, the maintenance of skin hydration levels can be attributed to important factors such as the presence of intercellular lipids, corneocytes immersed in the lipid matrix, and natural hydration factor (NHF) [3,4], as well

as hyaluronic acid [5] and aquaporin 3 (AQP-3), a member of the AQP family of membrane proteins that facilitate the transport of molecules such as water and glycerol [6,7].

Structural and functional changes occur in the skin as individuals age, including a decrease in cell renewal and in collagen and elastin synthesis, a reduction in the capacity to neutralize free radicals, and progressive loss of skin hydration, factors that contribute to the process of skin aging [8,9]. It is therefore important to invest in preventive cosmetic products such as moisturizers [10]. Formulations with hydration potential are developed to improve and maintain the skin's barrier function, preventing the establishment of dry skin (xerosis) [11,12].

Topical hydration is an alternative to help maintain water content; its mechanism involves applying products directly to the skin. The moisturizing ingredients present in a formulation can act through different mechanisms such as wetting and occlusion. Humectants have the capacity to attract and retain water in the skin, i.e., water retention occurs from the formulation, the atmosphere, and water lost by the most superficial zone of the stratum corneum. Occlusive substances form a superficial layer that prevents surface evaporation of water, known as transepidermal water loss [13–15].

Cosmetic formulations developed based on polymers that can form polymeric films can reduce transepidermal water loss [16,17]. In view of the growing ideal for healthier skin and awareness of the risks associated with the use of chemical products, the search for cosmetics that contain natural products has intensified [18]. Within this context, the use of seaweed in the field of cosmetics has gained prominence and there are several possible applications [19]. *K. alvarezii* (Rhodophyta, Gigartinales) is an economically important seaweed that is cultivated in tropical regions across more than 20 countries [20]. The main product derived from its biomass is carrageenan, a sulfated polysaccharide [21] which, in addition to its emulsifying and gelling properties [22], has moisturizing potential [23]. Although research involving seaweed, particularly *K. alvarezii*, has increased in recent years, further studies are still needed to fully explore its potential and applications, especially in the fields of biotechnology and cosmetics [24,25]. Most available data on *K. alvarezii* concern carrageenan used as a food or pharmaceutical excipient, whereas few studies have examined cosmetic serums containing minimally processed fluid gels derived from this seaweed in human in vivo investigations. Evidence concerning the short-term moisturizing performance and the mechanical and bioadhesive properties of *K. alvarezii*-based serums compared with established moisturizing formulations remains scarce.

In the present study, we chose to formulate a serum, a more fluid and easy-to-apply cosmetic product that favors the formation of a superficial film on the skin and that could contribute to skin hydration. This choice was also based on traditional practices observed among shellfish farmers who use the natural gel from seaweed as hand protection, claiming that the gel improves the dryness caused by constant exposure to salt water and environmental conditions.

The aim of the present study was to characterize a cosmetic serum containing a gel extract of the seaweed *K. alvarezii*, and to evaluate in vivo the moisturizing effect of the formulation on the skin, including sensory analysis.

2. Material and Methods

2.1. Materials

The following excipients were used for preparation of the formulations: Sclerotium Gum (Amigel®) and Aminomethyl Propanol purchased from PharmaSpecial (São Paulo, SP, Brazil); Silanetriol and Hyaluronic Acid (Hyaxel®) obtained from Biotec (São Paulo, SP, Brazil); Phenoxyethanol (and) Ethylhexylglycerin (ProTeg SL, Belo Horizonte, Brazil) purchased from Biovital (São Paulo, SP, Brazil); Propylene Glycol and Disodium EDTA

purchased from Fagron (São Paulo, SP, Brazil), and fragrance obtained from ATR Essências (São Bernardo do Campo, SP, Brazil).

The seaweed samples were obtained from *K. alvarezii* farms located in the city of Paraty, Rio de Janeiro, Brazil (23º13′39.6″ S, 44º37′25.6″ W). Some samples were separated for the production exsiccates. The samples were identified and registered in the herbarium of the Institute of Biosciences, University of São Paulo.

2.2. Preparation of the Formulations

The cosmetic formulations were developed to obtain a polysaccharide-based serum with film-forming properties. Formulation F1 is a serum based on Sclerotium Gum supplemented with Silanetriol (and) Hyaluronic Acid (fractionated hyaluronic acid). Formulation F2 is a serum based on fluid gel from *K. alvarezii*. Preliminary, non-reported formulation trials indicated that 1.5% (*w*/*w*) *K. alvarezii* fluid gel provided suitable viscosity, spreadability, and sensory acceptability for cosmetic application. In addition, this concentration was selected to approximate the polymer content of F1 (1.5% sclerotium gum), allowing comparison between formulations containing similar polysaccharide levels from different sources. Formulation F1 was prepared under stirring and heating. The components of the aqueous phase (Disodium EDTA, Propylene Glycol, and Aqua/Water) were added and heated to approximately 60 °C. Next, Sclerotium Gum was added under stirring until formation of a gel. After cooling to below 40 °C, the active ingredient of Silanetriol (and) Hyaluronic Acid was added. The mixture was again submitted to mechanical stirring for 1 min at 100 rpm and the preservative was added.

Formulation F2 was prepared under stirring and heating. The gel obtained was filtered and the following components were added: Disodium EDTA, Propylene Glycol and Phenoxyethanol (and) Ethylhexylglycerin. At a temperature below 40 °C, the fragrance was added and the mixture was again submitted to mechanical stirring for 1 min at 100 rpm. The pH was measured and adjusted with Aminomethyl Propanol. Sclerotium gum was selected for formulation F1 because it is also a polysaccharide of natural origin, allowing for greater biocompatibility with the alga-derived polymeric component present in formulation F2.

In this study, the natural fluid gel of *Kappaphycus alvarezii* was used, obtained without the use of organic solvents or conventional extraction processes. All cosmetic formulations were prepared in a sterile vertical laminar flow cabinet using autoclaved materials. Table 1 shows the composition of the formulations.

Table 1. Composition of the serum formulations (% *w*/*w*).

Ingredients	F1	F2
Aqua/Water	q.s.	q.s.
Silanetriol (and) Hyaluronic Acid	2%	-
Sclerotium Gum	1.5%	-
Propylene Glycol	2%	2%
Kappaphycus alvarezii	-	1.5%
Phenoxyethanol (and) Ethylhexylglycerin	1%	1%
Disodium EDTA	0.5%	0.5%
Fragrance	q.s.	q.s.
Aminomethyl Propanol	-	pH 5.0–5.5

2.3. Cytotoxicity Assessment of the Seaweed Fluid Gel

Cytotoxicity was assessed using human keratinocytes (HaCaT) acquired from the Rio de Janeiro Cell Bank (BCRJ). The cells were cultured in RPMI-1640 medium (Sigma-Aldrich®, St. Louis, MO, USA) supplemented with 10% fetal bovine serum (Cultilab, Campinas, SP, Brazil) and antibiotics [penicillin (10.000 U·mL^{-1}), streptomycin

(10.000 μg·mL^{-1}), kanamycin (5 mg·mL^{-1}), ciprofloxacin (50 mg·mL^{-1}), and amphotericin B (250 μg·mL^{-1})], at 37 °C in a humidified 5% CO_2 atmosphere.

For the assays, the cells were seeded in 96-well opaque plates at a concentration of 1×10^4 cells/well and incubated for 24 h for adhesion. After this period, the culture medium was removed, the cells were washed with saline (Hanks), and the *K. alvarezii* fluid gel (test compound) diluted in medium to a concentration of 1.5% (with and without preservative), the concentration used in the formulation, was added. Negative and positive control groups were also prepared. The plates were incubated at 37 °C for an exposure period of 24 h. The cytotoxic effect was evaluated using the CellTox™ Green Cytotoxicity Assay (Promega Corporation, G8741, Medison, WI, USA), following the manufacturer's recommendations [26]. Briefly, after 24 h of cell treatment, the Celltox™ Green reagent was prepared and the assay buffer and reagent were pipetted into an Eppendorf tube at a ratio of 1:500 and homogenized by vortexing. Next, 20 μL of this solution was added to each well. In the positive control, the lysis reagent was added at a ratio of 1:25, 30 min before reading. The plates were shaken on an orbital shaker for 1 min at 700 rpm and then kept at room temperature for 15 min, protected from light. The plates were read in a microplate reader (Glomax® Discover, Promega Corporation, Medison, WI, USA) at a wavelength of 550 nm.

2.4. Stability Analysis of the Serum Formulations

The stability of the formulations was assessed following the Cosmetic Product Stability Guide, complemented by Brazilian Pharmacopoeia methodologies. The formulations were stored at room temperature (25 ± 2 °C), and the tests were performed over a period of 60 days.

Organoleptic and microbiological characteristics, pH, and rheological behavior of the formulations were analyzed. The samples were visually evaluated regarding appearance, color, and odor 72 h after preparation of the formulations (T0) and after 30 (T30) and 60 days (T60). Microbiological testing was performed following Brazilian Pharmacopoeia methodologies for non-sterile products and general plate counting methods for aerobic microorganisms, fungi, and pathogenic microorganisms such as *Escherichia coli* (ATCC 8739), *Staphylococcus aureus* (ATCC 6538P), and *Pseudomonas aeruginosa* (ATCC 9027) [27]. For analysis of the results, the parameters of Resolution RDC 907/24 of the Collegiate Board of the Brazilian Health Regulatory Agency (ANVISA) for microbiological control of personal hygiene products, cosmetics, and perfumes classified as type I and type II were followed [28]. The pH of the formulations was measured with a Gehaka PG1800 pH meter (Gehaka, São Paulo, Brazil) and the mean of triplicate measurements was obtained. The microbiological analyses and pH measurements were performed at T0, T30, and T60.

Rheological evaluation was performed in triplicate at room temperature (25 °C) using a rheometer (R/S plus Rheometer, Brookfield, New York, NY, USA) equipped with a cone-plate measuring system (40 mm), 100 μm (0.1 mm) gap, and P50 spindle. The device was calibrated and approximately 2 g of each formulation was applied to the plate and maintained for 60 s. The flow curves were obtained at a shear rate tau (Pa) of 1 to 120 s^{-1} over 60 s. The Origin 6.1 program (OriginLab, Northampton, MA, USA) was used for calculation of the hysteresis areas. The integrals of the ascending and descending curves were generated and the values of the descending curve were subtracted from the values of the ascending curve. The results were obtained as the mean of triplicate measurements.

2.5. Texture Profile Analysis

The mechanical properties of the F1 and F2 formulations containing fluid gels were determined by texture profile analysis in a texture analyzer (TA-XT, Stable Micro Systems

Ltd., Godalming, UK). Adapted from the method of Jones, Woolfson and Djokic [29], the probe (25 mm in diameter) connected to the analyzer was inserted vertically into the sample and was then compressed twice at a compression rate of 2 mm·s^{-1}, depth of 2 cm, and interval of 15 s between the end of the first and the beginning of the second compression. The following parameters were determined: compressibility (capacity of reduction when a force is applied), cohesiveness (resistance of the material to dissociation or separation), hardness (maximum force required to achieve a certain deformation of the material), and elasticity (property of the product to return to its original condition after partial compression). The analyses were performed in triplicate and the results were obtained with the Exponent software Version 5 (Stable Micro Systems Ltd., Godalming, UK).

2.6. Ex Vivo Evaluation of Bioadhesive Strength

The project was approved by the Research Ethics Commitees: UNAERP and FCFRP/USP–CAAE 82038424.5.0000.5498, approved on 4 October 2024, and CAAE 82038424.5.3001.5403, approved on 6 December 2024.

For analysis, human breast skin samples collected during plastic surgeries performed at the Lotus Clinic, Ribeirão Preto, SP, were used. After collection, the skin samples were immediately sent to the laboratory and cleaned, including the removal of adipose tissue. The fresh skin samples were placed on the support of the TA-XT texture analyzer (Stable Micro Systems Ltd., Godalming, UK) and the formulation was attached to the probe connected to the device. The probe was then moved downwards until it reached the skin surface, maintaining contact at a force of 0.5 N for 3 min. After this period, the accessory was moved upwards at a constant speed of 1 mm·min^{-1}. Using the Exponent software (version 5), the force required to detach the formulation from the skin and the bioadhesion work (area under the force vs. distance curve) were determined. Formulations F1 and F2 were tested. The assay was performed in triplicate.

2.7. Statistical Analysis

The results are presented as mean and standard deviation. Statistical analyses were performed using the GraphPad Prism 9.0 software (GraphPad Software, Boston, MA, USA). The *t*-test was used to compare the means of two groups. For more than two groups and multiple comparisons, data were evaluated using ANOVA, followed by Tukey's post hoc test.

2.8. Short-Term In Vivo Study

2.8.1. Study Protocol and Participants

This study complied with the ethical principles of the Declaration of Helsinki and was approved by the Research Ethics Committees of the University of Ribeirão Preto, UNAERP and the Faculty of Pharmaceutical Sciences of Ribeirão Preto, USP (FCFRP/USP), where the study was conducted (CAAE 82038424.5.0000.5498, approved on 04/10/2024, and CAAE 82038424.5.3001.5403, approved on 06/12/2024, respectively). This study was designed as a randomized, triple-blind, parallel-group clinical trial. All participants were fully informed about the objectives and procedures of the clinical study and voluntarily signed an informed consent form before participation. After approval, 28 participants were selected to participate in the study. Eligible participants were healthy, non-pregnant, healthy individuals of both sexes aged 18 to 60 years with verbal communication and understanding capacity, who were interested and available to participate in the study, were included. The following exclusion criteria were established: withdrawal from the study, report of allergies to any of the components present in the formulations, presence of any dermatological disease on the hands that could interfere with the study, and use of any

moisturizing product in the experimental area 2 days before the start of the study and on the day of study.

Participants who met the inclusion criteria were invited to participate in the study and received the informed consent form and information about the study in order to decide whether or not they want to participate. After reading the informed consent form, individuals who agreed to participate in the study signed the document, which was issued in two copies, one remained with the person responsible for the study and the other with the participant. Participants were randomly assigned to two groups: one group received formulation F1 and the other group received formulation F2, using a simple randomization method with a 1:1 allocation ratio. The random allocation sequence was generated and applied by a researcher not involved in participant evaluation or data analysis. Both groups had female and male participants, aged between 18 and 60 years. The formulation to be applied was randomly selected; thus, this was a randomized, triple-blind trial, in which the physician, participants and main researcher did not know which formulation each participant was using. The study was conducted following CONSORT guidelines for randomized clinical trials [30].

Measurements were taken in the center of the palm and dorsal of the hands (Figure 1) before (baseline) and 10, 30 and 60 min after application of the serum formulations. Formulation F1 was used as a control and F2 was the test formulation. Participants performed a single application of formulations. Temperature and relative humidity were maintained at 20 °C and 40–60%, respectively, according to the operating manual of the equipment to eliminate possible interferences.

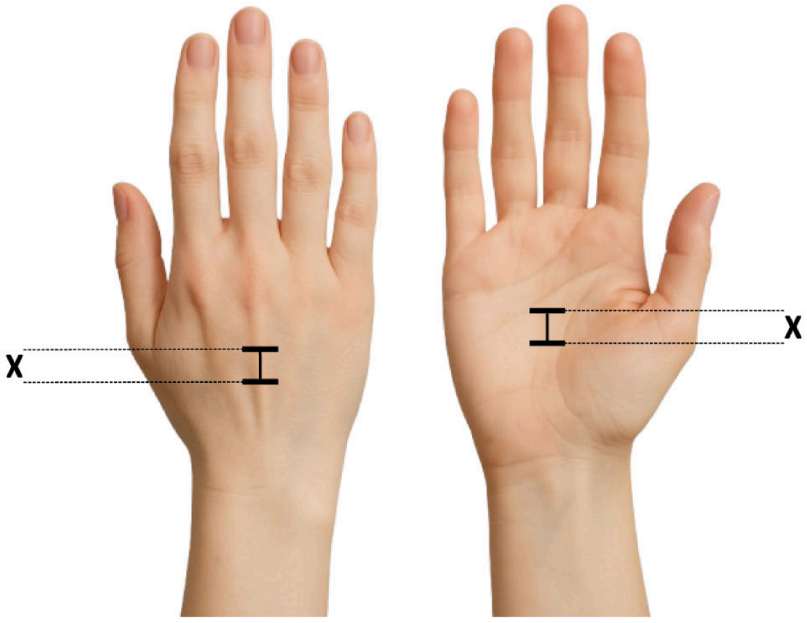


Figure 1. Representation of the hand regions delimited for hydration assessment.

2.8.2. Sample Size

The sample size was determined based on in vivo studies in humans using formulations with moisturizing potential. Due to the exploratory nature of the study, a sample of 28 participants was considered sufficient to detect short-term changes in skin hydration.

2.8.3. Instrument Used in the Assay

The water content of the *stratum corneum*–hydration level of the skin surface–was evaluated using the Corneometer® CM 825 (Courage & Khazaka Electronic GmbH, Köln, Germany). This device measures the electrical capacitance of the stratum corneum. Val-

ues are expressed as arbitrary units (AU), which indicate the level of hydration, with a theoretical variation of 0 to 120 AU [31,32].

2.8.4. Sensory Analysis

The 28 healthy, non-pregnant participants (mean age of 36.1 ± 11.81 years) of both sexes with verbal communication and understanding capacity, who were interested and available to participate in the study, were enrolled in this analysis. Sensory analysis was performed after application of the formulations. Thus, skin hydration was assessed at the end of the study through application of a questionnaire completed by the participants. The participants in each group evaluated only the formulation they had received. The analysis was based on the efficacy perceived by the participant. Parameters such as spreadability, absorption sensation, and hydration were evaluated.

2.8.5. Statistical Analysis of the Clinical Study Data

Sociodemographic data, skin type, frequency of use of moisturizing products, and conditions of the participants were tabulated in Microsoft Office Excel® (Office 365, Redmonda, WA, USA). Fisher's exact test was used for the comparison of two categories and the chi-square test for the comparison of more than two categories. The results of the in vivo test were expressed as mean and standard deviation. Analysis of variance (ANOVA) followed by Tukey's post hoc test was applied to assess the statistical significance of the results using the GraphPrism 9.0 software (GraphPad Software, Boston, MA, USA). A p-value less than 5% ($p < 0.05$) was considered significant. The results of sensory analysis were analyzed using the GraphPrism 9.0 software.

3. Results and Discussion

3.1. Cytotoxicity of the Fluid Gel

The cytotoxic effect of *K. alvarezii* fluid gel samples on HaCaT cells at a 1.5% concentration, the same used in the formulation, showed a cytotoxicity level of 13.3%. When the preservative was included, the result was negative, in contrast to the positive control, which reached 93.9%. There was a significant difference in the effect of the gel extract compared to the positive control group, with a lower percentage of cell death, and a nonsignificant effect ($p > 0.05$) compared to the gel with preservative, demonstrating that the seaweed present in F2 does not pose significant cytotoxic risks. When compared to other red seaweeds tested under similar conditions, such as the lipophilic extract of *Gracilaria fisheri*, which also showed no significant cytotoxic effect at low concetrations ($\leq$25 μg mL^{-1}), the crude extract maintained cell viability above 70% in HaCaT cells [33], and from *Gelidium corneum*, which markedly reduced cell viability at 1000 μg·mL^{-1} (19.3% and 26.4% viable cells, respectively) and maintained cytotoxicity down to 100 μg·mL^{-1} [34], the *K. alvarezii* gel also exhibited a notably safe profile. These comparisons reinforce that *K. alvarezii* can be considered of low cytotoxicity, supporting its suitability as a cosmetic ingredient. The values were found in relative fluorescence units (RFU) and were expressed as percentage of cytotoxicity (Figure 2). Overall, the cytotoxicity assessment was conducted as an exploratory analysis at a single concentration (1.5%), corresponding to the level used in the cosmetic formulation, and within this context the results support a favorable safety profile for *K. alvarezii* gel at its intended use concentration, although more detailed dose–response studies would be valuable in future work.

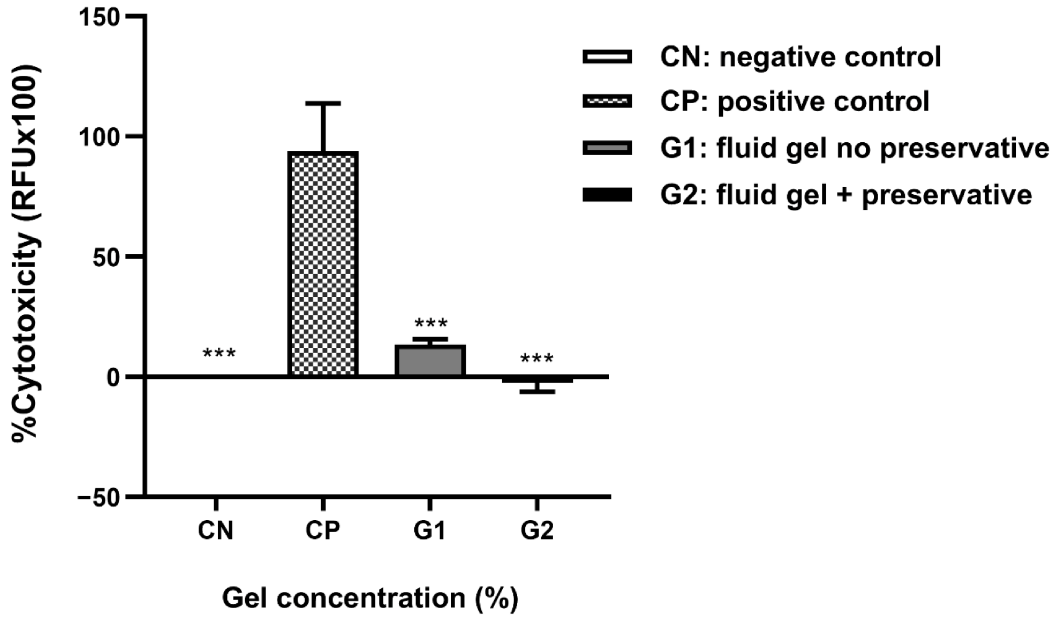


Figure 2. Cytotoxicity of *Kappaphycus alvarezii* gel. *** $p < 0.001$ significant difference compared to the positive control group (one-way ANOVA followed by Tukey's post hoc test) ($p < 0.05$).

3.2. Stability of the Formulations

The formulations were classified as normal, without alterations, after 60 days of storage at room temperature, showing no significant apparent changes in appearance, color, or odor.

The microbiological analyses revealed no contamination with *P. aeruginosa*, *S. aureus* or *E. coli* in any of the formulations. Regarding mesophilic microorganisms, following the criteria of the Brazilian Pharmacopoeia, the count was less than one time the factor of the corresponding lowest dilution, i.e., less than 10 CFU/g or mL, for both formulations, meeting the limits established by ANVISA for microorganisms in type I and II cosmetic products [27,28].

The pH values of the formulations remained stable over the period studied and were compatible with the skin pH, which ranges from 4.6 to 5.8 [11] (Table S1).

The rheograms of the formulations (Figure 3) permitted to analyze the rheological profile as a function of storage time. Formulations F1 and F2 exhibited non-Newtonian behavior (pseudoplastic and thixotropic fluid). Thixotropy describes the ability of a material to restructure and recover its original structure after the cessation of shear stress, i.e., once applied to the skin, the formulation tends to recover its original viscosity, preventing it from running. Thus, the presence of thixotropic behavior is essential [35,36]. The ascending curve permitted to classify the flow behavior as non-Newtonian, while the descending curve enabled the identification of the thixotropic behavior [37]. Furthermore, pseudoplastic behavior is important for topical formulations since it improves flow when subjected to tension, enabling better distribution and spreadability on the skin surface [38].

The hysteresis area was calculated from the ascending and descending flow curves. Formulation F2 showed a significant difference in hysteresis area when compared to F1 ($p < 0.001$) ($F_{2.12} = 21.95$), with an increase in this area and consequently in thixotropy over the 60 days of study (Table S2). This finding is possibly due to the presence of hyaluronic acid in F1, which more dynamically reduces the time required for the structure of the formulation to reorganize. This active ingredient also has viscoelastic properties that contribute to its ability to return to its original shape after deformation [39].

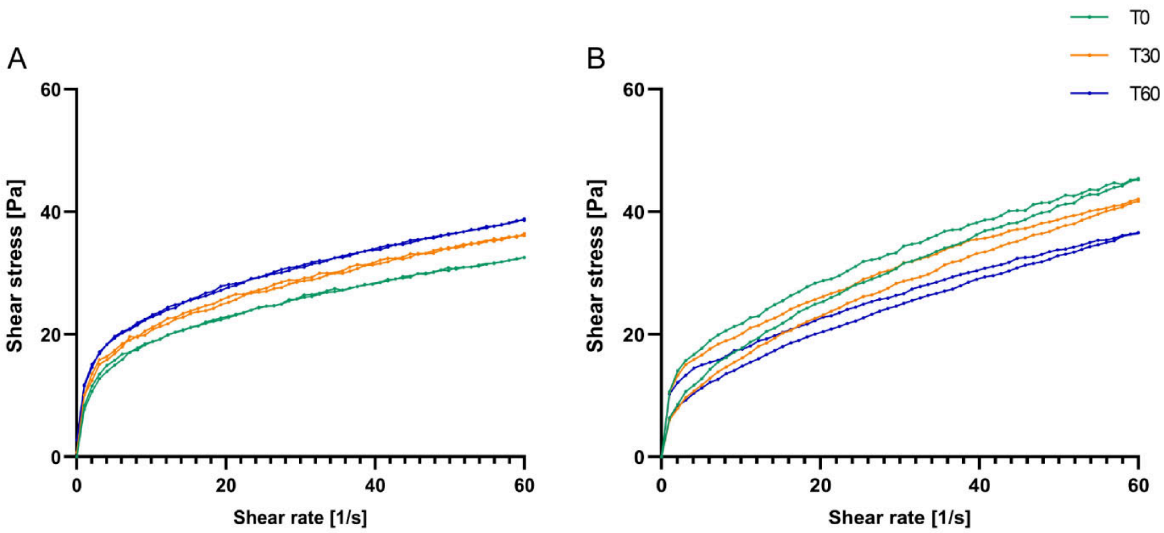


Figure 3. Flow curves (shear stress vs. shear rate) of formulations F1 (**A**) and F2 (**B**). The formulations were stored at room temperature and evaluated 3 days after preparation (T0) and after 30 (T30) and 60 (T60) days.

3.3. Characterization and Evaluation of the Properties of the Formulations

Formulations F1 and F2 had a light texture and fluid characteristics and were homogenous. Each formulation had a specific color.

Table 2 shows the mechanical properties of the formulations at a temperature of 25 °C. Assessment of the mechanical and bioadhesive properties of a topical formulation is essential to ensure its adhesion and efficacy. For this purpose, the bioadhesive profile and texture of the formulation are evaluated, which enable the measurement of parameters such as hardness, cohesiveness, compressibility, and elasticity, in addition to detachment strength and bioadhesion work [29]. The lower hardness and compressibility suggest that F1 was easier to apply and had better spreadability compared to F2. Regarding cohesiveness, there were no significant differences between formulations (*t*-test, $p > 0.05$), suggesting good adhesion of both F1 and F2 to the skin. Furthermore, the formulations were similar in terms of elasticity, with no significant differences (*t*-test, $p > 0.05$), suggesting that F2 also possesses elastic and restructuring capacity similar to F1, which was used as control.

Table 2. Mechanical properties of serum formulations.

Formulation	Hardness (N)	Compressibility (N·mm)	Cohesiveness	Elasticity
F1	0.3327 ± 0.004	1.003 ± 0.012	0.8863 ± 0.026	0.9996 ± 0.000
F2	0.4346 ± 0.023 **	1.377 ± 0.048 ***	0.8609 ± 0.035	0.9999 ± 0.000

Data are presented as mean ± standard error of the mean. ** $p < 0.01$ and *** $p < 0.001$: significant difference compared to F1 (control) according to the *t*-test ($p < 0.05$).

Formulation F2 exhibited a slightly lower detachment force than F1 (Figure 4). Consequently, the bioadhesion work, i.e., the energy required to detach F1 from the skin was significantly lower when compared to F2. However, the formulations did not differ significantly in terms of bioadhesive strength (*t*-test, $p > 0.05$), suggesting good adhesion to the skin as indicated by the mechanical properties. In bioadhesion analysis, a greater force is required to detach the formulation from the skin [40]. Bioadhesive systems can extend the permanence of formulations at the site of application, reducing the frequency of application [41–43].

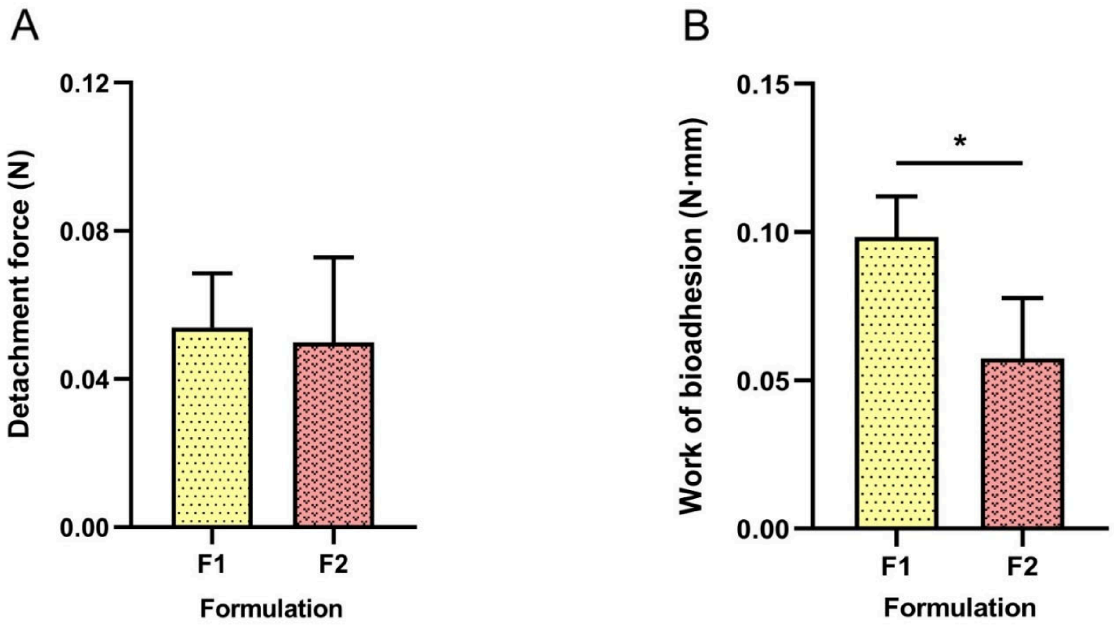


Figure 4. Bioadhesive properties of formulations F1 and F2. (**A**) Detachment force; (**B**) Bioadhesion work. * $p < 0.05$: significant difference compared to F1 according to the *t*-test ($p < 0.05$).

Although the adequate fluidity of a serum formulation ensures easy application and good spreadability on the skin, features essential for practical use, the degree of skin adhesion is also a critical attribute. In this context, the authors hypothesized that the natural gel of *K. alvarezii* may form a protective film capable of reducing dryness caused by constant exposure to salt water and adverse environmental conditions. This hypothesis is supported by evidence showing that *K. alvarezii* biomass is rich in carrageenan, a sulfated polysaccharide with well-recognized gelling, film-forming, and water-binding properties, widely exploited in cosmetic formulations as moisturizers and stabilizers [16,17]. Moreover, the incorporation of *K. alvarezii* into fluid-gel cosmetic serums has been shown to promote film formation on the skin surface, significantly enhancing hydration and improved skin hydration in previous studies [16]. Comparable benefits have also been demonstrated for fucoidan, another marine-derived polysaccharide from brown seaweeds, which improve hydration, reinforce the skin barrier, and reduce wrinkle formation in clinical studies [44]. Collectively, these findings indicate that the use of *K. alvarezii* in cosmetic formulations is grounded by experimental evidence, highlighting its potential as a sustainable and effective natural ingredient with moisturizing and protective properties.

3.4. In Vivo Evaluation of Skin Hydration

3.4.1. Characteristics of the Study Participants

Thirty-nine participants were recruited for application of the formulations using a data collection questionnaire. Analysis of the responses led to the exclusion of 11 participants from the study because they did not meet the inclusion criteria. Figure 5 shows the flowchart of participant selection for the in vivo study. Fourteen participants in the control group (50%) and 14 in the test group (50%) completed the study. There were no complications during the study.

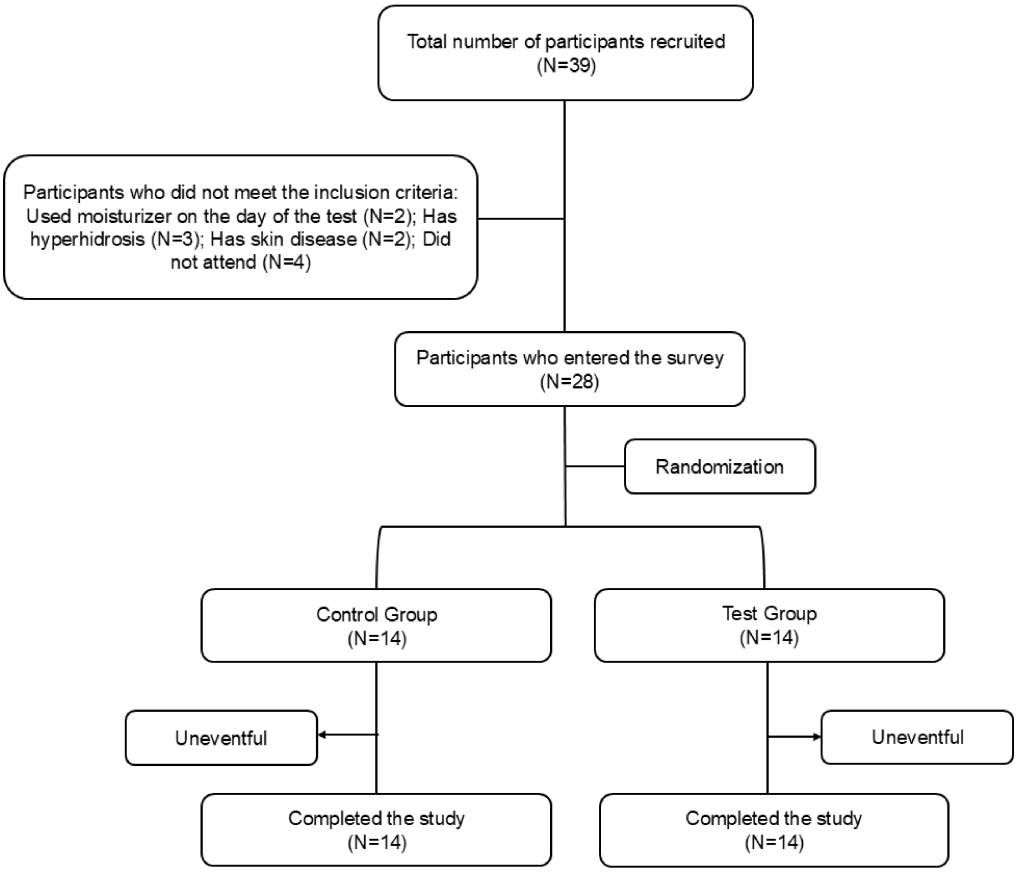


Figure 5. Flowchart of participant selection for the in vivo study.

The sociodemographic data of the participants included in the study are presented in Table 3. The mean age of the participants was 36.1 years (SD = 11.81), ranging from 18 to 60 years. Regarding sex, 82% of the participants were female and 18% were male (Table 3). Thus, the majority of participants in the study were white females ranging in age from 18 to 30 years.

Table 3. Sociodemographic data of the participants.

Population	Control Group (F1) (n = 14)	Frequency (%)	Test Group (F2) (n = 14)	Frequency (%)	p-value
Sex					
Female	11	78.6	12	85.7	>0.999 *
Male	3	21.4	2	14.3	
Race					
White	14	100	13	92.9	>0.999 *
Brown	0	0	1	7.1	
Age (years)					
18–30	7	50	4	28.6	0.097 #
31–40	5	35.7	3	21.4	
41–50	0	0	5	35.7	
51–60	2	14.3	2	14.3	

* Fisher's exact test ($p < 0.05$). # Chi-squared test.

In addition to sex, race and age, skin type and frequency of use of moisturizing products for hand care were analyzed based on the participants' responses (Table 4). When asked to describe their type of skin on the hands, most participants in the control and test groups responded to have normal skin. Regarding the frequency of use of moisturizing

products for hand care, the majority of participants reported to use them "sometimes" (Table 4), demonstrating a lower frequency of use of specific products for hands and feet by the population.

Table 4. Skin type and frequency of use of hand moisturizers according to the responses of the study participants.

Population	Control Group (n = 14)	Frequency (%)	Test Group (n = 14)	Frequency (%)	p-value
Hand skin type					
Normal	10	71.4	8	57.1	0.695 *
Dry	4	28.6	6	42.9	
Frequency of use of moisturizing product					
Daily	5	35.7	5	35.7	
Sometimes	7	50	6	42.9	0.871 #
Never	2	14.3	3	21.4	

* Fisher's exact test ($p < 0.05$). # Chi-squared test.

3.4.2. Sensory Analysis

Sensory analysis is important for assessing the efficacy of cosmetic products. In the case of affective methods, for example, the product and/or formulation can be evaluated by potential participants without technical knowledge, with the results being based on their preference and acceptance of the samples tested [45].

The mechanical, rheological, and bioadhesive properties of a formulation are known to influence the evaluation of its characteristics [46]. Although the analysis of mechanical (Table 2) and bioadhesive properties (Figure 4) demonstrated similar features of the applied formulations, spreadability, absorption sensation and hydration were also evaluated for better validation. The sensory attributes were analyzed separately for each group, as shown in Figure 6.

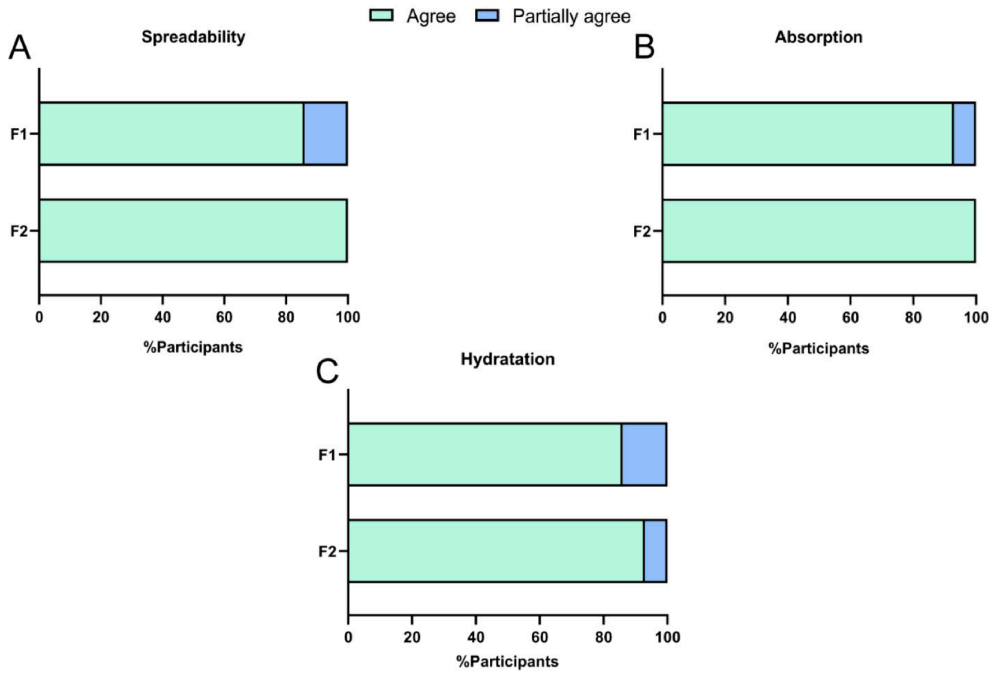


Figure 6. Sensory analysis (spreadability, absorption sensation, and hydration) of the formulations applied.

After application of the formulations, there was a slight difference in hydration, with F2 providing a better sensation of skin hydration than F1. Regarding spreadability and absorption sensation, 86% and 93% of the participants, respectively, agreed with the statements "the cosmetic formulation showed good spreadability" and "the formulation absorbed quickly into the skin" for formulation F1. In contrast, participants who received F2 agreed 100% with both statements, experiencing better spreadability and absorption sensation.

3.4.3. Evaluation of Skin Hydration After Application of the Formulations

In the present study, first, skin hydration of the participants was measured before application of the formulations based on skin surface capacitance expressed as AU and the mean values obtained for the palm and dorsal of the hands were calculated (Table S3).

Significant differences exist between dorsal and palmar hand skin. The dorsal skin is thin, with little adipose tissue and few hairs, while the palmar skin is thicker and rich in adipose tissue. The latter possesses sweat glands, but no hairs, and lacks sebaceous glands. This type is known as glabrous skin [47]. These features, combined with a less acidic pH, weaken the protective acid barrier and compromise the hydrolipidic layer, reducing the ability to retain moisture. Consequently, the hands are more susceptible to dehydration and dryness.

Values less than 30 AU indicate very dry skin, while values between 30 and 45 AU indicate dry skin. Values above 45 AU indicate sufficiently hydrated skin, according to the equipment's operating manual. Thus, considering the hydration degree values, it was found that, at baseline (before application of the formulations), the control group presented an average of 42.6 AU (SD = 12.3) and 44.5 AU (SD = 6.9) in the palm and dorsal of the hand, respectively, indicating dry skin in both areas. In the test group, the mean value was 32.9 AU (SD = 6.6) for the palm of the hand and 42.2 AU (SD = 7.2) for the dorsal, indicating dry skin. These results differ from the statements of the participants (Table 4) regarding their hand skin type, with 71.4% in the control group and 57.1% in the test group perceiving their skin as normal, that is, hydrated.

It is important to highlight that these hydration levels can be directly related to factors that interfere with the skin's hydrolipidic film. Individual characteristics, age, sex, and body area also exert an influence [48]. The more balanced the hydrolipidic film, the higher the water content of the skin, achieving a condition of adequate hydration.

The participants were also asked about their daily sun exposure, use of topical chemotherapy drugs, and treatments for precancerous and cancerous lesions on their hands. None of the participants reported being treated for lesions or taking chemotherapy drugs. However, regarding sun exposure, 39.3% of the participants answered "yes", as shown in Table 5. In addition, some participants mentioned the use of gloves for work and, occasionally, the application of alcohol gel, which influences skin condition.

Figure 7 shows the effect of the formulations on the hydration level of the dorsal and palmar skin of the hands 10, 30 and 60 min after their application compared to baseline (before application) in the control and test groups. According to the results presented, it is worth highlighting that, in addition to the main components, both formulations contain propylene glycol, which can act as a solvent but also as a humectant, promoting water retention in the stratum corneum [49]. After 60 min of application of formulation F1, a slight increase in skin hydration was observed after 10 min, but no significant increase compared to baseline. The formulation selected as a control, in turn, maintained its hydration level during the 60 min period evaluated and, despite containing hyaluronic acid, an active ingredient considered effective in hydration [50] and widely used in serum, no significant increase was observed, possibly due to the low concentration used, since the objective was to maintain similar proportions of the main moisturizing components in both formulations.

Furthermore, after application of the formulation, sensory analysis indicated that F1 was not completely absorbed by the skin in some participants, which may have interfered with the increased hydration result.

Table 5. Use of chemotherapy drugs, sun exposure and procedures for precancerous and cancerous lesions on the hands of the participants.

	Participants	Frequency (%)
Daily sun exposure		
Yes	11	39.3
No	17	60.7
Use of topical chemotherapy drugs		
Yes	0	0
No	28	100
Have you had procedures for precancerous and cancerous lesions on your hands?		
Yes	0	0
No	28	100

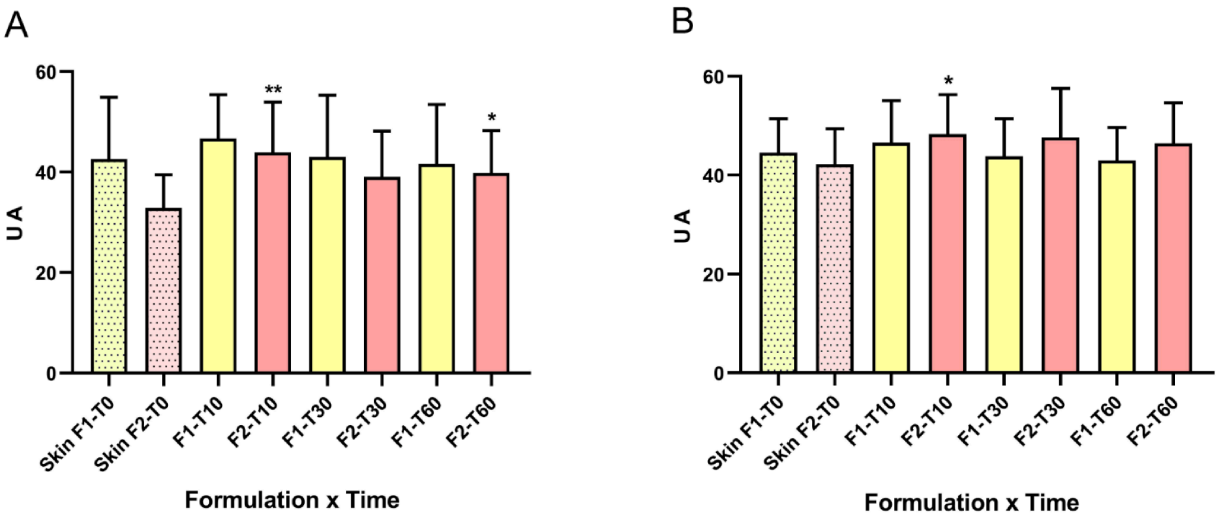


Figure 7. Skin hydration of the palm (**A**) and dorsal of the hand (**B**) at baseline (T0) and 10, 30 and 60 min after application of the formulations. Skin F1-T0: control group at baseline; Skin F2-T0: test group at baseline; F1: control formulation (AH); F2: test formulation. Data are presented as mean and standard error of the mean. * $p < 0.05$ and ** $p < 0.01$: significant difference compared to the respective baseline value of the test group (Skin F2-T0) according to one-way ANOVA followed by Tukey's post hoc test ($p < 0.05$).

The formulations were developed as complete systems, considering different compositional strategies with relevance to cosmetic application. In this context, the formulation containing *Kappaphycus alvarezii* was evaluated as a functional system, in which the observed effects arise from the interaction among its components and the overall formulation structure. Thus, the present experimental design does not allow the specific contribution of *K. alvarezii* to the observed effects to be independently distinguished, but rather reflects the performance of the formulation as a whole.

On the other hand, formulation F2 led to a slight but significant increase in the hydration level on the dorsal of the hand and a considerable increase on the palm 10 min after application, while after 60 min this significant effect was observed only on the palm. These results suggest that the components present in the seaweed gel enhance water retention on the skin surface, contributing to hydration. An intrinsic characteristic of the hands is

their lower amount of lipids and the reduced capacity to retain moisture when compared to other parts of the body. This may explain the oscillation in skin hydration observed between prolonged periods, considering that the efficacy tends to increase with longer use as observed for most products. Because only skin capacitance was measured, these results demonstrate improved surface hydration but do not allow conclusions regarding changes in skin barrier function or transepidermal water loss. Future studies comparing otherwise identical base formulations with and without *K. alvarezii*, and/or varying its concentration, will be required to quantify its individual contribution to efficacy.

4. Conclusions

The serum formulations exhibited pseudoplastic and thixotropic rheological behavior, consistent with their intended cosmetic application. The short-term in vivo study demonstrated that both formulations contributed to maintaining or modestly improving skin surface hydration over 60 min, with F2 showing a slightly more pronounced effect on palmar capacitance. Within the limitations of a single-application, short-duration study focused exclusively on corneometry measurements, these findings indicate the feasibility of formulating a *Kappaphycus alvarezii*-based serum with hydrating potential, while the underlying mechanisms involved (such as film formation or reduction in transepidermal water loss) remain to be elucidated.

The present findings also encourage further investigation of natural and renewable ingredients in cosmetic formulations, including seaweed-derived materials such as *K. alvarezii*. The use of seaweed-derived ingredients may represent an alternative approach aligned with current industry interest in sustainable raw materials. However, broader socioenvironmental and economic impacts, as well as potential contributions to sustainability-related goals, were not directly evaluated in the present study.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/cosmetics13030123/s1. Table S1. pH values of the formulations measured over a period of 60 days. Table S2. Hysteresis area of the formulations over the 60 days of study. Table S3. Level of skin hydration (AU) before application of the formulations.

Author Contributions: L.T., B.A.M., R.F.V.L. and M.M. designed the experiments. L.T., L.d.M.C. and B.A.M. conducted the experiments and carried out the analyses. L.T., B.d.S.A.A., J.d.S.C., A.L.F., R.F.V.L. and M.M. evaluated the data. L.T., S.d.C.F. and M.M. wrote the manuscript. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data will be available upon reasonable request.

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