International Journal of Consumer Studies

International Journal of Consumer Studies ISSN 1470-6423

Impact of water hardness on consumers' perception of laundry washing result in five European countries

Konstadinos Abeliotis[1], Cevza Candan[2], Caroline Amberg[3], Ada Ferri[4], Miguel Osset[5], Jeremy Owens[6] and Rainer Stamminger[7]

[1]Department of Home Economics and Ecology, Harokopio University, Athens, Greece
[2]Department of Textile Engineering, Technical University of Istanbul, Istanbul, Turkey
[3]Swissatest Testmaterialien AG, St. Gallen, Switzerland
[4]Department of Applied Science and Technology, Politecnico di Torino, Turin, Italy
[5]Independent researcher, Barcelona, Spain
[6]Independent researcher, Milton Keynes, UK
[7]Institute of Agricultural Engineering, Household and Appliance Technology Section, Bonn University, Bonn, Germany

Keywords
Consume, household, sustainable, technology, textiles.

Correspondence
Konstadinos Abeliotis, Department of Home Economics and Ecology, Harokopio University, El. Venizelou 70, 17671 Athens, Greece.
E-mail: kabeli@hua.gr

doi: 10.1111/ijcs.12149

Introduction

Washing clothes, laundry and other home textiles is one of the most widespread housework in the world (Pakula and Stamminger, 2010). The washing performance depends on the following four factors, depicted by the Sinner circle, namely: chemical action, mechanical action, temperature effect and time (Sinner, 1960; AISE, 2013). If the role of one factor is reduced, the loss must be compensated for by increasing one or more of the other factors to maintain the same level of washing performance. On the other hand, water has always been the most important commodity in any type or size of laundry. Thus, water has been introduced by Stamminger (2010) as a fifth factor to show the importance of water as essential element in wet cleaning.

Water comes, mainly, from two sources: surface and underground aquifers. Rainwater dissolves mineral matter as it flows over and through the ground on its way to rivers, lakes, springs and the ground water supply. The dissolved matter consists of a wide variety of minerals including calcium, magnesium and iron compounds. Calcium and magnesium ions (present as sulphates, chlorides, carbonates and bicarbonates) cause water to be hard. Water chemists measure water impurities in mmols per litre, but water hardness is also often expressed in German (°dH) or French (°fH) degrees. Table 1 gives common classifications for hard water with values listed in the three most common scales. The different scales can be interrelated mathematically (see Table 1).

Hardness in laundry water is a problem because the minerals that cause it interfere with the cleaning action of soaps and detergents. Surfactant molecules constitute the part of the detergent mixture that does the actual cleaning work. In most laundry detergents, the main surfactant used is an anionic surfactant. These surfactants are very effective at drawing oily materials and oil/clay soil into emulsion in the wash water. However, positively charged magnesium ions (Mg^{+2}) and calcium ions (Ca^{+2}), which are present in hard water, tend to bind themselves to the negatively charged heads of these surfactant molecules. Surfactant molecules that have reacted with the water in this way fall out of solution, as they no longer have the electrically charged head as it was this 'polar' end that was keeping them dissolved. As a result, larger amounts of detergents are needed to counteract the minerals, and laundry results are not as good as when there is no hardness present. Hardness minerals also react with carbonate builders commonly found in non-phosphate detergents. The resulting product is a white precipitate, calcium and magnesium carbonate that makes fabrics stiff and harsh and leaves a film on fabrics which tends to make colours appear faded or streaked with white. No precipitate is formed when the carbonate-built detergents are used in soft water. Furthermore, in recent years, there has been renewed interest in soap, but the difference in performance in hard and soft water is more dramatic when soap is used. Soap reacts with the calcium in hard water to form sticky curds: hence, there must be more soap than is needed to react with all the calcium in the water before it can start to clean. The soap curds formed by the reaction mentioned earlier cause a problem in laundering because they cling to clothes and trap soil on fabrics. Therefore, rinse water should be softened as well as wash water to prevent soap curd formation and to eliminate chemical and detergent residue in fabrics.

Table 1 Classification of water hardness in different scales

Water classification	Chemical concentration of Ca^{2+}, Mg^{2+} (mmol/l)	Hardness in German degrees (°dH)	Hardness in French degrees (°fH)
Soft	0–1.5	0–8	0–15
Medium hard	1.5–2.5	8–14	15–25
Hard	>2.5	>14	>25

1°dH = 0.178 mmol/l; 1°fH = 0.1 mmol/l.

Literature review

Very few published research data can be found on the effect of water hardness on the laundry process. Arai (1966) studied the effect of concentration and kind of detergent, and the impact of oil on soil removal efficiency in hard water. He found that there was a linear relationship between concentration of detergent and water hardness at maximum soil removal efficiency. This relationship was dependent on the nature of the oily soil and kind of detergent. In his study, Cameron (2007) showed that lime deposits on fabrics may have caused discoloration of fabrics and made them harsh and scratchy to touch, i.e. water hardness reduced the satisfaction of the consumer by the washing process. In another study in the US by the same author (Cameron, 2011), it was revealed that these mineral deposits could decrease the life of appliances and reduce the efficiency of the detergent. Also, that regarding the effect of water hardness on the action of detergents, liquid detergents performed equally well in all water conditions. Finally, it was found that powdered detergents outperformed liquid detergents in soft water (Cameron, 2011). The same author reported that more than 30% of additional detergent may have been required to allow powdered detergents to perform as effectively in hard water as they did in soft water (Cameron, 2011). Nagarajan and Paine (1984) used an experimental method to evaluate the relative water hardness control performance of different ion exchange builder types under conditions closely simulating those of detergent's end-use. Brown *et al*. (1991) discussed the effect of water hardness level on washing quality using commercial detergents. They determined the water hardness for 10 samples of water. They found that a wide variation of water hardness ranged from very soft to very hard. Also, they evaluated the effectiveness of six commercial laundry detergents of different formulations. The authors showed that the detergent containing a non-ionic surfactant with a phosphate builder gave the best whiteness results, regardless of water hardness. Umber *et al*. (1992) evaluated water hardness on washing performance of surfactants, and they used five different surfactants at 2.0% concentrations. They found that the most and least effective ones were Synthrapol N and Ahcowet RS, respectively, based on their rating of whiteness index. Also, Synthrapol N and Ahcowet RS were evaluated with the addition of sodium carbonate, sodium tripolyphosphate and a 1:1 combination of the two builders. They showed that in both cases the addition of a builder improved the cleaning efficiency of the surfactant, and that although each builder alone improved the cleaning efficiency, the combination of sodium carbonate and sodium tripolyphosphate improved efficiency at a lower total concentration. Cameron and Brown (1995) evaluated the effectiveness of 42 detergents (11 non-phosphate containing powdered, 12 phosphate containing powdered, 11 unbuilt liquid and eight built liquid), of varying formulations, in cleaning a standard soiled fabric in water of varying hardness. They demonstrated that powdered detergents were significantly affected only at very high water hardness levels. They showed that increasing water hardness had no significant effect on liquid detergents, and that powdered detergents performed better than liquid detergents in cleaning the standard soiled fabric.

The literature survey revealed that the studies about the effect of hard water on washing performance in general is very limited, even though there are many published researches on the laundry habits of consumers focusing on the resource efficiency of washing (Pakula and Stamminger, 2010; Hustvedt, 2011; Laitala *et al*., 2011; Yamaguchi *et al*., 2011) and on the main washing factors such as temperature, detergent type, etc. (Rowe, 2006; Stamminger, 2011; Laitala *et al*., 2012; Jack, 2013; Kruschwitz *et al*., 2014). Furthermore, the data available in the literature do not provide satisfactory information as far as the impact of water hardness on consumer's perception of washing results is concerned. Accordingly, the present research was conducted in order to identify consumers' perception on water hardness effects in laundering in five European countries. Also, the degree of satisfaction of the consumers from the washing process was examined and correlated to the water hardness. Finally, in order to get a better understanding of the washing habits of the respondents, information such as washing temperatures per clothing item and use of washing additives (e.g. textile softener, water softener, colour catcher, machine cleaner, etc.), were also identified.

Wash habits and practices vary a lot throughout the world (Pakula and Stamminger, 2010). Thus, the aim of the study was to investigate how well the consumer is aware on the effect of water hardness on household laundry and how much this is perceived by the consumers' washing result.

Methodology

The research was conducted using a structured questionnaire compiled by the members of the Board for Washing Excellence[1]. The use of questionnaires is well documented in issues related to the identification of consumer behaviour towards household technology (Stamminger, 2011). The research took place via the Internet from 8 to 18 March 2013 in five European countries, namely Germany, France, Italy, Russia and the UK. Approximately 1000 people were conducted in each country by a professional marketing company for a total of 5053 respondents. However, before performing the statistical analysis of the results, each questionnaire was checked for consistency based on the comparison of the results of the following two questions: the first one was straightforward 'How many loads of laundry do you do each week?' The second question was phrased as 'How often do you wash at the following temperatures?' where various washing temperatures (15/20°C, 30°C, 40°C, 50°C, 60°C, 90°C) were given along with the washing frequency. The weekly frequencies of washing at each

[1]The board aims to improve all aspects of household laundry washing by providing practical guidance and sharing knowledge and insights into the role that science, innovation and education play (Board for Washing Excellence, 2014).

Table 2 Consistency check of the responses based on the number of weekly wash loads

	1–2 loads	3–4 loads	5–6 loads	7+ loads	Not sure	Total
1–2 loads	658	726	171	124	54	1733
3–4 loads	73	689	665	468	45	1940
5–6 loads	4	30	279	560	16	889
7+ loads	0	6	20	431	14	471
Not sure	6	0	0	2	12	20
Total	741	1451	1135	1585	141	5053

Only those respondents in the grey field were taken for the final evaluation of results.

Table 3 Demographics of the sample

		Gender (%)		Age group (%)					
	Respondents	Male	Female	18–24	25–34	35–44	45–54	55–64	65+
Germany	848	48.1	51.9	15.6	18.5	26.7	24.2	12.3	2.8
France	826	46.2	53.8	17.1	19.4	23.8	20.9	14.6	4.1
Italy	752	45.6	54.4	12.8	19.1	27.4	23.4	14.2	3.1
Russia	687	42.8	57.2	17.3	23.4	22.9	22.4	11.9	2.0
UK	895	42.5	57.5	4.5	16.2	17.7	22.7	20.7	18.3

Table 4 Mean washing temperature (°C) per laundry item

	Whites	Coloured	Linens and towels	Underwear	Delicates
Germany	51.4	39.7	56.1	52.2	33.2
France	53.1	37.9	51.4	38.6	28.5
Italy	50.2	35.1	51.0	43.3	28.2
Russia	55.9	41.1	59.5	43.3	33.4
UK	44.1	37.1	44.5	39.2	32.0
Overall	50.7	38.1	52.2	43.3	31.0

temperature were then summed up (see Table 2). The number of consistent consumers in each country is presented in the second column of Table 2, summing up to a total of 4008. Also, the gender and age demographics distributions of the consistent sample are presented in Table 3. Questionnaires of non-consistent consumers were eliminated from all subsequent analysis. Also note that, where references are made to specific countries in the following text, this only refers to respondents from that country involved in this study. It is not meant to imply that the respondents are fully representative of the specified country.

Results and discussion

The first consumer habit to be identified was the washing temperatures used for each of the different clothing items that are washed. The weighted average of washing temperatures per washing item is presented in Table 4. The highest wash temperature (52.2°C) is used for washing linens and towels while the lowest (31.0°C) is used for washing the delicate items. Consumers in Russia use the highest temperatures for each clothing item except underwear; in this case, the German consumers use the highest temperature. On the other hand, consumers in the UK use the lowest temperatures in washing whites, linens and towels, while among the remaining clothing categories, they use the lowest washing temperatures. Moreover, these results exemplify that huge differences exist for the washing habits in the five European countries examined: for the linens and towels, the washing temperature difference between Russia (highest temperature) and the UK (lowest temperature) is 15 K while for the underwear washing temperature, the difference between Germany (highest temperature) and the UK (lowest temperature) is 13 K. The differences in the washing temperatures among the five countries do not differ significantly for coloured and delicate clothing items.

The next question was about the information that consumers receive from the care labels of the clothes, as guidelines on washing can be found on the label attached to every clothing item. Fig. 1 presents the results obtained from each one of the five countries for the question ‘Do you read care labels in garments and laundry items before washing?’ Most of the consumers in each one of the five countries claim that they read the care label all of the time. The highest percentage is found in Germany (64.5%) while the lowest is in Russia and Italy (47.3%). Also, many consumers claim that they read the care label only for new garments. Overall, approximately 85% of the total sample claims that they read the care label at least once. This is a very promising finding because in this label important information is found regarding the care of the garment. However, one has to be very careful; it is one thing to read a label, another thing to comprehend its meaning. And of course, the most important thing of all is to correctly apply the guidelines given to you for the care of the garment during washing.

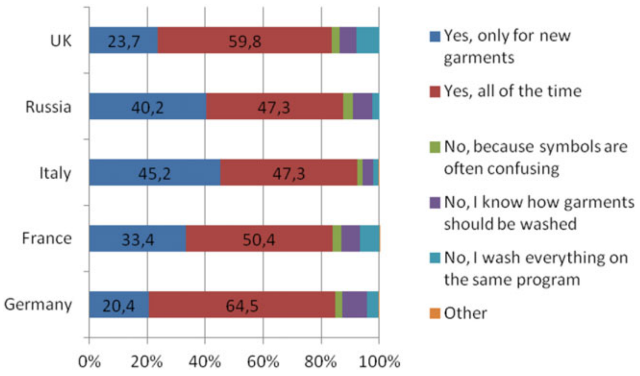

Figure 1 Answers to question: 'Do you read care labels in garments and laundry items before washing?'

Effect of hard water on the age of the washing machines

Table 5 presents the results per country of the water hardness in the area of residence. These results are based on the self-reported knowledge of the respondent, because the actual water hardness measurement requires a chemical analysis. Alternatively, accurate water hardness data could have been obtained from the water suppliers, but doing this would have required the respondents' post codes and these were not collected in the survey. Note that water hardness varies even within a country, depending on the source of the water supply of each area. Normally, water originating from underground aquifers has higher hardness (Godskesen *et al.*, 2012). The percentage of respondents reporting that they live in areas with hard water ranges from 30.7% (in Italy) to 40% in Russia. On the other hand, the respective percentage of respondents reporting that they live in areas with soft water ranges from 10.1% in Italy to 22% in the UK. These results indicate that people are aware of the water hardness of the area that they live in or at least that they have a perception of knowledge of the water hardness.

Hard water may lead to precipitation of $CaCO_3$ on surfaces in contact with water, particularly in devices operated at elevated temperatures such as washing machines (Van der Bruggen *et al.*, 2009). These mineral deposits resulting from water hardness are reported to shorten the life of the washing machines: the lower the water hardness, the longer the service life of household appliances (Cameron, 2011; Godskesen *et al.*, 2012). In order to check the hypothesis 'Is the washing machine age affected by the water hardness of the area that the machine is operated in?', consumers in the five countries were asked to report the age of their washing machines. The results are presented in Table 6. From there it is evident that in each one of the five countries examined, more than 70% of the washing machines are between 1 and 6 years old. Also, approximately 10% of the washing machines in each country were bought during the past 12 months from the date that the research was contacted.

As the problems resulting from the water hardness are more likely to be exhibited in older washing machines, in the present research, binary logistic regression was used to explore the association between water hardness with probability to have a washing machine older than or equal to 7 years. Those questionnaires that had no information on the level of water hardness and on the age of the washing machine were excluded from the analysis. Binary logistic regression estimated the probability of the event ($Y = 1$: washing machine ≥ 7 years) from the model that contains as predictor the water hardness, as a categorical variable with two categories: hard or medium-hard (reference level), and soft. The model contains three more variables considered as potential confounding variables:

- loads of laundry in a week, as a categorical variable with two categories: ≤ 4 loads of laundry, ≥ 5 loads of laundry (reference level);
- respondents' age as a categorical variable with two categories: age ≤ 34 years (reference level), age ≥ 35 years; and
- country, as a categorical variable with five categories: Germany (reference category), France, Italy, Russia, UK.

Among the most important logistic regression results presented in Table 7, it is observed that the odds ratio for water hardness indicates that when holding all other variables constant, if the water is soft, it is 1.262 times more likely to own a washing machine over 7 years of age, compared with hard or medium hard water. Also, the odds ratio for the weekly wash loads indicates that when holding all other variables constant, if the number of weekly wash loads is less or equal than four it is 1.791 times more likely to own a washing machine over seven years of age, compared with five weekly wash loads or more. In other words, the regression indicates that washing machines in soft water areas last slightly longer than those in medium hard or hard water areas; also washing machines that are used less than four times a week last longer than whose that are used more often.

Consumer satisfaction and the effect of water hardness

The next task was to identify the consumers' satisfaction from the washing result by asking them 'Are you generally satisfied or dissatisfied with the washing result of your laundry?' The responses were given on a Likert-type scale ranging from 'Very satisfied' to 'Very dissatisfied'. As presented in Fig. 2, most of the consumers in all five countries are somewhat satisfied by the washing result. The respective percentage ranges from 50.8% in Russia to 70.3% in France. Very satisfied consumers from the washing result can be mostly found in the UK (40.9%) and Russia (39.3%).

As already reported in the literature, the washing result, and thus satisfaction of consumers, depends on water hardness (Cameron and Brown, 1995). In order to test the hypothesis 'Is the level of consumer satisfaction higher in soft water areas?' for the responses of the present research, the chi-square test of independence was employed. For statistical purposes, a new category was created termed 'not satisfied', which includes the following three initial categories presented in Fig. 2: 'neither satisfied, nor dissatisfied', 'somewhat dissatisfied' and 'very dissatisfied'. The results presented graphically in Fig. 3 indicate that there is a statistically significant difference in the degree of satisfaction with the washing result ($P = 0.002 < 0.05$) among the areas of different water hardness. More specifically, the percentage of consumers that are not satisfied with the washing result is 7.3% in hard water areas while the respective percentage is 4.8% in soft water areas. On the other hand, the percentage of consumers that are very

Table 5 Self-reported water hardness in the area of residence

	Hard (%)	Medium-hard (%)	Soft (%)	Do not know (%)
Germany	38.4	38.3	12.3	11.0
France	32.0	42.9	13.3	11.9
Italy	30.7	49.7	10.1	9.4
Russia	40.0	47.5	10.6	1.9
UK	38.9	24.2	22.0	14.9

Table 6 Washing machine age distribution

	<1 year (%)	1–3 years (%)	4–6 years (%)	7–10 years (%)	>10 years (%)	Do not know (%)
Germany	9.3	38.0	33.3	11.3	7.4	0.7
France	9.6	35.4	34.0	12.3	7.4	1.3
Italy	9.3	41.9	31.5	9.0	7.4	0.8
Russia	10.6	42.4	27.8	13.8	4.9	0.4
UK	9.7	39.7	32.0	9.3	5.5	3.9

Table 7 Logistic regression table presenting the independent variables of the model

	B	SE	Wald	df	Sig.	Odds ratio	95% confidence interval	
							Lower	Upper
Respondent's age	0.927	0.113	66.993	1	0.000	2.527	2.024	3.156
Country	–0.366	0.116	9.932	1	0.002	0.694	0.553	0.871
Water hardness	0.233	0.119	3.855	1	0.050	1.262	1.000	1.593
Weekly loads	0.583	0.104	31.467	1	0.000	1.791	1.461	2.195
Constant	–2.598	0.129	406.334	1	0.000	0.074	–	–

df, degrees of freedom; SE, standard error.

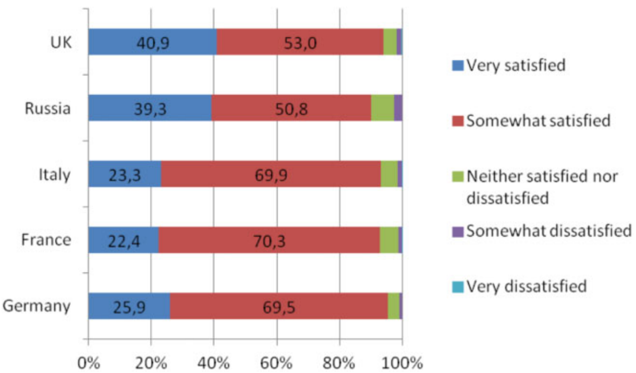

Figure 2 Degree of satisfaction from the washing result.

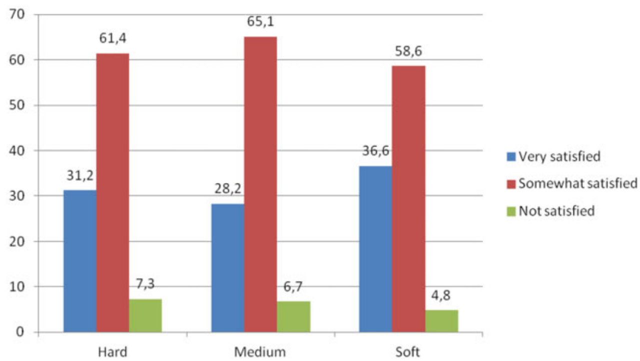

Figure 3 Degree of satisfaction from the washing result vs. water hardness (in all countries).

satisfied in soft water areas is 36.6% while the respective percentage in hard water areas is 31.2%. Overall, most people living in hard water areas seem to understand what to do to get a good wash, but a significant number do not.

The next research objective was to identify which are the specific reasons for not being satisfied by the washing result. The consumers were asked to report what kind of problems they face when they are not satisfied with the washing result of their laundry. Note, however, that they were not asked to report the degree of dirtiness of their garments. Approximately, one in three (29.4%) of those not being satisfied by the washing result claims that insufficient soil/stain removal is the reason. Next, the problem resulting from the white residues on the garments was mentioned by 15.5% of the respondents. Finally, colour fading of bright garments and greying of white garments was the next reason selected by 14.4%, followed by bad smell on the garments selected by 11.8% of the non-satisfied respondents.

As reported in the literature, the level of water hardness plays an important role in the success or failure of the washing process (Cameron and Brown, 1995). The effects of hard water are

Table 8 Frequency of water softener use (%)

	Every wash	Several times per week	Once week	Once a month	Less often	Never
Germany	13.2	4.2	6.3	9.0	16.6	50.7
France	9.0	1.5	3.6	2.5	7.5	75.9
Italy	15.2	7.4	15.0	16.5	16.9	29.0
Russia	20.5	6.3	8.7	7.3	13.5	43.7
UK	5.1	1.7	2.7	2.3	8.9	79.2
Total	12.2	4.0	7.0	7.3	12.5	57.0

typically lime deposits on fabrics and the interior of the washing machine. These deposits, termed as limescale, may cause discoloration of fabrics and make them harsh and scratchy to touch (Cameron, 2007) or in other words water hardness reduces the satisfaction of the consumer with the washing process.

Thus, the next question was straightforward regarding the effects of limescale on the quality of garments: 'Does limescale affect the quality of your garments?' Of the respondents, 39.3% replied that limescale does not affect the quality of the garments. However, 28.5% of the respondents replied that limescale makes their fabrics feel rigid and harsh to touch, 21.9% answered that limescale makes their fabrics appear duller while 8.5% of the respondents noted that limescale affects the shape of their fabrics.

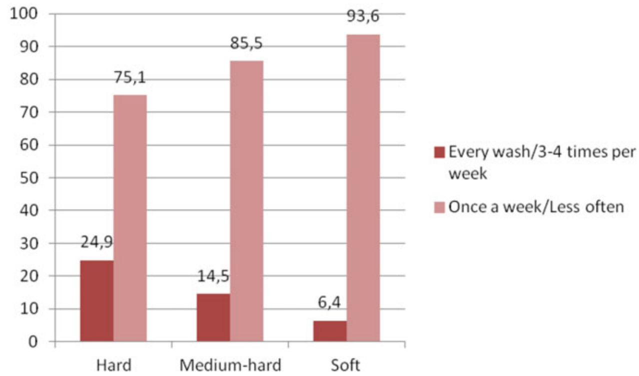

Figure 4 Frequency of water softener use vs. water hardness (in all countries).

Determinants of water softener use by the consumers

The use of softened drinking water in the households has several positive effects such as reduced consumption of energy and laundry detergents and prolonged service lives of household appliances (Godskesen *et al.*, 2012). Reduction in detergent quantity leads to an economic benefit for the consumer, but also to a significant reduction of the environmental impact of washing clothes, especially in terms of the aquatic ecosystem, but also for energy-related impacts, as energy is consumed in the production and formulation of detergents (Cameron, 2011). Thus, water softening has plenty of financial and environmental advantages (Van der Bruggen *et al.*, 2009). Water softening can be achieved by central water treatment plants (Godskesen *et al.*, 2012) or at home using ion exchangers (Van der Bruggen *et al.*, 2009). However, this option is expensive in both financial and environmental terms, because ion exchangers require concentrated salt solution for regeneration, which are then a waste stream that is difficult and costly to treat (Van der Bruggen *et al.*, 2009). A more practical solution is the use of water softeners in each washing cycle. Household water softeners are available in the form of powder, tablets or, in most of the countries, gels. Chemically speaking, the household water softeners are similar to the builders, a key constituent already present in any household detergent. Therefore, the adverse effect of increased water hardness on the laundry outcome can be also neutralized if consumers use the increased detergent dose recommended by detergent manufacturers, found on every European detergent packaging container.

Part of the current research was the identification of the frequency of use of water softeners as additives to the household laundering process. The reported use frequency of water softener per country is presented in Table 8. Approximately 80% of the respondents in the UK have never used a water softener; on the other hand, 20.5% of the Russians report that they use water softener in every wash followed by the Italians: 15.2% of them use water softener in every wash. Using the chi-square test of independence, it is revealed that the gender and age of the respondent have a statistically significant effect on the use frequency of water softeners only in Italy among the five countries. More specifically, women are more likely than men ($P = 0.029$) to use water softener frequently (i.e. in every wash or three or four times a week); also, people in the age group 35–54 years are more likely ($P = 0.007$) to use water softener frequently.

In order to test the research hypothesis 'Do people living in hard water areas use water softener more frequently (i.e. in every wash or three to four times a week)?', the chi-square test of independence was employed. The results, presented in Fig. 4, indeed confirm ($P = 0.000 < 0.05$) the hypothesis that the percentage of people living in hard water areas that use water softener frequently (24.9%) is three times higher compared with the fraction of consumers that use water softeners while living in soft water areas (6.4%).

Conclusions

Water hardness is a key factor in the successful outcome of the washing process. For the first time, a research was conducted in five European countries aiming at identifying the perception of the consumers on the effect of the water hardness in the washing cleaning performance. In terms of water hardness, the respondents seem to be well aware that the areas that they live in face problems with the water hardness. The results also indicate that satisfaction on the washing outcome, although reported in high levels, depends on the water hardness. People living in hard water areas are less satisfied compared with those living in soft water areas. Despite the fact that people blame the water hardness for deteriorating the quality of the washed garments, the percentage of people using water softeners is relatively low in all the countries examined. Although the results reveal that people living in hard water areas use water softeners more frequently compared with those living in soft water areas, the absolute percentage of people living in hard water areas and using water softener is quite low. A limitation of the study is that it was based on the self-reported water hardness and not on actual analytical laboratory results of this water property. On the other hand, an implication of the present research might be that many consumers are aware of the adverse effect of water hardness on the outcome of the washing process, and that they are applying various methods to neutralize this effect. Further investigation is required for the effect of water hardness on people's perceptions in other European countries.

Acknowledgement

For the implementation of the consumer research, financial support from an unrestricted educational fund by Reckitt-Benckiser is greatly acknowledged.

References

Arai, H. (1966) Study of detergency: I. Effect of the concentration and the kind of detergent in hard water. *Journal of the American Oil Chemists' Society*, **43**, 312–314.

Board for Washing Excellence (2014) *Our Mission*. [WWW document]. URL http://www.washing-excellence.org/bwe/our-mission.aspx (accessed on 20 May 2014).

Brown, D.M., Cameron, B.A., Meyer, S.S. & Umber, J.J. (1991) The effects of water hardness level on washing quality using commercial laundry detergents. *Journal of Consumer Studies & Home Economics*, **15**, 215–222.

Cameron, B.A. (2007) Laundering in cold water: detergent considerations for consumers. *Family and Consumer Sciences Research Journal*, **36**, 151–162.

Cameron, B.A. (2011) Detergent considerations for consumers: laundering in hard water – How much extra detergent is required? *Journal of Extension*, **49**, 1–11. Article Number 4RIB6. [WWW document]. URL: http://www.joe.org/joe/2011august/pdf/JOE_v49_4rb6.pdf (accessed on 20 May 2014).

Cameron, B.A. & Brown, D.M. (1995) A survey of commercial laundry detergents – how effective are they? Part III: powders, liquids and hard water. *Journal of Consumer Studies and Home Economics*, **19**, 85–97.

Godskesen, B., Hauschild, M., Rygaard, M., Zambrano, K. & Albrechtsen, H.-J. (2012) Life cycle assessment of central softening of very hard drinking water. *Journal of Environmental Management*, **105**, 83–89.

Hustvedt, G. (2011) Review of laundry energy efficiency studies conducted by the US Department of Energy. *International Journal of Consumer Studies*, **35**, 228–236.

International Association for Soaps, Detergents and Maintenance Products (AISE) (2013) The case for the 'A.I.S.E. Low Temperature Washing' Initiative, Substantiation Dossier/June 2013. [WWW document]. URL http://www.iprefer30.eu/component/attachments/attachments?task=download&id=244 (accessed on 20 May 2014).

Jack, T. (2013) Laundry routine and resource consumption in Australia. *International Journal of Consumer Studies*, **37**, 666–674.

Kruschwitz, A., Karle, A., Schmitz, A. & Stamminger, R. (2014) Consumer laundry practices in Germany. *International Journal of Consumer Studies*, **38**, 265–277.

Laitala, K., Boks, C. & Klepp, I.G. (2011) Potential for environmental improvements in laundering. *International Journal of Consumer Studies*, **35**, 254–264.

Laitala, K., Klepp, I.G. & Boks, C. (2012) Changing laundry habits in Norway. *International Journal of Consumer Studies*, **36**, 228–237.

Nagarajan, M.K. & Paine, H.L. (1984) Water hardness control by detergent builders. *Journal of the American Oil Chemists' Society*, **61**, 1475–1478.

Pakula, C. & Stamminger, R. (2010) Electricity and water consumption for laundry washing by washing machine worldwide. *Energy Efficiency*, **3**, 365–382.

Rowe, H.D. (2006) Detergents, clothing and the consumer with sensitive skin. *International Journal of Consumer Studies*, **30**, 369–377.

Sinner, H. (1960) Ueber das Waschen mit Haushaltwaschmaschinen: in welchem Umfange erleichtern Haushaltwaschmachinen und-geraete das Waeschewaschen im Haushalt? Haus und Heim-Verlag, Hamburg.

Stamminger, R. (2010) Reinigen. In *Lebensmittelverarbeitung im Haushalt, aid-Verlag* (ed. by U. Gomm), pp. 307–334. aid-Infodienst, Bonn. (978-3-830°8-0851-0).

Stamminger, R. (2011) Modelling resource consumption for laundry and dish treatment in individual households for various consumer segments. *Energy Efficiency*, **4**, 559–569.

Umber, J.J., Brown, D.M., Cameron, B.A., Meyer, S.S., Powell, J.A. & Sisco, B.R. (1992) The effect of water hardness on washing performance of built and unbuilt surfactants. *Journal of Consumer Studies & Home Economics*, **16**, 151–159.

Van der Bruggen, B., Goossens, H., Everard, P.A., Stemgée, K. & Rogge, W. (2009) Cost-benefit analysis of central softening for production of drinking water. *Journal of Environmental Management*, **91**, 541–549.

Yamaguchi, Y., Seii, E., Itagaki, M. & Nagayama, M. (2011) Evaluation of domestic washing in Japan using life cycle assessment (LCA). *International Journal of Consumer Studies*, **35**, 243–253.