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TOWARDS MORE SUSTAINABLE CONSUMPTION VIA QUALITY MANAGEMENT OF GLASSWARE WASHING

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Abstract. Over the past twenty years, the number of households equipped with automatic dishwashers has increased more than fifteenfold in Poland. Numerous studies indicate that mechanical washing, in addition to several advantages, most often results in faster deterioration of dishes compared to manual washing. An experiment was developed to subject decorated glassware to repeated mechanical washing with various chemicals to determine the nature of the effect of the substances on the surface of the decoration. It was necessary to develop a new objective test method, as the current methods are highly subjective. The results of the experiment show that the cleaning agent used significantly affects the degree of material loss in a statistically significant way. These differences are evident both when considering the time of appearance of the first loss and the rate at which the losses increase. It can be stated that the regular use of the same agent for a prolonged period will have a significant impact on the durability of the decoration, and therefore, on the service life of decorated glass. This is important because in today's sustainable world, it's critical not to make purchases of things that aren't needed. Consumers who know the relationship between glassware decoration and dishwasher detergents will be more aware and informed, which may result in better purchases.

Keywords: mechanical washing; resistance of decorations; glass; paint; detergents; sustainable consumption; circular economy

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1. Introduction and review of literature

Over the past twenty years, the number of households equipped with automatic dishwashers has increased more than fifteenfold in Poland. Currently, this type of equipment is found in more than 50% of all households (Alejandro et al., 2024). These devices are designed to speed up and simplify the process of cleaning dishes, which, with the current pace of life and numerous work obligations, is a great convenience for many people. Therefore, it can be assumed that the popularity of this type of equipment will continue to grow in the future. Automatic dishwashing brings many advantages, the most important of which include:

- saving time devoted to household chores (Dubis et al., 2024);
- automatic dishwashing leaves significantly less bacteria on the products than handwashing. The study conducted at the University of Louisville shows that the average number of bacteria on dishwasher-washed dishes was less than one, while on the same dishes washed by hand the average number of bacteria was 390 per plate (Gambogi et al., 2008);

- the automatic dishwashing procedure using proper detergents removes certain viruses from the dishes (Schilling-Loeffler et al., 2024);
- saving water and detergents, which translates directly into care for the environment (Stamminger & Bockmühl, 2025);
- energy saving, as many users desire low-energy consumption dishwashers (Tewes et al., 2024a, 2024b);
- reduction of the generated carbon footprint – modern dishwashers are constantly being improved in this regard (Alejandre et al., 2022);
- long lifespan of dishwashers, allowing these appliances to be used for a long time, usually for several years, although some models operate efficiently for up to 20 years (Tecchio et al., 2019).

On the other hand, issues related to sustainable consumption are becoming increasingly important today. Sustainable consumption is inherently connected to the broader concept of sustainable development, which refers to a stable form of progress that integrates resource use, investment activities, technological advancement, and institutional transformation and interdisciplinary approach (Ead et al., 2023).

Such an approach ensures that current developmental processes do not compromise the ability of future generations to fulfill their own needs and aspirations. Sustainable consumption involves the deliberate and efficient use of available resources to support development while minimizing negative environmental impacts and safeguarding the well-being of both present and future generations. A key factor in achieving this goal is the presence of conscious and responsible consumers – typically represented by households – who understand the motivations behind their choices and align their behaviors with the principles of sustainable consumption (Baláková et al., 2024; Srbová & Jaderná, 2024; Atkociuniene et al., 2025). This chapter discusses selected examples of consumer practices and behaviors whose implementation plays a crucial role in advancing sustainable consumption (Cabańska et al., 2024).

From the perspective of environmental protection and resource conservation, it is necessary to build new consumer habits (Gomez-Olmedo et al. 2024). One element of the circular economy concept is managing natural resources so that their circulation in the economy is as long as possible (Muradin, 2024). One solution may be for consumers to adopt a philosophy of minimalism, meaning they should stop using unnecessary products (Agrawal et al., 2025. Nguyen et al., 2025).

However, to assess which products meet the principle of minimalism and are truly essential, research is needed to understand the interrelationships between specific product groups and their environmental impact. Individual user habits are also important. The results of such research can be useful in developing new consumer habits (Blackburn et al., 2025).

Automatic dishwashing reduces detergent and energy consumption (Venkatesh, 2022); however, it can also lead to the faster deterioration of glassware, necessitating more frequent replacement of dishes. Short-term use of the same dishes is therefore inconsistent with sustainable consumption.

Numerous studies have been carried out, indicating that mechanical washing, in addition to several advantages, most often results in faster deterioration of dishes compared to manual washing. Both the material from which the dish is made and the decorations, such as those made with paint, can be destroyed. Manufacturers of kitchen accessories are constantly looking for methods to strengthen their products and make them more and more resistant to dishwasher washing.

Detergents are also used in the mechanical washing process and are primarily responsible for removing dirt. They differ in composition (there are chlorine- or phosphorus-based agents) and form (capsules or liquid agents). Most cleaning products include:

- anionic surfactant compounds (AZPC) – responsible for: surface moisturizing, emulsification and dispersion of contaminants, and deep penetration into the dirt layer. More important groups of anionic surfactant compounds include: alkyl nesulfonates, soaps, sodium, potassium and ammonium salts of alkyl sulphates, salts of esters of sulphosuccinic acid with fatty alcohols, as well as salts of alpha-olefin sulfonates;

- non-ionic surfactant compounds (NZPC) – may function as: emulsifiers, dispersants or greasing agents. They are also perfect for dirt removal, and when combined with anionic surfactants, they often exhibit a synergistic effect. They can also function as foam stabilizers. The largest share among NZPCs are ethoxylates of: fatty alcohols, esters, and oils;
- sequestrants – are compounds that remove ions (e.g., calcium, magnesium) contained in hard water, among others, by creating complexes. This group of compounds includes: sodium polyphosphate, ethylenediaminetetraacetic acid sodium salt (EDTA), sodium gluconate, and sodium citrate;
- organic solvents – are responsible for supporting the cleaning process. They have properties of dissolving contaminants or accelerating the drying of cleaned surfaces. Depending on composition and usage of a cleaner, the function of solvents may vary. The most commonly used ones include hydrophilic solvents, e.g., ethyl, isopropyl and isobutyl alcohol, glycol ethers and hydrophobic, fat-soluble solvents, i.e. paraffin, fatty acid methyl esters, paraffin oil, and silicone oils;
- abrasives – support the mechanical removal of dirt. They help reduce the cohesiveness of dirt, detach it from a surface and disperse it. The choice of an abrasive and its suitable granulation depends on the type and hardness of the cleaned surface. Initially, sand or ash were used as abrasives in cleaners. Currently, wood flour, chalk, silica, ground quartz, glass powder, and pumice are used. There are also abrasives based on macromolecular compounds such as: granulated polyvinyl chloride (PCV), granulated polythene, and polyurethane powder. Products containing abrasives are produced in the form of powder, polish and liquid suspension;
- viscosity modifiers – lead to a product with viscosity suitable for technical and commercial requirements. Commonly used viscosity modifiers can be divided into the following groups: natural and synthetic polymers, surfactants, and inorganic compounds.

Numerous studies carried out to date indicate that mechanical washing, in addition to several advantages, most often results in faster deterioration of dishes compared to manual washing. Both the material from which the dish is made and the decorations made with paint, for example, can be destroyed. Manufacturers of kitchen accessories are constantly looking for methods to strengthen their products and make them more and more resistant to dishwasher washing (Tewes et al., 2024a; 2024b).

There are also several methods for studying the damage caused by washing. Unfortunately, most of these methods are subjective and rely on organoleptic and visual assessments. They provide qualitative results but do not provide meaningful quantitative results (Dubis et al., 2024).

2. Materials and methods

An experiment was developed to subject decorated glassware to repeated mechanical washing with various chemicals to determine the nature of the effect of the substances on the surface of the decoration. It was necessary to develop a new test method, as the current methods had been developed even before modern detergents appeared on the market (Brückner et al., 2010; Lisowski & Sikora, 2023).

The principle of the developed method is based on determining the percentage loss of mechanically cleaned decorations through computer analysis of graphic files that show the condition of the decoration at different stages of the experiment. This analysis consists of extracting the areas covered with thermoplastic paint in the individual photos and measuring the number of pixels present in each area using graphical image processing software. After successive washing treatments, the area covered with paint decreases, causing the number of pixels in the photograph to decrease.

Assessing the quantitative loss of decoration involves determining the amount of loss on each test object using the sample average value (with an assumed accuracy of 2%) and relating it to the size of the decoration before the washing process. This will allow the calculation of the percentage loss of the tested decoration after each washing stage. The method developed is described in detail in the paper written by Dubis and his team (Dubis et al., 2024).

Ingredients of household chemicals can cause damage to surfaces that are being cleaned. This may be a result not only of the percentage amount of each ingredient in the cleaning agent, but may also depend on the type of surface that is being cleaned. Test samples were selected in a way that ensures surface repeatability (glass products coming from the same production batch). It should therefore be assumed that the losses of decoration are caused by differences in the chemical composition of individual cleaning agents.

The following cleaning agents were used:

- cleaning agent labelled “S1” with the following composition:
 - phosphates: over 30%;
 - oxygen based bleaching agents, polycarboxylates, non-ionic surfactants: from 5% to 15% in total;
 - phosphonates: max. 5%;
 - enzymes (protease, amylase);
 - fragrance composition.
- cleaning agent labelled “S2” with the following composition:
 - phosphates: over 30%;
 - oxygen-based bleaching agents, polycarboxylates: from 5% to 15% in total;
 - non-ionic surfactants, phosphonates: max. 5%;
 - enzymes (protease, amylase);
 - fragrance composition.
- cleaning agent labelled “S3” with the following composition:
 - phosphates: over 30%;
 - oxygen-based bleaching agents: from 5% to 15%;
 - polycarboxylates: from 5% to 15%;
 - non-ionic surfactants: max. 5%;
 - phosphonates: max. 5%;
 - enzymes (protease, amylase);
 - fragrance composition.

The use of these cleaning agents is justified by the fact that, in research surveys, they were indicated by customers as being the most frequently used by them. All the cleaning agents used were in tablet form, as tablets are the form most often used by consumers (Tewes et al., 2024a, 2024b).

It is noteworthy that the declared composition of washing preparations by manufacturers is only an approximate composition, in which the ingredients are divided into groups defined as ranges. The effect of this situation is the impossibility of recognizing differences between particular agents based only on their composition stated on the packaging. Consumers, therefore, have no way of differentiating between the properties of a preparation before it is applied.

3. Results and discussion

The results of the measurements included material obtained after taking 12,600 photographs, covering a total of thirty glasses. Photographs were taken five times of each of the seven sections of each glass before the start of washing and after each cycle performed until the paint disappeared entirely on the tested products.

The results were analyzed using descriptive and mathematical statistical methods. The analysis included:

- determining the values of the basic measures: position (arithmetic mean) and dispersion (standard deviation, extreme values);
- determining the functions reflecting the change in the amount of paint remaining on the products resulting from washing (calculated as the percentage loss of pixels), where X – the number of the washing procedure, Y – the number of pixels or the percentage loss of the number of pixels (The analysis was conducted using Statistica 10 package);
- verification of the hypothesis about the normality of the distribution of measurement results – χ^2 compliance test, the result of which determines the test used in the analysis of variance, (Mynarski, 2003; Stanisz, 2006);
- verification of the hypothesis about the variation in the number of pixels (after each subsequent washing procedure) depending on the type of cleaning agent. For this purpose, the method of one-factor analysis of

variance (Fisher-Snedecor F test) was used, supplemented by *post-hoc* analysis in the form of the least significant NIR difference test.

Verification of all hypotheses was carried out at the selected significance level $\alpha = 0.05$. The results of pixel count measurements for individual decoration elements are presented in Table 1. In the further analysis, the results after the 7th, 8th, 9th, and 10th washings in solutions S1 and S2, as well as after the 9th and 10th washings in S3, were excluded due to the majority of glasses showing a result of 0.

Table 1. Average measurement results of square elements (number of pixels) for each glass.

Agent	Glass	Number of washing procedures										
		0	1	2	3	4	5	6	7	8	9	10
S1	1	3,028	3,045	3,000	1,991	1,509	1,019	164	12	0	0	0
	2	3,375	3,345	2,987	2,210	1,241	627	0	0	0	0	0
	3	3,539	3,668	3,012	2,106	1,252	557	405	42	0	0	0
	4	3,625	3,280	3,024	1,540	1,014	316	59	0	0	0	0
	5	3,480	3,166	2,478	835	559	67	0	0	0	0	0
	6	3,406	2,906	2,482	924	541	42	0	0	0	0	0
	7	3,984	3,336	2,363	962	409	88	0	0	0	0	0
	8	3,351	3,247	2,640	2,029	977	473	36	0	0	0	0
	9	3,421	2,896	2,763	1,044	447	78	0	0	0	0	0
S2	1	3,316	3,160	2,798	2,779	2,461	1,699	994	0	0	0	0
	2	3,388	3,050	2,801	2,730	2,115	1,117	261	68	0	0	0
	3	3,461	3,380	2,839	2,546	1,676	212	100	0	0	0	0
	4	3,503	3,235	3,005	2,760	2,002	876	312	245	31	0	0
	5	3,369	3,182	2,876	2,454	1,182	52	0	0	0	0	0
	6	3,599	3,139	3,096	2,961	1,896	883	105	0	0	0	0
	7	3,665	3,414	3,275	2,937	1,679	225	2	0	0	0	0
	8	3,892	3,249	3,246	2,600	2,162	1,141	635	260	0	0	0
	9	3,600	3,485	3,097	2,841	1,845	473	73	0	0	0	0
S3	1	4,033	3,836	3,675	3,186	3,138	2,235	1,795	1,483	215	0	0
	2	3,696	3,447	3,264	3,241	3,052	2,844	2,168	1,243	0	0	0
	3	3,757	3,421	3,304	3,292	3,035	2,763	1,787	1,269	83	0	0
	4	3,736	3,251	3,368	3,226	2,989	2,711	2,078	1,307	256	98	0
	5	3,693	3,540	3,420	3,372	3,166	2,724	2,068	1,223	0	0	0
	6	3,552	3,296	3,378	3,392	3,117	2,631	2,319	1,706	416	0	0
	7	3,155	3,114	3,046	2,898	2,330	2,431	1,592	1,152	270	117	71
	8	3,984	3,847	3,535	3,529	3,241	3,254	1,818	1,150	0	0	0
	9	3,300	2,959	2,892	2,968	2,936	2,061	1,899	761	50	0	0

Source: own study

In further analysis, the results of the measurement after the 7th, 8th, 9th and 10th washes with S1 and S2 and after the 9th and 10th washes with S3 were dropped due to the result of 0 for the vast majority of glasses. The results of the pixel count measurements for each decoration section are presented in Table 2.

Table 2. Average measurement results of each section (number of pixels) for each glass.

Agent	Glass	Number of washing procedures										
		0	1	2	3	4	5	6	7	8	9	10
S1	1	99,578	97,053	92,283	60,058	49,660	40,160	12,744	2,878	454	0	0
	2	103,570	103,387	89,457	52,621	40,478	21,741	5,705	1,665	0	0	0
	3	101,161	100,316	84,508	55,222	31,232	13,527	5,349	386	0	0	0
	4	105,820	105,471	89,337	51,713	33,428	13,490	3,379	797	0	0	0
	5	101,494	101,463	73,476	25,566	13,697	3,037	500	0	0	0	0
	6	101,704	94,315	73,397	34,163	20,871	2,486	0	0	0	0	0
	7	109,892	101,178	75,581	30,842	10,112	802	342	160	0	0	0
	8	101,417	101,095	89,060	64,674	47,899	23,466	7,237	255	0	0	0
	9	103,410	98,867	93,697	23,391	8,973	3,797	176	0	0	0	0
	10	97,981	95,437	78,289	41,759	25,824	9,740	633	0	0	0	0
S2	1	100,799	99,955	98,754	94,899	87,299	54,898	33,018	13,290	5,160	493	0
	2	98,984	97,361	93,878	79,986	49,172	32,023	8,224	2,532	408	0	0
	3	95,046	94,341	93,487	88,728	73,639	14,094	3,533	1,983	0	0	0
	4	104,495	102,982	98,078	89,907	66,388	31,235	16,551	12,795	1,824	0	0
	5	102,931	101,014	95,558	83,501	33,557	6,411	914	0	0	0	0
	6	101,269	99,232	98,691	96,037	62,088	37,044	11,613	2,469	527	0	0
	7	104,708	101,438	96,574	93,235	46,781	19,862	4,009	2,427	0	0	0
	8	107,425	104,440	100,106	96,321	84,901	36,464	17,409	4,802	749	0	0
	9	104,692	100,306	98,551	89,216	42,098	10,719	2,543	362	0	0	0
	10	100,817	99,288	95,121	85,982	57,964	26,990	10,248	4,437	695	0	0
S3	1	108,052	106,181	105,178	104,195	104,525	77,197	62,448	51,268	13,294	2,999	903
	2	113,009	112,542	110,806	108,926	108,688	80,355	71,908	24,193	2,339	0	0
	3	116,186	114,604	113,664	112,304	111,551	89,275	76,061	48,161	3,788	134	0
	4	115,276	113,945	113,104	112,449	111,331	104,647	62,831	41,767	3,393	1,309	0
	5	123,591	123,142	121,987	121,155	120,894	86,596	69,287	43,589	11,377	0	0
	6	114,026	113,487	113,188	112,905	112,218	87,618	61,063	30,311	4,141	355	0
	7	98,811	98,454	98,197	97,921	97,213	82,990	61,847	41,664	12,780	5,874	1,207
	8	123,657	123,236	122,560	122,560	118,637	104,519	41,280	20,574	744	0	0
	9	108,844	106,778	105,952	103,959	101,912	70,773	66,078	21,464	2,328	0	0
	10	111,446	110,074	109,075	107,125	100,806	77,166	58,240	34,905	6,128	1,112	227

Source: own study

In further analysis, the results of measurement after 8, 9 and 10 washes with S1, after 9 and 10 washes with S2 and after 10 washes with S3 were dropped due to the result of 0 for the vast majority of glasses.

The results of testing the hypothesis of whether the empirical distribution matches the theoretical (normal) distribution, using the χ^2 test, are presented in Table 3.

Table 3. Results of verification of the hypothesis of normality of distributions.

	Agent		Number of washing procedures								
			0	1	2	3	4	5	6	7	8
Circle	S1	χ^2	17.99*	11.71*	8.27*	17.52*	18.97*	14.70*	6.65*	-	-
		p	0.207	0.469	0.31	0.225	0.215	0.399	0.355	-	-
	S2	χ^2	0.68*	5.52*	0.27*	2.06*	10.78*	11.72*	12.17*	-	-
		p	0.998	0.992	1	0.999	0.547	0.551	0.501	-	-
	S3	χ^2	0.77*	6.46*	3.78*	4.10*	3.24*	3.71*	5.80*	-	-
		p	0.992	0.989	0.999	0.999	0.999	0.998	0.76	-	-
Square	S1	χ^2	7.94*	16.90*	20.74*	22.09*	16.06*	19.58*	12.04*	-	-
		p	0.54	0.392	0.156	0.106	0.188	0.133	0.099	-	-
	S2	χ^2	0.06*	0.79*	0.92*	1.98*	7.99*	8.06*	13.74*	-	-
		p	1	0.992	0.999	0.999	0.844	0.427	0.132	-	-
	S3	χ^2	0.30*	0.35*	0.08*	0.96*	13.49*	5.48*	1.27*	-	-
		p	0.999	0.999	1	0.987	0.703	0.996	0.999	-	-
Sections	S1	χ^2	8.15*	1.90*	8.61*	5.15*	11.91*	10.11*	107.15	120.04	-
		p	0.148	0.168	0.126	0.273	0.103	0.124	0	0	-
	S2	χ^2	0.90*	0.95*	1.93*	8.82*	10.71*	13.34*	84.85	301.3	-
		p	0.999	0.999	0.999	0.657	0.468	0.305	0	0	-
	S3	χ^2	1.44*	8.98*	10.09*	14.26*	16.64*	11.56*	27.78	18.31*	-
		p	0.999	0.832	0.756	0.355	0.216	0.564	0.001	0.369	-

Source: own study

Symbol (*) next to the χ^2 value indicates no significant difference between the empirical and normal distribution at the significance level $\alpha = 0.05$. The χ^2 statistic values show that almost all tested empirical distributions closely resemble the shape of a normal distribution ($p < \alpha$). However, values in bold indicate a significant difference, allowing the hypothesis of normality to be rejected. Therefore, variance analysis (F-test) was performed only for distributions consistent with the normal distribution (circular and square elements – washes 0 to 6, sections – washes 0 to 5).

The average pixel counts for circular elements, square elements, and entire sections after successive washing treatments are shown in Figure 1, Figure 2 and Figure 3.

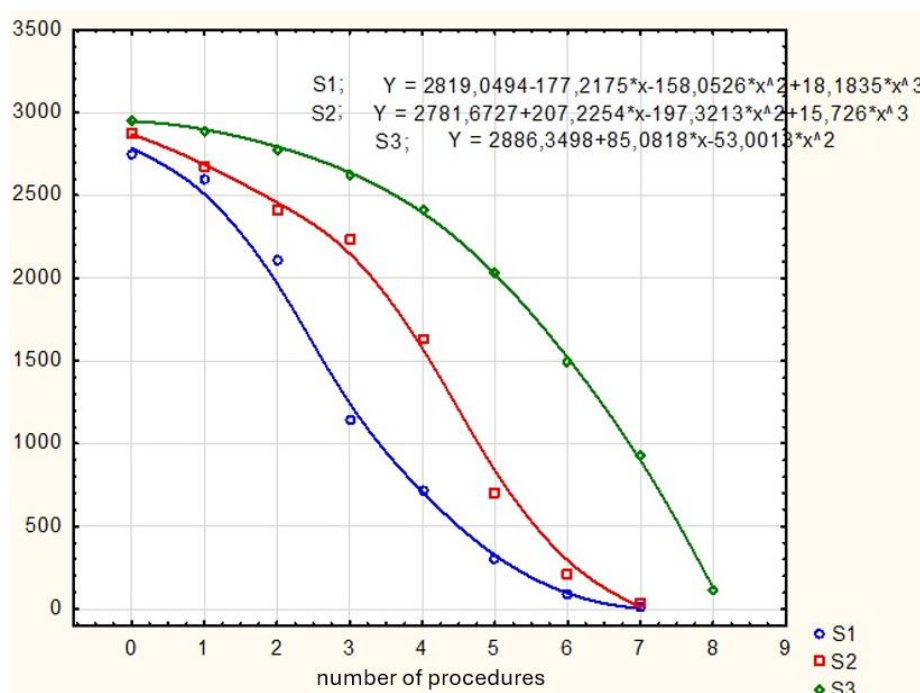


Figure 1. Average results of measurements of the number of pixels of circular elements after successive washing treatments with different agents.
Source: own study

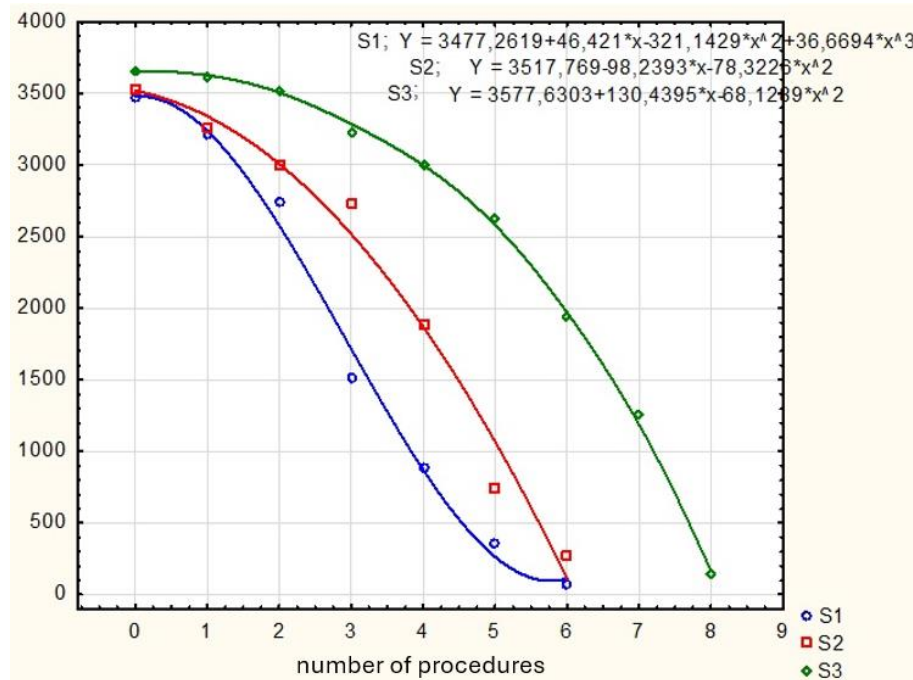


Figure 2. Average results of measurements of the number of pixels of square elements after successive washing treatments with different agents.
Source: own study

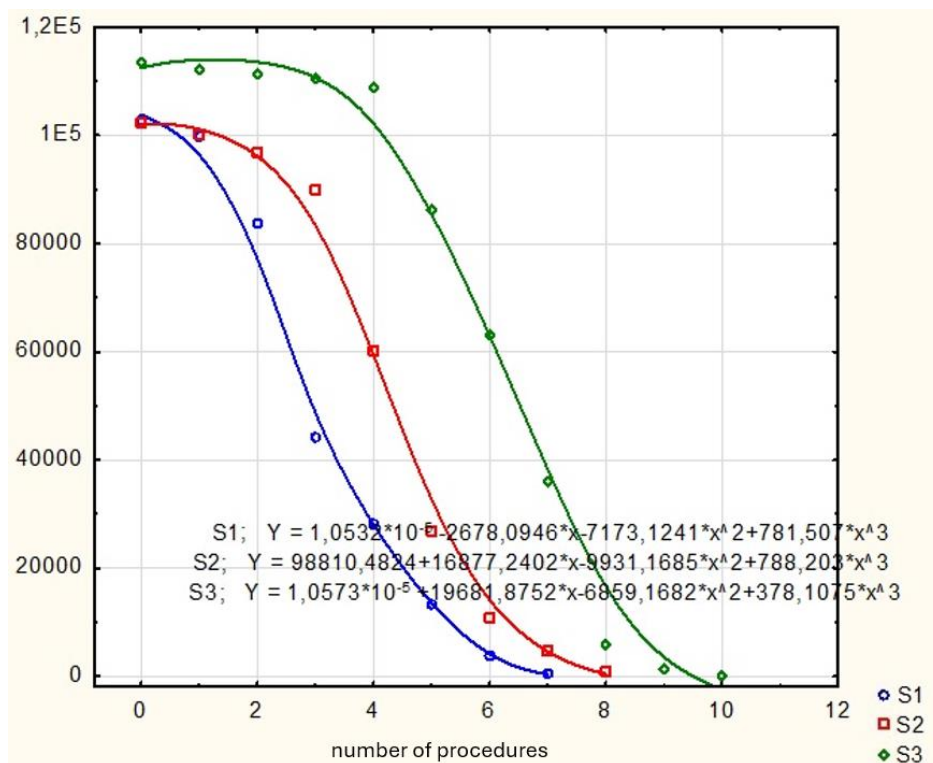


Figure 3. Average results of measurements of the number of pixels in sections after successive washing treatments with different agents. Source: own study

The measurement results for round elements, square elements, and individual sections (pixel count) of all glasses after successive washing treatments with different agents are presented in Tables 4, 5, and 6.

Table 4. Measurement results of round elements (pixel count) of all glasses after successive washing treatments with different agents (selected statistical measures and results of variance analysis).

Number of washing procedures	Cleaning agent	Statistical measure				Analysis of variance	
		Average	Standard deviation	Minimum	Maximum	F	p
0	S1	2,753.7	206.77	2,426.3	3,127.2	1.86	0.177
	S2	2,871.3	136.03	2,673.8	3,133.6		
	S3	2,954.0	292.63	2,438.4	3,354.8		
1	S1	2,595.9	225.65	2,238	2,987.7	0.86	0.436
	S2	2,667.7	189.41	2,512.9	3,024.6		
	S3	2,883.7	290.85	2,336.1	3,206.6		
2	S1	2,108.0 a	124.83	1,922.5	2,278.1	24.32*	0
	S2	2,408.5 b	152.98	2,171.3	2,658.1		
	S3	2,768.8 c	220.12	2,303.7	2,947.4		
3	S1	a 1,140.8	339.23	725.1	1,562.0	76.99*	0
	S2	b 2,232.7	210.93	1,821.4	2,480.1		
	S3	c 2,624.4	218.53	2,318.3	2,946.7		
4	S1	a 712.6	344.80	231.4	1,093.2	70.06*	0
	S2	b 1,633.9	311.92	1,286.6	2,285.8		
	S3	c 2,413.3	251.27	1,975.2	2,795.2		
5	S1	a 304.5	267.11	0.0	670.1	79.07*	0
	S2	b 698.0	320.75	109.0	1,239.1		
	S3	c 2,038.8	328.78	1,595.4	2,736.0		
6	S1	a 94.6	117.67	0.0	341.1	139.27*	0
	S2	b 209.7	265.60	0.0	753.1		
	S3	c 1,497.3	182.18	1,189.1	1,827.9		

Source: own study

The symbol (*) next to the F-value indicates that the hypothesis of no differences should be rejected ($\alpha = 0.05$). Identical letter symbols next to mean values indicate no statistically significant differences between them ($\alpha = 0.05$). The calculated F-values justify rejecting the null hypothesis after the 2nd, 3rd, 4th, 5th, and 6th washing treatments, thus it can be concluded that the washing agent significantly affects the degree of degradation. Before washing and after the 1st wash, no significant differences were observed. The NIR test showed that after the 2nd, 3rd, 4th, 5th, and 6th washes, agent S1 caused the highest degradation, while S3 – the lowest

Table 5. Measurement results of square elements (pixel count) of all glasses after successive washing treatments with different agents (selected statistical measures and results of variance analysis).

Number of washing procedures	Cleaning agent	Statistical measure				Analysis of variance	
		Average	Standard deviation	Minimum	Maximum	F	p
0	S1	3,467.7	254.48	3,027.7	3,983.8	1.38	0.271
	S2	3,532.5	179.03	3,315.7	3,891.8		
	S3	3,656.0	286.74	3,154.7	4,032.5		
1	S1	3,210.0	242.42	2,896.4	3,668.0	1.80	0.187
	S2	3,254.9	143.29	3,050.0	3,485.3		
	S3	3,612.3	299.81	2,959.2	3,846.8		
2	S1	a 2,749.9	266.94	2,363.4	3,024.4	13.61*	0
	S2	b 3,003.8	185.87	2,798.0	3,275.3		
	S3	b 3,520.3	236.94	2,892.3	3,674.7		
3	S1	a 1,515.6	576.91	835.1	2,209.8	52.38*	0
	S2	b 2,734.2	172.81	2,454.2	2,961.1		
	S3	c 3,233.9	200.12	2,898.4	3,529.3		

4	S1	a 883.1	406.17	408.6	1,508.9	82.09*	0
	S2	b 1,890.8	363.37	1,181.8	2,460.6		
	S3	c 3,000.4	268.16	2,330.1	3,241.0		
5	S1	a 362.8	335.20	41.7	1,018.5	75.04*	0
	S2	b 742.0	542.00	52.1	1,698.8		
	S3	c 2,628.1	351.50	2,060.7	3,254.3		
6	S1	a 73.8	135.36	0.0	404.9	156.73*	0
	S2	a 275.8	334.93	0.0	993.5		
	S3	b 1,947.1	227.22	1,591.6	2,319.1		

Source: own study

The symbol (*) next to the F-value indicates that the hypothesis of no differences should be rejected ($\alpha = 0.05$). Identical letter symbols next to mean values indicate no statistically significant differences between them ($\alpha = 0.05$).

The calculated F-values justify rejecting the null hypothesis after the 2nd, 3rd, 4th, 5th, and 6th washing treatments, thus it can be concluded that the washing agent significantly affects the degree of degradation. Before washing and after the 1st wash, no significant differences were observed. The NIR test showed that:

- after the 2nd wash, agent S1 caused greater degradation than S2 and S3,
- after the 3rd, 4th, and 5th washes, agent S1 caused the highest degradation, while S3 – the lowest,
- after the 6th wash, agent S3 caused less degradation than the other two agents.

Table 6. Measurement results of sections (pixel count) of all glasses after successive washing treatments with different agents (selected statistical measures and variance analysis)

Number of washing procedures	Cleaning agent	Statistical measure				Analysis of variance	
		Average	Standard deviation	Minimum	Maximum	F	p
0	S1	a 102,602.7	4,736.38	92,599.6	118,256.2	68.48*	0
	S2	a 102,116.4	5,018.64	91,534.8	113,289.0		
	S3	b 113,289.7	8,641.84	90,651.8	130,449.0		
1	S1	a 99,858.2	6,029.12	75,319.2	112,014.6	78.48*	0
	S2	a 100,035.7	4,598.38	89,385.2	112,235.8		
	S3	b 112,244.2	8,827.55	90,459.8	128,240.8		
2	S1	a 83,908.4	13,497.91	32,663.0	105,830.8	143.39*	0
	S2	b 96,879.9	4,185.32	89,003.2	109,542.0		
	S3	c 111,371.1	8,758.84	89,733.2	128,728.4		
3	S1	a 44,000.8	20,314.61	735.0	93,011.2	427.13*	0
	S2	b 89,781.1	8,678.28	51,144.2	100,584.0		
	S3	c 110,349.6	8,895.15	90,424.6	125,302.8		
4	S1	a 28,217.2	18,881.01	0.0	72,631.6	344.27*	0
	S2	b 60,388.7	23,738.23	11,729.8	104,561.8		
	S3	c 108,777.4	9,114.68	90,329.2	125,465.8		
5	S1	a 13,224.5	15,816.73	0.0	60,745.8	365.53*	0
	S2	b 26,973.9	20,133.52	0.0	91,961.4		
	S3	c 86,113.5	14,358.35	56,507.0	121,456.6		

Source: own study

The * symbol next to the F value means that the hypothesis about the lack of differences should be rejected ($\alpha = 0.05$). Identical letter symbols next to the mean values indicate the lack of significant difference between them ($\alpha = 0.05$). The calculated F-test values justify the rejection of the null hypothesis after all six washing treatments, which means that the washing agent significantly affects the degree of material loss. The NIR test showed that:

- in each of the tested points, agent S3 caused the lowest degradation (compared to agents S1 and S2);
- after washes 2, 3, 4 and 5 agent S1 caused more degradation than agent S2.

The percentage losses of round elements, square elements and entire sections after consecutive washing procedures are shown in Figure 4, Figure 5 and Figure 6.

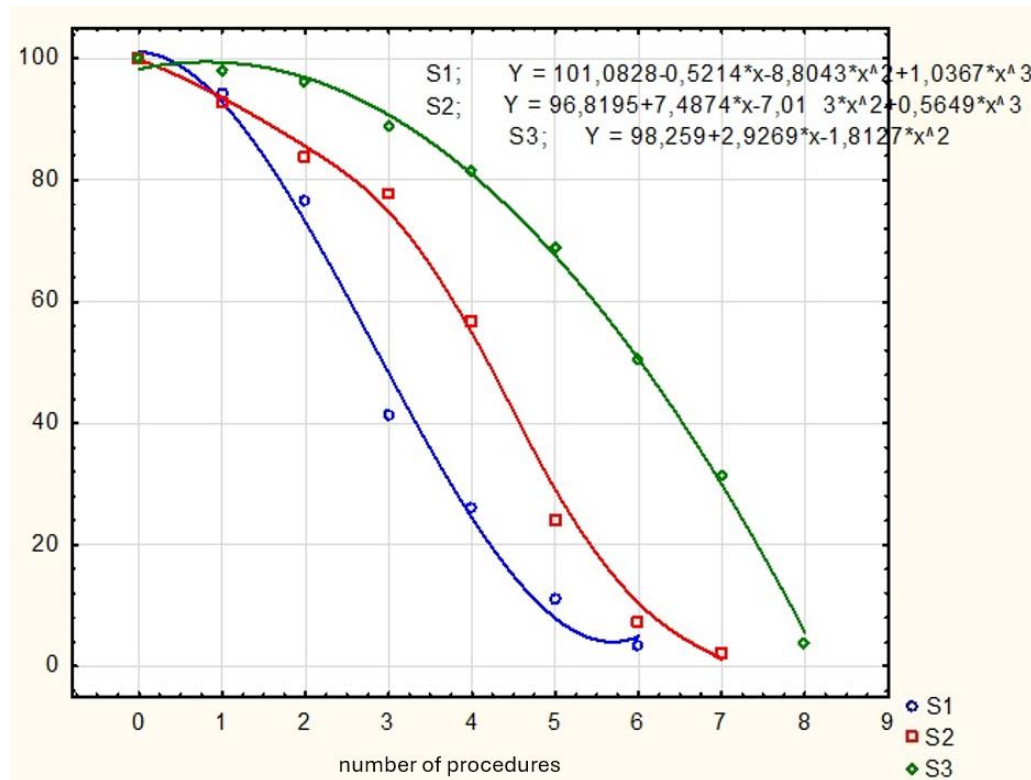


Figure 4. Percentage loss of round elements after consecutive washing treatments with different agents.
Source: own study

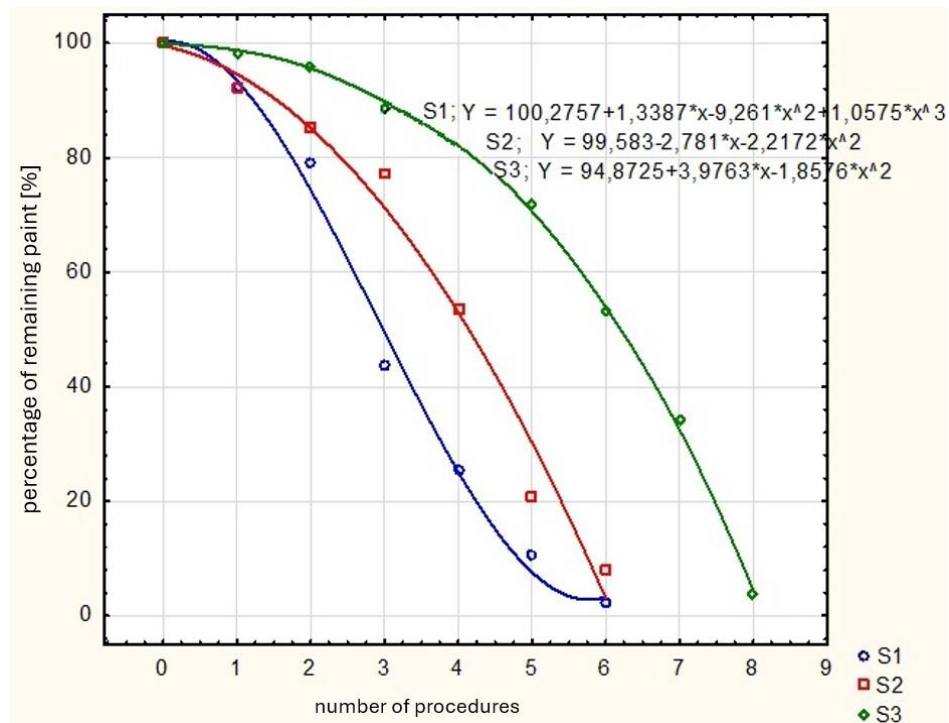


Figure 5. Percentage loss of square elements after consecutive washing treatments with different agents.
Source: own study

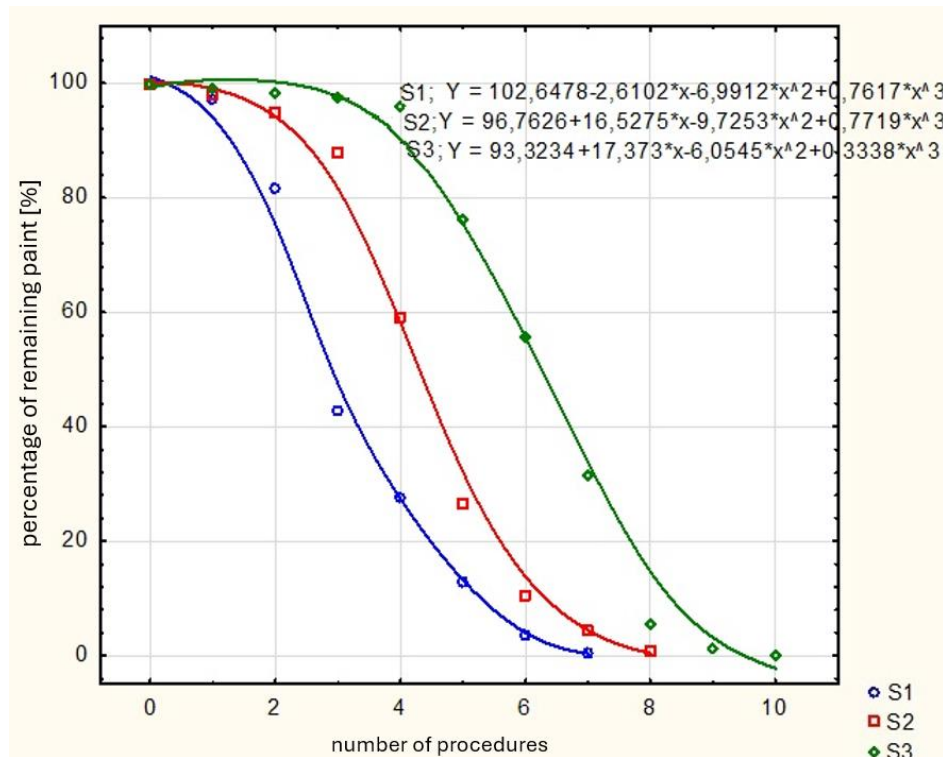


Figure 5. Percentage loss in sections after consecutive washing treatments with different agents.

Source: own study

The results of the experiment show that the cleaning agent used significantly affects the degree of material loss in a statistically significant way. These differences are evident both when considering the time of appearance of the first loss and the rate at which the losses increase.

Conclusions

It can be stated that the regular use of the same agent for a prolonged period will have a significant impact on the durability of the decoration, and therefore, on the service life of decorated glass.

Studies clearly showed that the cleaning agent labelled S3 was the least aggressive toward decorations applied to the glass because:

- the number of washing cycles required to cause the first losses in the decorations is up to four times greater when using this agent compared to the other agents,
- the rate of deterioration of the decorations applied to the glass is up to 50% lower with this agent compared to the other agents.

All three cleaning products used in the study, according to the ingredients listed on their packaging, contain components belonging to the following groups:

- phosphates,
- enzymes that break down proteins and complex sugars,
- compounds based on active oxygen,
- pH regulators,
- solvents,
- foaming agents,
- and fragrances.

Other studies have shown that cleaning agents containing chlorine compounds have a more destructive effect than those based on phosphorus. All agents used in this study were phosphorus-based. However, it is evident that even among them, there are significant differences in the extent of damage they cause to decorations.

Determining the cause of the damage to the surface of glass coated with paint should therefore be considered on several levels:

Does the product contain chlorine-based compounds?

Has the composition of individual ingredients been selected in such a way as to enhance the action of the household chemical product (synergism) in order to achieve the final cleaning effect? The removal of dirt, and thus the synergistic effect, leads to increased activity of the active components and, consequently, to changes in the surface structure of the glass.

Have solid substances (so-called abrasives) been added?

Since none of the products used in the study contain active chlorine compounds, it can be concluded that the following factors may have had a decisive influence on the changes in the glass surface, depending on the cleaning agent used:

- The product labelled S1 contains the most diverse group of surfactants (non-ionic, cationic and anionic surfactants), which most likely contributes to the synergistic effect,
- The product labelled S1 contains a variety of abrasive ingredients such as kaolin, titanium dioxide and carbonates – mineral substances in solid form.

At the same time, it is worth noting that the conducted analysis aimed to compare the effects of the cleaning agents on decorated glass. No comparisons were made under other conditions or with dishes made of materials other than decorated glass. The most "aggressive" agent for decorated glass may show the best performance on heavily soiled metal or porcelain vessels. Such studies, however, were not the subject of interest in this paper. The conducted research cannot provide a basis for an overall evaluation of the cleaning agents, as these agents were tested solely from the perspective of a single quality factor.

The conducted research, however, provides the basis for formulating a general conclusion that the best durability results of the decoration can be achieved by cleaning the glass with appropriately mild cleaning agents.

Other researchers conducted a study to investigate the effectiveness of various cleaning agents and dishwasher programs. They showed that different detergents available for sale to the general consumers show very different effectiveness in removing soiling. The same is true of different dishwasher programs. They also concluded that the chemicals used can work in conflict with the program used for washing. This is because it may turn out that the user uses a very mild program, but at the same time a very aggressive agent. This can, on the one hand, produce a good cleaning effect, but on the other hand, damage the glassware (Tewes et al. 2024a, 2024b).

In contrast, the present study shows that detergents, which are designed to clean glassware, can also cause damage to the decorations on that glass. Different detergents exhibit significant differences in their ability to remove and destroy decorations.

According to research, water hardness affects the effectiveness of cleaning products. This effectiveness generally decreases with increasing water hardness. Therefore, it may be worthwhile in future studies to investigate the effect of water hardness on the rate of deterioration of decorations on glass.

It is also worth analyzing whether the greater effectiveness of the cleaning agent translates into greater effectiveness in destroying the decoration.

The construction of consumer behaviour models that reflect the actual trends in consumption patterns should be based on taking into account how consumers perceive the relationships between their own individual goals, preferences, motives and modes of action and the use of natural resources (Rumianowska, 2013). Findings reveal that green product attributes and environmental awareness significantly influence purchase intention (Pramesti & Nuvriasari, 2025). Another study confirmed the significant positive impact of green self-identity, environmental lifestyle, environmental knowledge on sustainable purchasing behavior (Ashwini et al., 2025). In practical terms, focusing on people's commitment to environmental protection could thus be a promising avenue for directly promoting sustainable lifestyles (Henn et al., 2025). The study conducted by Alt et al. (2023) highlights the need for marketers and policymakers to design effective green marketing strategies and promote

sustainable consumer practices. The global economy's growing reliance on non-renewable resources, coupled with their progressive depletion, the accelerating impacts of climate change, and the persistent generation of vast quantities of waste, poses significant challenges to the sustainability of future socio-economic development. In response, circular business models have emerged as a promising framework, offering strategies to extend product lifecycles through practices such as repair, refurbishment, the recovery of raw materials from by-products, recycling of end-of-life goods, and initiatives promoting collaborative consumption and product sharing. The proposed solutions must consider various consumer motivations, including the desire to save money, environmental concerns, and the ethical aspects of product selection (Cabańska et al., 2024).

Ultimately, this research underscores the significance of aligning environmental values with consumer identity to foster lasting behavioral change toward sustainability. It is therefore crucial to examine the interrelationships between products and their impact on the natural environment, and then, based on the findings, build new consumer habits. Studies such as those in this paper provide useful results that can help marketers promote appropriate consumer attitudes and, consequently, create valuable social change.

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