Microbiological quality of bottled water brands sold in retail outlets in New Zealand

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ABSTRACT

The microbiological quality of bottled water has been studied over the past 30 years as bottled water can contain pathogens. The aim of this study was to determine if retailed bottled water in New Zealand complied with the Australia and New Zealand Food Standards (ANZFS) Code (2002) and the New Zealand Microbiological Reference Criteria (1995). Thirty-eight domestic and imported bottled water brands were tested for Total Coliforms, *Escherichia coli*, *Pseudomonas aeruginosa*, Enterococci, HPC, Yeasts and Moulds. Three brands did not comply with both of the above criteria for Total Coliforms. Seventeen brands did not comply with HPC criteria and 21 brands displayed mould growth. A questionnaire was used to assess the impact of manufacturing procedures on bottled water quality. Four responding manufacturers, which represented 11 bottled water brands, bottled at least one brand that did not comply with the ANZFS Code for HPC. Our study demonstrated that even 10 years after the initial study in New Zealand microbiological contamination in bottled waters was still being detected. We further demonstrated that monitoring of bottled water microbiological quality was essential and that the presence of manufacturers' procedures for ensuring satisfactory bottled water microbiological quality did not always guarantee it.

Key words | bottled water, coliforms, compliance, microbiological quality, mineral water

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INTRODUCTION

Consumption of bottled water continues to increase steadily as a result of public concerns about the palatability and microbial and chemical contaminants of tap water. According to the International Bottled Water Association (Beverage Marketing Corporation 2008), the consumption of bottled water worldwide in 2002–2007 had increased by 7.6%, although in 2008 sales of bottled water fell by 9%, the first time they have declined in more than 30 years (International Bottled Water Association 2008).

Bottled waters are not subjected to the same extensive quality standards as municipal water (Olayemi 1999). Bottled water is any potable water offered for sale in any sealed container, such as a bottle, jug or can. The source of bottled water could be springs, wells, glaciers, municipal or other approved sources. The water may be distilled, carbonated, ozonated or filtered. Natural mineral water is not sterilised, pasteurised or treated to remove or destroy microorganisms (Armas & Sutherland 1999). The major differences between the different types of bottled waters seen around the world are the water source, method of abstraction and the treatment that water is subjected to (Table 1).

There is now an increasing concern that the entry of microorganisms into groundwater supplies may pose risks if bottled waters are consumed (Kerr *et al.* 1999). Contamination of source water with any microorganisms, and especially with *E. coli*, poses a significant risk should that water be bottled. Interestingly, *E. coli* and coliforms have been previously identified in bottled waters (Kerr *et al.* 1999; Olayemi 1999; Bharath *et al.* 2003; Lal & Kaur 2006; Kassenga 2007; Zamberlan da Silva *et al.* 2008).

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Table 1 | Main types of bottled waters

Type of bottled water	Description
Spring water	Water from an underground source which flows naturally to the surface of the earth and is bottled at source without any treatment
	Is collected only at the spring or through a borehole that taps into the aquifer feeding the spring
	In some countries, e.g. the UK, certain treatments, such as the removal of certain minerals, are permitted for spring waters
Purified water	Is water produced through distillation, deionisation, reverse osmosis or some other water treatment process of either tap water or groundwater
Natural mineral water	Must come from an identified and protected source, usually from a spring, and contains only the minerals found in the water as it flows from the ground. In some cases carbon dioxide is added to make the water sparkle
	'Natural Mineral Water status' implies that the waters are free from pollution and have a characteristically stable composition
Mineral water	It contains more than 250 parts per million (ppm) of total dissolved solids (TDS) that are present at the point of abstraction from the source. Minerals cannot be added to this water and it cannot be drawn from a municipal source
Sparkling/carbonated bottled water	This water contains the same amount of carbon dioxide that it contained when it was drawn from the source
Artesian well water/Artesian water	Is drawn from a well that taps into a confined aquifer
Well water	Comes from a hole bored or drilled that taps the water of an aquifer. It must be pumped to the surface
Tap water	Municipal water piped into the buildings
Table water	Bottled filtered tap water

A variety of other microorganisms have been recovered from bottled water. Venieri *et al.* (2006) isolated *P. aeruginosa*, *Pseudomonas* spp., *Aeromonas* spp., *Pasteurella* spp., *Citrobacter* spp., *Flavobacterium* spp., *Providencia* spp. and *Enterococcus* spp. in bottled non-carbonated mineral waters in Greece and found that 14% of tested bottled water samples did not comply with the Greek bottled water regulations. In a recent study *P. fluorescens*, *Corynebacterium* spp. *J-K*, *S. paucimobilis*, *P. versicularis*, *A. baumannii*, *P. chlororaphis*, *F. indologenes*, *A. faecalis* and *P. cepacia* were isolated in bottled waters sold in Puerto Rico (Reyes *et al.* 2008).

Drinking Water Standards for New Zealand (2005) are applicable to water intended for drinking, irrespective of its source, treatment and distribution system, whether it is from a public or private supply, and where it is used. The Standards specify maximum acceptable values (MAVs) for the microbiological, chemical and radiological determinants of public health significance.

The exception to this is bottled water, which is subject to different standards and is covered by food legislation, namely the New Zealand Microbiological Reference Criteria (NZMRC) for Food (Ministry of Health 1995) and the Australia New Zealand Food Standards (ANZFS) Code (Standard 1.6.1), 2002.

In the early 1990s concerns about the rapidly expanding bottled water industry resulted in a survey being undertaken by the Consumer's Institute in association with the Ministry of Health. The survey tested 23 brands of local and imported bottled waters. Five samples of each brand were tested. None of the brands had detectable levels of coliforms, *E. coli*, faecal streptococci or *Pseudomonas aeruginosa* (Consumer's Institute 1999).

In 1999 another microbiological survey was undertaken for the New Zealand Ministry of Health. From January to March 1999, 100 batches of bottled water brands were tested. While the results did not identify any major public health issues, some batches did show that the water bottlers

did not have processing and preparation procedures fully under control. Fungi were isolated in five brands, all originating from New Zealand bottling plants. This could have been due to poor quality control of either the water or the containers (Hasell & Capill 2000). Faecal streptococci were found in one brand, which suggested the inadequacy of the source water quality. One brand had high coliform counts, which suggested hygiene failure. A persistently low level of *Pseudomonas* spp., which could have been due to poor plant hygiene or source water quality, was observed in one brand. These results indicated the necessity for regular monitoring of the microbiological quality of bottled water.

Due to the increase of bottled water consumption in New Zealand since 1999, it was appropriate to carry out another survey to evaluate the microbiological quality of bottled water sold in retail outlets in New Zealand. In this study, randomly selected samples of 38 different types of domestic and imported bottled water brands were purchased from the selected local retail stores in Wellington region. In our study we examined a variety of bottled waters, which included carbonated or sparkling water, still water, natural water, mineral water, natural mineral water and flavoured water. The bottled water samples were tested for Total Coliforms, *Escherichia coli*, Enterococci (Group D streptococci), *Pseudomonas aeruginosa*, Heterotrophic Plate Count (HPC), Yeasts and Moulds. Microbiological compliance with the New Zealand Ministry of Health's Microbiological Reference Criteria for Packaged Waters (S.5.21), 1995, and the Australia and New Zealand Food Standards (ANZFS) Code (Standard 1.6.1), 2002, was ascertained. A questionnaire was also conducted to investigate the manufacturers' practices during the water bottling processes and to determine the sources of possible and potential contamination.

MATERIALS AND METHODS

Sample collection

Five samples from the same batch of randomly selected 38 domestic and imported bottled water brands were purchased from local retail stores in the Wellington region. These samples, that represented different types of bottled waters, were tested for Total Coliforms, *Escherichia coli,* Enterococci (Group D streptococci), *Pseudomonas aeruginosa*, Heterotrophic Plate Count (HPC), and Yeasts and Moulds.

Methods for detection of microorganisms

Total coliforms and *E. coli* in the bottled water samples were detected using the Colilert^{TM} System incubated at 35°C ± 0.5°C (IDEXX Laboratories, Westbrook, Maine, USA) (Abbott 2001). Enterococci were examined using Enterolert^{TM} system (IDEXX Laboratories), which was designed for the rapid detection and enumeration of Enterococci at 41°C ± 0.5°C and has a sensitivity of 99.8% and a specificity of 97.0% (Abbott *et al.* 1998).

Nutrient agar plates were used to enumerate aerobic colonies of the HPC by the surface spread dilution method at 35°C ± 0.5°C (Method #9215, Standard Methods 1995).

Pseudomonas aeruginosa enumeration was carried out using *Pseudomonas* MPA agar plates incubated at 41.5°C ± 0.5°C (Method #9213E, Standard Methods 1995).

Yeasts and moulds were enumerated on Sabouraud dextrose agar plates incubated at 20–24°C (Method #9610C, Standard Methods 1995).

Questionnaire

In addition to the microbiological testing listed above, a questionnaire was designed and distributed to all manufacturers of the bottled water brands tested. The aim of the questionnaire was to investigate relationships between microbiological quality of the final product and the source water quality, type of abstraction, pipework materials, transportation, bottling process, staff training, policies and procedures.

Analysis of data

Escherichia coli, Pseudomonas aeruginosa, Enterococci (group D streptococci) and total coliform counts obtained in this study were compared with the values detailed in the New Zealand Microbiological Reference Criteria for Food (Table 2) and the Australia New Zealand Food Standards Code (Table 3). Total coliform counts and fungal spore

Table 2 | Microbiological reference criteria for foods: packaged waters (including mineral waters and those bottled from natural underground sources)

Food microorganism	*n*	*c*	*m*	*M*
Coliform (/100 mL)	$n = 5$	$c = 1$	$m = 10$	$M = 10^2$
Escherichia coli (/100 mL)	$n = 5$	$c = 0$	$m = 0$	
Group D streptococci (/100 mL)	$n = 5$	$c = 1$	$m = 10$	$M = 10^2$
Pseudomonas aeruginosa (/100 mL)	$n = 5$	$c = 0$	$m = 0$	

n = The number of sample units which must be examined from a lot of food to satisfy the requirements of a particular sampling plan; c = The maximum allowable number of defective sample units. When more than this number is found, the lot is rejected by the sampling plan; m = Represents an acceptable level, and values above it are marginally acceptable or unacceptable in the terms of the sampling plan; M = A microbiological criterion which separates marginally acceptable quality from defective quality. Values above M are unacceptable in the terms of the sampling plan, and detection of one or more samples exceeding this level would be cause for rejection of the lot.

counts were used as a measure of assessing the overall microbiological quality of the samples selected (Hassel & Capill 2000).

RESULTS AND DISCUSSION

Out of the 38 bottled water brands tested, there were 26 domestic brands and 12 imported brands (Table 4). The categories of the tested bottled waters were: still (45%), flavoured (23%), mineral (16%) and carbonated (16%). Some brands belonged to more than one category, e.g. mineral flavoured water (Brand 4) or still natural mineral water (Brand 36), as detailed on the labels.

Two domestic brands (both were flavoured waters) were sold in glass bottles and 24 brands were sold in plastic bottles (Table 4). Out of the 12 imported brands seven were sold in glass bottles and five were sold in plastic bottles. Six brands were sold in sealed bottles (five domestic and one imported).

Total coliforms were detected in three domestic brands: 7, 9, and 17. The average number of total coliforms detected in each brand was 11 Colony Forming Units per hundred millilitres (CFU/100 mL), 21 CFU/100 mL and >201 CFU/100 mL, respectively. Therefore these three brands did not comply with the NZMRC for Packaged Waters and the ANZFS Code for total coliforms. The presence of total coliforms indicated contamination and the possibility of presence of other pathogenic microorganisms. All other tested bottled waters had levels of total coliforms less than 1 CFU/100 mL; hence they were compliant with the NZMRC for Packaged Waters and the ANZFS Code for total coliforms. Our results are not uncommon. *E. coli* and coliforms have been detected regularly in bottled waters in other countries such as Trinidad (Bharath *et al.* 2003), Tanzania (Kassenga 2007), India (Lal & Kaur 2006), Nigeria (Olayemi 1999) and Brazil (Zamberlan da Silva *et al.* 2008).

We detected microorganisms in both glass and plastic (PVC) bottles, which is consistent with the findings

Table 3 | Australia New Zealand microbiological standard for mineral water and packaged water and ice

	Food microorganism	*n*	*c*	*m*	*M*
Mineral water	Coliforms (/250 mL)	$n = 5$	$c = 0$	$m = 0$	
	Pseudomonas aeruginosa (/250 mL)	$n = 5$	$c = 0$	$m = 0$	
Packaged water and ice	Coliforms (/250 mL)	$n = 5$	$c = 0$	$m = 0$	
	Pseudomonas aeruginosa (/250 mL)	$n = 5$	$c = 0$	$m = 0$	
	Standard Plate Count (SPC)/mL*	$n = 5$	$c = 0$	$m = 10^2$	

*Standard Plate Count (SPC) is an equivalent of Heterotrophic Plate Count (HPC) and Total Viable Count (TVC).

n = The number of sample units which must be examined from a lot of food to satisfy the requirements of a particular sampling plan; c = The maximum allowable number of defective sample units. When more than this number is found, the lot is rejected by the sampling plan; m = Represents an acceptable level, and values above it are marginally acceptable or unacceptable in the terms of the sampling plan; M = A microbiological criterion which separates marginally acceptable quality from defective quality. Values above M are unacceptable in the terms of the sampling plan, and detection of one or more samples exceeding this level would be cause for rejection of the lot.

Table 4 | Descriptive characteristics of tested bottled water brands

Brand number	Domestic (D)/imported (I)	Bottles: glass (G), plastic (P)	Bottle colour	Caps: plastic (P), pump (PU), metal (M)	Bottle sealed (Y/N)	Categories (determined from the label)*
1	D	P	Clear	P	N	S
2	D	P	Clear	P	N	NW
3	D	P	Clear	P	N	SP
4	D	P	Dark green	P	N	MW
5	I (Australia)	P	Clear	PU	Y	F
6	D	P	Clear	PU	N	S
7	D	P	Clear	PU	N	S
8	D	P	Clear	PU	N	S
9	D	P	Clear	PU	N	S
10	I (Italy)	G	Dark green	M	N	C, NMW
11	I (France)	P	Clear	P	N	S
12	D	P	Clear	P	N	SR
13	D	P	Clear	PU	Y	F
14	D	P	Clear	PU	N	S
15	I (Australia)	P	Clear	P	N	S, SW
16	I (Australia)	P	Clear	P	N	Organic
17	D	G	Clear	M, Screw-On	N	F, SP
18	D	P	Clear	PU	N	Distilled
19	D	G	Dark green	M, Screw-On	N	SP, F
20	D	P	Clear	PU	N	MW
21	I (Italy)	G	Dark blue	P	N	C
22	D	P	Clear	PU	N	S
23	I (Italy)	G	Dark blue	P	N	S
24	I (Austria)	P	Clear	P	N	S
25	D	P	Clear	PU	Y	F, SP
26	I (Italy)	G	Dark green	M, Beer	N	NMW, SP
27	I (Italy)	G	Dark green	M, Beer	N	S, NMW
28	I (France)	G	Dark green	M, Screw-On	N	C, F
29	D	P	Dark green	PU	Y	F
30	I (Italy)	G	Dark green	M, Beer	N	C, NMW
31	D	P	Clear	P	N	S
32	D	P	Clear	PU	Y	F
33	D	P	Clear	PU	Y	F
34	D	P	Clear	P	N	S, NMW
35	D	P	Clear	PU	N	SR
36	D	P	Clear	P	N	NMW
37	D	P	Green	PU	N	S, NMW
38	D	P	Clear	P	N	C, NMW

*Carbonated (C), Still (S), Sparkling (SP), Natural Mineral Water (NMW), Flavoured (F), Spring (SR), Natural Water (NW), Mineral Water (MW).

of the study carried out by Massa *et al.* (1997). This indicated that the type of packaging the bottled water is contained in does not have significant influence on preventing microbial growth.

We did not detect any *Pseudomonas aeruginosa* or Enterococci in any of the domestic and imported brands we tested; however, Reyes *et al.* (2008) isolated *P. aeruginosa* in bottled waters sold in Puerto Rico and Venieri *et al.* (2006) isolated *Pseudomonas aeruginosa* and Enterococci in Greek bottled waters.

To fully assess the compliance with the ANZFS Code, the bottled water samples were examined for the Heterotrophic Place Count (HPC), which in Australia and New Zealand is referred to as Total Viable Count (TVC) or Standard Plate Count (SPC) (Table 3). HPC was observed in 24 brands (10 imported and 14 domestic). In our study the HPC counts ranged from 5 to too numerous to count (TNTC) CFU/mL. The following 17 brands (45%) exhibited HPC counts of over 100 CFU/mL and thus failed to comply with the ANZFS Code for HPC: 7, 9, 10, 11, 12, 14, 15, 19, 21, 22, 23, 26, 27, 28, 29, 34 and 36 (Table 5). HPC has been used as a microbiological test in other countries when monitoring their bottled waters (Bharath *et al.* 2003; Jeena *et al.* 2006; Venieri *et al.* 2006; Kassenga 2007). Jeena *et al.* (2006) concluded that high levels of HPC bacteria with multiple drug resistance posed a significant health hazard to immunocompromised consumers. Papapetropoulou *et al.* (1997) also stressed that, when bottled water is going to be consumed by immunocompromised patients, the opportunistic microorganism count in bottled water is a useful guide to the hygienic quality.

The findings of our study demonstrated that sealing the bottle with a thin metallic foil prior to capping was a relatively satisfactory measure for controlling the microbiological quality of bottled water. Out of the six sealed brands tested, only one domestic brand (Brand 29) displayed non-compliant HPC counts (Table 5).

Table 5 | Average counts of HPC growth obtained after testing the 38 bottled water brands

	Brand numbers	HPC average counts, CFU/mL (Accepted microbiological level is 10^2)	Manufacturers responded to the survey
Brands that complied with the ANZFS Code for HPC	38	1	
	35	13	Y
	37	17	
	24, 30	20	
	17	30	
	8	40	
Brands that did not comply with the ANZFS Code for HPC	36	137	Y
	10	350	
	23	1,630	
	12	1,740	
	9	2,290	Y
	7	2,410	Y
	22	2,580	
	11	2,670	
	34	2,950	Y
	19	3,090	
	14	3,380	
	15	3,540	
	21, 26, 27, 28, 29	TNTC	Y (26)

Out of the 17 brands that failed to comply with the ANZFS Code's Microbiological Compliance Criteria for Packaged Water and Ice for the HPC, seven brands were bottled in glass bottles (brands 10, 23, 19, 21, 26, 27, 28) and 10 brands in plastic bottles (brands 36, 12, 9, 7, 22, 11, 34, 14, 15, 29). Out of these 17 brands, nine were domestic New Zealand brands: 7, 9, 12, 14, 19, 22, 29, 34 and 36 (Table 4).

Yeasts and moulds

Twenty-four brands displayed colonies on Sabouraud dextrose agar plates, of which growth of moulds was observed in 21 brands. Interestingly, brands 7, 9 and 17, which did not comply with ANZFS Code and NZMRC for total coliforms, had fungal growth. This may point towards the presence of the contaminants at the source of water collection.

The fungi detected in this study were not characterised. While testing for yeasts and moulds was not required under the New Zealand Microbiological Reference Criteria for Food (Ministry of Health 1995) and the Australia New Zealand Food Standards Code (2002), the presence of yeasts and moulds does give a general indication of process safety and the level of quality control (Hassell & Capill 2000). Previously, fungal contamination arising from multiple sources, such as *Penicillium* spp., *Cladosporium* spp. and *Trichoderma* spp., have been isolated in a water bottling plant (Ribeiro *et al.* 2006). *Aspergillus* spp. and *Paecilomyces* spp. were isolated from Indian bottled waters (Lal & Kaur 2006). Several foodborne fungi have the ability to produce mycotoxins, which may be responsible for allergic reactions or cause infections, especially in immunocompromised persons, HIV-infected individuals or patients on chemotherapy (USFDA 2001). Therefore, eliminating the presence of fungi is potentially an important public health concern.

While this study was based solely on previously unopened bottled water, work done by Raj (2005) pointed to the potentially progressive bacterial growth in bottled waters once bottles were opened. Raj (2005) suggested the development of guidelines for refrigeration and expiration time once a bottle is opened.

Questionnaire

A questionnaire was designed and distributed to the bottled water manufacturers and importers of the 38 brands tested in this project. Some manufacturers were bottling or importing more than one brand of bottled water. Manufacturers representing 29% of the bottled waters tested in this project responded to the survey. A variety of questions were asked to ascertain the source of bottled water, method of abstraction, pipework materials, transportation (if any), bottling process, sterilisation and what microbiological testing was carried out to determine water microbiological quality (Table 6).

Four manufacturers that bottled 11 brands (10 domestic and one imported) responded to the survey. The 10 domestic brands bottled by the four manufacturers were brands 2, 3, 5, 6, 8, 9, 12, 34, 35 and 36 and the imported brand was brand 26.

All manufacturers responded that they did carry out microbiological monitoring and testing of their final product (Table 6); however, they did not specify the frequency of monitoring. No manufacturers confirmed whether they carried out water testing at source. The source of water for the 11 brands was bore water, artesian bore or municipal water supply (Table 6). All four manufacturers carried out testing for *E. coli* and coliforms; three manufacturers (1, 2 and 4), that represented 10 brands further tested their final product for *P. aeruginosa*; manufacturers 1 and 3 included testing for yeasts and moulds, and manufacturers 1 and 2 carried out testing for Enterococci. In addition to the microbiological testing, manufacturer 2 daily tested bottled water for pH and conductivity, annually carried out a full chemical analysis and conducted radiological testing every four years.

There was no clear indication of whether the piping materials, treatment of water, abstraction methods and sterilisation process had any significance in preventing microbiological growth as it was found that all four manufacturers bottled at least one brand (9, 12, 26, 34, and 36) that did not comply with the ANZFS Code for HPC. The brands that grew mould colonies were 6, 8, 9 and 26. Although the manufacturers of brands 6, 8 and 26 tested their bottled waters for yeasts and moulds, we detected moulds in these brands. Our positive result for growth of

Table 6 | Questionnaire results

Brand Nr	Manu-facturer	Source of water	Piping materials	Water treatment/ disinfection method	Abstraction method	Method to sterilise bottles	Test for *E. coli* & Coliforms*	Test for yeasts & moulds*	Test for *P. aeruginosa**	Test for Enterococci*
2	1	Municipal supply and bore	Stainless steel & PVC	Filtration & ozonation	Pump and gravity	Not specified	Y	Y	Y	N
6	1	Municipal supply and bore	Stainless steel & PVC	Filtration & ozonation	Pump and gravity	Not specified	Y	Y	Y	N
8	1	Municipal supply and bore	Stainless steel & PVC	Filtration & ozonation	Pump and gravity	Not specified	Y	Y	Y	N
12	1	Municipal supply and bore	Stainless steel & PVC	Filtration & ozonation	Pump and gravity	Not specified	Y	Y	Y	N
35	1	Municipal supply and bore	Stainless steel & PVC	Filtration & ozonation	Pump and gravity	Not specified	Y	Y	Y	Y
3	2	Bore	Stainless steel & metal	Filtration & UV	Water under pressure	Ozonated water	Y	N	Y	Y
5	2	Municipal supply	Stainless steel & metal	Filtration & UV	Town water supply	Ozonated water	Y	N	Y	Y
9	2	Bore	Stainless steel & metal	Filtration & UV	Water under pressure	Ozonated water	Y	N	Y	Y
34	2	Bore	Stainless steel & metal	Filtration & UV	Water under pressure	Ozonated water	Y	N	Y	Y
26	3	Artesian bore	Stainless steel	None	Gravity	High temperature and caustic washing	Y	Y	N	Y
36	4	Artesian bore	Stainless steel	Filtration	Pump	Autoclaving	N	N	Y	N

*Microbiological testing performed by the manufacturers.

moulds in the batches of brands 6, 8 and 26 that we examined may mean that either the manufacturers were not carrying out the microbiological monitoring frequently enough or perhaps they did not test all batches of bottled waters that they produced. As the bottled water of brand 9 was not tested for yeasts and moulds by the manufacturer, it was not unexpected to observe mould counts in this brand. Brand 9 also did not comply for total coliforms with the ANZFS Code and NZMRC.

None of the manufacturers supplied copies of their procedures for sourcing water, transporting water, bottling water, delivery and dispatch of bottled water, water protection against contamination at the source, water protection against contamination during transportation of bottled water, water protection against contamination during bottling, cleaning the pipework, tanks and bottling equipment. If all procedures for ensuring satisfactory bottled water quality were adhered to then it was interesting to note that five brands representing the four manufacturers that responded to the questionnaire did not comply with the ANZFS Code for HPC.

Due to the low response rate of the questionnaire, no clear links could have been established between the microbiological quality of bottled waters and the source water quality, treatment, bottling process and documentation of the manufacturers. However, even from a low response rate it was clear that either the procedures for preventing microbiological contamination in bottled water were not effective in all cases or Good Manufacturing Practice (GMP) and Hazard Analysis of Critical Control Points (HACCP) were not adopted or implemented. The importance of GMP has been previously highlighted by Defives *et al.* (1999).

CONCLUSIONS

Hassell & Capill (2000) identified that one brand out of the 23 surveyed in their study did not comply with the New Zealand Microbiological Reference Criteria for Food (Ministry of Health 1995) for total coliforms. The authors concluded that their study did not identify any issues of public health concern. However, they reasoned that to control the potential risk factors that may affect bottled water microbiological quality regular microbiological testing was required. In our study we have demonstrated that three (Brands 7, 9 and 17) out of the 38 brands we tested did not comply with the New Zealand Microbiological Reference Criteria for Food (Ministry of Health 1995) and Australia and New Zealand Food Standards Code (2002) for total coliforms. The presence of coliforms was an indicator of hygiene failure. The manufacturer of brand 9 responded to our questionnaire. This manufacturer did perform *E. coli* and total coliform monitoring testing. There was, however, no indication of how regularly the microbiological monitoring occurred in the plant, but evidently the result of not testing regularly resulted in an unsatisfactory bottled water quality end product being sold.

While yeasts and moulds are not amongst the ANZFS Code or NZMRC compliance criteria, if detected in bottled waters they could have originated either from a water source, or contaminated plant or bottles. Hassel & Capill (2000) isolated fungi in five of 23 brands tested in their study. In our study 63% of the brands that we tested contained yeasts and moulds. Brands 9 and 36 grew fungi. The manufacturers of these two brands stated that they did not test their bottled water for yeasts or moulds, so it was not surprising that brands 9 and 36 tested positive for yeasts and moulds. However, while the manufacturers of brands 6, 8, 12 and 26 did test their bottled waters for yeasts and moulds, we detected fungal growth in these brands. Again this suggests that regular microbiological monitoring was not occurring, resulting in bottled water of poor microbiological quality being sold.

In our study we examined bottled waters for HPC, as this is a compliance criterion of the ANZFS Code (2002) for Packaged Water and Ice. We showed that 17 bottled water brands, nine of them New Zealand domestic brands, failed to demonstrate compliance for HPC. Since high HPC counts may indicate unsatisfactory water quality with possible public health issues, they should be monitored as a matter of quality control. From the information on the treatment processes of brands that responded to our questionnaire we noted that the brands that had filtration and ozonation in place complied with the ANZFS Code (2002) for HPC. The brands that were subjected to filtration and UV treatment (brands 9 and 24), filtration only (brand 36) or no treatment at all (brand 26) did not comply with the ANZFS Code (2002) for HPC. It was not unexpected to

observe non-compliance for HPC in brand 26 as it was a natural mineral water brand and it should have not been subjected to any treatment to remove or destroy micro-organisms (Armas & Sutherland 1999).

In addition to subjecting the bottled water samples for microbiological testing, we carried out a questionnaire to examine the impact of the manufacturing practices on the microbiological quality of bottled waters tested. We had a low response rate, receiving questionnaires from four manufacturers representing 11 of the bottled water brands tested. Even though most manufacturers (Table 6) carried out microbiological monitoring, we still identified contaminated bottled water brands, demonstrating that GMP procedures were not fully effective. These findings support the conclusions made by Zamberlan da Silva *et al.* (2008), who highlighted the need for an improved surveillance system in the bottled water industry.

We have demonstrated that New Zealanders should not assume that all bottled water sold in New Zealand is of a satisfactory drinking water standard. Some domestic and international brands that we tested did not comply with the NZMRC. Our project has supported the previous study performed in the late 1990s in New Zealand and has demonstrated that we have not learnt from the result of the previous study, as we were still detecting microbiological contamination in bottled waters 10 years later. The microbiological monitoring procedures of bottled waters sold in New Zealand need to be reassessed. Our study also supported the need for a review of the microbiological quality monitoring criteria for ensuring safe and acceptable quality of bottled waters around the world.

RECOMMENDATIONS

A Code of Practice with a special legal status should be developed and implemented to regulate bottled water manufacturing and the microbiological quality of bottled water in New Zealand.

Any future studies of bottled water microbiological quality in New Zealand should include HPC in the microbiological testing criteria.

Yeasts and moulds should be included in the Microbiological Reference Criteria for Packaged Water and Ice and for Mineral Waters under the Australia and New Zealand Food Standards Code as a measure of product safety and process quality control.

More regular routine microbiological monitoring should be adopted by the water bottling operators.

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