

QUALITY MANAGEMENT OF FUNCTIONAL FOOD BASED ON INSTANT OATMEALS: PROPERTIES, SAFETY AND CONSUMER PERCEPTION

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Purpose: The aim of this article was to assess the quality, safety, and functional properties of three instant oatmeal variants and determine their relevance in quality management processes for functional foods. The study sought to identify key parameters influencing stability, microbiological safety, and consumer acceptance.

Design/Methodology/Approach: Three flavored instant oatmeal variants were analyzed using physicochemical methods (moisture content, water activity, flow properties, bulk and tapped density, Hausner and Carr indices), microbiological assays (total count, molds and yeasts, indicator bacteria, *Salmonella* spp.), sensory evaluation (10-person panel), and sorption analysis based on isotherms and BET parameters (V_m , SSA). The selected methods enabled interpretation of results within a HACCP-based quality management framework.

Findings: Statistically significant differences ($p < 0.05$) were observed between variants in water activity, moisture content, selected flow parameters, and sorption characteristics. All products exhibited low water activity ($a_w < 0.40$), confirming high microbiological stability. The strawberry variant showed the highest hygroscopicity and sorption surface area, indicating greater sensitivity to storage humidity, whereas the apple–cinnamon variant demonstrated the lowest water activity and the most favorable flowability indices. Microbiological analyses confirmed compliance with safety criteria, with no *Salmonella* spp. detected and indicator microorganisms below critical limits. Sensory attributes received high ratings (≥ 4.4), although overall acceptance remained moderate, suggesting that flavor–texture integration plays a decisive role in consumer perception.

Research limitations/conclusions: The study was limited to one product category and three variants, restricting generalization. The relatively small sensory panel may also affect robustness. Future research should include products from different manufacturers, storage-condition analyses, and advanced sorption modeling (e.g., GAB).

Practical and social implications: The results support manufacturers in optimizing formulation, drying, mixing, and packaging processes, particularly regarding moisture control and barrier properties. They also emphasize the role of functional foods in promoting healthy dietary habits.

Originality/value: The study proposes an integrated quality-management model linking physicochemical, microbiological, sensory, and sorption parameters with HACCP-based Critical Control Points. It demonstrates that measurable indicators such as water activity, V_m , SSA, microbiological status, and flowability can serve as operational tools for risk assessment, storage prediction, and process control. The framework may be transferable to other instant functional foods.

Keywords: instant oatmeal; functional food; quality management; food safety.

Article category: Research paper.

1. Introduction

Functional foods are currently one of the fastest-growing segments of the global food market, driven by consumers' growing health awareness, changing lifestyles, and the search for products that combine nutritional value with convenience (Diplock et al., 1999; Roberfroid, 2002). By definition, functional foods have a documented, beneficial effect on health beyond their basic nutritional value (Roberfroid, 2002). The growing popularity of this category aligns with global trends related to the prevention of diet-related diseases, increased physical activity, and the search for products that support well-being.

Among functional foods, oat-based products, including instant oats, occupy a special place. Thanks to their high dietary fiber content, especially β -glucan, they exhibit lipid-lowering, hypoglycemic, and immunomodulatory properties (Whitehead et al., 2014; Rasane et al., 2013). Numerous studies also confirm the antioxidant and anti-inflammatory effects of oat bioactive components and their beneficial effects on the intestinal microbiota (Gibiński et al., 2005). From the consumer's perspective, instant oatmeal is perceived as a healthy, nutritionally valuable, and easy-to-prepare product, which is reflected in the survey results presented in this empirical study.

However, instant products, as low-water foods, pose a technological and qualitative challenge. Their shelf life and microbiological safety are determined primarily by water activity, hygroscopicity, and sorption properties (Labuza, 1980; Fontana, 2008). In the case of instant oatmeal, these parameters influence not only microbiological stability but also the tendency to caking, texture changes, rehydration capacity, and the sensory qualities of the final product. The phenomenon of intense moisture sorption is typical for products based on cereal flakes and flours.

Managing the quality of instant products therefore requires monitoring a range of physicochemical (water activity, bulk density, angle of repose), microbiological, and sensory parameters. HACCP, GMP, and GHP systems emphasize the need to control critical points in the manufacturing process and continuously assess the safety of products with reduced AW (Codex Alimentarius, 2003). At the same time, it is consumer perception, including assessment

of taste, texture, nutritional value, and ease of preparation, that determines the final acceptance of the product and its market success (Granato et al., 2020; Kaczorowska, Rejman, 2021).

Despite numerous publications on the properties of oats and functional foods, there is still a lack of studies presenting an integrated quality assessment of instant oatmeal, encompassing physicochemical, microbiological, and sensory analysis, from a quality management perspective. This study, based on a comprehensive evaluation of three instant oatmeal variants available on the market, fills this research gap. The aim of the study was to conduct a multidimensional analysis of the quality of instant oatmeal, including physicochemical properties, microbiological safety, sensory characteristics and sorption properties, and to assess their importance for the quality management processes of functional foods.

2. Material and Method

The research material consisted of three flavor variants of instant oatmeal: oatmeal with chocolate (I), oatmeal with apple and cinnamon (II), and oatmeal with strawberries (III). The products studied belong to the instant breakfast food category and were manufactured in Poland. All samples came from the same product line and were available in general retail stores.

2.1. Methods of Physicochemical Analysis

Physicochemical analysis included determining parameters crucial for the quality and shelf life of instant products, including water content, water activity, flow properties, and product density. The selection of methods was based on their high suitability for assessing the quality of oat products and their importance for the microbiological and technological stability of food.

2.1.1. Determination of water content and activity

The moisture content was determined using the thermal drying method to constant weight at 104°C, in accordance with commonly applied procedures for the analysis of cereal-based products. Water activity (a_w) was measured with an AquaLab 4TE analyzer (Decagon Devices, USA) with an accuracy of ± 0.003 , at a temperature of 20 ± 2.5 °C. Each measurement was performed in triplicate to ensure the representativeness of the results.

2.1.2. Determination of selected physicochemical properties

The angle of repose and the angle of repose were determined using methods used to assess the flow properties of food powders. The static angle of repose (CA) was determined based on the geometry of the cone of repose, while the kinetic angle of repose (AR) was determined using the inclined surface method, using a constant sample volume. These parameters describe the product's flowability and susceptibility to movement, which is important in characterizing instant powders (Leśmian-Kordas, 2001; Ruszkowska, Wiśniewska, 2017; Beakawi Al-Hashemi et al., 2018). The assessment of physicochemical properties was supplemented by

measurements of loose and tapped bulk density, conducted in accordance with the PN-ISO 8460:1999 standard. The obtained values were used to calculate two indices: the Hausner index and the Carr index, which classify powders in terms of their ability to flow and their susceptibility to clumping (Abdullah & Geldart, 1999; Samborska et al., 2011).

2.1.3. Microbiological Parameter Determination

The microbiological evaluation of instant oatmeal included the determination of key microbial groups, in accordance with the requirements for low water activity foods. Analyses were performed in accordance with applicable ISO standards, using surface and deep plating methods and selective microbiological media. The following parameters were determined: total aerobic mesophilic microorganism count (ISO 4833), yeast and mold count (ISO 21527), coliforms and *Escherichia coli* (ISO 16649; ISO 4832), Enterobacteriaceae (ISO 21528), *Staphylococcus aureus* (ISO 6888), presumptive *Bacillus cereus* (ISO 7932), and detection of *Salmonella* spp. according to the PN-EN ISO 6579-1:2017-04/A1:2020-09 standard. Samples were prepared by performing a series of decimal dilutions, and the results were expressed as colony-forming units (CFU/g). The scope of the analyses meets the microbiological safety requirements for instant products and allows for a comprehensive assessment of their health-related quality.

2.1.4. Sensory Analysis

The sensory evaluation of instant oatmeals was conducted with a panel of 10 trained assessors using a five-point hedonic scale. The analysis covered attributes essential for product perception: appearance, color, aroma, taste, and texture. Samples were prepared according to the manufacturer's instructions and served under conditions ensuring a neutral sensory environment, at room temperature, under daylight illumination, and in random order. The results were presented as mean scores from the panelists, which enabled comparison of the sensory profiles of the individual flavor variants.

2.2. Determination of Sorption Properties Governing Storage Stability

The sorption properties of the instant oatmeals were determined using the static desiccator method, establishing water vapor sorption isotherms within the water activity range $a_w = 0.07-0.92$. The tests were carried out under controlled relative humidity conditions generated by saturated salt solutions, in accordance with procedures described for highly hygroscopic products (Tańska et al., 2017).

2.3. Systemic Approach to Quality Management and Critical Control Points (HACCP) in the Evaluation of Instant Oatmeals

To ensure a comprehensive assessment of the quality and health safety of instant oatmeals, elements of a systemic quality-management approach were incorporated, based on GHP/GMP principles, HACCP hazard analysis, and the requirements of ISO 22000. Inclusion of these elements in the research methodology stems from the fact that the evaluated physicochemical,

microbiological, sensory, and sorptive parameters constitute key indicators used in practice to monitor and supervise the quality of instant products.

The parameters analyzed in this study correspond to critical control points in food safety evaluation:

- water activity and moisture content — critical limits for microbial growth,
- flowability and density parameters — related to quality control of mixing, transport, and packaging processes,
- microbiological load — verification of CCP effectiveness during processing and packaging,
- sensory evaluation — monitoring the consistency of organoleptic quality in line with consumer expectations,
- sorption properties — assessment of storage stability and product durability.

Integrating the HACCP-based systemic approach into the research methodology allows the results to be interpreted not only in terms of product characteristics but also in relation to compliance with critical food safety requirements. Consequently, the analysis is directly linked to quality-management practice, forming an integral part of the evaluation of functional food products.

3. Results and Discussions

3.1. Evaluation of Water Content and Activity

Water content and water activity are among the most important parameters determining the storage stability and safety of instant products. They directly influence the rate of biological, chemical, physical, and microbiological processes occurring in food (Labuza, 1980; Fontana, 2008). In powdered products such as instant oatmeal, low water content and low water activity are essential for maintaining high shelf life and resistance to quality changes. The measurement results are summarized in Table 1.

Table 1.
Water content and activity of the tested products

Product	Water content [g/100 g. s.m.]		Water activity [-]	
	M	SD	M	SD
Product I	8.587 ^b	0.019	0.388 ^b	0.0004
Product II	7.487 ^a	0.028	0.277 ^a	0.0006
Product III	8.724 ^b	0.040	0.354 ^b	0.0004
	Value „p”			
	0.000		0.000	

M – Mean; SD – standard deviation, Explanatory notes: Mean values denoted with the same letter do not differ significantly in the LSD test.

Source: own research.

In the analyzed instant oatmeals, a low moisture content (7.49-8.72 g/100 g d.m.) and very low water activity (0.277-0.388) were found, which is characteristic of powdered products with high storage stability (Labuza, 1980; Fontana, 2008). The lowest moisture content and water activity were recorded for product II — the apple–cinnamon oatmeal — indicating its highest resistance to moisture adsorption and the lowest risk of quality deterioration. Higher moisture and water activity values in the strawberry and chocolate variants may result from differences in the composition of flavor additives and their water-binding capacity.

Compared to the literature on powdered products, including milk powder (3.34-3.68 g/100 g d.m.), the analyzed oatmeals exhibited higher moisture levels; however, their aw values remained much lower than those reported for cereal brans (aw 0.525-0.643), confirming their high storage stability (Domian, Lenart, 2000; Jensen et al., 2005).

Statistical analysis revealed significant differences in both moisture content and aw between the variants ($p < 0.05$), with the apple–cinnamon oatmeal differing significantly from the other two products.

The results confirm that all instant oatmeals meet microbiological safety criteria, and $aw < 0.4$ eliminates the risk of pathogen growth, which was validated by the microbiological tests. These parameters are crucial in quality management and HACCP systems, where moisture content and water activity serve as critical limits for monitoring food safety and shelf-life stability. In the context of the study's objective—evaluating the quality and stability of functional instant oatmeals—the obtained results clearly confirm the high storage stability and safety of the analyzed products.

3.2. Evaluation of Selected Physicochemical Properties

The angle of repose and the angle of slide are fundamental parameters characterizing the flowability of powdered materials. The angle of repose reflects the ability of particles to freely flow; its higher value indicates reduced flowability and greater cohesiveness of the product. The angle of slide, in turn, defines the minimum inclination at which material begins to move; its magnitude depends on factors such as friction, moisture, and particle structure (Drzewieniecka, 2000). These parameters are essential for the stability of instant powders and their behavior during packaging, transport, and consumer use.

In the present study, product III — the strawberry oatmeal — exhibited the highest angle of repose (78.33°), while product II — the apple–cinnamon oatmeal — showed the lowest value (74.83°) (Table 2). All values were clearly higher than the natural angles reported for unprocessed grains: oats (21-54°), wheat (23-38°), or millet (20-25°). This indicates that the analyzed instant oatmeals had noticeably poorer flowability than cereal grains, which results from their powdered structure, functional additives, and hydrothermal processing that affects particle surface and shape. Statistical analysis showed no significant differences between the products ($p > 0.05$), confirming similar flow characteristics across all flavor variants.

Table 2.
The angle of repose and dumping of the tested products

Product	Angle of repose [°]		Angle of repose - rough surface [°]		Angle of repose - smooth surface [°]	
	M	SD	M	SD	M	SD
Product I	75.00	5.48	40.00 ^b	0.000	22.50 ^c	2.739
Product II	74.83	32.34	35.00 ^a	0.000	16.67 ^b	2.582
Product III	78.33	2.58	34.17 ^a	2.041	13.33 ^a	2.582
	<i>p</i>					
	0.938		0.000		0.000	

M – Mean; SD – standard deviation; Explanatory notes: Mean values denoted with the same letter do not differ significantly in the LSD test.

Source: own research.

In the assessment of the angle of repose, the highest values were recorded for product I – the chocolate-flavored oatmeal, both on the smooth surface (22.50°) and the rough surface (40.00°), which indicates greater cohesion and higher frictional resistance in this product (Table 2). The lowest angles of repose were obtained for product III – the strawberry-flavored oatmeal, suggesting better flowability and easier particle movement. Compared to extruded cereal porridges, which are characterized by angles of repose ranging from 23.3° to 29.7°, the values obtained on the smooth surface were similar, whereas those measured on the rough surface were significantly higher, confirming the greater susceptibility of instant oatmeals to interactions with the substrate and their tendency to hinder movement.

Statistical analysis showed significant differences between the tested products for the angle of repose on both rough and smooth surfaces ($p < 0.05$), indicating variations in particle structure and differing behavior of the products during dynamic processes.

The next stage of the study involved determining the bulk and tapped densities and calculating flowability indicators: the Hausner ratio and Carr index (Table 3). These parameters reflect the structure of the powder, its degree of cohesion, the size of the interparticle pores, and its susceptibility to compression during transport or storage, all of which are crucial for quality assessment and the design of technological processes (Abdullah, Geldart, 1999; Samborska et al., 2011; Ruszkowska, Wiśniewska, 2017). Bulk and tapped densities were determined according to PN-ISO 8460:1999.

Among the instant oatmeals studied, the highest bulk and tapped densities were recorded for the strawberry-flavored oatmeal (0.414 and 0.509 g/cm³), whereas the lowest values were obtained for the chocolate-flavored oatmeal (0.395 and 0.473 g/cm³). These values fall within the typical range for powdered products and are comparable to literature data for milk powder (0.27-0.45 g/cm³), the presence of which in the composition of the oatmeals may have influenced the obtained results (Samborska et al., 2011).

The Hausner ratio reached its highest value for product III – the strawberry-flavored oatmeal (1.229), indicating the highest cohesiveness and stronger interparticle forces. This trend was confirmed by the Carr index, which also reached its highest value (18.62) for this variant, suggesting lower flowability (Abdullah, Geldart, 1999). The most free-flowing

product was product II – the apple-and-cinnamon oatmeal, characterized by the lowest Carr index (16.23) and one of the lowest Hausner ratios. Statistical analysis revealed significant differences in bulk and tapped densities between the products ($p < 0.05$), while the Hausner ratio and Carr index showed no statistically significant differences ($p > 0.05$), indicating generally similar flowability characteristics across all flavor variants.

These results demonstrate that the tested instant oatmeals exhibit flow properties typical of instant food products, which are important from the standpoint of storage stability, dosing, and consumer convenience. The evaluation of these parameters aligns directly with the aim of the study, which included a comprehensive assessment of the quality and functionality of instant oatmeals as functional food products.

Table 3.
Bulk density and flow coefficients

Product	Loose density [g/cm ³]		Shaked density [g/cm ³]		Hausner's Co.		Carr's Index	
	M	SD	M	SD	M	SD	M	SD
Product I	0.395 ^a	0.004	0.473 ^a	0.007	1.199	0.022	16.57	1.525
Product II	0.403 ^{ab}	0.011	0.481 ^a	0.016	1.196	0.056	16.23	3.872
Product III	0.414 ^b	0.003	0.509 ^b	0.011	1.229	0.024	18.62	1.601
	<i>p</i>							
	0.001		0.000		0.268		0.253	

M – Mean; SD – standard deviation; Explanatory notes: Mean values denoted with the same letter do not differ significantly in the LSD test.

Source: own research.

3.3. Microbiological Assessment

Microbiological assessment is a key element in verifying the safety of instant foods, especially cereal products enriched with functional ingredients. The test determined the total microbial count (OLC), the number of molds and yeasts, and selected groups of indicator bacteria: *Escherichia coli*, coliforms, Enterobacteriaceae, *Bacillus cereus*, *Staphylococcus aureus*, as well as the presence of *Salmonella* spp., in accordance with applicable hygiene and sanitation requirements for food (Commission Regulation (EC) No. 2073/2005; PN-EN ISO 4833-1:2013; PN-EN ISO 6579-1:2017).

In all analyzed instant oatmeal samples, no *Salmonella* spp. were detected in 25g, which is a necessary condition for the safety of ready-to-eat cereal products. Furthermore, the counts of *Staphylococcus aureus*, Enterobacteriaceae, and *E. coli* in all variants were below the detection limit (<10 cfu/g), indicating that high hygiene standards were maintained during production and there was no secondary contamination (Silva et al., 2017).

Differences between the variants mainly concerned OLD, molds and yeasts, and the presence of *Bacillus cereus*. The highest total microbial counts were observed in the apple and cinnamon oatmeal (5.0×10^3 cfu/g), while the lowest were in the chocolate version (4.4×10^2 cfu/g). Molds and yeasts were also detected in two variants, strawberry and apple and cinnamon, which is typical for products with increased water activity due to fruit additions and

their hygroscopicity (Beuchat, 1981). The chocolate version showed no evidence of these pathogens (<10 cfu/g), suggesting greater microbiological stability of the raw materials used in this variant.

For *Bacillus cereus*, a known pathogen frequently found in cereal products, growth was observed in two variants: the apple and cinnamon oatmeal and the chocolate oatmeal, with values of 3.0×10^1 and 2.4×10^2 cfu/g, respectively. Only the strawberry oatmeal showed no evidence of this pathogen. However, all obtained results remain below the values considered hazardous for ready-to-eat foods, where the critical level is 10^4 - 10^5 cfu/g (ICMSF, 2005).

The test results confirmed that the instant oatmeals tested met microbiological safety criteria and were within acceptable limits for low water activity cereal products. Minor differences between samples may be due to the presence of fruit additives, natural variability of raw materials and differences in their microbiological load, which is consistent with literature observations for plant-based products (Tournas et al., 2009).

Table 4.

Bulk density and flow coefficients

Product type/tested bacteria (jtk/g)	OLD	PD	EC	TC	EB	BC	SA	S
Product I	7.7×10^2	7.0×10^1	<10	2.0×10^1	<10	<10	<10	nw
Product II	5.0×10^3	1.0×10^2	<10	2.0×10^1	<10	3.0×10^1	<10	nw
Product III	4.4×10^2	<10	<10	<10	<10	2.4×10^2	<10	nw

OLD – total microbial count, PD – count of molds and yeasts, EC – count of *Escherichia coli*, TC – count of coliform bacteria, EB – count of *Enterobacteriaceae*, BC – count of *Bacillus cereus*, SA – count of *Staphylococcus aureus*, S – presence of *Salmonella* spp. in 25 g).

Source: own research.

3.4. Sensory evaluation

Sensory evaluation is a key element in analyzing the quality of instant products because it links technological parameters with subjective consumer perception and directly influences consumer acceptance and purchasing decisions (Lawless, Heymann, 2010). The study assessed the color, taste, aroma, texture, and overall acceptability of three flavored oatmeal variants. The results are presented in Table 5.

Table 5.

Sensory evaluation of the tested products

Product	Color	Taste	Smell	Consistency	Product Acceptance	Product Average
Produkt I	4.9	4.6	5.0	4.5	3.7	4.54
Product I	4.5	4.8	4.7	4.6	3.5	4.42
Product II	4.8	4.7	4.7	4.7	3.7	4.52

Source: own research.

Product I – oatmeal with chocolate – received the highest color rating (4.9 points), which may have been due to the intense, uniform color typical of cocoa additives. Product III – oatmeal with strawberries achieved a similar score (4.8 points), while product II – oatmeal with apple and cinnamon – received the lowest color rating (4.5 points). All products scored above 4.5 points, indicating the high visual appeal of the products, which is important for initial consumer perception (Szczesniak, 2002).

In the taste assessment, the oatmeal with apple and cinnamon achieved the best score (4.8 points), characterized by a natural sweetness and spice aroma. Oatmeal with chocolate received the lowest score (4.6 points), although this score still confirms high taste acceptance. All variants exceeded 4.5 points, indicating the very good sensory quality of the analyzed products. The chocolate oatmeal received the highest rating for aroma (5 points), while the apple and strawberry versions received identical scores (4.7 points). These results indicate that all variants presented a distinctive, intense aroma consistent with the product's flavor profile, a key attribute in instant foods (Drake et al., 2003).

In terms of texture, the strawberry oatmeal received the highest rating (4.7 points), while the chocolate variant received the lowest (4.5 points). All products were rated as soft, dense, firm, and springy, indicating the desired texture characteristic of oatmeal-based instant meals.

In overall acceptance, the chocolate oatmeal and the strawberry oatmeal received the highest ratings (3.7 points), followed by the apple and cinnamon oatmeal (3.5 points). Considering the average score for all parameters, the chocolate oatmeal received the highest score (4.54 points), followed by the strawberry oatmeal (4.52 points), and the apple and cinnamon oatmeal (4.42 points). This indicates that the chocolate variant is the most preferred product from the consumer's point of view, which is also confirmed by market observations regarding the high popularity of chocolate-flavored instant products (Rasane et al., 2015).

3.5. Evaluation of Sorption Properties

The sorption properties of the tested oats were determined based on sorption isotherms determined using the static desiccator method in the water activity range $a_w = 0.07-0.92$. All products exhibited a sigmoidal isotherm shape characteristic of type II in the Brunauer, Emmett, and Teller (BET) classification, typical of foods high in biopolymers such as starch or fiber (Brunauer et al., 1938; Labuza, 1980) (Figure 1). This confirms the presence of hydrophilic fractions and the ability to bind water in multiple layers.

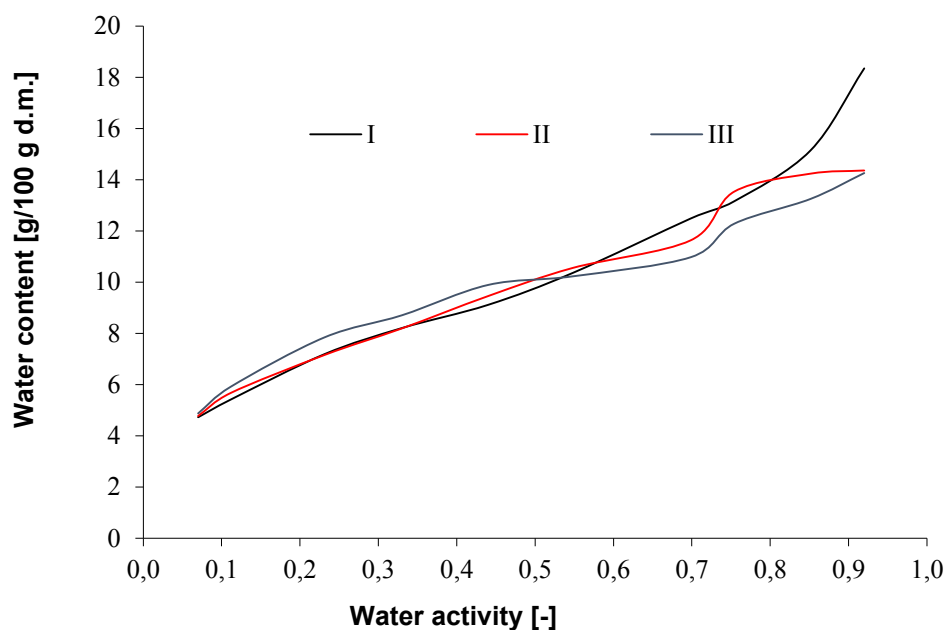


Figure 1. Sorption isotherm of the tested products determined in an environment with $a_w = 0.11-0.92$, during 63 days, at 20°C, (I - oatmeal with chocolate, II - oatmeal with apple and cinnamon, III - oatmeal with strawberries).

Source: own research.

In area I ($a_w = 0.07-0.44$), the desorption process dominated, and the products differed significantly ($p < 0.05$) in terms of equilibrium water content. The highest hygroscopicity in this range was demonstrated by product III – oatmeal with strawberries, while the lowest was demonstrated by product I – oatmeal with chocolate. In area II (multilayer sorption), statistical differences were also found at $a_w = 0.55$, indicating a different ability of particles to adsorb water. In the range $a_w = 0.70$, the differences between the products were small and statistically insignificant ($p > 0.05$). In area III (capillary condensation), oatmeal with chocolate showed the highest hygroscopicity, which may be related to greater structural porosity and a higher number of sorption-active capillaries (Labuza, 1980; Wolf et al., 1985).

Table 6.

Statistical results of sorption properties

Water activity		Product I	Product II	Product III	„p”
0.07	M	4.590 ^a	4.776 ^b	4.971 ^c	0.000
	SD	0.228	0.009	0.184	
0.11	M	5.396 ^a	5.673 ^b	6.000 ^c	0.000
	SD	0.025	0.011	0.152	
0.23	M	7.154 ^a	7.165 ^a	7.834 ^b	0.000
	SD	0.055	0.007	0.014	
0.33	M	8.220 ^a	8.195 ^a	8.741 ^b	0.000
	SD	0.018	0.015	0.053	
0.44	M	9.122 ^a	9.499 ^b	9.869 ^c	0.000
	SD	0.016	0.068	0.043	
0.55	M	10.39 ^a	10.61 ^b	10.98 ^c	0.000
	SD	0.049	0.084	0.002	

Cont. table 6.

0.70	M	12.49	12.30	11.02	0.057
	SD	0.009	1.177	1.395	
0.75	M	13.14	13.60	13.08	0.495
	SD	0.044	0.098	1.392	
0.85	M	15.41 ^c	14.02 ^b	13.24 ^a	0.000
	SD	0.472	0.394	0.014	
0.92	M	18.60 ^b	14.42 ^a	14.45 ^a	0.000
	SD	0,450	0.104	0.316	

Source: own research.

Monolayer capacity (V_m) values, calculated using the BET equation, ranged from 5.75 to 6.23 g H₂ O/100 g dry weight (Table 7). The highest V_m was found for product III – oatmeal with strawberries, suggesting a greater number of polar sites available for water molecules, likely due to the addition of a fruit component rich in hydrophilic compounds. A similar trend was observed for the specific sorption surface area (SSA), the highest value of which was also obtained for the strawberry variant (218.79 m²/g) (Table 7). Differences between the products confirm the influence of raw material composition and flavor additives on sorption activity, consistent with previous reports for food powders (Rizvi, 1995; Al-Muhtaseb et al., 2002). The obtained results indicate that the hygroscopicity of instant oatmeal depends on both its composition and the initial water content, which is the driving force behind sorption processes. These parameters are crucial from a quality management perspective, as they determine storage stability, susceptibility to caking, and packaging requirements for instant products.

Table 7.

BET equation parameters and sorption specific surface area (SSA)

Product	V_m [g/100 g s.m.]	c_e [kJ·/mol ¹]	R ²	SSA [m ² /g]
Product I	5.8220	41.7037	0,9987	204.55
Product I	5.7538	52.4468	0,9991	202.16
Product II	6.2274	42.5575	0,9957	218.79

Explanatory notes: V_m - capacity of monomolecular layer, C_e - energy constant, R² - coefficient of determination, SSA - specific surface area of sorption.

Source: own research.

3.6. A Systematic Approach to Quality Management and Critical Control Points (HACCP) in the Assessment of Instant Oats

Contemporary quality assessment of instant products, including functional foods such as oats, requires the integration of laboratory test results with a systematic approach to quality and food safety management. According to classical quality concepts (Deming, 1986; Crosby, 1979) and the ISO 9000 definition, quality denotes a product's ability to meet defined requirements, with safety being one of its fundamental dimensions. In instant food production, each stage of the technological process can generate specific biological, chemical, or physical hazards, which is reflected in the risk analyses recommended by Codex Alimentarius and mandatory in HACCP systems (FAO/WHO, 2020). Therefore, the physicochemical,

microbiological, sensory, and sorption parameters analyzed in this study should be interpreted not only as descriptions of product properties but also as critical control indicators used in monitoring the quality and shelf life of instant products. This methodological approach allows for linking research results to the real-world requirements of industrial practice, reinforcing the applied and expert nature of the analysis.

The results of the studies conducted for instant oatmeal indicate that the analyzed quality parameters directly correlate with the requirements set by food safety management systems. Low water activity ($a_w < 0.40$) and water content at levels typical of instant foods are within the critical limits described in the literature as necessary to ensure the microbiological stability of powdered products (Labuza, 1980; Fontana, 2008). The obtained results confirm the effectiveness of the drying and moisture stabilization steps, which correspond to critical control points (CCP 2) in the HACCP system (Table 9).

The flow properties of the products, such as loose and tapped density, the Hausner coefficient, and the Carr index, indicate the stability of the powder structure and the predictability of its behavior during mixing and packaging (Table 9). These parameters are crucial for process management because they influence dosing uniformity and minimize the risk of ingredient segregation, as confirmed by previous studies on powdered products (Teunou, Fitzpatrick, 1999; Abdullah, Geldart, 1999).

The results of the microbiological assessment showed full compliance with applicable food safety criteria, suggesting effective implementation of GHP/GMP principles and the proper functioning of the stages related to heat treatment and hygiene of raw materials (European Commission, 2005). The presence of *Bacillus cereus* in some variants confirms the importance of monitoring milk powder and flavorings, which, according to the literature, are considered high-risk raw materials (Granum, Lund, 1997). When assessing the storage stability of products based on sorption analyses, it was found that sorption isotherms with shapes typical of products with a high carbohydrate content (Brunauer type II) confirm their hygroscopicity and, at the same time, enable precise prediction of qualitative changes during storage (BET; Brunauer et al., 1938; Rockland, Beuchat, 1987). The v_m monolayer and SSA parameters indicate differences resulting from flavor additives, which can provide a basis for optimizing recipes and packaging. Integration of research results with the HACCP approach indicates the consistency of instant product properties with food safety requirements: from the effectiveness of heat treatment (CCP 1), through moisture and a_w control (CCP 2), control of raw materials and additives (CCP 3), to flow properties determining the stability of packaging processes (CCP 4) and shelf life (CCP 5) (Table 8). The obtained results confirm that the assessment of instant oatmeal in physicochemical, microbiological, sensory and sorption terms provides a comprehensive basis for managing the quality of functional products, in accordance with the requirements of modern safety systems.

Table 8.

Linking research parameters with critical control points (CCPs) in the instant oatmeal production process

CCP	Process Stage	Main Hazards	Applied Analytical Parameters	Relevance for Quality & Safety Management
CCP 1	Hydrothermal treatment, enzymatic stabilization	Biological: survival of pathogenic microflora, <i>Bacillus cereus</i>	OLD, PD, BC, S	Assessment of processing effectiveness and elimination of biological hazards
CCP 2	Drying and water activity stabilization	Biological: microbial growth; Chemical: degradation reactions	Moisture content, Water activity	Establishing critical limits for microbiological stability
CCP 3	Addition of milk powder and flavor additives	<i>B. cereus</i> , Enterobacteriaceae, <i>E. coli</i> , molds	BC, EB, EC, PD, sensory evaluation	Control of high-risk raw materials and production hygiene
CCP 4	Mixing and packaging	Physical: foreign bodies; Technological: bridging, segregation	Density, Hausner ratio, Carr index, flow angles, sensory (texture)	Ensuring uniformity and proper functioning of packaging lines
CCP 5	Storage and distribution	Biological and physicochemical: hygroscopicity, caking	Sorption isotherms, V_m , SSA, Ce	Determination of shelf-life, packaging requirements, and storage conditions

Source: own research.

4. Summary and Conclusions

The analysis of three commercial instant oats allowed for a comprehensive assessment of their quality from a physicochemical, microbiological, sensory, and sorption perspective. All tested products were characterized by low water content and low water activity ($a_w < 0.40$), which guarantees high storage stability and minimizes the risk of microbial growth. These results confirm the proper maintenance of critical parameters typical of instant foods.

The microbiological assessment demonstrated compliance with all safety requirements – no *Salmonella* spp. was detected, while the number of indicator bacteria was below the detection limit. All products can be considered safe, and the slight differences between the variants were mainly due to the presence of flavor components.

Physicochemical properties, including the angle of repose, angles of repose, and density parameters, indicate the moderate flowability of the tested powders, typical of instant oat products. The Hausner coefficient and Carr index classified the oats as powders with stable flow properties, which is important for mixing and packaging processes. Sensory analysis confirmed high acceptance of all variants, with the chocolate oatmeal receiving the highest rating. All products received average scores above 4.4 points, indicating their good organoleptic quality.

The sorption properties, in turn, showed that the oatmeals tested were clearly hygroscopic, and the shape of the type II isotherms confirmed their ability to bind water, typical of carbohydrate-rich foods. BET parameters and specific surface area of sorption differed between variants, reflecting the influence of flavor additives on sorption capacity.

Incorporating the perspective of HACCP and GHP/GMP systems showed that the analyzed parameters correspond to key critical control points in the production of instant products, such as drying and stabilization of water activity, raw material hygiene, flow properties during packaging, and storage stability. This confirms the usefulness of comprehensive quality analysis in managing the safety and shelf life of functional foods. Based on the conducted research, it was found that all instant oatmeal products tested met quality and safety requirements, exhibited favorable sensory properties, and exhibited stability typical of low-water foods. The results can provide a basis for further research on recipe optimization, storage stability, and consumer perception of instant oat products. Producers should pay particular attention to:

1. Maintaining low water content and water activity ($a_w < 0.40$) to ensure high shelf life and microbiological safety.

The study results confirm that low moisture and water activity levels are crucial for storage stability and the prevention of microbial growth. Therefore, producers should particularly monitor drying, stabilization, and hygiene parameters of raw materials, considering them critical control points in HACCP systems.

2. Improving flavor formulations and monitoring sorption properties, as flavor additives influence sensory acceptance and hygroscopic parameters of the product.

The chocolate oatmeal received the best sensory evaluation, and the differences in sorption parameters between the variants confirm the effect of additives on water-binding capacity. This means that manufacturers should optimize the composition of flavor additives to increase consumer acceptance while also considering their impact on product stability and packaging requirements.

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References

1. Abdullah, E.C., Geldart, D. (1999). The use of bulk density measurements as flowability indicators. *Powder Technology, Vol. 102*, pp. 151-165.
2. Al-Muhtaseb, A.H., McMinn, W.A.M., Magee, T.R.A. (2002). Moisture sorption isotherm characteristics of food products: A review. *Food and Bioproducts Processing, Vol. 80, Iss. C*, pp. 118-128.
3. Beakawi, Al-Hashemi, H.M., Baghabra Al-Amoudi, O.S. (2018). A review on the angle of repose of granular materials. *Powder Technology, Vol. 330*, pp. 397-417.
4. Beuchat, L.R. (1981). Microbial stability as affected by water activity. *Cereal Foods World, Vol. 26*, pp. 345-349.
5. Brunauer, S., Emmett, P.H., Teller, E. (1938). Adsorption of gases in multimolecular layers. *Journal of the American Chemical Society, Vol. 60*, pp. 309-319.
6. Codex Alimentarius Commission (2003). *Recommended International Code of Practice – General Principles of Food Hygiene (CAC/RCP 1-1969, Rev. 4-2003)*. Rome: FAO/WHO.
7. Crosby, P.B. (1979). *Quality Is Free: The Art of Making Quality Certain*. New York: McGraw-Hill.
8. Deming, W.E. (1986). *Out of the Crisis*. Cambridge, MA: MIT Press.
9. Diplock, A.T., Aggett, P.J., Ashwell, M., Bornet, F., Fern, E.B., Roberfroid, M.B. (1999). Scientific concepts of functional foods in Europe: Consensus document. *British Journal of Nutrition, Vol. 81, Suppl. 1*, pp. S1-S27.
10. Domian, E., Lenart, A. (2000). Wpływ warunków przechowywania na właściwości sorpcyjne mleka w proszku. *Przemysł Spożywczy, Vol. 54, Iss. 5*.
11. Drake, M.A., Civille, G.V. (2003). Flavor lexicons. *Compr. Rev. FoodSci.*, 2, 33-40.
12. Drzewieniecka, B. (2000). Badanie kąta nasypu i naturalnego zsypania w aspekcie bezpieczeństwa przewozu ziarna drogą morską. *Zeszyty Naukowe, 58*. Wyższa Szkoła Morska w Szczecinie, pp. 39-53.
13. European Commission (2005). Commission Regulation (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs. *Official Journal of the European Union, L 338*, pp. 1-26.
14. FAO/WHO (2020). *General Principles of Food Hygiene CXC 1-1969. Hazard Analysis and Critical Control Point (HACCP) System and Guidelines for Its Application*. Rome: FAO/WHO.
15. Fontana, A.J. (2008). Water activity in control of microbial growth in foods. In: G.V. Barbosa-Cánovas, A.J. Fontana, S.J. Schmidt, T.P. Labuza (Eds.), *Water Activity in Foods: Fundamentals and Applications* (pp. 239-272). Ames, IA: Blackwell Publishing, Institute of Food Technologists.

16. Gibiński, M., Gumul, D., Korus, J. (2005). Prozdrowotne właściwości owsa i produktów owsianych, *Żywność. Nauka. Technologia. Jakość*, pp. 49-60.
17. Granato, D., Nunes, D.S., Barba, F.J. (2017). An integrated strategy between food chemistry, biology, nutrition, pharmacology, and statistics in the development of functional foods: A proposal. *Trends in Food Science & Technology, Vol. 62*, pp. 13-22.
18. Granum, P.E., Lund, T. (1997). *Bacillus cereus* and its food poisoning toxins. *FEMS Microbiology Letters, Vol. 157*, pp. 223-228.
19. ICMSF – International Commission on Microbiological Specifications for Foods (2005). *Microorganisms in Foods 6: Microbial Ecology of Food Commodities* (2nd ed.). New York: Kluwer Academic/Plenum.
20. ISO 16649. *Microbiology of the food chain – Horizontal method for the enumeration of beta-glucuronidase-positive Escherichia coli*.
21. ISO 21527. *Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of yeasts and moulds – Colony-count technique in products with water activity ≤ 0.95* .
22. ISO 21528. *Microbiology of the food chain – Horizontal method for the detection and enumeration of Enterobacteriaceae*.
23. ISO 4832. *Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of coliforms – Colony-count technique*.
24. ISO 6888. *Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of coagulase-positive staphylococci (Staphylococcus aureus)*.
25. ISO 7932. *Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of presumptive Bacillus cereus – Colony-count technique at 30 °C*.
26. Jensen, P.N., Risbo, J., Skibsted, L.H., Bertelsen, G. (2005). Storage stability of packaged roasted coffee. *Journal of Agricultural and Food Chemistry, Vol. 53*, pp. 2657-2663.
27. Kaczorowska, J., Rejman, K., Halicka, E., Szczybyło, A., Górska-Warsewicz, H. (2021). Parental food choices and engagement in raising children's awareness of sustainable behaviours in urban Poland. *International Journal of Environmental Research and Public Health, Vol. 18, No. 4*, 1778.
28. Labuza, T.P. (1984). *Moisture Sorption. Practical Aspects of Isotherm Measurement and Use*. St. Paul, MN: American Association of Cereal Chemists.
29. Lawless, H.T., Heymann, H. (2010). *Sensory Evaluation of Food: Principles and Practices* (2nd ed.). New York: Springer.
30. Leśmian-Kordas, R. (2001). Terms and Definitions of Selected Physical Properties of Cargoes, Important in Storage, Handling and Transport. *Scientific Journal of the Szczecin Maritime University, 61*, 59-73.
31. PN-EN ISO 22000:2018. *Systemy zarządzania bezpieczeństwem żywności – Wymagania dla każdej organizacji w łańcuchu żywnościowym*.

32. PN-EN ISO 4833-1:2013. *Mikrobiologia łańcucha żywnościowego – Horyzontalna metoda oznaczania liczby drobnoustrojów – Część 1: Liczenie kolonii w temperaturze 30 °C – Metoda płytkowa.*
33. PN-EN ISO 6579-1:2017-04/A1:2020-09. *Mikrobiologia łańcucha żywnościowego – Horyzontalna metoda wykrywania, oznaczania liczby i serotypowania Salmonella – Część 1: Wykrywanie Salmonella spp. – Aneks A1.*
34. PN-ISO 8460:1999. *Materiały sypkie – Oznaczanie gęstości nasypowej luźnej i utręsionej.* Warszawa: Polski Komitet Normalizacyjny.
35. Rasane, P. et al. (2015). Nutritional and health benefits of oats. *Nutrition & Food Science*, 45(3), 304-318.
36. Rasane, P., Jha, A., Sabikhi, L., Kumar, A., Unnikrishnan, V.S. (2015). Nutritional advantages of oats and opportunities for its processing as value added foods – A review. *Journal of Food Science and Technology*, Vol. 52, pp. 662-675.
37. Rizvi, S.S.H. (1995). Thermodynamic properties of foods in dehydration. In: M.A. Rao, S.S.H. Rizvi, J. Datta (Eds.), *Engineering Properties of Foods* (pp. 223-309). New York: Marcel Dekker.
38. Roberfroid, M.B. (2002). Global view on functional foods: European perspectives. *British Journal of Nutrition*, Vol. 88, Suppl. 2, pp. S133-S138.
39. Rockland, L.B., Beuchat, L.R. (Eds.) (1987). *Water Activity: Theory and Applications to Food.* New York: Marcel Dekker.
40. Rozporządzenie Komisji (WE) nr 2073/2005 z dnia 15 listopada 2005 r. w sprawie kryteriów mikrobiologicznych dotyczących środków spożywczych. Dziennik Urzędowy UE, L 338/1.
41. Ruszkowska, M., Wiśniewska, K. (2017). Flowability and density of selected food powders. *Agricultural Engineering*, Vol. 21, No. 1, pp. 151-160.
42. Samborska, K., Gondek, E., Kamińska-Dworznicka, A., Witrowa-Rajchert, D. (2011). Właściwości proszków mlecznych otrzymanych różnymi metodami suszenia. *Żywność. Nauka. Technologia. Jakość*, Vol. 18(4).
43. Silva, N., Junqueira, V., Silveira, N., Taniwaki, M., Santos, R., Gomes, R. (2017). *Microbiological Examination Methods of Food and Water: A Laboratory Manual* (4th ed.). Boca Raton: CRC Press.
44. Szczesniak, A.S. (2002). Texture is a sensory property. *Food Quality and Preference*, Vol. 13, pp. 215-225.
45. Tańska, M., Konopka, I., Ruszkowska, M. (2017). Sensory, physico-chemical and water sorption properties of corn extrudates enriched with spirulina. *Plant Foods for Human Nutrition*, Vol. 72, pp. 250-257. doi: 10.1007/s11130-017-0628-z
46. Teunou, E., Fitzpatrick, J.J. (1999). Effect of relative humidity and temperature on food powder flowability. *Journal of Food Engineering*, Vol. 42, pp. 109-116.

47. Tournas, V.H., Katsoudas, E. (2009). Moulds and yeasts in meat and meat products. *Food Microbiology, Vol. 26*, pp. 372-377.
48. Whitehead, A., Beck, E.J., Tosh, S., Wolever, T.M.S. (2014). Cholesterol-lowering effects of oat β -glucan: A meta-analysis of randomized controlled trials. *American Journal of Clinical Nutrition, Vol. 100*, pp. 1413-1421.
49. Wolf, W., Spiess, W.E.L., Jung, G. (1985). Standardization of isotherm measurements (COST Project 90 and 90 bis). In: D. Simatos, J.L. Multon (Eds.), *Properties of Water in Foods* (pp. 661-679). Dordrecht: Martinus Nijhoff.