Accra, Ghana, 10-12 November 2009

WEST AFRICA REGIONAL SANITATION AND HYGIENE SYMPOSIUM

Improving food hygiene in Africa where vegetables are irrigated with polluted water

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Due to inappropriate and inadequate urban sanitation infrastructure in Ghana wastewater from households and other facilities ends up in nearby water bodies, which are often used as sources of irrigation water. However, this practice could have adverse public health and environmental effects, especially because untreated wastewater has high population of pathogenic organisms.

The purpose of this study was to determine the current level of exposure of the Ghanaian local population to faecal coliform (FC) through the consumption of wastewater irrigated vegetables and to analyse and improve the effectiveness of common washing methods for the reduction of faecal microorganism populations on the surface of wastewater-irrigated vegetables. The levels of pathogen on market vegetables produced with wastewater were determined.

Questionnaire interviews were also used to gather information on common methods used for washing vegetables in 11 cities in West Africa. The efficacy of the common decontamination methods was measured in terms of log reductions in FC populations on homogenised contaminated vegetable samples. High FC and helminth eggs contamination levels exceeding common guidelines for food quality were recorded on the market vegetables.

Methods used to wash vegetables vary widely within and between Ghana and neighbouring francophone West African (WA) countries. However, several of the most common methods do not reduce the contamination to any desirable level. Significantly, different log reductions are achieved depending on the washing method and contact time.

Tests to improve the apparent ineffective methods were especially promising in view of the relatively expensive vinegar. However, up to 3 log units reduction is also possible at a much lower price with 'Eau de Javel' (bleach), which is commonly used in francophone WA. Washing vegetables before consumption is important for health risk reduction. However, any washing method will need complementary efforts to reduce pathogen contamination.

Introduction

Raw and minimally-processed fruits and vegetables are essential part of people's diet all around the world but in recent years, fresh produce consumption has increased with increased health awareness (Bauchat, 1998). However, present practices (e.g. the use of polluted water, manure, poor produce handling etc) in many regions of the world cannot assure vegetables that are free from pathogens. Many studies have shown higher levels of pathogen contamination on both farm and market vegetables which pose health risk to consumers in Ghana (Klemesu *et al.*, 1998; Drechsel *et al*., 2000; Mensah *et al*., 2001; Sonou, 2001; Mensah *et al*., 2002).

In recent years, the frequency of outbreaks epidemiologically associated with raw fruits and vegetables have increased in some industrialized countries as a result of change in dietary habits and increased import of food (Altekruse *et al.,* 1997). There have been some outbreaks of diseases like typhoid in Santiago, Chile and helminth infections in Egypt and Jerusalem that have been associated with crop contamination from wastewater irrigation (Blumenthal *et al*., 2000). In developing countries, foodborne illnesses caused by contaminated fruits and vegetables are frequent and in some areas they cause a large proportion of illness. However, due to lack of foodborne disease investigation and surveillance in most of these countries, most outbreaks go undetected and the scientific literature reports only on very few outbreaks (Bauchat, 1998). A study on diarrhoeal diseases in an urban high density area in Accra revealed that about 60% of 951 mothers fed their children with purchased cooked food (Mensah *et al*., 1999). These purchased foods, more often than not, contain uncooked irrigated vegetables possibly from urban and peri-urban sites.

Faecal coliform and helminth egg populations on vegetables from irrigated urban sites could still be high at the retail point even if no further contamination occurs through market handling (Amaoh et al., 2007a). Hence, effective pathogen decontamination processes, especially at the food preparation points, are crucial to minimize health risks associated with consumption of contaminated vegetables.

The simple practice of washing vegetables in potable water or water containing sanitizing agent removes a portion of the pathogenic microorganisms that may be present. Even though several methods of washing vegetables have been recommended, the extent and effectiveness of these methods still vary. Additionally, there are few objective guidelines to determine which are the most appropriate and cost effective of the many sanitizers available in the markets to use in washing vegetables. This study therefore examined the microbiological quality of wastewater irrigated vegetables and the effectiveness of common methods of washing on the reduction of faecal coliform and helminth egg populations on the surface of fresh vegetables and factors affecting their efficacy.

Methodology

The study area(s)

Most of the activities of this study were carried out in Ghana. Additionally, questionnaire interviews were carried out in other West African countries (Burkina Faso, Côte d'Ivoire, Benin and Togo) to gather information on indigenous methods used for washing vegetables. Ghana lies at the shores of the Gulf of Guinea in West Africa . It borders Burkina Faso to the north, Togo to the east and Côte d'Ivoire to the west. It has a population of about 19 million, with annual growth rate of 2.7%. About 44% of Ghana's total population lives in urban areas. Some urban centres have annual growth rates as high as 6%, more than twice the country's average rate (Ghana Statistical Services (GSS), 2002. Data from Ghana were collected from three major cities (Accra, Kumasi and Tamale). Accra is the capital city of Ghana with a population of about 1.7 million (GSS, 2002). It is located in the Gulf of Guinea in the coastal savannah belt. Kumasi is the capital town of the Ashanti Region and the second largest city in Ghana with a population of about one million (GSS, 2002). Tamale is the administrative and regional capital of the Northern Region. It is located in Ghana's savannah zone and has a population of about 300,000 (GSS, 2002). In contrast to Accra and Kumasi, the Tamale Municipality is poorly endowed with water bodies. There are only a few seasonal streams.

Faecal coliform and helminth egg populations on irrigated vegetables sold in Ghanaian markets

The pathogen populations on irrigated vegetables sold in Ghanaian markets were determined. A total of one hundred and eighty (180) vegetable (*lettuce, cabbage and spring onion)* samples were collected from nine major markets and twelve specialized individual[1] vegetable and fruit sellers in Accra, Kumasi and Tamale. At each market, samples were collected under normal purchase conditions, from three randomly selected sellers. A minimum of 3 composite samples- *each containing 2 whole lettuces*), 3 bunches of spring onions (*each containing 2 bulbs*) and 3 cabbages, were collected from the upper, middle, and lower shelves of each seller, put in sterile polythene bags and then transported on ice to the laboratory where they were analysed immediately or stored at 4^{o} C and analysed within 24 h for faecal coliform and helminth egg populations.

Exploratory surveys to gather information on common methods used for washing vegetables in seven West African countries.

This exploratory surveys carried out in 11 cities in Sub-Saharan Africa targeted a cross section of 210 restaurants of different standards and about 950 randomly selected household consumers. The survey was carried out with assistance of CREPA by different local teams in the cities of Cotonou, Porto-Novo, and Sèmè-podji (all Benin), Ouagadougou (Burkina Faso), Niamey (Niger), Lomé (Togo), Bamako (Mali) and Dakar

[1] These are sellers with permanent stalls outside designated markets.

(Senegal) and Accra, Kumasi and Tamale (Ghana). City selection was based on intensity of wastewater irrigated urban vegetable production and proximity of markets for irrigated crops. Data collection was mainly by both structured and semi structured questionnaire interviews supplemented by direct observation by trained interviewing teams. To harmonise the survey in the various countries, study terms of reference and questionnaire were developed, pre-tested and discussed with the various city teams.

Interviews were conducted in the different communities in the cities to cover a broad spectrum of the population. Inner-urban sites were stratified based upon wealth (high, medium, and low class areas) and at least two communities from each stratum were randomly selected for the survey. The purpose of the interviews was to assess the general risk awareness and identify prevalent washing methods used for pathogen decontamination of vegetables during preparation for consumption.

Efficacy trials for common washing methods used in pathogen decontamination of lettuce

These trials were based on the results of the stakeholder interviews on common washing methods used for washing vegetables. Laboratory analyses were conducted to determine the efficacy of these common practices on faecal coliform and helminth egg decontamination. The efficacies of these methods were measured in terms of helminth egg populations and log reductions in faecal coliform. The effect of selected factors (e.g. sanitizer concentration, and contact time) on the efficacy of the methods was also determined.

Sampling lettuce for decontamination trials

Lettuce samples from wastewater-irrigated farms in Accra were randomly collected into sterile polythene bags and transported on ice to the laboratory for analysis. These samples were pooled and homogenized. Vegetable samples used for each of the microbial decontamination trials were derived from the same pool of lettuce.

Sample preparation for microbiological analysis

Samples for the common decontamination methods were prepared as follows: Washing in a bowl of water, washing under running cold tap water, in salt (NaCl) solution at the concentration 7 ppm, 23 ppm and 35 ppm; in vinegar solution of 6818 ppm, salt/vinegar solution at 7 ppm/6818 ppm, and potassium permanganate solution at 100 ppm.

Before these treatments were imposed, faecal coliform and helminth egg populations on the vegetable samples were determined using standard methods. Fifty grams of lettuce leaves were asceptically weighed into 1 liter of each washing media and washed immediately (i.e. washing started as soon as lettuces were put in the washing medium) and for a contact time of two minutes in the washing medium before washing began. Washing in both cases lasted for about two minutes. The treated (washed) vegetables were rinsed with sterile tap water before the microbiological analysis.

The effect of concentration, contact time and type of vegetable on the efficacy of vinegar

Vinegar concentration

Different concentrations of vinegar; ranging between 12500 and 33300 ppm were prepared by diluting varying amounts of vinegar (5%) with clean tap water. Concentrations below 12500 ppm which produced up to 1 log reduction[2] or less during initial trials were not included. The pH of each vinegar solution prepared was also measured after which 50 g of lettuce was submerged in 1 litre of each of the solutions for two minutes and washed for additional two minutes. The washed lettuce was then rinsed with cold tap water before analysis. The cut off point of vinegar concentration at which maximum faecal coliform reduction occurred was determined and used in subsequent trials.

Contact time

50 g samples of lettuce were held for different contact times between dipping and 10 min of washing in a vinegar solution with a concentration of 21400 ppm (*cut off point for highest faecal coliform reduction*), rinsed in cold tap water and analysed for faecal coliforms counts. The efficacy of vinegar solution at a lower

[2] One log reduction means that 90% of the microorganisms physically removed or inactivated by a given process. Two log correspond to 99%, three log correspond to 99.9% etc.

concentration of 12500 ppm on faecal coliform contamination of lettuce with increased contact times of 5 and 10 minutes was also tested. Each test was replicated 10 times.

Type of vegetable
The efficacy of vinegar was also tested on cabbage and spring onions at contact times of 5 and 10 minutes using vinegar concentrations of 12500 and 21400 ppm.

The efficacy of other detergents

Using detergent (OMO©)
Lettuce leaves were held in a detergent (OMO©, Nestle, Ghana) solution of concentration 200 ppm for five and 10 minutes before washing and rinsing in clean water. The leaves were then analysed for faecal coliform counts.

Eau de javel, potassium permanganate, and chlorine tablets

Lettuce leaves were washed in 100 ppm of 'eau de javel' (bleach) (SIPRO-CHIM, La Cote D'IVOIRE©), 200 ppm of potassium permanganate (PHARMAQUIC S. A. 06 Cotonou, Benin, USP 24©) and 100 ppm chlorine (tablets) containing sodium dichloroisocyanurate (NaDCC) and sold in Ghana for salad decontamination (Foodsaf© - Hydrachem Ltd. Sussex, England). For potassium permanganate and chlorine tablets, manufacturer's instructions were followed during the solution preparations. Fifty grams of lettuce was held in each solution for 5 and 10 minutes, washed for about two minutes, and rinsed with tap water before analyzing for faecal coliform population.
Raw and washed vegetables were analysed for faecal coliform and helminth eggs.

Microbiological examination of washed vegetables

Samples were analysed quantitatively for faecal coliform and helminth eggs. Coliforms counts were estimated in about 20 g of vegetables (both washed and unwashed), which was weighed into 180 ml of phosphate-buffered saline and rinsed vigorously. Further ten-fold serial dilutions were made and triplicate tubes of MacConkey broth (MERCK, KgaA 64271 Darmstadt, Germany) were inoculated from each dilution and incubated at 44^{o}C for faecal coliforms (FC) for 24–48 h (APHA-AWWA-WEF, 2001). Positive tubes (acid or gas production or both) were selected and the corresponding numbers of faecal coliforms obtained from MPN (Most Probable Number) tables. Helminth eggs were enumerated using the concentration method (Schwartzbrod, 1998[3]).

Data handling and analysis

The data were analysed using SPSS for Windows 10 (SPSS Inc., Chicago. IL, USA). Faecal coliform populations (Most Probable Number [MPN]) were normalized by log transformation before analysis of variance (ANOVA). ANOVA (multiple comparisons) was used to compare faecal coliform levels on different vegetables washed. T tests were also used where appropriate. Results of analysis are quoted at $p < 0.05$ level of significance or $p < 0.01$.

Results

Figure 1 shows faecal coliform level on vegetables from Accra, Kumasi, and Tamale. All vegetables from all cities were faecally contaminated with mean faecal coliform levels exceeding the International Commission on Microbiological Specifications for Foods (ICSMF, 1974) recommended levels. The results revealed that lettuce had significantly higher faecal coliform levels than cabbage and spring onions

[3] This is a modified US-EPA method but same principle (floatation/sedimentation) compared to Ayres and Mara (1996) in that both use similar reagents e.g. $ZnSO_4$ solution (specific gravity, d =1.2), ether or ethyl acetate, detergent solution (e.g. tween), and a buffer solution. The differences between the two methods are: 1) the buffers are different, acetoacetic buffer (Ayres and Mara) and acid/alcohol buffer solution (H_2SO_4 at 0.1 N at 35 % ethanol (Schwartzbrod, 1998); 2) different centrifugation speeds are used and the $ZnSO_4$ solutions are applied at different stages in both methods.

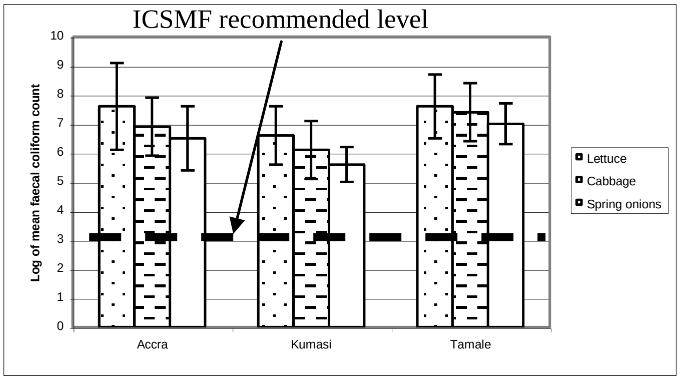

Fig 1 Faecal coliform levels in lettuce, cabbage, and spring onions sold in Accra, Kumasi and Tamale markets.

Methods used for washing vegetable by food vendors and consumers before consumption

There was generally high level (>90%) of awareness of potential health risks from consuming raw vegetables and the corresponding unanimous application of risk mitigation measures, ranging from water to sanitizers in all the cities. The applied risk mitigation strategies varied largely in each city and differed significantly also between the Francophone country group and Ghana. Also, the quantities of disinfectant used per quantity of product or water varied strongly.

In general, 56-90% of the households and 80-100% of the restaurants used some kind disinfectant for washing leafy vegetables to be eaten raw, the other ones used only water. The most common disinfectants used in the Francophone restaurants were bleach (55%) and Potassium Permanganate (31%), followed by salt/lemon or soap (both 7%). In the households, the prevalent method was the use of bleach (50%), followed by Potassium Permanganate (22%), salt (14%), and water only (12%). Every second respondent rinsed the leaves after washing. On the contrary, the use of bleach and potassium permanganate were both practically unknown as food disinfectant in Ghana. There was a clear tendency in the selected Francophone cities that in lower classes more often only water or water with salt, soap, and lemon juice was used, while in middle and upper class households and restaurants, the use of bleach or permanganate appeared to be prevalent

Also in Cotonou and Dakar as examples, 5-12% of the restaurants used only water, 30-35% water and a sanitizer and 53-65% in addition rinsed the leaves after washing. In the corresponding households, 28-42% used only water, 27-33% in addition a disinfectant and 31-40% rinsed finally.

In Ghana, various salt and vinegar solutions are dominantly used besides cleaning in water only (Table 1). Salt is preferred to vinegar for cost reasons (Rheinlaender, 2006).

Table 1 Vegetable washing methods practiced in Accra, Kumasi and Tamale

Vegetable washing method	Accra (N=235)	Kumasi (N=117)	Tamale (N=100)
	Percentage of respondents		
Tap water in a bowl (no sanitizer)	28	18	9
Running tap	0	0	34
Salt solution	40	61	55
Vinegar solution	30	21	2
Potassium permanganate solution	2	0	0

Efficacy of selected washing methods on faecal colifom and helminth egg populations

Common methods used for washing vegetables in the study areas vary among and within cities. Washing vegetables irrespective of the method used reduced FC levels in lettuce. For locally common methods tested, FC population reductions under a contact time of two minutes ranged from 1.4 to 2.2 log units, while reductions of 0.2 to 1.2 log units were observed when vegetables were washed immediately

For all methods tested, significant reductions ($p<0.005$) were recorded at a contact time of two minutes but reductions were significant only at a higher concentration of NaCl solution (35 ppm) when vegetables were washed immediately. Increased salt concentration from 7 ppm to 35 ppm improved its efficacy from 1.4 to 2.1 log units. However, at high concentration (35 ppm), the lettuce leaves became soft, thus reducing its quality. For example, the efficacy of salt and vinegar solutions increased significantly between about 1 to 2 log reduction, when the solutions temperature are increased from 25 ºC to 40 ºC.

All the treatments employed could at least reduce helminth egg population by half. Washing under running tap without any sanitizer could reduce helminth egg contamination level from about 9 (*on unwashed vegetables*) to 1 (*on washed vegetables*) egg $100g^{-1}$ wet weight.

The effect of concentration and contact time on the efficacy of vinegar

Vinegar concentration

Increases in vinegar concentration improved the performance of vinegar in reducing faecal coliform levels by a maximum of about 4.5 log units (Table 2). Maximum reductions occurred at a vinegar concentration of 21400 ppm and beyond. About 99% (R^2) of variations in pH of the vinegar solution can be explained through different vinegar concentrations. Further test revealed that at this concentration (21400 ppm) a contact time of about 20 seconds is adequate to achieve the observed reductions in faecal coliform levels.

Effect of contact time on efficacy of sanitizer (lower concentration of vinegar e.g. 12500 ppm used)

At the low vinegar concentration (12500 ppm), increasing contact time from 2 minutes to 5 or 10 minutes, significantly ($p < 0.05$) increased its efficacy. For example, holding lettuce leaves for 10 minutes at this concentration reduced faecal coliforms populations by about 3.5 log units (Table 2).

Significantly higher faecal coliform reductions (e.g. 1.64 log units in Cabbage and 2.83 log units in spring onions) than achieved for lettuce.

Table 2 Summary of methods used and effects on faecal coliform levels

Method	Use	Contact time	Mean $\log_{10}$ FC levels before and after treatment: Before	95% CI of mean: Lower	95% CI of mean: Upper	After	95% CI of mean: Lower	95% CI of mean: Upper	Log reduction
Cold water	I	3 – 4 sec[1].	5.5	4.9	6.1	4.5	3.8	5.1	1.0
	I	2 min.	6.1	5.2	6.9	4.7	4.0	5.4	1.4
Running tap	I	3-4 sec.	5.5	4.9	6.1	5.2	4.7	5.9	0.3
	I	2 min.	6.1	5.2	6.9	3.9	3.3	4.5	2.2
$NaCl_7$[2]	I	3 – 4 sec.	5.5	4.9	6.1	5.0	4.4	5.7	0.5
$NaCl_{23}$	I		5.5	4.9	6.1	4.7	4.2	5.3	0.8
$NaCl_{35}$	I		5.5	4.9	6.1	4.4	3.8	4.8	1.1
$NaCl_7$	I	2 min.	6.1	5.2	6.9	4.7	4.1	5.2	1.4
$NaCl_{23}$	I		6.1	5.2	6.9	4.6	3.5	5.6	1.5
$NaCl_{35}$	I		6.1	5.2	6.9	4.0	3.2	4.9	2.1
$NaCl_7$ + Vin_{6818}	I	3-4 sec.	5.5	4.9	6.1	5.2	4.3	6.0	0.3
		2 min.	6.1	5.2	6.9	4.7	3.9	5.4	1.4
$Vinegar_{6818}$	I	3-4 sec.	5.5	4.9	6.1	5.3	4.2	5.7	0.2
		2 min.	6.1	5.2	6.9	5.1	3.5	5.6	1.0
$Vinegar_{12500}$	C	5 min.	3.7	3.4	3.8	1.9	-0.3	1.3	1.8
		10 min.	3.7	3.4	3.8	0.0	0.0	0.0	3.6
$Vinegar_{21400}$	C	5 min.	4.7	3.8	5.6	0.0	0.0	0.0	4.7
		10 min	4.7	3.8	5.6	0.0	0.0	0.0	4.7
Removal of outer leaves	C	5 min.	4.3	3.8	4.9	3.8	3.4	4.2	0.5
(Vinegar $_{12500}$)	C	10 min.	4.3	3.8	4.9	3.4	3.0	3.8	0.9

Laundry Omo™	C	5 min	4.3	3.8	4.9	1.7	0.9	2.4	2.6
(Detergent)	C	10 min	4.3	3.8	4.9	1.9	1.1	2.7	2.4
Eau de javel™	I	5 min	6.4	6.3	6.5	4.0	3.7	4.3	2.4
(Bleach:I65µS/cm)	C	10 min	6.4	6.3	6.5	3.5	3.3	3.8	2.9
Thick Bleach™	C	5 min	6.3	5.7	6.9	3.8	3.1	4.4	2.5
(248µS/cm)	C	10 min	6.3	5.7	6.9	3.8	2.7	4.9	2.5
Power Zone™	C	5 min	6.3	5.7	6.9	4.1	3.8	4.6	2.2
(Bleach:223µS/cm)	C	10 min	6.3	5.7	6.9	3.3	3.1	3.4	3.0
KM_{100}	I	3-4 sec	5.5	4.9	6.1	4.8	4.3	5.2	0.7
		2 min	6.1	5.2	6.9	4.9	4.2	5.4	0.6
KM_{200}	C	5 min	6.4	6.3	6.5	4.4	4.2	4.5	1.0
		10 min	6.4	6.3	6.5	3.9	3.8	4.0	2.5
CL $tabs_{100}$	C	5 min	6.4	6.3	6.5	4.1	3.8	4.3	2.3
	C	10 min	6.4	6.3	6.5	3.7	3.3	4.1	2.7

Source: (Amoah et al., 2007 modified)
[1]Contact time of dipping vegetables in the washing solution; [2]subcript represent sanitizer concentration in ppm; I: Commonly used; C: Tested variation; KM: Potassium permanganate ; CL : Chlorine tablets
Note: Washing salad crops, vegetables and fruits with water and weak disinfectant solution and rinsing with clean water reduces pathogens by 1 and 2 log units, respectively

Use of OMO laundry powder

Faecal coliform reductions of about 2.6 and 2.4 log units were obtained when lettuce leaves were kept for 5 and 10 minutes, respectively, in a detergent (OMO™ laundry powder) solution, for 2 minutes and then rinsed with tap water (Table 2). These reductions were both significant (P = 0.001; CI = 1.6892 to 3.5453 and P = 0.001; CI = 1.4452 to 3.3013 for five and ten minutes holding times). The difference in faecal coliform levels between the two holding times were however not significant.

Eau de javel, potassium permanganate and chlorine tablets

Significant (P = 0.001) log reductions were observed between unwashed and all planned treated lettuce. Reductions ranged between 2.03 and 2.87 log units. Although higher log reductions in faecal coliform counts were observed for each treatment, significant difference was observed between treatments with different sanitizers.

Discussion

Several factors may account for the high levels of total and faecal coliform contamination recorded in most of the analysed vegetables. Among these is the use of polluted irrigation water and fresh poultry manure. Both the irrigation water and the manure are applied directly on the crops. Another contamination source is market-related handling especially where provision for better sanitary standards (e.g. clean water for crop washing and 'refreshing') is lacking. Previous studies in Accra show faecal coliform population of irrigation water sources ranging between 4.8×10^3 and 2.8×10^6 100 ml^{-1} (Mensah *et al*., 2001; Keraita *et al.*, 2002) which exceed the WHO recommended level of 1×10^3 100 ml^{-1} for unrestricted irrigation. Drechsel *et al*. (2000) reported that fresh poultry litter samples sometimes used without sufficient drying for vegetable production in Kumasi had equally high faecal coliform counts ranging from 3.6×10^4 to 1.1×10^7.

There was unanimous understanding of the need to wash vegetables and therefore all the people interviewed in the cities used various methods to wash their vegetables before consumption or selling to other consumers. However, unlike the study sites in Ghana where salt solution was the dominant method used for washing vegetables, other sanitizers e.g. bleach (sodium hypochloride, NaOCl; *eau de javel*) and potassium permanganate are the main methods used. The fact that all people washed vegetables before consumption suggests that the food preparation points (e.g. household, restaurants, and hotels) are important points for health risk reduction.

Washing lettuce according to common practices showed that it reduces the bacteria populations irrespective of the method used. The results of helminth egg populations of washed and unwashed lettuce leaves further confirmed the fact that washing with or without disinfectants can significantly reduce worm load on contaminated vegetables. However for eggs it depends more on physical removal than the use of chemicals. Faecal coliform load decreased significantly after washing under running tap for two minutes confirming reports of other writers （Beuchat, 1998; Elorm, 2002). Washing vegetables in a bowl with potable water, then again washing or rinsing in potable water would aide in removing microorganisms. Additional 10-fold to 100-fold reductions can sometimes be achieved by treatment with disinfectants (Beuchat, 1998).

According to Parish *et al.* (2003), the efficacy of the method used to reduce microbial populations is usually dependent upon the type of treatment, type and physiology of the target microorganisms, characteristics of produce surfaces, exposure time and concentration of cleaner/sanitizer, pH, and temperature. Some of these factors (e.g. temperature, concentration, contact or exposure time and pH) accounted for the low faecal coliform reduction levels and are described below.

Generally, the efficacy of all methods tested increased with increasing temperature confirming the sanitizing effect of high temperature. For example, the efficacy of salt and vinegar solutions increased significantly between about 1 to 2 log reduction, when the solutions temperature are increased from 25 ºC to 40 ºC. It should be noted that though increased temperature generally increased sanitizer efficacy, it had a deteriorating effect on lettuce leaves at 40 ºC. This confirms the report that using hot water could adversely affect color and texture of the produce (especially for vegetable likely to be consumed raw) and limit the usefulness of this treatment (Parish *et al*., 2003)

Even though the efficacy of each treatment improved with increased contact time, considerably high levels of faecal coliforms and helminth eggs still remained on the vegetables. This suggests that none of the common methods usually applied in households and kitchens can be relied upon to completely decontaminate wastewater irrigated lettuce. However, their efficacy could be improved significantly if other factors relating like sanitizations are reviewed. Increased contact time in salt (NaCl) solution with concentrations of 23 mgl^{-1} and 35 mgl^{-1} had a considerable deteriorating effect on the lettuce leaves and therefore may not be desirable. At a higher vinegar concentration of 21400 ppm (approximately 1 part vinegar in 2 parts water) the efficacy of the sanitizer completely removed faecal coliform levels in less that one minute. This may be too expensive for the poor households and will have low adoption rate but increasing the contact time at a lower vinegar concentration (approximately 1 part vinegar in 5 parts water) improved its efficacy significantly.

From the above discussions, it is deduced that washing vegetables before consumption is a very important step in the reduction of the potential risks associated with the consumption of contaminated vegetables. However, their efficacy is variable and none are able to ensure total elimination of pathogens. The WHO (2006) has set a health protection level of $\leq 10^{-6}$ DALY (Disability Adjusted Life Years) per person per year. This could be achieved through a faecal coliform reduction of about 6 – 7 log units which is achievable mainly through produce cooking (WHO 2006). Parish *et al.* (2003) reported that there are no known mitigation strategies that will completely remove pathogens after contamination has occurred while maintaining produce freshness. Consequently it is not possible to rely solely on washing and or disinfection with or without sanitizers to control contamination by pathogens. Beuchat (1998) reported that prevention of contamination at all points of the food chain is preferred over the application of disinfectants. It would therefore be expected that combinations of washing and other intervention methods, at various entry points would be appropriate. For example, strict adherence to Good Agricultural Practices (GAPs), Good Handling Practices (GHPs) and other relevant strategies that prevent contamination from occurring. The concept of using multiple intervention methods at various entry points which is analogous to “hurdle technology” or the multiple barrier approach where two or more preservation technologies are used to prevent growth of microorganisms in or on foods (Leistner and Gorris, 1995; Leistner, 2000; Howard and Gonzalez, 2001).

Conclusion

The study revealed that washing vegetables irrespective of the methods used reduces the faecal coliform population levels. Common methods vary widely and are often applied ineffectively because of lack of information or appropriate instructions. None of the common methods used in the household could be relied upon to remove any significant amount of faecal coliforms populations on vegetables. However, the efficacy of these methods could be improved by using the correct sanitizer concentrations and for desirable contact times. The study showed that there is a high potential in Ghana to strengthen health risk reduction efforts through improved vegetable washing before consumption. Consequently there are significant opportunities for food safety campaigns as well as the private sector to support public health. In addition, the adoption of the multiple barrier approach is required where risk reduction strategies are applied at various entry points before the vegetables even reach the kitchen. The results of this study have shown that typical microbiological contamination levels of vegetables in Ghanaian markets pose a threat to human health. This is, however, not feasible as such an effort threatens the livelihood of many. Washing or cooking of food before eating is common in Ghanaian households. This could reduce or eliminate much of the microbiological and pesticide residues if done properly.

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