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Sustainable Approach for Development Dried Snack Based on *Actinidia deliciosa* Kiwifruit

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Featured Application: The drying process enables the obtainment of snacks that can be stored at room temperature. Freeze drying better preserves bioactive compounds compared to hot air drying; however, its high porosity requires a specific storage method—without access to the air. The freeze-dried samples were more appreciated by consumers than the air-dried ones, as well as those containing a small amount of additional sweetener. The valorization of waste products can help to improve the health and well-being of consumers through the development of new products enriched with valuable bioactive compounds. Thus, guaranteeing improved environmental sustainability as well as attractive food products.

Abstract: The aim of this study was to evaluate the method of producing shelf-stable snacks based on kiwifruit with the objective of obtaining an appealing snack with good taste, color, and nutritional value. Less valuable kiwifruits for size and shape were utilized in order to reduce kiwifruit production waste. To obtain the snacks, two drying methods were used: freeze-drying and hot air drying. Physical and chemical analyses were conducted. Furthermore, a sensory evaluation was undertaken. The results showed that both hot-air and freeze-drying methods are suitable for obtaining a good quality snack, which was attractive to consumers. However, the freeze-dried snack was better assessed than hot-air dried. Moreover, consumers preferred snacks with additional sucrose or trehalose to those without it. It was observed that products produced using the freeze-drying process had lower water content, and lower water activity, were brighter, had a more saturated color, and had similar or higher antioxidant activity, especially for samples made from kiwi, fennel, and spinach. The drying process allows for obtaining a snack that can be stored at room temperature. Freeze drying better preserved bioactive compounds compared to air drying. The freeze-dried samples were more appreciated by consumers than the air-dried and those containing sweetener.

Keywords: *Actinidia deliciosa* fruit snacks; freeze-drying; hot air drying; sensory analysis; color; water activity; antioxidant activity

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1. Introduction

According to data from the Food and Agriculture Organization of the United Nations (FAO), as much as 1/3 of the food produced globally annually is lost or wasted. This applies to the entire food chain, from primary production to households. Food production consumes large amounts of energy, water, and other raw materials and contributes to greenhouse gas emissions [1,2]. For this reason, the problem of food waste is recognized as a key challenge on the way to sustainable resource management [3]. Losses and waste of raw materials and food products have a negative impact on the natural environment, the nutritional status of the population, and food security [4–6]. In countries with lower income, the largest losses are observed in the initial stages of production. This is due to financial and technical constraints and poor management. Limiting this phenomenon is important due to the big problem of maintaining food security in those societies [2,7,8]. While in middle- and high-income countries, most food losses occur at the consumer level. They result mainly from bad habits and insufficient awareness of people. The lack of cooperation between individual links in the food chain and the unfavorable conditions of contracts concluded between farmers and sellers also play a significant role [2,6]. Food raw materials are sometimes rejected due to their visual unattractiveness and unusual shape or size [2,6,8].

Food waste prevention is considered a priority issue [3]. The world has limited natural resources, and on the other hand, the population is constantly growing, which requires increased food production to meet growing needs. The sustainable management of already produced foodstuffs seems to be crucial in efforts to ensure safe and nutritious food for all [2,5,9]. Recently, attention has been paid to the possibility of using innovative scientific achievements to prevent waste and to process by-products so that they are attractive products for consumption [6]. Currently, many scientific teams in the world are dealing with this issue. Particularly much interest is devoted to fruit and vegetable processing due to the abundance of valuable bioactive substances of a health-promoting nature. For example, attempts have been made to use apple pomace to produce a powder rich in polyphenols and fiber, to obtain blackcurrant seed oil, or to replace part of the flour in cookies with dried raspberry pomace [10].

In the process of producing functional food based on fruit and vegetables, which has a health-promoting effect, various drying methods are used, which allow for extending the shelf life and easier transport and marketing of the product. Longer exposure times result in significant changes (chemical and physical) in the character of products dried by convection. An alternative is, e.g., the freeze-drying process (using lower temperatures and reduced pressure), which is more expensive but allows for much better preservation of bioactive ingredients [11,12].

Kiwifruit is most often eaten fresh, although over the years, it has also been used in the production of processed food, such as jams, juices, nectars, wines, or dried snacks [13]. It is worth noting that a certain limitation in the use of green kiwi varieties for the production of products with an extended shelf life is the phenomenon of chlorophyll degradation under the influence of heat treatment. As a result, a loss of the attractive intense green color is observed [14]. An interesting study on the use of the addition of kiwi puree to fruit juices as an ingredient with high acidity and viscosity was carried out by Yi et al. [15]. In these studies, a number of parameters influencing the quality of apple juice produced by high pressure and stored at 4 °C were compared, enriching some of the samples with the addition of kiwi puree. The results seem very promising and indicate the great potential of this type of additive, and the presence of actinidia delayed the browning process by at least 28 days, extended the stability of the product by up to 42 days, and positively influenced the preservation of flavor and aroma characteristics. Noteworthy are also the attempts to use kiwifruit waste in the form of skins and pomace, which were made by the team of Soquetta et al. [16]. These raw materials are usually rejected as inedible, but they are a rich source of dietary fiber and bioactive ingredients. This is what prompted scientists to produce flour from them, which can be used to enrich food with health-promoting ingredients. Interestingly, flours from the skins of green (unripe) kiwifruits contained more chlorophyll, carotenoid pigments and flavonoids than those from the skins of ripe fruits, while flours from the skins of ripe fruits were richer in vitamin C.

Thus, the aim of this study was to propose a sustainable approach for using the undersized kiwifruit treated as waste for the development of dried snacks. For this purpose, different compositions were developed, and different methods of drying were used to obtain dried snacks. Moreover, the water content and water activity, color, sensory properties, and antioxidant activity (with DPPH radical) were analyzed.

2. Materials and Methods

2.1. Snack Preparation

2.1.1. Materials and Puree Preparation

The main raw materials used for the snack production were kiwifruits *Actinidia deliciosa*, cv Jintao with a diameter lower than 70 g. The fruits came from Chilean crops from the province of Colchagua, from one batch, and they were stored in a cold room at a temperature of 4 ± 1 °C. Due to the high acidity of kiwi, other fruits and vegetables were added, which were selected on the basis of preliminary research. For the production of snacks with a pleasant taste, fennel, spinach leaves, strawberries, and organic lemons (with peel suitable for consumption) were chosen, which were bought from the local market (Apofruit, Cesena, Italy) on the day that the snacks were prepared. All of the raw materials, with the exception of lemons from Sicily (Almaverde Bio, Cesena, Italy), came from the Emilia-Romagna region of Italy. Two different sugars have been used as sweeteners: refined beet sugar Eridania Italia SPA (Bologna, Italy) or trehalose (EXACTA + OPTECH Labcenter S.p.A., San Prospero, Italy). Additionally, all of the fruits and vegetables were mixed into a puree form, and citrus pectin (Sigma-Aldrich, Steinheim, Germany) was used to obtain a jelly structure that was suitable for drying.

All of the reagents used in the study had the following purities: DPPH ≥90% (elemental analysis, SIGMA ALDRICH), ethanol ≥96% (pure for analysis, AVANTOR), and methanol min 99.5% (pure for analysis, J.T. Baker).

The snack preparation process is present in Figure 1, while the snack formulations are given in Table 1.

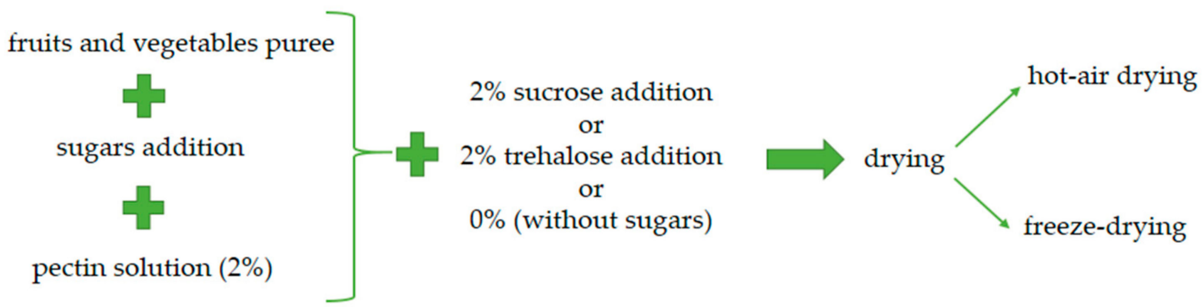

Figure 1. Flowchart of snacks preparation process.

Before processing, the kiwifruits were washed and peeled, while the other fruits and vegetables were washed, and the inedible parts were removed. The fruit and vegetable puree was obtained by grinding the fruits and vegetables in an Electrolux ESB9300 blender (Milan, Italy) using the formulations listed in Table 1. Sweeteners, such as sucrose or trehalose, were added to the puree to a final concentration of 2% (*w*/*w*). As a control sample, a puree without any sweetener was used. Then, a gelling agent like pectin 2% (*w*/*v*) was prepared by adding the citrus pectin to hot water and then being cooled to 70 °C. The pectin solution was added at a ratio of 1:4 (20% pectin solution at 2% (*w*/*v*) and 80% of puree of fruit and vegetables) and mixed.

Table 1. Snacks formulations prepared based on undersized kiwifruit with the addition of other fruit and vegetable puree, sugar, and pectin solution.

Snack Symbol	Fruit and Vegetable Ingredients (%)	Sugar	2% (*w*/*v*) Pectin Solution	Method of Drying	Abbreviation
A	44% kiwifruit 21.6% strawberry 12% fennel 2.4% lemon juice	0 sucrose 2% (s) trehalose 2% (t)	20%	Hot air (HA)	HA_A HA_A_s HA_A_t
				Freeze drying (FD)	FD_A FD_A_s FD_A_t
B	52% kiwifruit 24% fennel 3.88% lemon juice 0.12% lemon peel	0 sucrose 2% (s) trehalose 2% (t)	20%	Hot air (HA)	HA_B HA_B_s HA_B_t
				Freeze drying (FD)	FD_B FD_B_s FD_B_t
C	56% kiwifruit 16% fennel 8% spinach	0 sucrose 2% (s) trehalose 2% (t)	20%	Hot air (HA)	HA_C HA_C_s HA_C_t
				Freeze drying (FD)	FD_C FD_C_s FD_C_t

2.1.2. Drying of the Snack

Two methods of drying were used to obtain the fruit snack: hot air drying and freeze drying.

Hot-air drying was conducted using the following settings: temperature, 70 °C; air velocity, 2 m/s; air renewal fee, 50%. Then, 15 g of the prepared puree formulations was spread into a thin layer (20 × 30 mm) on laminated paper sheets, which were then placed on perforated metal plates to allow air circulation. The metal plates containing the samples were then placed in a hot air cabinet dryer for 6 h (POL-EKO-APRATURA SP.J., Wodzislaw Slaski, Poland). Later, after the process, the leather-like fruit snacks were cut into rectangular strips with a sharp knife measuring approximately 20 × 50 mm.

The freeze-drying was performed by placing 15 g of the prepared puree formulations into plastic molds (25 × 20 × 20 mm) and then placing them into a freezer at a temperature of −40 ° C for 48 h. The frozen samples were placed in a freeze-dryer (Lio2000, CinquePascal S.r.l., Milan, Italy), and the primary drying was conducted under a vacuum of 25.12 Pa for 24 h; afterward, a secondary drying at a temperature of 40 °C was performed. The drying was performed at least 2 times to obtain enough samples to perform all of the analyses and measurements.

The dried samples were stored in hermetic packaging before the analysis for no longer than 2 weeks. Three independent drying cycles were carried out for each method of drying.

2.2. Analysis of Snacks Properties

2.2.1. Water Content

The water content (WC) was determined by using the gravimetric method [17]. For the analysis, the dried snacks used were pre-crushed or cut into small pieces and weighed on a laboratory scale with an accuracy of ±0.0001 g. The samples were placed in aluminum dishes and kept for 24 h at 70 °C in a laboratory oven. Afterward, they were cooled in a desiccator to room temperature and weighed again. The determination was performed in three repetitions for each of the samples, and the water content in the tested snacks was calculated according to the following Equation (1):

$$WC = 100 - ((m_s - m_n)/m_{n+p} - m_n) \times 100\%), \quad (1)$$

where m_s is the mass of the dish with the sample after drying [g], m_{n+p} is the mass of the dish with the sample before drying [g], and m_n is the mass of an empty dish [g].

2.2.2. Water Activity

Water activity was determined with an accuracy of ±0.001 at 25 °C using the AquaLab CX-2 measuring device (Dekagon Device Inc., Pullman, WA, USA) [18]. The dried snacks were cut into small pieces and placed in a measuring cup, and the water activity measurement was performed in triplicate.

2.2.3. Color of Snacks

The color determination of the hot-air dried and freeze-dried snacks was performed using a HUNTERLAB spectrophotometer (Color-FlexTM, A60-1010-615, Reston, VA, USA), operating in the CIE *L*a*b** system. D65 light source settings, a 10-degree observation angle, and a port with a diameter of 12 mm were used for the measurement [19]. Before starting the determination, the device was calibrated using the black and white standards included in the kit. The color of each sample was measured five times. The color parameters of the puree formulations before drying were measured analogously. Based on the obtained parameters, the color saturation was calculated using the following Equation (2):

$$C = \sqrt{(a^*)^2 + (b^*)^2}, \quad (2)$$

where C represents the saturation, a^* represents the chromatic coordinate describing red (+) and green (−) and b^* is the chromatic coordinate describing yellow (+) and blue (−).

The total color difference (ΔE) between the fresh fruit and vegetable puree with different formulations and the sample obtained after drying was calculated according to the following Equation (3):

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}, \quad (3)$$

where ΔE is the total color difference, ΔL^* is the brightness difference, Δa^* is the difference of the chromatic coordinates a^* describing red (+) and green (−), and Δb^* is the difference the of chromatic coordinates b^* describing yellow (+) and blue (−).

2.2.4. Sensory Analysis

The sensory evaluation of the snacks was performed by a panel of 10 trained persons. The snack was assessed by taking into account the color homogeneity, kiwi flavor intensity, sweetness, sourness, kiwi flavor intensity, crunchiness, kiwi-specific pungency, and overall palatability. The scale of the evaluation of the samples was from 1 to 9, where 1 meant the least and 9 meant the greatest intensity of a given feature. The snacks were assessed in separate rounds; e.g., the evaluators in the panel received the samples based on the same flavor but dried with different methods (hot air or freeze-dried).

2.2.5. Antioxidant Activity

The samples were ground in the IKA A10 Basic laboratory mill. Then, 0.3 g of the dried snacks was weighed into 100 mL beakers, and then 20 mL of an 80% ethanol solution was added and heated under cover until reaching its boiling point. Then, it was filtered through a paper filter, and the flask was filled up to 50 mL with an ethanol solution (80%). Two extracts were made from each sample.

Antioxidant activity was determined by examining the degree of scavenging of the synthetic 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical by antioxidants contained in the extracts of the dried snacks [18]. DPPH radical (Sigma-Aldrich, Steinheim, Germany) was used from one package for the analysis of all of the obtained samples.

A DPPH solution was prepared by adding 0.025 g (±0.0001 g) of the radical to a 100 mL volumetric flask that was then filled with a 99% methanol solution. The solution prepared in this way was stirred and left for 24 h at a cooling temperature of 4 °C, protected from light. Then, 18 mL of the DPPH solution was placed in a 100 mL beaker and filled to the mark with an 80% ethanol solution to obtain the DPPH working solution. The absorbance of such a solution at a wavelength of 515 nm was in the range of 0.680 to 0.720.

For each of the samples, extracts from the dried snacks were prepared with the following volumes: 40, 80, 120, and 240 µL, which were filled with an 80% ethanol solution to a total volume of 2 mL, and then 2 mL of the DPPH working solution was added. The whole was mixed on a vortex shaker. The samples were left out of the light at room temperature for 30 min, and the absorbance was monitored at 515 nm by using a spectrophotometer (Spectronic 200; Thermo Fisher Scientific Inc., Waltham, MA, USA) against an 80% ethanol solution. Additionally, a control test was performed with ethanol instead of the extract. Each extract was evaluated twice.

Antioxidant activity was determined based on the IC_{50} index, e.g., the concentration of the dry substance in the extract prepared from kiwi-based snacks, which is necessary for scavenging 50% of the DPPH radicals. It was determined by calculating it according to the following Equation (4):

$$\text{Scavenging Effect [\%]} = (\text{Abs}_{\text{DPPH}} - \text{Abs}_{\text{Extract}}) \times 100/\text{Abs}_{\text{DPPH}}, \quad (4)$$

with:

Abs_{DPPH} = absorbance at 515 nm of DPPH solution of blank,
$\text{Abs}_{\text{Extract}}$ = absorbance at 515 nm of DPPH solution of the extract.

2.3. Statistical Analysis

Statistica 13 software (TIBCO Software, Palo Alto, CA, USA) and analysis of variance (ANOVA) followed by the Tukey test (α = 0.05%) were used to assess the significant differences among the samples.

3. Results and Discussion

3.1. Water Content and Water Activity of Snacks

Water is an important component of food products inasmuch as the amount of water in food is crucial for its storage stability and physical properties. In fresh fruit and vegetables, water constitutes 77 to 96% of the total mass [20,21]. In the case of the puree, which was the base of the snacks, the water content ranged from 84.9 ± 0.1% to 88.6 ± 0.1%, while the dry matter content ranged from 11.4 ± 0.1% to 15.1 ± 0.1%, depending on the puree formulation. The water contents of fresh formulations A, B, and C were 88.6 ± 0.1, 85.5 ± 0.1, and 84.9 ± 0.1%, respectively.

One of the parameters determining the state of water in food is water activity (a_w). Water activity largely determines the course of biological, chemical, and physical processes; therefore, it is an important parameter when designing new products [22]. The oxidation of fats and fat-soluble substances takes place even at very low values of a_w, and the greatest slowdown of this reaction is observed at a_w from 0.1 to 0.3. In turn, the rate of the oxidation of fat-soluble substances, such as chlorophylls, vitamin C, or anthocyanins, is proportional to the increase in water activity. The reactions of non-enzymatic browning, which cause unfavorable modifications of the color or smell and increase the hardness of the product, require a sufficiently high proportion of water in the environment. Their highest intensity is noted at a_w from 0.3 to 0.7. In addition, it is assumed that food is the most stable in terms of physical changes (associated with unfavorable changes in texture) when its water activity corresponds to the share of water in the monolayer [23]. The water activity is also used to assess the microbiological safety of the product. It is assumed that most bacteria do not grow below a_w of 0.9, yeast below a_w = 0.8, and mold below a_w = 0.7 [21].

The water content and water activity of the differently formulated and prepared snacks are shown in Figures 2 and 3, respectively. In each of the snack flavor variants, significant differences were observed in the obtained water content (Figure 2) and water activity levels (Figure 3), depending on the drying method used.

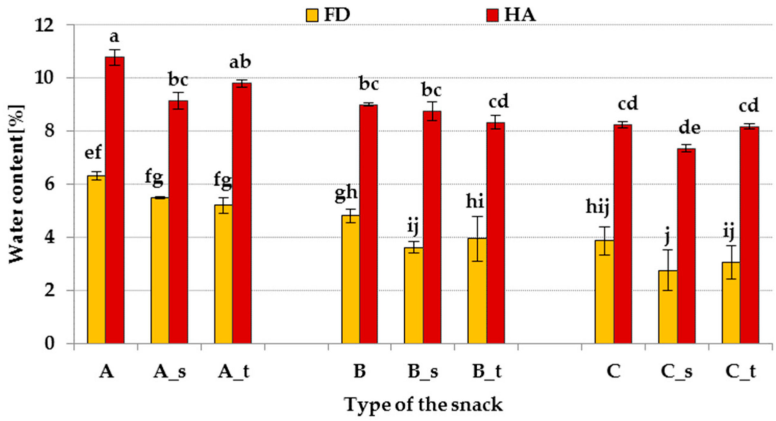

Figure 2. Water content of snacks based on undersized kiwifruit for the formulations (A–C): FD, freeze-dried snack; HA, hot-air-dried snack. The same letters given for each column are homogenous groups and indicate no significant differences (α = 0.05) between considered samples. Bars in the figure represent standard deviations.

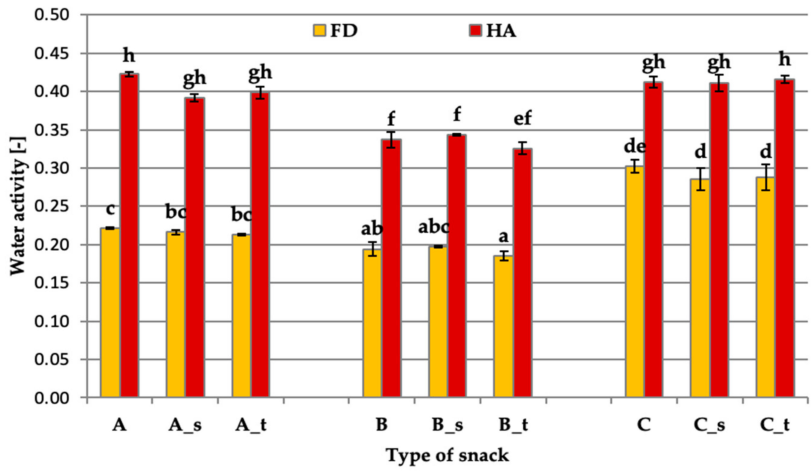

Figure 3. Water activity of snacks based on undersized kiwifruit for the formulations (A–C): FD, freeze-dried snack; HA, hot-air-dried snack. The same letters given for each column are homogenous groups and indicate no significant differences (α = 0.05) between considered samples. Bars in the figure represent standard deviations.

The hot-air-dried snacks were characterized by a higher water content as well as water activity, indicating that the selected drying method and parameters had a decisive influence on the degree of water removal from the fresh material [24]. For example, in formulation A of the snack with strawberry, fennel, and lemon juice, the water activity was 0.221 ± 0.001 in the case of freeze drying, while when hot-air drying was used, this value was equal to 0.423 ± 0.003. The measured water content of the variant A snack was 6.3 ± 0.2% and 10.8 ± 0.3% for the freeze-dried and hot-air snacks, respectively. In any case, both drying methods have led each of the obtained snacks to a water activity below 0.6, so it can be concluded that the drying process ensured their durability and microbiological stability [25].

3.2. Color of Snacks Based on Undersized Kiwi

The external perception of food consists of several features, such as color, texture, size, shape, gloss, or variety. These features, perceived by the eye, determine the first impression that a food product makes on the consumer [26]. The appearance of food, and in particular its color, affects the perception of its attractiveness, quality, taste, and willingness to eat it [26,27]. In food, blue is rarely seen and generally disliked by consumers, while colors such as red, green, and yellow are more popular and liked. Research has shown that in the case of vegetables, those with bright and vivid colors are perceived as the most attractive [26]. One of the problems that producers of fruit-based products have to face is browning caused by a series of changes occurring during technological processes and storage. This is an important issue due to the fact that consumers associate brown color with decreased quality, which negatively affects purchasing decisions [27,28].

Generally, the color of the fruits is connected to the presence of natural pigments, e.g., anthocyanins, chlorophyll, carotenoids, etc. [9,29] The color of the snacks produced (Figure 4, Table 2) was analyzed using the L^* brightness parameters, the a^* chromatic coordinate and the b^* chromatic coordinate, as well as the C saturation and the total color difference (ΔE) were calculated to observe their change compared to fresh fruit and vegetable puree. In general, no significant effect of the choice of trehalose or sucrose addition on the color of the obtained snacks was observed; thus, in Figure 4, the color of one type of sample (without any addition of sugar) from each formulation is presented.

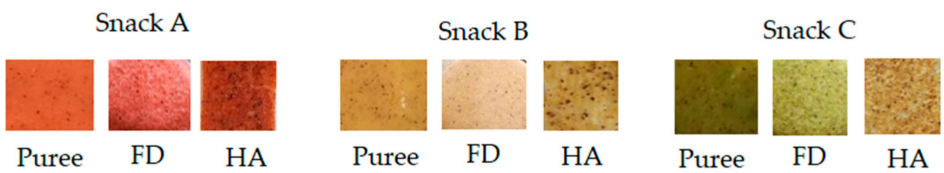

Figure 4. Color of snacks based on undersized kiwifruit for the formulations (**A**–**C**): FD, freeze-dried snack; HA, hot-air-dried snack.

The color of the snacks is determined by their composition as well as processing [9]. Among the three flavor variants of the snacks, those made based on kiwifruit, fennel, lemon juice, and lemon peel (snack B) were characterized by the highest brightness. Compared to other formulations, they did not contain ingredients with a very intense color (such as strawberries or spinach), but they were characterized by the largest share of fennel (24%) and lemon juice (3.88%). The darkest ones were snacks with the addition of spinach (snack C). In snacks B and C, the freeze-drying process resulted in a significant increase in brightness compared to fresh puree, while hot air drying resulted in a decrease in brightness (Table 2). The increase in brightness in freeze-dried fruit in relation to fresh raw material is due to the fact that freeze-drying takes place at a low temperature, oxygen access is limited, and water in the solid phase goes directly into the gaseous state without reaching the liquid phase, which does not create favorable conditions for the enzymatic browning reaction [28]. It is assumed that the advantage of freeze-drying is the good preservation of the color characteristic of the raw material [30,31].

In snack A (with the addition of strawberries), the brightness of the hot-air-dried snack was similar to the fresh puree, while the freeze-drying process increased the brightness (Table 2). The darkening of convection-dried snacks results from the degradation of naturally occurring pigments and enzymatic and non-enzymatic browning reactions that are accelerated by the raised temperature during this process [27,32–34]. In comparison, the freeze-drying method is known as the best method for assuring the lowest color changes [9]. Higher values of the L* parameter observed in freeze-dried snacks may also be related to the chosen method of color determination, which consisted in recording the light reflected from the sample. Radiation is reflected in a different way from a porous surface (which is a freeze-dried product), in a different way from a compact surface without visible pores, and in another way from a wet surface, as in the case of puree [35]. Puree A type, with the addition of strawberry, fennel, and lemon juice, was characterized by an intense red color (Table 2). The hot-air drying process caused a statistically significant change in the red color to the lower value, which may be due to the degradation of red anthocyanins [36]. However, the use of the freeze-drying process results in higher values of the *a** parameter. For example, in a fresh puree, the *a** parameter was 21.05; in a freeze-dried snack without the addition of sweeteners, it was 30.83; and in a hot-air-dried snack, it was 12.56.

Table 2. *L** (brightness), *a** (red-green), and *b** (yellow-blue) parameters in dried snacks based on undersized kiwifruit for the formulations A, B, and C: FD, freeze-dried snack; HA, hot air-dried snack. The same letters provided for each column are homogenous groups and indicate no significant differences (α = 0.05) between considered samples. The mean value and standard deviation are provided in the table.

Type of Sample	*L**	*a**	*b**	*C*	Δ*E*
A puree	40.98 ± 0.28 b	21.05 ± 0.25 j	16.89 ± 0.24 bcd	26.99 ± 0.02 e	-
B puree	58.64 ± 0.64 de	5.93 ± 0.04 g	31.14 ± 0.60 gh	31.70 ± 0.03 f	-
C puree	40.18 ± 0.40 b	−6.75 ± 0.15 a	32.72 ± 0.38 h	33.40 ± 0.02 g	-
HA_A	40.43 ± 0.88 b	12.56 ± 0.89 i	18.57 ± 1.17 d	22.42 ± 1.43 d	8.80 ± 0.69 a
HA_A_s	40.12 ± 0.84 b	12.25 ± 0.48 i	15.58 ± 0.84 bc	19.82 ± 0.94 c	9.01 ± 0.59 a
HA_A_t	39.63 ± 0.44 b	11.34 ± 0.53 h	16.36 ± 0.77 c	19.91 ± 0.88 c	9.85 ± 0.57 a
FD_A	61.30 ± 1.62 ef	30.83 ± 1.14 l	15.86 ± 0.80 bc	34.67 ± 1.38 g	22.63 ± 1.25 fg
FD_A_s	62.67 ± 2.54 f	30.40 ± 0.93 kl	15.85 ± 0.77 bc	34.28 ± 1.17 g	23.70 ± 2.21 g
FD_A_t	63.29 ± 1.85 f	29.88 ± 1.11 kl	15.49 ± 0.97 bc	33.66 ± 1.42 g	24.10 ± 1.50 g
HA_B	49.40 ± 0.88 c	3.79 ± 0.36 ef	12.24 ± 0.48 a	12.82 ± 0.54 a	21.16 ± 0.69 cdef
HA_B_s	49.49 ± 0.69 c	3.74 ± 0.59 ef	11.96 ± 0.37 a	12.54 ± 0.43 a	21.38 ± 0.57 def
HA_B_t	49.95 ± 0.95 c	3.86 ± 0.50 f	12.29 ± 0.47 a	12.88 ± 0.57 a	20.88 ± 0.62 cdef
FD_B	78.17 ± 1.38 h	2.09 ± 0.20 c	23.71 ± 0.85 f	23.80 ± 0.86 d	21.91 ± 2.45 defg
FD_B_s	77.50 ± 3.35 h	1.96 ± 0.20 c	22.67 ± 1.00 ef	22.76 ± 1.01 d	21.18 ± 2.47 cdef
FD_B_t	74.25 ± 0.56 g	2.17 ± 0.12 cd	22.21 ± 1.14 e	22.32 ± 1.13 d	18.61 ± 0.99 b
HA_C	33.42 ± 1.83 a	2.98 ± 0.57 de	16.35 ± 1.41 c	16.63 ± 1.41 b	20.28 ± 1.44 bcde
HA_C_s	32.07 ± 1.49 a	3.33 ± 0.35 ef	14.86 ± 1.14 b	15.24 ± 1.10 b	22.09 ± 1.21 efg
HA_C_t	33.99 ± 1.15 a	3.18 ± 0.36 ef	15.78 ± 1.10 bc	16.10 ± 1.09 b	20.61 ± 1.25 bcdef
FD_C	58.72 ± 2.24 d	−3.88 ± 0.19 b	30.06 ±1.15 g	30.31 ± 1.16 f	19.00 ± 2.15 bc
FD_C_s	59.65 ± 1.38 de	−4.14 ± 0.24 b	31.03 ± 1.76 gh	31.30 ± 1.78 f	19.79 ± 1.42 bcd
FD_C_t	58.29 ± 2.64 d	−3.95 ± 0.21 b	30.34 ± 1.09 g	30.59 ± 1.09 f	18.51 ± 2.69 b

In the case of variant B, with the addition of fennel, as well as lemon juice and peel, both drying methods caused a decrease in the value of the *a** parameter, which suggests a partial loss of red pigments. This phenomenon was more noticeable in freeze-dried snacks. Nevertheless, the raw materials used in this formulation were not characterized by large quantities of red pigments.

In the case of snacks C, with the addition of fennel and spinach, naturally rich in green chlorophyll pigments, the fresh puree was characterized by the negative *a** values. The freeze-dried process caused an increase in this parameter (even though still negative), while hot air drying resulted in positive values (Table 2). Chlorophyll—the pigment responsible for the green color of fruits and vegetables—under the influence of acids, easily degrades to olive green or olive yellow pheophytin. In addition, as a result of lipoxidase activity in an aerobic environment, it undergoes oxidation [37]. The increase in the *a** parameter can be explained by the occurrence of these processes and the degradation of chlorophyll derived from spinach leaves. Roshanak et al. [38], in their research on methods of drying green tea leaves, recognized the freeze-drying method as the best in terms of chlorophyll preservation (17.35 mg/L), while hot air drying at 60 °C resulted in the most unfavorable results (5.73 mg/L), which was explained by the negative impact of the high temperature and long duration of the process.

The b^* parameter in all cases showed a positive value, indicating that samples were characterized by a yellow share of color. In the case of a snack enriched with strawberries (snack A), none of the drying methods significantly affected the value of this parameter (Table 2). B snacks (composed of yellow kiwi, fennel, lemon juice, and lemon skin) partially lost their yellow color to a significantly greater extent after hot air drying and to a lesser extent due to freeze-drying. A similar trend was observed for snacks C with the addition of spinach (Table 2). Drying with hot air caused a smaller decrease in the b^* value in relation to fresh puree than in the case of freeze-drying. Additionally, Roshanak et al. [38], who dried green tea, observed lower values of the b^* parameter in the case of hot air drying and higher in the case of freeze-drying. However, Mohammadi et al. [39] analyze the kinetics of color changes in kiwifruit slices subjected to hot air drying in five temperatures: 40, 50, 60, 70, and 80 °C. The final value of the a^* parameter turned out to the higher values with the increased temperature (which was associated with the loss of the green pigment), while the value of the b^* parameter decreased with increasing temperature. Researchers explained this phenomenon by the degradation of chlorophyll and carotenoids. The freeze-drying process is associated with obtaining greater porosity and increased surface area of the dried material compared to other drying methods. On the one hand, this is its advantage; on the other hand, the increased surface area means increased oxygen access, which is associated with a higher risk of adverse degradation of chlorophyll or anthocyanins during storage of freeze-dried fruits and vegetables [28,37].

Based on the color parameters measurements, the color saturation, C, was calculated. Analyzing the obtained results, significantly higher values of the C parameter were found in the snacks obtained using the freeze-drying process compared to those dried by using hot air (Table 2).

The greatest changes in the total color difference ΔE were observed in the case of snacks A, with the addition of strawberry, fennel, and lemon juice (Table 2). Its values in freeze-dried products were: 22.6 ± 1.3 in the snack without sweeteners, 23.7 ± 2.2 in the one with sucrose, and 24.1 ± 1.5 with trehalose. For comparison, in the hot-air drying method, the values were, respectively, 8.8 ± 0.7, 9.0 ± 0.6, and 9.8 ± 0.6. In the case of the other two snacks (B and C), the differences between freeze-dried and hot-air-dried snacks were mostly not statistically significant. It can be assumed that the different compositions of the snacks, the type of drying process used as well as the effect of high temperature played an important role in the obtained results. The presence of various fruits and vegetables with different chemical compositions makes it difficult to indicate with certainty specific reactions and transformations causing changes in color.

3.3. Sensory Evaluation of Snacks Based on Undersized Kiwi

The results of the sensory evaluation of snacks based on undersized kiwifruit for formulation A (with the addition of strawberry, fennel, and lemon juice), B (with the addition of fennel, juice, and peel, respectively, with lemon), and C (with the addition of fennel and spinach) are presented in Figures 5–7, respectively. The samples were characterized by the kiwifruit aroma with slightly perceptible other aromas from additional raw materials. The intensity of the aroma typical of kiwifruit was assessed by the panel in the range from 4.2 (for HA_s snack C) to 7.5 points (for FD snack C). Regardless of the type of snack, the intensity of the aroma typical of kiwifruit was the highest for dried fruit without the addition of a sweetener. Nevertheless, the addition of sucrose and trehalose reduced the characteristic aroma of kiwifruit. In the case of snacks B and C, those freeze-dried received higher points than those dried by hot air. The intensity of the flavor typical of kiwifruit in most cases (except for FD_s and HA_s samples of A formulation) was assessed, with higher scores yielded by the freeze-dried snacks compared to the hot-air-dried snacks. This is in line with the literature, according to which the freeze-drying process, unlike hot air drying, preserves the typical taste and aroma of the raw material [28].

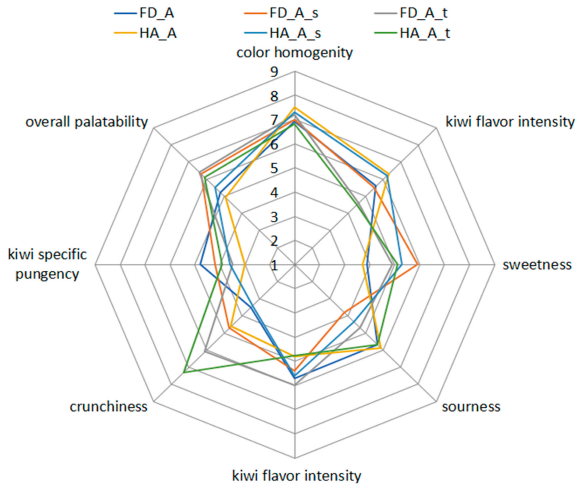

Figure 5. Sensory evaluation of snacks based on undersized kiwifruit for the formulation A: FD, freeze-dried snack; HA, hot-air-dried snack; s, with sucrose (2%); t, with trehalose (2%).

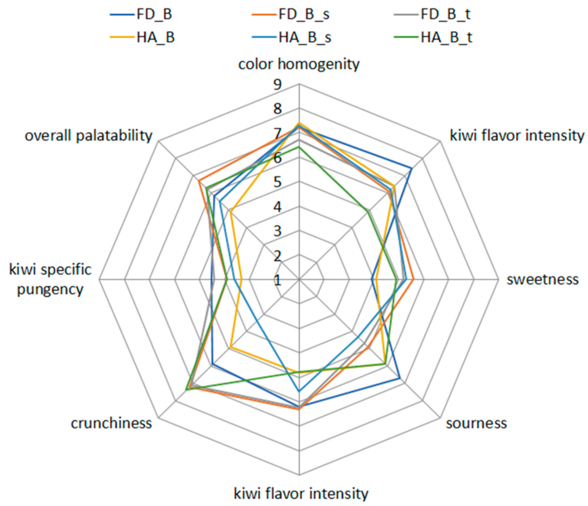

Figure 6. Sensory evaluation of snacks based on undersized kiwifruit for the formulation B: FD, freeze-dried snack; HA, hot-air-dried snack; s, with sucrose (2%); t, with trehalose (2%).

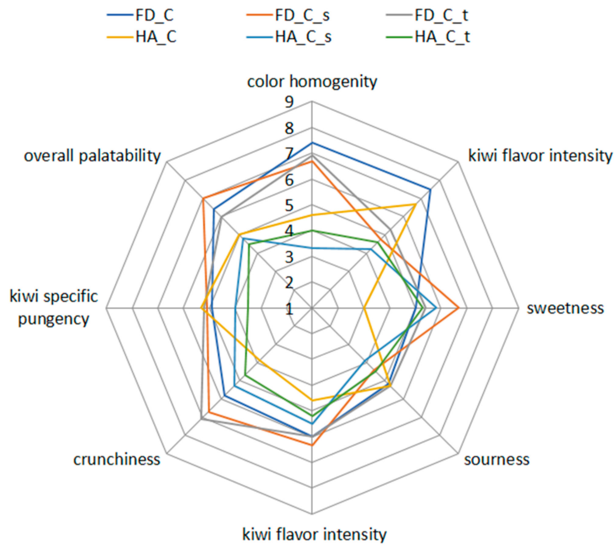

Figure 7. Sensory evaluation of snacks based on undersized kiwifruit for the formulation C: FD, freeze-dried snack; HA, hot-air-dried snack; s, with sucrose (2%); t, with trehalose (2%).

The sweetness of the snacks, regardless of the drying method used and snack formulation was rated in a range from 3.0 (for HA snack C) to 6.7 points (for FD_s snack C). As expected, regardless of the drying method, snacks containing sucrose were the sweetest in comparison with those made using trehalose or without sweeteners. Trehalose is at least 50% less sweet than sucrose; therefore, the sweetness of the obtained snacks was also lower compared to the sucrose-sweetened snacks. In addition, the sweetness of trehalose is neutral, without a foreign aftertaste, and the time profile of its sweetness is longer, e.g., sweetness after consumption is felt by consumers longer than in the case of sucrose [40]. Similarly, the acidity was assessed inversely (except samples FD_s and FD_t of snack A and FD and FD_t of snack C). The snacks without sweeteners were considered the most acidic, while those with sucrose were considered the least acidic. At the same time, in snacks A, it was noticed that the freeze-dried snacks were characterized by a lower degree of acidity and a higher degree of sweetness (except for FD_t and HA_t) compared to the material dried using hot air. Valentina et al. [28] noted that in the sensory analysis of various types of freeze-dried fruit, some of them were assessed as much more acidic than before this process. This proves the complexity of the process of drying plant tissues.

Furthermore, regardless of the composition, freeze-drying was characterized by higher crunchiness, while air-dried snacks were rather soft. This is linked to the high porosity of freeze-dried snacks. A similar structure was noted in freeze-dried snacks made from vegetable by-products with apple pomace [9], multilayer snacks made from different vegetables [23], and strawberry jelly [41]. The porous structure is attractive to consumers. However, less crunchy snacks were obtained through the use of hot air drying after the process resembling soft leather and it is considered a good method for obtaining healthy snacks [42].

3.4. Antioxidant Activity of Snacks Based on Undersized Kiwifruit

The antioxidant capacity evaluates the potential of the food products to fight against reactive species, such as free radicals [43]. Many studies have reported a noticeable positive correlation between the presence of phenolic compounds (polyphenols and phenolic acids) and the antioxidant capacity of fruits and vegetables, which, if consumed in a daily diet, may reduce the risk of several societal diseases. The beneficial effect of phytochemical compounds on the body is determined not only by their quantity but also by the presence of other compounds with which they interact and their location within the cellular matrix [44]. The phenolic compounds contained in plants are trapped in membranes and cell walls, so using processing methods such as freezing or applying high temperatures can cause their release and better bioavailability [45]. Scientific studies on the effect of high temperature on the content of polyphenols have yielded different results—some of them report the increased degradation of these compounds, while others indicate the opposite effect due to the release of these compounds and their easier availability [46,47].

The antioxidant capacity of the snacks based on undersized kiwifruit was expressed in IC_{50} values using the DPPH radical (Figure 8). A lower value of this parameter indicates the higher antioxidant capacity of the sample.

Generally, in most cases of the A snacks (with the exception of the A_t snack containing strawberry, fennel, and lemon juice with trehalose) and B, no significant changes in antioxidant activity were observed. The lack of statistical changes in the freeze-dried and hot-air-dried snacks, as well as those indicating the greater antioxidant capacity of the hot-air-dried snacks and the lack of statistical differences in freeze-dried and hot-air-dried snacks, may also be related to the phenomenon observed by Vega-Gálvez et al. [48], who studied dried slices of Granny Smith apples. The apples were dried at three temperatures, 40, 60, and 80 °C, respectively, at different airflow velocities, i.e., 0.5, 1.0, and 1.5 m/s. The antioxidant capacity did not show any significant differences for the samples dried at 40 and 80 °C although different values of phenolic compounds were observed in these samples; this behavior was explained by the progressive occurrence of Maillard reactions and at the same time transformations, leading to the accumulation of antioxidant compounds in the food matrix.

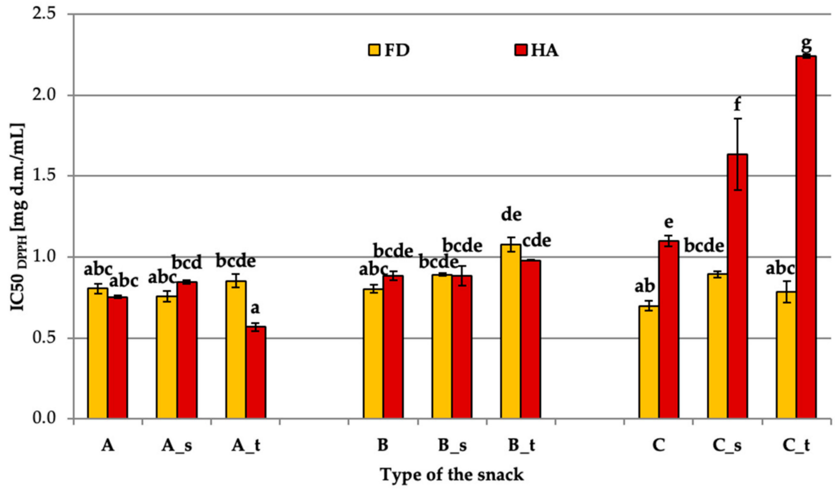

Figure 8. Antioxidant capacity (expressed in IC50) of snacks based on undersized kiwifruit for the formulations (A–C): FD, freeze-dried snack; HA, hot-air-dried snack. The same letters given for each column are homogenous groups and indicate no significant differences (α = 0.05) between considered samples. Bars in the figure represent standard deviations.

Statistically significant differences in antioxidant activity were noted for snack C (with spinach and fennel) depending on the method of drying. In all of the C snacks, the IC_{50} value was much higher in the hot-air-dried samples, which means that the freeze-dried snacks were characterized by higher antioxidant activity. It was particularly visible in the snack with the addition of trehalose, wherein the freeze-dried version was characterized by the IC_{50} value at the level of 0.79 $\pm$ 0.07 mg d.m./mL, and the hot air dried, which had much lower antioxidant activity because there was only 2.24 $\pm$ 0.01 mg d.m./mL. In addition, the results obtained for the hot-air-dried snacks in snacks C with the addition of sucrose and trehalose were significantly higher than the other samples, which indicates their poor antioxidant capacity. However, it can also be related to the extraction process, where not only antioxidants but also antagonistic compounds are transferred from the sample to the solvent, which may falsify the final result [9]. Kajacan et al. [49] reported a higher retention of the antioxidant activity measured by using the DPPH method for Asian pear drying with freeze-drying instead of hot air drying at 50 °C for 420 min; this could probably be ascribed to the decreased degradation of the antioxidant compounds.

4. Conclusions

The developed method of manufacturing snacks allowed for the obtainment of attractive products through the use of hot air drying as well as freeze-drying techniques. In most cases, the snacks were characterized by good taste and obtained an overall palatability rating of 7 points out of 9. The sensory analysis showed that the freeze-dried snacks with the addition of sucrose in two formulations: fennel and spinach (snack C) and fennel, lemon juice, and peel (snack B), were the tastiest. The lower scores were given to the hot-air-dried snacks, which were related to the color of the samples. In addition, the presence of sucrose or trehalose in the snacks had a positive effect on the sensory impressions.

The method of drying snacks significantly influenced the color. The hot-air-dried snacks were darker than the freeze-dried snacks. This was caused, among other reasons, by enzymatic and non-enzymatic browning reactions. Regarding the antioxidant properties, better preservation was observed for freeze-dried snack C (containing fennel and spinach), while air drying, regardless of the based formulation, provoked the degradation of bioactive compounds.

All of the snacks obtained using convection drying and the freeze-drying method presented a water activity lower than 0.6, which allows them to be considered microbiologically stable. Therefore, it should be concluded that the production of dried snacks is a good method for the management of yellow kiwifruit of a size that does not meet the criteria for retail sale, which allows reducing losses and waste of these fruits.

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