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Impact of the Drying Agents Maltodextrin and Gelatin Used in Whey Powders on the Quality Characteristics of Yogurt

Abdelghani Mouzai [1], Katarzyna Szkolnicka [2,*], Afaf Kheroufi [1], Izabela Dmytrów [2], Anna Mituniewicz-Małek [2] and Halima Boughellout [1]

[1] Laboratoire de Génie Agro-Alimentaire (GENIAAL), Équipe Génie des Procédés Alimentaires, Biodiversité et Agroenvironnement (GPABAE), INATAA Université Frères Mentouri Constantine 1, Constantine 25000, Algeria; abdelghani.mouzai@umc.edu.dz (A.M.)
[2] Department of Toxicology, Dairy Technology and Food Storage, Faculty of Food Sciences and Fisheries, West Pomeranian University of Technology in Szczecin, Papieża Pawła VI Street 3, 71-459 Szczecin, Poland
* Correspondence: katarzyna.szkolnicka@zut.edu.pl

Abstract

Drying agents used in the process of spray drying whey enhance the quality of whey powders and may consequently improve the properties of yogurts to which these powders are added. This study examined the quality characteristics of yogurts enriched with whey powders using maltodextrin or gelatin as drying agents. The following yogurt variants were produced: a control (C) without whey powder; W with whey powder but without a drying agent; M with whey powder containing maltodextrin; and G with gelatin as a drying agent. Whey powders were added at a concentration of 1.5% (*w*/*w*). The samples were tested after 3, 6, 10 and 14 days of refrigerated storage (4 ± 1 °C), and analyses were performed in 3–6 repetitions. Enrichment of milk with powdered whey had a noticeable impact on the quality characteristics of yogurts. Fortified yogurts exhibited a significantly higher total solids content (11.43–12.22% in the control; 12.45–13.33% in W, G and M) and higher acetaldehyde concentration (0.31–1.11 ppm in the control; 0.44–1.82 ppm in W, G and M) than the control. Titratable acidity and pH varied among samples. However, the syneresis index was lower in the control yogurt (39.09–46.74%) than in yogurts with powdered whey (53.71–58.48%). Significant differences were observed in color parameters (L, a*, b*, WI, YI). The texture properties (firmness, consistency, cohesiveness, index of viscosity) of samples with whey powders had higher values than the control. In sensory evaluation, yogurts with whey powders obtained high scores. The study demonstrated that the use of maltodextrin or gelatin not only supports the process of spray drying whey but also alters the characteristics of the resulting yogurts. The impact of the study comes from the fact that it bridges the gap between whey processing (spray drying) and the formulation of the final product.

Keywords: whey powder; drying agent; maltodextrin; gelatin; yogurt

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1. Introduction

Whey is an abundant and highly nutritious by-product of cheese production in the dairy industry [1–3]. Its production in large quantities can be harmful to the environment if discharged as wastewater. Each year, whey production exceeds two hundred million kilograms [2,4]. Whey is made up of about half of the components of milk. This material is composed of about 93% water and solids in a ratio of 6–7%. Lactose, soluble proteins, lipids and mineral salts account for most of the dry matter fraction [5,6]. The spray drying of whey

is a technique for converting a by-product into a food powder, thus offering possibilities for subsequent use, which makes this product highly valuable [2,3,7,8]. In the food industry, whey powder is deployed in different products, whether as an additive, as a substitute or as a drying agent. It is widespread in dairy products, bakery products, deli meats, beverages and chocolate thanks to its important techno-functional properties [9–12]. In addition to its use as an ingredient in the food industry, whey powder has been used as a drying medium to enhance the qualities of food powders [8,13–15]. It has been used as a spray-drying agent for probiotics [16,17] and sumac extract [18] and as biodegradable packaging [19]. Despite the number of applications of powdered whey, the process of whey drying is related to challenges that may lead to impaired quality and low powder yield [3]. One possible approach to overcoming these problems is to use drying agents (carrier agents), which facilitate the spray-drying process, improve powder yield and protect the compounds in the dried product; hydrocolloids, such as maltodextrin and gelatin, are common carrier agents favored for spray drying [20]. Moreover, the use of drying agents positively influences the structure of powders. According to Mahdi Jafari et al. [8], the addition of maltodextrin to whey before spray drying leads to the formation of smoother and more spherical powder particles. In other publications focused on whey drying, various drying agents, such as maltodextrin, silica and starch, were used in order to obtain stable powders with the desired properties [21,22].

When making yogurt, several studies have highlighted the importance of using whey powder [9,23–25]. Furthermore, according to other studies, the use of maltodextrin, gelatin and other agents in yogurt has been shown to improve its properties or to serve as a fat substitute [11,26–28]. However, the literature review revealed that there is a lack of studies investigating the impact of these drying agents incorporated into whey on the potential application of whey powder in yogurt production.

From the previous research, we concluded that spray drying whey using drying agents brings benefits both to the spray-drying process and to the properties of the whey powder. Our assumption was that the presence of drying agents in the whey powder used for yogurt production would influence the quality properties of the product by altering whey powder properties. To verify this hypothesis, the purpose of the study was to examine the impact of the drying agents maltodextrin and gelatin, used in the spray drying of whey, on the quality characteristics of yogurt enriched with whey powder and to analyze the quality changes during refrigerated storage.

2. Materials and Methods

2.1. Materials

2.1.1. Whey Powders with Drying Agents

In this study, whey powder was produced by drying sweet whey from Camembert cheese production in accordance with the procedure described by Mouzai et al. [2], either without a drying agent or using gelatin and maltodextrin as drying agents at different concentrations, namely 1.5% (*w*/*v*) and 7.5% (*w*/*v*), respectively. These concentrations were chosen based on the solubility and other quality properties of the powders, which had been tested beforehand with various concentrations of the aforementioned agents. According to the tests (data not published), maltodextrin requires relatively high concentrations to raise the glass transition temperature and reduce stickiness during spray drying. Lower concentrations are generally insufficient to ensure the optimal process yield and adequate powder stability. On the other hand, gelatin exhibits pronounced structuring, thickening, and stabilizing effects owing to its high molecular weight, which enables it to be effective at relatively low concentrations.

2.1.2. Yogurt Production

Normalized and pasteurized cow's milk used for yogurt production was purchased from a local producer in Poland. Whey powders were added to milk at a concentration of 1.5% (*w*/*w*), which was chosen based on the results of preliminary studies (data not included). Four variants of yogurt were prepared: one control (C) without whey powder and three variants with whey powder: W—with whey powder but without a drying agent; M—with whey powder containing maltodextrin; and G—with whey powder containing gelatin. After dissolving the whey powders, the milk was homogenized, pasteurized (72 °C, 10 min), cooled down to 42 ± 1 °C and inoculated with DVS yogurt culture YO-122 containing *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* added at a concentration of 0.1 g/L (Biochem s.r.l., Rome, Italy). Each yogurt type was prepared at a volume of 3000 mL, poured into 40 disposable containers and tightly sealed. Fermentation was conducted at 42 ± 1 °C until coagulation occurred (4.5–5 h). The final pH reached 4.92 for the control and 4.92, 5.32, and 5.08 respectively for the W, M, and G yogurts. Finally, the yogurts were cooled down and stored at 4 ± 1 °C for 14 days.

2.2. Methods

2.2.1. Assessment of Milk and Whey Powders

Before yogurt production, we recorded the following measurements based on the physicochemical characteristics of milk: pH with a pH meter (Elmetron, Zabrze, Poland); titratable acidity expressed as the percentage of lactic acid; density; the content of total solids tested by the drying method; fat content tested by the Gerber method; and total protein content tested by the Kjeldahl method [29]. In the whey powders, we assessed water content by the drying method [29].

2.2.2. Yogurt Assessment

The experimental yogurts were assessed for their physicochemical properties. In addition, the syneresis index, color parameters, texture and sensory properties were evaluated. Analyses of yogurts were conducted during two weeks of refrigerated storage at 4 ± 1 °C (on days 3, 6, 10 and 14). Fat and total protein content were analyzed once, on day 3. Other analyses were conducted in three (pH, titratable acidity, total solids, fat, total protein, acetaldehyde content, syneresis index) or six (color, texture, sensory assessment) replicates. We performed destructive sampling, and on each day, new random samples were tested.

Physicochemical assessment included pH (tested with a pH meter, Elmetron, Zabrze, Poland), titratable acidity (expressed as % of lactic acid), the content of total solids evaluated by the drying method, fat content evaluated by the Gerber method, and total protein content evaluated by the Kjeldahl method [29]. Acetaldehyde content was evaluated by the Conway micro-diffusion method [30].

The syneresis index (SI) was evaluated by the centrifuge method [26], with modifications. A 20 g sample of yogurt was placed carefully into 50 mL centrifuge tubes and centrifuged for 20 min at 3000 rpm. The separated whey was gently removed and weighed. We calculated the syneresis index (SI) using the following formula:

$$\text{SI (\%)} = (\text{mass of whey, g})/(\text{mass of yogurt, g}) \times 100 \quad (1)$$

Color parameters were tested with a portable colorimeter, equipped with an 8 mm aperture (model FRU® WR-18, Shenzhen Wave Optoelectronics Technology Co., Ltd., Shenzhen, China). Color was expressed in the CIELab system, and L* (lightness), a* (redness/greenness), and b* (yellowness/blueness) parameters were evaluated. Additionally,

we calculated the whiteness index (WI) and the yellowness index (YI) using Equations (1) and (2) [24,31,32]:

$$WI = 100 - [(L^*)^2 + (a^*)^2 + (b^*)^2]^{0.5} \quad (2)$$

$$YI = 142.86b^* \cdot L^{*-1} \quad (3)$$

Texture parameters were performed using the backward extrusion test with a TA-XT Plus texture analyzer (Stable Micro Systems, Surrey, UK). The assessment parameters were a 25 mm diameter aluminum cylindrical probe; a test speed of 1 mm/s; a trigger force of 10.0 g; an immersion depth of 20 mm; and a test duration of 5.0 s. In each repetition, the new sample was tested. The following parameters were recorded and calculated using Exponent software (version 6.1.1.0): firmness, which is defined as the maximum compressive force exerted on the sample (g); consistency, which is defined as the area under the curve during extrusion (g·s); cohesiveness, which is defined as the maximum compressive force during the withdrawal of the probe from the sample (g); and the viscosity index, which is defined as the area in the negative region of the curve during probe withdrawal (g·s) [33].

In the sensory assessment, appearance, taste, aroma, and consistency were assessed using a scoring method with a 5-point scale, where 1 point indicated unacceptable quality and 5 points indicated excellent quality of the evaluated attribute. Six trained evaluators, all qualified researchers, participated in the analysis. The yogurt samples for testing, coded with three-digit random numbers, had a temperature of 4–6 °C and were served in 100 mL sealed disposable containers. During the assessment, the evaluators were provided with water to cleanse their palates [34,35]. According to the practices of the West Pomeranian University of Technology, where the sensory assessment was conducted, ethical approval is not required for this type of evaluation. The participants took part voluntarily, were aware of the type of products being evaluated, and were informed that they could withdraw from the study at any time without consequences.

2.2.3. Statistical Evaluation

The compiled results were analyzed by the use of Statistica 13.3 software (StatSoft Inc., Tulsa, OK, USA), with a significance level of $p = 0.05$. Mean values and standard deviations were calculated. Prior to statistical analysis, the normal distribution of variables using the Shapiro–Wilk test was evaluated. One-way (for total solids in whey powders, fat and total protein content in yogurts) and two-way (for the other parameters) analyses of variance (ANOVA) followed by Tukey's post hoc test were applied to determine differences among the samples.

3. Results and Discussion

3.1. Milk and Whey Powder Characteristics

The quality of milk is one of the main determinants of the quality of yogurt. The milk used for yogurt preparation had the following composition: 12.22 ± 0.01% of total solids, 3.2 ± 0.05% of fat, and 2.51 ± 0.05% of protein. The lactic acid content was 0.168 ± 0.01%, pH was 6.67 ± 0.01 and density was 1.031 g/cm^3. The fat content was normalized and adjusted within the range of 0.1–10%, which is typical for yogurt [36]. Milk protein was slightly lower than the minimum protein content required for yogurt according to the Codex Alimentarius (CA) Standard for Fermented Milks [36], which amounts to 2.7%. Additionally, the solid-non-fat (SNF) content, which amounted to approximately 8.72%, was slightly too low for yogurt production. According to Sfakianakis and Tzia [37], it should be in the range of 9–16%. Thus, standardization of the total solids and protein content through the addition of whey powder may be reasonable. Nevertheless, it was commercially available normalized and pasteurized milk purchased on the market. In the

case of the whey powders, water content was 3.87 ± 0.31% for the whey powder without a drying agent, 3.35 ± 0.27% for the whey powder with maltodextrin, and 5.36 ± 0.60% for the whey powder with gelatin as a drying agent. Statistical analysis revealed significant differences in water content among samples (Table A1). In accordance with the Codex Alimentarium [38], water content in whey powders must not exceed 5%. This indicates that, in the present study, only the whey powder with gelatin did not comply with the standard. Gelatin forms a microstructure network, which preserves water [39]. According to the literature, one of the methods for increasing the total solids content in yogurts is the addition of whey powder at a concentration of 1–2%. Higher levels of whey supplementation are not recommended because they lead to flavor deviations and a softer consistency in yogurt, perhaps due to the insufficient casein concentration [35,40].

3.2. Physicochemical Analysis of Yogurts

Fat and total protein contents were measured after 3 days of refrigerated storage (Tables 1 and A1). Regarding fat, the highest value was observed in yogurt M containing whey powder with maltodextrin, whereas the lowest was recorded in yogurt G with whey powder with gelatin; however, only yogurt M differed significantly from the control sample. The highest total protein content (2.95%) was found in yogurt G, which was the only one to meet the requirements of the Codex Alimentarius [37], according to which, the total protein content of yogurt must not be lower than 2.7%. The reason for the low total protein content is its low concentration found in milk (2.51%).

Table 1. Fat and total protein content of yogurts with whey powders.

Product	Fat, %	Total Protein, %
C	3.2 ± 0.28 ^{a,b}	2.50 ± 0.05 ^{b}
W	3.2 ± 0.10 ^{a,b}	2.30 ± 0.07 ^{a}
M	3.5 ± 0.10 ^{b}	2.43 ± 0.05 ^{a,b}
G	2.8 ± 0.14 ^{a}	2.95 ± 0.06 ^{c}

Explanations: The results are presented as mean values ± standard deviation. C—control yogurt without whey powder; W—yogurt with whey powder but without a drying agent; M—yogurt with whey powder with maltodextrin; G—yogurt with whey powder with gelatin. Different superscript letters (a–c) indicate significant differences between samples ($p \leq 0.05$).

The results for the total solids, titratable acidity, pH, and acetaldehyde content of the yogurts are presented in Table 2. The total solids of the yogurts exhibited considerable variability, with sample W showing the highest value (13.20 ± 0.35%), whereas sample C displayed a significantly lower value (12.22 ± 0.20%). According to the provided table, no significant differences ($p > 0.05$) were observed throughout the entire storage period between the samples containing whey powder with drying agents (maltodextrin, gelatin) and those containing whey powder without a drying agent. Nevertheless, the content of total solids in the above-mentioned samples differed significantly from that of the control. This may be explained by the amount of added dry matter. Additionally, a general decrease in total solids was observed for all products, which was most likely related to the metabolic activity of the lactic acid bacteria.

The pH of the yogurt samples was within the range of 4.50 to 4.91, which is consistent with the results reported by Pancapalaga et al. [41]. Initially, the lowest pH values were observed in samples W and G (pH 4.61 and 4.64, respectively), suggesting differences in the intensity of fermentation activity. Moreover, in the samples with whey powders (W, M, G), the drop in pH noted directly after fermentation and after 3 days of storage was more pronounced than in the control. During the storage period, a gradual and statistically significant decrease ($p < 0.05$) in pH was observed for all samples, with the lowest pH

(4.50) recorded in sample G on the 14th day. By fortifying the milk with whey powders, we increased the lactose content, which is a substrate for lactic acid bacteria to produce lactic acid, which translates into an acidity increase. Approximately one third of the lactose present in milk is used during the fermentation of yogurt and converted into lactic acid by yogurt bacteria. The rest of the lactose is a substrate for the post-acidification process that occurs during storage [35,42]. According to the literature [42], a decrease in pH and an increase in titratable acidity indicate that the post-acidification process is occurring, which is attributed to the continued biosynthesis of lactic acid and, to a lesser extent, hydrogen peroxide by the lactic acid bacteria added as a starter culture.

Table 2. Physicochemical analysis of yogurts with whey powders.

	Product			
Days	**C**	**W**	**M**	**G**
Total solids, %				
3	$12.22 \pm 0.20^{A,b}$	$13.20 \pm 0.35^{B,a}$	$12.99 \pm 0.24^{B,a}$	$12.92 \pm 0.04^{B,a,b}$
6	$11.50 \pm 0.13^{A,a}$	$12.46 \pm 0.56^{B,a}$	$12.84 \pm 0.24^{B,a}$	$13.33 \pm 0.47^{B,b}$
10	$11.46 \pm 0.02^{A,a}$	$12.64 \pm 0.006^{B,a}$	$12.76 \pm 0.09^{B,a}$	$12.59 \pm 0.11^{B,a}$
14	$11.43 \pm 0.02^{A,a}$	$12.64 \pm 0.25^{B,a}$	$12.62 \pm 0.46^{B,a}$	$12.45 \pm 0.18^{B,a}$
Titratable acidity, % of lactic acid				
3	$0.72 \pm 0.01^{B,a}$	$0.80 \pm 0.00^{C,a}$	$0.66 \pm 0.00^{A,a}$	$0.79 \pm 0.00^{C,a}$
6	$0.72 \pm 0.00^{B,a}$	$0.81 \pm 0.01^{C,a}$	$0.67 \pm 0.00^{A,a}$	$0.81 \pm 0.01^{C,a}$
10	$0.78 \pm 0.01^{B,c}$	$0.81 \pm 0.01^{B,a}$	$0.73 \pm 0.00^{A,b}$	$0.81 \pm 0.00^{B,a}$
14	$0.76 \pm 0.00^{B,b}$	$0.83 \pm 0.00^{C,a}$	$0.71 \pm 0.00^{A,b}$	$0.87 \pm 0.01^{D,b}$
pH				
3	$4.70 \pm 0.01^{B,c}$	$4.61 \pm 0.01^{A,a,b}$	$4.85 \pm 0.01^{C,b}$	$4.64 \pm 0.01^{A,c}$
6	$4.64 \pm 0.01^{B,b}$	$4.62 \pm 0.01^{B,a,b}$	$4.91 \pm 0.01^{C,c}$	$4.61 \pm 0.01^{A,b}$
10	$4.61 \pm 0.00^{B,a}$	$4.63 \pm 0.01^{B,b}$	$4.69 \pm 0.00^{C,a}$	$4.52 \pm 0.00^{A,a}$
14	$4.60 \pm 0.00^{B,a}$	$4.59 \pm 0.01^{B,a}$	$4.70 \pm 0.00^{C,a}$	$4.50 \pm 0.00^{A,a}$
Acetaldehyde, ppm				
3	$0.84 \pm 0.14^{A,b}$	$1.42 \pm 0.2^{B,b,c}$	$0.95 \pm 0.17^{A,b}$	$1.82 \pm 0.08^{B,c}$
6	$0.42 \pm 0.18^{A,a}$	$0.91 \pm 0.13^{B,C,a,b}$	$0.68 \pm 0.05^{A,B,a}$	$1.15 \pm 0.13^{C,b}$
10	$1.11 \pm 0.10^{A,b}$	$1.70 \pm 0.35^{B,c}$	$1.48 \pm 0.05^{A,B,c}$	$1.73 \pm 0.23^{B,c}$
14	$0.31 \pm 0.07^{A,a}$	$0.55 \pm 0.13^{B,a}$	$0.44 \pm 0.06^{A,B,a}$	$0.63 \pm 0.06^{B,a}$
Syneresis index, %				
3	$42.75 \pm 3.42^{A,a,b}$	$56.55 \pm 5.33^{B,a}$	$54.36 \pm 1.37^{B,a}$	$53.85 \pm 3.28^{B,a}$
6	$46.74 \pm 2.30^{A,b}$	$55.18 \pm 1.97^{B,a}$	$54.46 \pm 5.01^{A,B,a}$	$55.16 \pm 2.66^{B,a}$
10	$44.61 \pm 1.96^{A,a,b}$	$54.17 \pm 2.12^{B,a}$	$53.71 \pm 3.94^{B,a}$	$55.50 \pm 3.64^{B,a}$
14	$39.09 \pm 1.51^{A,a}$	$54.69 \pm 0.88^{B,a}$	$55.04 \pm 0.82^{B,C,a}$	$58.48 \pm 2.04^{C,a}$

Abbreviations as in Table 1. Different superscript letters (a–c) and superscript capital letters (A–D) are used as in Table 1 to indicate significant differences ($p \leq 0.05$).

The lactic acid content ranged from 0.71 to 0.87%, with a statistically significant difference ($p < 0.05$) between all samples. Samples C and M exhibited lower titratable acidity throughout the storage period, which may be attributed to the slower fermentation or reduced metabolic activity of the LAB cultures. In addition, an increase in titratable acidity was observed in all samples over time, with sample G reaching the highest level of acidity (0.87% of lactic acid) on day 14. These results are consistent with the findings of other studies [43–45], which also reported a decrease in pH accompanied by an increase in titratable acidity during the refrigeration of the yogurt samples. The results of the two-factor ANOVA (Table A2) showed that pH and titratable acidity are influenced by the type of sample, the storage time and the interaction between these factors.

Acetaldehyde is a key aroma compound found in fermented dairy products, playing a crucial role in the development of the characteristic yogurt flavor [46]. At the beginning of the storage period, samples G and W exhibited significantly higher acetaldehyde concentrations (1.82 and 1.14 ppm, respectively) than samples C and M ($p < 0.05$), and the control sample had the lowest concentration of this aroma compound. The lowest acetaldehyde concentrations in all samples were observed on day 14, and this decline is consistent with the high volatility and chemical instability of acetaldehyde during storage. Similarly to acidity, acetaldehyde content was affected by the sample type, the storage time and the interaction between these factors (Table A2). In yogurt, acetaldehyde can be synthesized by starter culture bacteria through different metabolic pathways from lactose, amino acid threonine, lipids, and nucleic acids [47]. By incorporating whey powders, we enriched the yogurts in lactose and threonine; thus, the substrates for acetaldehyde production were more accessible for the yogurt bacteria. This can explain the higher concentration of acetaldehyde in the samples with powdered whey. During storage, acetaldehyde is gradually reduced to ethanol by alcohol dehydrogenase enzymes [47,48], explaining the reduction observed in this study. According to the literature [40], to form the characteristic yogurt aroma, the concentration of acetaldehyde must be more than 8 ppm. This threshold is distinctly higher than that obtained in our findings. However, our results exceed the detection threshold of 0.11 ppm [47,49].

3.3. Syneresis Index

Syneresis reflects the expulsion of whey (serum) and is indicative of gel stability and quality [35,45]. It is generally regarded as an undesirable characteristic of fermented dairy products and serves as an important indicator of yogurt quality during storage [23,50]. Fermentation conditions, including time, temperature, and starter cultures, significantly affect yogurts' syneresis [51]. Our findings revealed that the control sample exhibited the lowest syneresis value (42.75%), whereas all the samples with whey powders showed significantly higher syneresis levels ($p < 0.05$), as indicated in Table 2. During storage, a slight, statistically non-significant decrease in syneresis ($p > 0.05$) was observed in sample W, while a non-significant increase ($p > 0.05$) was noted in samples M and G. On the contrary, the control sample exhibited a gradual reduction in the syneresis index, indicating improved gel stability during storage. The syneresis index was influenced by the sample type and by the interaction between samples and time (Table A2). Although whey proteins are known to immobilize water within the yogurt gel matrix, the samples supplemented with whey powders did not differ significantly in terms of syneresis during most of the storage time and were more susceptible to syneresis than the control. This phenomenon may be associated with the increased lactose content introduced by the whey powders. Lactose is converted into lactic acid and causes the increase in acidity, which has a negative effect on the water-holding capacity of the yogurt [51]. Moreover, the water-holding capacity is associated with the conditions related to the heat treatment of milk [51]. The drying agents used in this study, such as hydrocolloids, can act as stabilizers in yogurt manufacturing, and gelatin, in particular, is recognized as one of the most effective stabilizers for controlling syneresis in yogurt [51,52]. However, most likely due to their insufficient concentration in the yogurt formulation, the expected stabilizing effect of the drying agents was not observed. The estimated concentration of gelatin and maltodextrin in the final products was approximately 0.0225% and 0.1125%, respectively.

3.4. Color Parameters

Color parameters are significant factors indicating the sensory attractiveness and quality of fermented milk. Sample C (control) consistently exhibited the highest L* values throughout the storage period, indicating greater lightness and optical uniformity, which is

consistent with its lower syneresis and higher gel stability than the other samples. Samples W, M, and G showed slightly lower L* values, with statistically significant differences observed among them at specific time points. The a* parameter, describing the green (−)-to-red (+) axis of the CIE La*b* color space, was negative in all samples, indicating a shift toward the green hues typical of fermented milk products. Sample C exhibited slightly less negative a* values (−1.89 to −1.90), whereas samples W, M, and G showed more negative values ($p < 0.05$). Among these, sample W demonstrated the most pronounced green hue (−2.06 to −2.08) and maintained a slightly greener appearance throughout the storage period (Table 3). The intensified green tone in the whey-enriched samples may be linked to alterations in light scattering caused by changes in protein–serum interactions. The b* values were positive in all samples, indicating a predominantly yellow hue. Sample W exhibited the highest b* values over time, reaching a maximum of 5.41 on day 14, whereas sample C showed the lowest b* values, ranging from approximately 4.55 to 4.74. Two-way ANOVA showed that parameters L, a* and b* were affected by the sample type, storage time and their interaction (Table A2). Variations in yogurt color may be associated with differences in the biochemical activities of yogurt microorganisms, which induce structural changes in the casein matrix, transforming it from a micellar organization into a more dispersed gel network [53].

Table 3. Color parameters of yogurts with whey powders.

	Product			
Days	**C**	**W**	**M**	**G**
L*				
3	$77.24 \pm 0.48^{C,a}$	$74.47 \pm 0.65^{A,a}$	$74.89 \pm 0.39^{A,a}$	$74.45 \pm 0.38^{A,a}$
6	$77.71 \pm 0.09^{C,a}$	$75.55 \pm 0.05^{B,b}$	$75.12 \pm 0.41^{A,a}$	$75.1 \pm 0.13^{A,a}$
10	$77.52 \pm 0.24^{B,a}$	$75.09 \pm 0.23^{A,a,b}$	$74.99 \pm 0.22^{A,a}$	$74.71 \pm 0.35^{A,a,b}$
14	$77.34 \pm 0.26^{C,a}$	$75.64 \pm 0.16^{B,b}$	$75.23 \pm 0.40^{A,B,a}$	$74.67 \pm 0.47^{A,a,b}$
a*				
3	$-1.89 \pm 0.03^{B,a,b}$	$-2.06 \pm 0.02^{A,b}$	$-2.01 \pm 0.02^{A,a}$	$-1.92 \pm 0.04^{B,b}$
6	$-1.85 \pm 0.01^{C,b}$	$-2.00 \pm 0.02^{A,b}$	$-1.95 \pm 0.02^{B,b}$	$-1.99 \pm 0.2^{A,a}$
10	$-1.90 \pm 0.021^{C,a}$	$-2.08 \pm 0.02^{A,a}$	$-2.02 \pm 0.03^{B,a}$	$-2.03 \pm 0.02^{B,a}$
14	$-1.90 \pm 0.01^{C,a}$	$-2.07 \pm 0.01^{A,a}$	$-2.05 \pm 0.02^{B,a}$	$-2.05 \pm 0.04^{A,B,a}$
b*				
3	$4.55 \pm 0.20^{A,a}$	$4.89 \pm 0.18^{B,a}$	$4.71 \pm 0.15^{A,B,a}$	$4.87 \pm 0.18^{A,B,a}$
6	$4.70 \pm 0.05^{A,a}$	$5.23 \pm 0.04^{D,b}$	$4.95 \pm 0.05^{B,b}$	$5.14 \pm 0.05^{C,a,b}$
10	$4.64 \pm 0.11^{A,a}$	$5.32 \pm 0.09^{C,b}$	$4.92 \pm 0.13^{B,a,b}$	$5.14 \pm 0.11^{C,b}$
14	$4.74 \pm 0.08^{A,a}$	$5.41 \pm 0.09^{C,b}$	$5.04 \pm 0.13^{B,b}$	$5.39 \pm 0.20^{C,b}$
WI				
3	$76.72 \pm 0.43^{B,a}$	$73.93 \pm 0.61^{A,a}$	$74.38 \pm 0.36^{A,a}$	$73.92 \pm 0.34^{A,a}$
6	$77.14 \pm 0.09^{B,b}$	$74.92 \pm 0.05^{B,b}$	$74.56 \pm 0.39^{A,B,a}$	$74.50 \pm 0.12^{A,a}$
10	$76.97 \pm 0.22^{A,a,b}$	$74.44 \pm 0.21^{A,a,b}$	$74.43 \pm 0.20^{A,a}$	$74.11 \pm 0.32^{A,a}$
14	$76.77 \pm 0.25^{B,b}$	$74.97 \pm 0.14^{B,b}$	$74.65 \pm 0.38^{B,a}$	$74.02 \pm 0.48^{A,a}$
YI				
3	$8.41 \pm 0.33^{A,a}$	$9.38 \pm 0.28^{B,a}$	$8.99 \pm 0.25^{B,a}$	$9.34 \pm 0.31^{B,a}$
6	$8.65 \pm 0.09^{A,a}$	$9.90 \pm 0.08^{C,b}$	$9.43 \pm 0.05^{B,b}$	$9.79 \pm 0.09^{C,a}$
10	$8.56 \pm 0.19^{A,a}$	$10.13 \pm 0.16^{C,b}$	$9.38 \pm 0.24^{B,b}$	$9.84 \pm 0.18^{C,a,b}$
14	$8.76 \pm 0.15^{A,a}$	$10.23 \pm 0.17^{C,b}$	$9.58 \pm 0.22^{B,b}$	$10.32 \pm 0.43^{C,b}$

Explanations: Abbreviations as in Table 1, with the addition of L*—lightness, indicating the brightness of the sample; a*—position on the green (−) to red (+) axis; b*—position on the blue (−) to yellow (+) axis. Additionally, WI—whiteness index and YI—yellowness index were calculated from the L*, a*, and b* values. Different superscript letters (a–b) indicate significant differences in the same yogurt on different storage days. Superscript capital letters (A–D) indicate significant differences between yogurts on the same storage day ($p \leq 0.05$).

In the color evaluation, the whiteness index (WI) and yellowness index (YI) were calculated (Table 3). Statistical analysis showed that both parameters were influenced by the yogurt variants as well as the storage time. The WI was also affected by the interaction between these variables (Table A2). Yogurts with the addition of whey powders had a significantly lower WI for the entire tested period. The type of drying agent significantly affected this parameter, and the lowest WI was noted in yogurt G, containing whey powder with gelatin. In the case of the YI, the addition of whey powders caused a significant increase in this attribute, and the highest YI values were observed in yogurts W and G. The whey powder with maltodextrin had the least pronounced effect on the YI. In the control sample, the intensity of the yellow color remained stable, whereas in the samples containing whey powders, it tended to increase throughout the period of refrigerated storage. According to Bierzuńska et al. [24], the addition of whey protein concentrate (WPC) also results in a decrease in whiteness and an increase in yellowness in yogurts, which is consistent with the present findings.

3.5. Texture Parameters

Texture is a crucial indicator of yogurt quality, as it determines sensory acceptability and should remain stable during storage [24]. Firmness, consistency and cohesiveness were influenced by both the storage time and the sample type. The index of viscosity was affected only by the sample type (Table A2). The values of the texture parameters are compiled in Table 4.

Table 4. Texture parameters of yogurts with whey powders.

	Product			
Days	**C**	**W**	**M**	**G**
Firmness, g				
3	$31.08 \pm 1.06^{A,a}$	$97.40 \pm 8.94^{C,a}$	$67.96 \pm 3.41^{B,a}$	$88.2 \pm 7.26^{C,a}$
6	$47.69 \pm 2.69^{A,b}$	$83.25 \pm 5.57^{C,a}$	$67.96 \pm 3.14^{B,a}$	$88.2 \pm 7.26^{C,a}$
10	$49.39 \pm 1.78^{A,b}$	$90.46 \pm 4.36^{C,a}$	$74.74 \pm 5.24^{B,a}$	$95.65 \pm 17.36^{C,a}$
14	$47.95 \pm 2.97^{A,b}$	$89.03 \pm 10.35^{B,C,a}$	$74.37 \pm 6.21^{B,a}$	$92.77 \pm 15.53^{C,a}$
Consistency, g·s				
3	$348.66 \pm 8.35^{A,a}$	$1268.9 \pm 87.35^{C,a}$	$945.07 \pm 47.20^{B,a}$	$1197.8 \pm 140.96^{C,a}$
6	$741.11 \pm 19.62^{A,b}$	$1175.4 \pm 78.54^{C,a}$	$938.37 \pm 54.81^{B,a}$	$1021.7 \pm 27.64^{B,a}$
10	$739.88 \pm 24.97^{A,b}$	$1175.4 \pm 78.54^{C,a}$	$1089.0 \pm 71.24^{B,b}$	$1207.2 \pm 174.97^{B,a}$
14	$729.1 \pm 20.25^{A,b}$	$1278.1 \pm 126.08^{C,a}$	1061.2 ± 72.61^{B}	$1221.7 \pm 107.12^{D,C,a}$
Cohesiveness, g				
3	$18.53 \pm 0.95^{A,a}$	$60.27 \pm 8.09^{C,a}$	$37.80 \pm 3.20^{B,a}$	$54.96 \pm 6.22^{C,a}$
6	$29.05 \pm 1.22^{A,b}$	$51.09 \pm 6.19^{C,a}$	$39.09 \pm 3.11^{B,a,b}$	$46.56 \pm 3.28^{C,a}$
10	$28.31 \pm 1.21^{A,b}$	$51.09 \pm 6.19^{C,a}$	$45.18 \pm 3.89^{B,b}$	$59.20 \pm 16.69^{B,a}$
14	$28.39 \pm 1.63^{A,b}$	$53.24 \pm 4.03^{B,C,a}$	$45.16 \pm 5.20^{B,b}$	$58.21 \pm 8.74^{C,a}$
Index of viscosity, g·s				
3	$15.30 \pm 0.91^{A,a}$	$81.94 \pm 11.46^{C,a}$	$58.60 \pm 5.96^{C,c}$	$70.31 \pm 11.40^{B,c,a}$
6	$30.56 \pm 1.37^{A,b}$	$75.84 \pm 6.32^{C,a}$	$57.08 \pm 6.74^{B,a}$	$69.06 \pm 5.11^{C,a}$
10	$31.15 \pm 1.55^{A,b}$	$75.48 \pm 6.32^{B,a}$	$64.98 \pm 6.35^{B,a}$	$69.45 \pm 16.61^{B,a}$
14	$30.31 \pm 1.48^{A,b}$	$74.16 \pm 4.81^{C,a}$	$59.69 \pm 7.48^{B,a}$	$76.34 \pm 3.38^{C,a}$

Explanations: The results are presented as mean values ± standard deviation. C—control yogurt without whey powder; W—yogurt with whey powder but without a drying agent; M—yogurt with whey powder with maltodextrin; G—yogurt with whey powder with gelatin. Different superscript letters (a–c) indicate significant differences in the same yogurt on different storage days. Superscript capital letters (A–D) indicate significant differences between yogurts on the same storage day ($p \leq 0.05$).

Firmness, consistency, cohesiveness and the viscosity index of yogurts supplemented with whey powders were consistently higher than those of the control product throughout the entire storage period. This indicates that the tested whey powders positively influenced the texture of the yogurts. The use of gelatin as a drying agent during whey powder production resulted in yogurts (G) with texture parameters comparable to those of yogurts containing whey powder without a drying agent (W). In contrast, yogurt M, containing whey powder produced with maltodextrin as the drying agent, was characterized by lower texture parameter values than samples W and G. These findings are related to the low concentration of drying agents in the final product. However, all texture parameter values remained distinctly higher than those of the control sample. The texture of samples W and G was stable throughout the storage period, whereas some fluctuations were observed in the control sample and in sample M containing whey powder produced with maltodextrin. This suggests that whey powder without the drying agent and whey powder with gelatin exhibit greater stabilizing capacity than whey powder with maltodextrin. The improved texture of yogurts with whey protein concentrate (WPC) and polymerized whey protein (PWP) compared with the control yogurt was observed by [24]. The control yogurt without any additives obtained by the cited authors [24] exhibited similar hardness to the control yogurt produced in the present study but differed in other texture attributes, which presumably resulted from the differences in fat content and pH of the compared samples as well as from the use of different starter cultures in yogurt production. According to previous studies [54], these factors significantly influence yogurt texture quality. An enhanced texture of yogurts fortified with whey protein concentrate (WPC) and whey protein isolate (WPI) was also reported by Delikanlı and Özcan [54], who attributed this effect to the denser structure of the fortified yogurts, as well as by other authors [55]. Similar findings, namely a substantial increase in texture parameters in yogurts containing WPC, fermented WPC and WPI, were observed in the study by [34]. In contrast, Brodziak et al. [53] reported different results, showing that the addition of WPC decreases the firmness and cohesiveness of yogurts while increasing consistency compared with the control. The increase in the firmness of yogurts containing whey can be explained by the fact that denaturated whey proteins aggregate with casein micelles via intermolecular disulfide bonds, thereby strengthening the casein gel structure [24,51]. The addition of hydrocolloids in yogurts aims to improve their texture, viscosity, appearance, and mouthfeel; however, in the current study, gelatin and maltodextrin were used as drying agents, and their concentration in the final products was too low to be effective.

3.6. Sensory Characteristics

The sensory test was conducted to evaluate consumer acceptability of yogurts containing different types of whey powders. It is one of the crucial tools for assessing consumer perception of a food product [31]. The results are shown in Figure 1. According to the ANOVA results (Table A2), the sensory score was influenced by the storage time and sample type.

The first sensory characteristic evaluated by the consumer is the appearance of the yogurts. This attribute remained stable throughout the study period except for yogurt G, which showed a significant deterioration from day 10 onwards. The control sample exhibited the best appearance, which may be related to its high whiteness index and low yellowness index. The taste of yogurts W and G was similar to that of the control, but the taste of yogurt M, containing whey powder produced with maltodextrin as the drying agent, was noticeably inferior. The aroma of all the yogurts was rated high. The control yogurt exhibited the best consistency and texture, which does not fully coincide with the instrumental texture analysis results (Table 4). Nevertheless, the differences in sensory scores

among samples were mostly insignificant. According to the literature [34], the sensory properties of yogurts are primarily affected by the milk composition, added ingredients, and processing conditions. In agreement with our findings, Bierzuńska et al. [24] stated that the sensory properties of yogurts containing polymerized whey protein (PWP) tended not to change during storage. In contrast, Brodziak et al. [53] observed a deterioration in sensory properties, particularly flavor, in yogurt containing WPC during storage. Delikanlı and Özcan [54] noted that the whey flavor can limit its use in food production due to sourness and bitterness; however, our findings did not confirm this observation. As shown on Figure 1, the sensory scores of the yogurts with whey powders ranged from 17.50 points (yogurt M on day 3) to 19.13 points (yogurt G on day 3) on a 20-point scale. These results indicate that the yogurts formulated with whey powders are likely to be acceptable to consumers. Similarly, Shukla et al. [56] reported positive consumer acceptance for yogurts containing 25–35% of liquid acid whey.

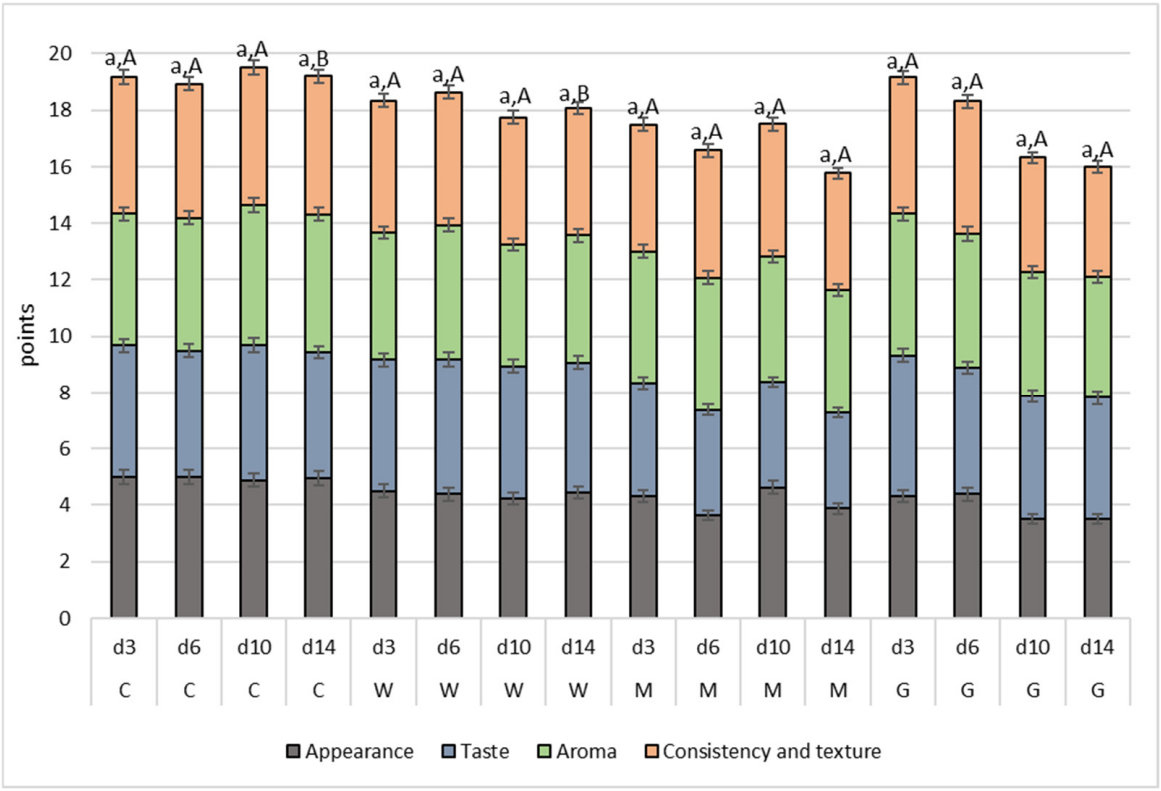


Figure 1. Sensory properties of yogurts with whey powders. Explanations: The same letter a indicates no significant differences ($p > 0.05$) in the same yogurt sample on different storage days (d3–d14, where d = day of storage). C—control yogurt without whey powder; W—yogurt with whey powder but without a drying agent; M—yogurt with whey powder with maltodextrin; G—yogurt with whey powder with gelatin. Capital letters (A–B) indicate significant differences between yogurt samples on the same storage day ($p \leq 0.05$).

4. Conclusions

This study examined the application of whey powders obtained by the spray drying of sweet whey from Camembert cheese production using maltodextrin and gelatin as drying agents. Yogurts containing whey powders exhibited a higher total solids content and increased acetaldehyde concentration compared with the control. Moreover, the use of maltodextrin as a drying agent decreased yogurt acidity, indicating a slower post-acidification process, which may contribute to a prolonged shelf life. Whey powders also affected color, resulting in less white and more yellow yogurts, and the appearance of

yogurts with added whey was rated lower. Taste and aroma were generally rated highly, and the use of whey powder with gelatin as a drying agent led to better sensory quality than whey powder with maltodextrin. The texture of yogurts with whey powders was higher than that of the control, particularly in the case of whey powder with gelatin. In summary, the results confirm that the use of whey powders with drying agents, especially gelatin, lead to good quality yogurt. The use of maltodextrin and gelatin not only facilitates the spray-drying process but also influences the quality characteristics of yogurts produced with whey powders. However, there is a need for further studies, especially related to the impact of drying agents on yogurt microflora. Our findings have direct technological implications for the dairy and food processing industries, bridging the gap between whey processing (spray drying) and final product formulation.

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Appendix A

The results of the one-factor and two-factor analysis of variance (ANOVA) performed on the quality characteristics of whey powders and yogurts with whey powders.

Table A1. The results of the one-factor ANOVA of the total solids in whey powders and fat and total protein content in yogurts with whey powders.

Product	Parameter	One-Factor ANOVA		
		F	*p*-Value	Test F
whey powders	total solids	18.6234	0.0027	5.1433
yogurts	total protein	65.9951	0.0000	4.0662
	fat	8.5857	0.0137	4.7571

Table A2. The results of the two-factor ANOVA performed on the characteristics of yogurts with whey powders.

Parameter	Factor	Two-Factor ANOVA		
		F	*p*-Value	Test F
total solids	Time	3.6663	0.0223	2.9011
	Sample	3.8746	0.0180	2.9011
	Interaction	3.6467	0.0031	2.1888

Table A2. *Cont.*

Parameter	Factor	Two-Factor ANOVA		
		F	*p*-Value	Test F
titratable acidity	Time	64.8723	0.0000	2.9011
	Sample	382.5428	0.0000	2.9011
	Interaction	11.7092	0.0000	2.1888
pH	Time	345.5111	0.0000	2.9011
	Sample	1144.8000	0.0000	2.9011
	Interaction	75.1901	0.0000	2.1888
acetaldehyde	Time	103.1758	0.0000	2.9011
	Sample	41.1335	0.0000	2.9011
	Interaction	2.6856	0.0190	2.1888
syneresis index	Time	0.3420	0.7951	2.9011
	Sample	48.3457	0.0000	2.9011
	Interaction	103.1758	0.0000	2.9011
L	Time	11.0232	0.0000	2.7482
	Sample	255.5752	0.0000	2.7482
	Interaction	2.1655	0.0362	2.0298
a*	Time	27.8306	0.0000	2.7482
	Sample	122.4949	0.0000	2.7482
	Interaction	5.6277	0.0000	2.0298
b*	Time	27.8306	0.0000	2.7482
	Sample	122.4949	0.0000	2.7482
	Interaction	5.6277	0.0000	2.0298
WI	Time	9.9455	0.0000	2.7482
	Sample	306.0289	0.0000	2.7482
	Interaction	2.2916	0.0268	2.0298
YI	Time	32.5496	0.0000	2.7482
	Sample	144.0481	0.0000	2.7482
	Interaction	1.9807	0.0561	2.0298
firmness	Time	4.7126	0.0058	2.7981
	Sample	30.6499	0.0000	3.1907
	Interaction	1.4248	0.2248	2.2946
consistency	Time	7.1900	0.0004	2.7981
	Sample	31.8146	0.0000	3.1907
	Interaction	1.5291	0.1890	2.2946
cohesiveness	Time	3.4404	0.0239	2.7981
	Sample	23.8650	0.0000	3.1907
	Interaction	1.8078	0.1175	2.2946
index of viscosity	Time	0.8714	0.4625	2.7981
	Sample	25.7709	0.0000	3.1907
	Interaction	1.0224	0.4223	2.2946
sensory score	Time	3.6612	0.0186	2.7981
	Sample	8.5843	0.0001	2.7981
	Interaction	1.4766	0.1838	2.0817

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