Biotechnology Advances 28 (2010) 232–254

Contents lists available at ScienceDirect

Biotechnology Advances

journal homepage: www.elsevier.com/locate/biotechadv

Research review paper

An overview of foodborne pathogen detection: In the perspective of biosensors

Vijayalakshmi Velusamy [a], Khalil Arshak [a,*], Olga Korostynska [a], Kamila Oliwa [b], Catherine Adley [b]

[a] Electronic and Computer Engineering Department, University of Limerick, Limerick, Ireland
[b] Microbiology Laboratory, Department of Chemical and Environmental Sciences, University of Limerick, Limerick, Ireland

ARTICLE INFO

Article history:
Received 9 July 2008
Received in revised form 3 December 2009
Accepted 4 December 2009
Available online 16 December 2009

Keywords:
Foodborne pathogen
Conventional methods
Biosensors
Bioreceptors
Optical transducer
Electrochemical transducer

ABSTRACT

Food safety is a global health goal and the foodborne diseases take a major crisis on health. Therefore, detection of microbial pathogens in food is the solution to the prevention and recognition of problems related to health and safety. For this reason, a comprehensive literature survey has been carried out aiming to give an overview in the field of foodborne pathogen detection. Conventional and standard bacterial detection methods such as culture and colony counting methods, immunology-based methods and polymerase chain reaction based methods, may take up to several hours or even a few days to yield an answer. Obviously this is inadequate, and recently many researchers are focusing towards the progress of rapid methods. Although new technologies like biosensors show potential approaches, further research and development is essential before biosensors become a real and reliable choice. New bio-molecular techniques for food pathogen detection are being developed to improve the biosensor characteristics such as sensitivity and selectivity, also which is rapid, reliable, effective and suitable for *in situ* analysis. This paper not only offers an overview in the area of microbial pathogen detection but it also describes the conventional methods, analytical techniques and recent developments in food pathogen detection, identification and quantification, with an emphasis on biosensors.

Contents

* Corresponding author. Tel.: +353 61 20 2267; fax: +353 61 33 8176.
E-mail address: khalil.arshak@ul.ie (K. Arshak).

0734-9750/$ – see front matter © 2009 Elsevier Inc. All rights reserved.
doi:10.1016/j.biotechadv.2009.12.004

1. Introduction

1.1. Food and health legislations

The food industry is the main party concerned with the presence of pathogenic microorganisms, where failure to detect a pathogen may lead to a dreadful effect. Although the safety of food has dramatically improved overall, progress is uneven and foodborne outbreaks from microbial contamination, chemicals and toxins are common in many countries (WHO, 2007b). International trade statistics (2007) by World Trade Organization (WTO) reported that Europe has accounted for 46% of world exports of agricultural products, where food represents 80% of agricultural exports (WTO, 2007). Trading of contaminated food between countries increases the potential for outbreaks and consequently, health risks posed by microbial pathogens in food are of major concern to all governments.

In November 2007, U.S. Food and Drug Administration (FDA) has developed a comprehensive 'Food Protection Plan', in which it has been mentioned that food must be considered as a potential vehicle for intentional contamination (FDA, Food Protection Plan, 2007). Such intentional contamination of food could result in human or animal illnesses and deaths, as well as economic losses.

It has been reported in the EU legislation on microbiological criteria for foodstuffs, that "foodstuffs should not contain microorganisms or their toxins or metabolites in quantities that present an unacceptable risk for human health", as laid down in Regulation (EC) No 2073/2005 (Regulation (EC), 2005). Recently, the World Health Assembly (WHA) established a global surveillance system for public health emergencies of international concern by adopting the International Health Regulations (IHR) on 23 May 2005 which came into force on 15 June 2007 (WHO, 2005).

All these current legislations on food and health provide an intense inspiration into the area of food pathogen detection. Therefore, a comprehensive literature survey has been carried out aiming to give an overview of the field of foodborne pathogen detection. First, some of the outbreaks caused by foodborne pathogens and the main pathogens that cause foodborne diseases are discussed. Next, the main conventional methods in pathogen detection are described, covering their strengths and weaknesses. Then the role of biosensors in the field of foodborne pathogen detection is analysed, comprising all main types. Since, the literature related to foodborne pathogens is vast; this paper reports on recent advances mainly on the detection, identification and quantification of pathogens, with an emphasis on biosensors.

1.2. Emerging foodborne pathogens

The World Health Organization (WHO) defines foodborne illnesses as diseases, usually either infectious or toxic in nature, caused by agents that enter the body through the ingestion of food. Though the global incidence of foodborne disease is difficult to estimate, it has been reported that in 2005 alone 1.8 million people died from diarrhoeal diseases and a great proportion of these cases can be attributed to contamination of food and drinking water (WHO, 2007a). In industrialized countries, the percentage of the population suffering from foodborne diseases each year has been reported to be up to 30%. For, example, the Centers for Disease Control and Prevention (CDC, 2005) estimated that around 76 million cases of foodborne diseases, resulting in 325,000 hospitalizations and 5000 deaths occur each year in the USA.

Some foodborne diseases are well recognized, but are considered emerging because they have recently become more common. Though there are various food borne pathogens that have been identified for food borne illness, *Campylobacter*, *Salmonella*, *Listeria monocytogenes*, and *Escherichia coli* O157:H7 have been generally found to be responsible for majority of food-borne outbreaks (Alocilja and Radke, 2003; Chemburu et al., 2005). For example, in Ireland, *Camplyobacter* is the most important cause of sporadic cases of foodborne illness, with 1815 cases of *Campylobacter* infection reported in 2006 (42.8/100,000 population), which was over four times the number of Salmonellosis cases reported in the same year (FSAI, 2006). Also, most of the earlier and recent food products recalls are also due to these pathogens (Belson and Fahim, 2007). List of pathogenic microorganisms responsible for foodborne illness and outbreaks caused by them are given in Tables 1 and 2 respectively.

There are many methodical programs like good agricultural practices (Kay et al., 2008; Umali-Deininger and Sur, 2007), good manufacturing practices (Mucchetti et al., 2008; Umali-Deininger and Sur, 2007), hazard analysis and critical control point (HACCP) (Jin et al., 2008; Taylor, 2007) and the food code indicating approaches (Piatek and Ramaen, 2001), which can significantly reduce the pathogenic microorganisms in food. But still, the role of pathogen detection technology is vital, which is the key to the prevention and identification of problems related to health and safety. Next, the traditional methods employed for foodborne pathogen detection over the past decades to the recent year will be discussed, by highlighting their strengths and weakness.

2. Various methods towards pathogen detection

Conventional methods for the detection and identification of microbial pathogenic agents mainly rely on specific microbiological and biochemical identification. Conventional methods being used for the detection of pathogens are illustrated in Fig. 1, where the culture and colony counting methods involve counting of bacteria, immunology-based methods involve antigen–antibody interactions and the third polymerase chain reaction (PCR) method which involves DNA analysis. While these methods can be sensitive, inexpensive and give both qualitative and quantitative information of the tested microorganisms, they are greatly restricted by assay time, also initial enrichment is needed in order to detect pathogens which typically occur in low numbers in food.

Table 1
Pathogenic microorganisms responsible for foodborne illness.

Microorganism	Associated foods (reported food contaminants)	Infective dose[a]V (no. of organisms)	Incubation period[b]	Symptoms	Name of the disease	References
Campylobacter jejuni	Raw milk, and raw or under-cooked meat, poultry or shellfish.	400–500	2 to 5 days	Fever, headache, and muscle pain followed by diarrhea, abdominal pain and nausea	Campylobacteriosis	(Bosilevac et al., 2007; Chai et al., 2007; Cole et al., 2006; Dao and Yen, 2006; Esteban et al., 2008; Freitas and Noronha, 2007; Gallay et al., 2008; Gellynck et al., 2008; Ghafir et al., 2007; Gormley et al., 2008; Hussain et al., 2007; Jayarao et al., 2006; Kegode et al., 2008; Kiess et al., 2007; Little et al., 2008c; Melly et al., 2007; Mena et al., 2008; Oermeci and Oezdemir, 2007; Sallam, 2007; Stoyanchev et al., 2007; Sulonen et al., 2007; Unicomb et al., 2008; Vindigni et al., 2007; Whyte et al., 2005; Wong et al., 2007; Workman et al., 2008; Yoda and Uchimura, 2006)
Salmonella spp.	Raw/undercooked eggs, poultry, and meat; raw milk and dairy products; seafood; chocolate; salad and spices	15–20	12 to 24 h	Stomach pain, diarrhea, nausea, chills, fever, and headache	Salmonellosis	(Abadias et al., 2008; Atanassova et al., 2008; Bosilevac et al., 2007; Brandl and Amundson, 2008; Cabedo et al., 2008; Chan and Chan, 2008; Christison et al., 2008; Dao and Yen, 2006; Eglezos et al., 2008; Esteban et al., 2008; Esteves et al., 2008; Gadaga et al., 2008; Kegode et al., 2008; Khaitsa et al., 2007; Knutson et al., 2006; Little et al., 2008c; Mitzscherling and Kuhne, 2008; Pinu et al., 2007; Su et al., 2005a; Urabe et al., 2008; Van et al., 2007; Vasavada, 2004; Vindigni et al., 2007; Vojdani et al., 2008)
E.. coli	Raw/undercooked eggs, poultry, and meat; raw milk and dairy products; seafood; and leafy vegetables	< 10	2 to 4 days	Stomach pain, diarrhea, nausea, chills, fever, and headache	Hemorrhagic colitis	(Abadias et al., 2008; Alexandre and Prado, 2003; Atanassova et al., 2008; Brandl and Amundson, 2008; Christison et al., 2008; Dao and Yen, 2006; Eglezos et al., 2008; Jayarao et al., 2006; Kegode et al., 2008; Kim and Harrison, 2008; Knutson et al., 2006; Little et al., 2008b; Macdonald et al., 1985; Manges et al., 2007; Manning et al., 2008; Najand and Ghanbarpour, 2006; O'Beirne, 2007; Ramaswamy et al., 2008; Sehgal et al., 2008; Valentin-Bon et al., 2008; Vasavada, 2004; Vojdani et al., 2008; Warren et al., 2008)
L. monocytogenes	Soft cheese, raw milk, improperly processed ice cream, raw leafy vegetables; raw meat and poultry	< 1000	2 days to 3 weeks	Fever, chills, headache, backache, sometimes abdominal pain and diarrhea	Listeriosis	(Abadias et al., 2008; Atanassova et al., 2008; Bosilevac et al., 2007; Cabedo et al., 2008; Christison et al., 2008; Esteban et al., 2008; Gounadaki et al., 2008; Jayarao et al., 2006; Kvenberg, 1988; Little et al., 2008a; Little et al., 2008b; Neves et al., 2008; Sireli and Gucukoglu, 2008; Sumner and Ross, 2002; Vasavada, 2004)
Bacillus cereus	Meats, milk, vegetables, fish, rice, pasta, and cheese	> 10^6/g	30 min to 15 h	Diarrhea, abdominal cramps, nausea, and vomiting	Bacillus cereus food poisoning	(Christison et al., 2008; Fricker et al., 2008; Kim et al., 2004; King et al., 2007; Kisla and Uzgun, 2008; Kivaria et al., 2006; Lapidus et al., 2008; Lee et al., 2007; Portnoy et al., 1976; Warminska-Radyko et al., 2007; Yokoyama et al., 1999)

Table 1 (*continued*)

Microorganism	Associated foods (reported food contaminants)	Infective dose[a]V (no. of organisms)	Incubation period[b]	Symptoms	Name of the disease	References
Clostridium botulinum	Improperly canned foods, garlic in oil, and vacuum-packaged and tightly wrapped food	< nano grams	12–36 h	Double vision, droopy eyelids, trouble speaking and swallowing, and difficulty breathing	Foodborne botulism	(Arritt et al., 2007; Bianco et al., 2008; Carlin et al., 2004; Cereser et al., 2008; Dressler, 2005; Gdynia et al., 2007; Kimura et al., 2008; Kissani et al., 2007; Kuplulu et al., 2006; O'Beirne, 2007; Peck, 2006; Ragazani et al., 2008; Shuler et al., 2006; Sumner and Ross, 2002; Wiwanitkit, 2006)
Clostridium perfringens	Undercooked meats, meat products, and gravies	$>10^8$	8–22 h	Abdominal cramps and diarrhea	Perfringens food poisoning	(Esteves et al., 2008; Juneja et al., 2006; Lee et al., 2007; Maslanka et al., 1999)
Shigella	Salads, raw vegetables, dairy products, and poultry	<10	12–50 h	Abdominal pain, cramps, fever, vomiting, and diarrhea containing blood and mucus	Shigellosis	(Agle et al., 2005; Chanachai et al., 2008; Ghosh et al., 2007; Kimura et al., 2006; Pinu et al., 2007; Selma et al., 2007; Warren et al., 2007)
Yersinia enterocolitica	Meat (mostly pork), oysters, fish, and raw milk	Unknown	1–3 days	Diarrhea and/or vomiting; fever and abdominal pain	Yersiniosis	(Arnold et al., 2006; Bhaduri et al., 2005; Fredriksson-Ahomaa et al., 2006; Fredriksson-Ahomaa et al., 2007; Gonc et al., 2007; Grahek-Ogden et al., 2007; Jayarao et al., 2006; Kasalica and Miocinovic, 2004; Selma et al., 2006; Siriken, 2004; Vasavada, 2004; Yucel and Ulusoy, 2006)
Vibrio parahaemolyticus	Raw, improperly cooked, or cooked, recontaminated fish and shellfish, and oysters	> 1 million	4 h–4 days	Diarrhea, abdominal cramps, nausea, vomiting, headache, fever, and chills	*V. parahaemolyticus* associated gastroenteritis	(Chan and Chan, 2008; Cohen et al., 2007; Davis et al., 2007; Gopal et al., 2005; Kudaka et al., 2008; Lhafi and Kuhne, 2007; Mahmud et al., 2007; Mitzscherling and Kuhne, 2008; Normanno et al., 2006; Su et al., 2005a; Sumner and Ross, 2002; Zimmerman et al., 2007)
Vibrio vulnificus	Raw or recontaminated oysters, clams, and crabs	<100	<16 h	Diarrhea, and wound infections	Syndrome called "primary septicemia"	(Colakoglu et al., 2006; Gopal et al., 2005; Jung et al., 2007; Lhafi and Kuhne, 2007; Mitzscherling and Kuhne, 2008; Normanno et al., 2006; Sumner and Ross, 2002; Wong and Liu, 2008)
Hepatitis A virus	Sandwiches, fruits and fruit juices, milk and milk products, vegetables, salads, shellfish, and iced drinks	10–100	Unknown	Fever, malaise, nausea, anorexia, and abdominal discomfort, followed by jaundice	Hepatitis A	(Bialek et al., 2007; Croci et al., 2005; Frank et al., 2007b; Greening, 2006; Hasegawa et al., 2007; Macaluso et al., 2006; Sanchez et al., 2007; Shieh et al., 2007; Sincero et al., 2006; Wheeler et al., 2005)
Norwalk virus/Norovirus	Raw oysters/shellfish, water and ice, salads, and frosting	Unknown but presumed to be low	1–2 days	Nausea, vomiting, diarrhea and abdominal cramps	Viral gastroenteritis, "stomach flu" or "winter vomiting disease"	(David et al., 2007; De Wit et al., 2007; Greening, 2006; Le Guyader et al., 2006; Maekawa et al., 2007; Mitzscherling and Kuhne, 2008; Nenonen et al., 2008; Thongsawad et al., 2007; Webby et al., 2007)

[a] Infective dose: the amount of agent that must be consumed to give rise to symptoms of foodborne illness.
[b] Incubation period: the delay between consumption of a contaminated food and appearance of the first symptoms of illness.

Table 2
Recent foodborne outbreaks caused by pathogenic microorganisms.

Pathogen	No of illness	Consumed food	Place and year of outbreak	Source of the outbreak	Reference
Campylobacter jejuni	33	Cooked chicken	High school in Japan, 2005	Secondary contamination in cooking practice	(Yoda and Uchimura, 2006)
Salmonella spp.	72	Egg, squash and seafood	Funeral service in South Korea, 2007	Infected food handler and/or the contaminated food	(Kim et al., 2007b)
Salmonella spp.	111	Cake	Nursing home in Germany, 2006	High ambient summer temperatures and failure to keep the cake refrigerated	(Frank et al., 2007a)
Salmonella spp.	46	Confectionary (éclairs)	Sports event in Berlin, Germany, 2006	Insufficient cooling of the éclairs during transport and before sale could have enhanced bacterial growth	(Wichmann-Schauer et al., 2006)
Salmonella spp. and *Shigella*	103	Mixed rice and chicken dish	School in Bangkok, and Thailand, 2005	Mixed contamination	(Chanachai et al., 2008)
Salmonella spp.	56	Pre-processed raw beef	Netherlands, 2005	Imported contaminated beef	(Kivi et al., 2007)
Salmonella spp.	21	Rucola lettuce	Norway, 2004	Imported rucola lettuce	(Nygard et al., 2008)
Salmonella spp.	98	Chicken with harusame (bean-jelly)	A nursery school in Kitakyushu City, Japan, 2004	Infected raw eggs contaminated the food through the food handlers hands and cooking utensils	(Tokuzaki and Takahashi, 2007)
Salmonella spp.	125	Cheese, lettuce and roma tomatoes	Restaurant in north-eastern United States, 2004	Contaminated roma tomatoes	(Gupta et al., 2007)
Salmonella spp.	1435 cases and 117 hospitalizations	Hard pastry with vanilla cream	During a festival in Catalonia, Spain, 2002	Inadequate handling of foods containing eggs	(Camps et al., 2005)
E. coli O157:H7	30	Hamburger patties	USA, 2007	Contaminated beef patties distributed by the meat processing plant	(Belson and Fahim, 2007)
E. coli O103 : H25	17cases and one death	Cured mutton sausage	Norway, 2006	Contaminated mutton	(Schimmer et al., 2008)
L. monocytogenes	54 cases; 8 deaths, and 3 fetal deaths	Turkey deli meat	USA, 2002	Contaminated turkey distributed by turkey processing plant	(Gottlieb et al., 2006)
L. monocytogenes	86	Cheese	Japan, 2001	Contaminated cheese products distributed by the cheese producing plant	(Makino et al., 2005)
Norovirus	26 confirmed and 53 clinical cases	Raw oysters	British Columbia, Canada, 2004	Not specified	(David et al., 2007)
Hepatitis A	601cases and 3 deaths	Green onions	Restaurant in Pennsylvania, USA, 2003	Contaminated green onions distributed to the restaurant	(Wheeler et al., 2005)
Norwalk-like viruses	130	Salad sandwiches	Farewell party in the nurses' hostel of a civil hospital in Delhi, India, 2002	Not specified	(Girish et al., 2002)

2.1. Culture and colony based methods

Conventional culture methods remain the most reliable and accurate techniques for food-borne pathogen detection. Although the culture based methods are found to be standard microbiological techniques to detect the single bacteria, amplification of the signal is required through growth of a single cell into a colony. Culture methods have been used for detection of *L. monocytogenes* (Artault et al., 2001; DeBoer and Beumer, 1999; Stephan et al., 2003), *S. aureus*, *Salmonella*, *Coliforms*, *E. coli*, etc. (Ayçiçek et al., 2004), *Campylobacter jejuni* (Sanders et al., 2007) and *Yersinia enterocolitica* (Weagant, Feb 2008) etc. Some standard methods for the detection of *L. monocytogenes* can require up to 7 days to yield results, as they rely on the ability of microorganisms to multiply to visible colonies (Artault et al., 2001; DeBoer and Beumer, 1999). In addition, viable bacterial strains in the environment can enter a dormancy state where they become non-culturable (viable-but non-culturable (VBNC)) which can subsequently lead to an underestimation of pathogen numbers or a failure to isolate a pathogen from a contaminated sample (Porter et al., 1995; Toze, 1999; Xu et al., 1982). Detection of *L. monocytogenes* performed in a two-step cultural enrichment process took on average one week until the biochemical identification of the *L. monocytogenes* suspicious colony is completed (Stephan et al., 2003). The ALOA® method (AES Laboratoire), which uses a chromogenic medium in conjunction with a *Listeria* monodisk for the detection of *L. monocytogenes*, can reduce detection time down to 3 days (Artault et al., 2001). It has been reported that to detect *Campylobacter*, 4–9 days are needed to obtain a negative result and between 14 and 16 days for confirmation of a positive result (Brooks et al., 2004).

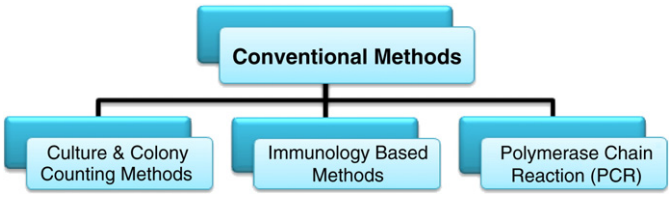

Fig. 1. Different conventional methods employed for pathogen detection.

The major drawbacks of microbiological methods are their labour-intensiveness and are time-consuming as it takes 2–3 days for initial results, and up to 7–10 days for confirmation. This is an obvious inconvenience in many industrial applications, particularly in the field of foods sector. In spite of their disadvantages, conventional culture methods still represent a field where progress is possible. These methods are often combined together with other pathogen detection methods like an automated or semi-automated DNA, antibody, or biochemical-based method to yield more robust results. Examples include the Vermicon identification technology (VIT®) a rapid commercial test system compared to a cultural standard method for *Listeria* (Stephan et al., 2003); Comparison of ELISA and PCR vis-a-vis cultural methods for detecting *Aeromonas* spp. (Arora et al., 2006). The detection of *Salmonella* spp. (Lofstrom et al., 2004; Murphy et al.,

2007), *L. monocytogenes* (Murphy et al., 2007) and *Campylobacters* (Josefsen et al., 2004; Magistrado et al., 2001) by PCR after culture enrichment has been reported. Also, culture and BAX PCR-based detection for *Listeria* spp. (Shearer et al., 2001) and *L. monocytogenes* (Hoffman and Wiedmann, 2001; Shearer et al., 2001) *Salmonella enteritidis* (Shearer et al., 2001), *E. coli* O157: H7 (Shearer et al., 2001) have been reported.

2.2. Immunology-based methods

Immunological detection with antibodies is perhaps the only technology that has been successfully employed for the detection of bacterial cells, spores, viruses and toxins alike (Iqbal et al., 2000). Methods based on antigen–antibody bindings are widely used for determining food-borne pathogens. Immunology-based methods has been used for the detection of *Escherichia coli* (Abdel-Hamid et al., 1999b; Aldus et al., 2003; Chen and Durst, 2006; Gehring et al., 2006; Magliulo et al., 2007; Sunwoo et al., 2006), *Salmonella* (Abdel-Hamid et al., 1999b; Chen and Durst, 2006; Magliulo et al., 2007; Schneid et al., 2006; Valdivieso-Garcia et al., 2003), *L. monocytogenes* (Chen and Durst, 2006; Churchill et al., 2006; Gangar et al., 2000; Hibi et al., 2006; Hudson et al., 2001; Jung et al., 2003; Magliulo et al., 2007; Sewell et al., 2003; Yu et al., 2004b), *Staphylococcal enterotoxins* (Bennett, 2005; Jechorek and Johnson, 2008; Rasooly and Rasooly, 1998; Schlosser et al., 2007), *Campylobacter* spp. (Borck et al., 2002; Che et al., 2001; Hochel et al., 2007; Siragusa et al., 2001). In order to ensure the reliable detection of foodborne pathogens using antibody-based methods, the influence of stress on antibody reactions should be thoroughly examined and understood first as the physiological activities in cells are often altered in response to a stress (Hahm and Bhunia, 2006).

The number of antibody types and formats are available for immunodetection. These include conventional and heavy chain antibodies, as well as polyclonal, monoclonal or recombinant antibodies. Polyclonal antibodies can be raised quickly and cost effectively associated with the production of monoclonal antibodies (Cahill et al., 1995) and it has been used as detection vehicles for several decades (Breitling and Dübel, 1999). Polyclonal antibodies are able to detect *L. monocytogenes* (Feldsine et al., 1997a; Jung et al., 2003), *Campylobacter* species (Hochel et al., 2007), *Fusarium* sp. — a primary corn pathogen (Meirelles et al., 2006). However, polyclonal antibodies are limited both in terms of their specificity and abundance (Leonard et al., 2003). Since the progress of hybridoma techniques (Kohler and Milstein, 1975) and the emergence of recombinant antibody phage display technology, developed during the past decade, immunological detection of microbial contamination has become more sensitive, specific, reproducible and reliable with many commercial immunoassays available for the detection of a wide variety of microbes and their products (Leonard et al., 2003).

Monoclonal antibodies are often more useful for specific detection of a molecule than polyclonal antibodies because they provide an indefinite supply of single antibody. Monoclonal antibodies are used to detect wide range of pathogens in food. Examples are *L. monocytogenes* [14, 32–36], and *Listeria* innocua (Solve et al., 2000), *Escherichia coli* O157 (Zhao and Liu, 2005), *Salmonella enterica* (Schneid et al., 2005), *Salmonella typhi* (Kumar et al., 2003), *Staphylococcus aureus enterotoxins* (Deckenback et al., 2002), *Shigella* (Warren et al., 2006), *zearalenone* — a worldwide occurring pathogen in cereal grains (Kawamura and Emoto, 2006) etc. An immunochromatography (ICG) strip test based on a monoclonal antibody for the detection of *L. monocytogenes* showed results within 20 min without complicated steps (Shim et al., 2007). In spite of their number of advantages over polyclonal antibodies, the monoclonal antibodies have few disadvantages as well. The problems with monoclonal antibodies are, there is a need for a skilled technician and specialized growth apparatus for tissue culturing, and also expensive to produce. But recombinant antibodies fill this void since they can be produced in reasonable quantities in short periods of time from bacterial expression systems.

While the immunological-based detection is not much specific and sensitive than nucleic acid-based detection, but it is faster, more robust and has the ability to detect not only contaminating organisms but also their biotoxins that may not be expressed in the organism's genome (Iqbal et al., 2000). Examples of immunological techniques include the enzyme immunoassay (EIA) (Borck et al., 2002), enzyme-linked immunosorbent assay (ELISA) (Bennett, 2005; Beumer and Brinkman, 1989; Mattingly et al., 1988; Palumbo et al., 2003), flow injection immuno-assay (Abdel-Hamid et al., 1999b), enzyme-linked fluorescent assay (ELFA) [11, 13], bioluminescent enzyme immunoassay (BEIA) (Valdivieso-Garcia et al., 2003), enzyme-linked immunomagnetic chemiluminescence (ELIMCL) (Gehring et al., 2006) immunochromatography (ICG) strip test (Shim et al., 2007), immunomagnetic separation (Dickson and Chen, 2001; Hudson et al., 2001; Refseth et al., 2001), immuno-precipitation assay (Feldsine et al., 1997b), agglutination test (Matar et al., 1997), radio-immunoassays (RIA), western blot test (Rasooly and Rasooly, 1998) and technically modified western blot include the line immunoassay (LIA) and the recombinant immunoblot assay (RIBA).

In spite of their very less assay time compared to traditional culture techniques, antibody-based detection is still lacking the ability to detect microorganisms in “real-time”. In addition, if quantities of the pathogen are high enough then immunoassays can be used to provide real-time information. But the problems that may arise with immunoassay-based methods are the low sensitivity of the assays, low affinity of the antibody to the pathogen or other analyte being measured, and potential interference from contaminants (Meng and Doyle, 2002). Immunology-based methods found coupled with other methods for pathogen detection, like immunomagnetic separation on magnetic beads is coupled with matrix-assisted laser desorption ionization-time of flight mass spectrometry for detection of staphylococcal enterotoxin B (Schlosser et al., 2007), combination of immunomagnetic separation with flow cytometry for detection of *L. monocytogenes* (Hibi et al., 2006; Jung et al., 2003).

2.3. Polymerase chain reaction (PCR)

Techniques to detect a single bacterium were realized almost 20 years ago with the invention of the polymerase chain reaction (PCR). This method can detect a single copy of a target DNA sequence, and thus, can be used to detect a single pathogenic bacterium in food. It is promising because it detects the organism by amplifying the target rather than the signal, and is therefore less prone to producing false-positives. A target DNA can be amplified 1-million-fold in less than an hour, with sensitivities in theory down to a single target pathogen (A.Batt, 2007). So PCR is a very widely used detection method for the pathogens in food, forming the basis for detection systems utilizing nucleic acid. Also it can be used to enhance the sensitivity of nucleic acid-based assays.

PCR has distinct advantages over culture and other standard methods for the detection of microbial pathogens and offers the advantages of specificity, sensitivity, rapidity, accuracy and capacity to detect small amounts of target nucleic acid in a sample (Toze, 1999). Recently it was reported that PCR assay was found to be the most sensitive in the detection of *Salmonella* in seafood when compared to culture, ELISA methods (Kumar et al., 2008). Lower detection rate with culture and ELISA assays could be attributed to greater sensitivity of the PCR method. Also when testing food samples, false negative PCR results can occur and may be due to interference with target-cell lysis necessary for nucleic acid extraction, nucleic acid degradation and/or direct inhibition of the PCR. Therefore, it is essential to include appropriate controls for the application of PCR to the detection of pathogens in food samples (Murphy et al., 2007).

PCR based methods are used in the detection wide range of pathogens like *S. aureus* (Kim et al., 2007a; Riyaz-Ul-Hassan et al., 2008), *L. monocytogenes* (Chen and Knabel, 2007; Kim et al., 2007a; Murphy et al., 2007; O'Grady et al., 2008; Oravcova et al., 2007; Perry et al., 2007), *Salmonella* (Choi and Lee, 2004; Kim et al., 2007a; Malorny et al., 2007; Murphy et al., 2007; Perry et al., 2007; Stark and Made, 2007), *Bacillus cereus* (Messelhausser et al., 2007; Perry et al., 2007), *Escherichia coli* O157: H7 [54, 58], *Yersinia enterocolitica* (Perry et al., 2007), *C. jejuni* (Ronner and Lindmark, 2007). The different PCR based methods used to detect pathogens are real-time PCR (Desai et al., 2008; Malorny et al., 2008; O'Grady et al., 2008; Ronner and Lindmark, 2007), multiplex PCR [54, 57, 66] and reverse transcriptase PCR (RT-PCR) (Choi and Lee, 2004). RT-PCR also is found as multiplex RT-PCR (Loisy et al., 2005; Nordstrom et al., 2007; Wolf et al., 2007) and real-time RT-PCR (Casas et al., 2007; Dubois et al., 2007; Loisy et al., 2005).

Compared to other PCR based methods, multiplex PCR is very useful as it allows the simultaneous detection of several by introducing different primers to amplify DNA regions coding for specific genes of each bacterial strain targeted (Touron et al., 2005). Examples of multiplex PCR technique for the simultaneous detection pathogens include multiplex PCR assay for rapid and simultaneous detection of *E. coli* O157:H7, *Salmonella, S. aureus*, *L. monocytogenes*, and *Vibrio parahaemolyticus* (Kim et al., 2007a), simultaneous detection of bacteria of the genus *Listeria*, *L. monocytogenes*, and major serotypes and epidemic clones of *L. monocytogenes* (Chen and Knabel, 2007) and the simultaneous detection of *E. coli* O157: H7 and *L. monocytogenes* (Mukhopadhyay and Mukhopadhyay, 2007). In recent years real-time PCR based technologies have emerged as a leading technology for rapid identification of pathogens due to their speed and high degree of sensitivity and specificity, also it permits to obtain quicker results without too much manipulation. But one of the main limitations of the above mentioned PCR techniques is that, the users cannot distinguish between viable and non-viable cells, since DNA is always present whether the cell is dead or alive. But this limitation can be overcome by using Reverse Transcriptase PCR (RT-PCR).

Yaron and Matthews (2002) developed an RT-PCR to detect only viable cells of *E. coli* O157:H7. Also they suggested that, if RT-PCR is to be used for detection of live cells in a sample without enrichment, then 10^7 colony-forming units (CFU) of the target organism are required. It was stated (Casas et al., 2007), that real-time RT-PCR yielded higher detection sensitivity than that obtained by conventional RT-nested PCR. Real-time RT-PCR detection eliminates some purification and concentration steps that are required for conventional RT-nested PCR detection. Other than RT-PCR, application of bacteriophages is found to be an alternative technique to detect viable cells (Hagens and Loessner, 2007; Loessner, 2005). The phages or phage-derived proteins not only be used to detect the presence of unwanted pathogens in food or the production environments but also allows quick and specific identification of viable cells.

PCR is also being found coupled to other techniques. Examples are a combination of immunofluorescent microscopy and a nested PCR (Moore et al., 2007), PCR — enzyme-linked immunosorbent assay (Gillespie et al., 2003), a combination of immunomagnetic separation with the reverse transcription multiplex TaqMan PCR system (Tsai et al., 2006) etc. In spite of its advantages, from an industrial point of view routine detection of microbes using PCR can be expensive and complicated, requiring skilled workers to carry out the tests. Other reported analytical methods of pathogen detection include, application of bacteriophages for detection and control of foodborne pathogens (Hagens and Loessner, 2007; Loessner, 2005), DNA oligonucleotide arrays (Quinones et al., 2007), in which specific identification of pathogens was achieved without the need for a PCR amplification.

Since all the traditional methods to detect foodborne pathogens are often time-consuming, there is a need for new technology that is rapid, reliable, simple, specific and sensitive. In addition, it should be able for *in situ* real-time monitoring at a low cost. In recent years, there has been much research activity in the area of biosensor development for detecting pathogenic microorganisms.

Next, an overview of recent efforts using biosensors in the field of food pathogen detection will be given. This overview aims to give a broad picture of the different existing technologies, effective methodologies and recent developments of biosensors in microbial pathogen detection.

3. Biosensors in foodborne pathogen detection

3.1. Introduction to biosensors

A biosensor is an analytical device, which converts a biological response into an electrical signal. It consists of two main components: a bioreceptor or biorecognition element, which recognizes the target analyte and a transducer, for converting the recognition event into a measurable electrical signal. A bioreceptor can be a tissue, microorganism, organelle, cell, enzyme, antibody, nucleic acid and biomimic etc. and the transduction may be optical, electrochemical, thermometric, piezoelectric, magnetic and micromechanical or combinations of one or more of the above techniques.

Fig. 2 shows schematic diagram of a biosensor. The bioreceptor recognizes the target analyte and the corresponding biological responses are then converted into equivalent electrical signals by the transducer. The amplifier in the biosensor responds to the small input signal from the transducer and delivers a large output signal that contains the essential waveform features of an input signal. The amplified signal is then processed by the signal processor where it can later be stored, displayed and analysed. Biosensors have been widely applied to a variety of analytical problems in medicine, the environment, food, process industries, security and defence.

3.2. Classifications of biosensor

Biosensors can be classified by their bioreceptor or their transducer type. Fig. 3 shows the biosensor classifications.

4. Bioreceptors

Bioreceptors or the biological recognition elements are the key to specificity for biosensor technologies. A bioreceptor is a molecular species that utilizes a biochemical mechanism for recognition. They

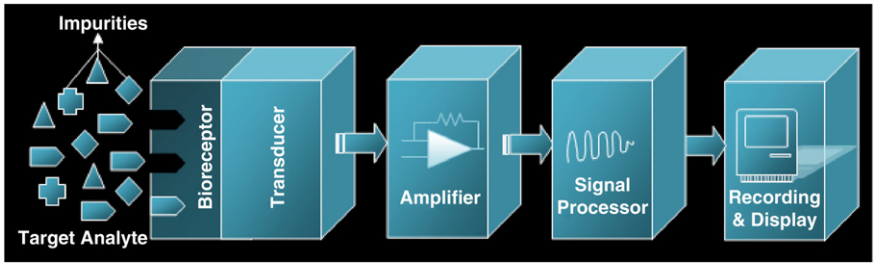

Fig. 2. Schematic diagram of a biosensor.

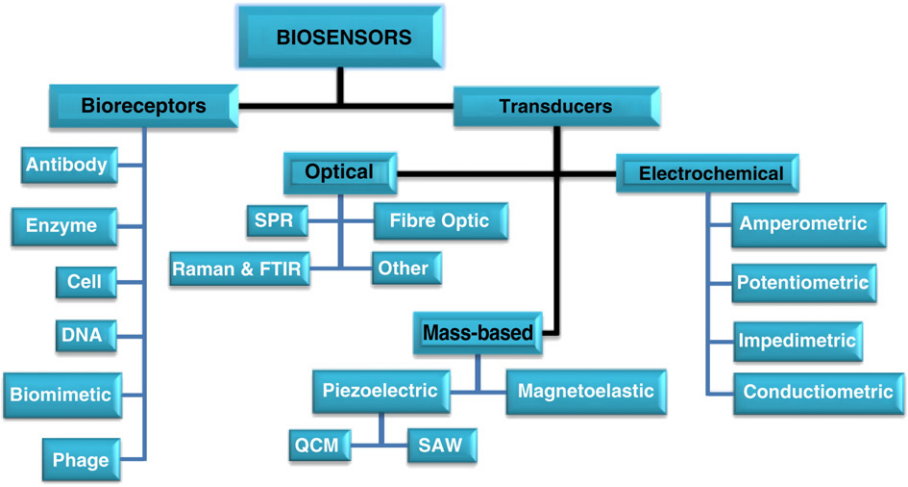

Fig. 3. Classifications of biosensor.

are responsible for binding the analyte of interest to the sensor for the measurement.

Bioreceptors can generally be classified into five different major categories. These categories include antibody/antigen, enzymes, nucleic acids/DNA, cellular structures/cells, biomimetic and bacteriophage (phage). The enzymes, antibodies and nucleic acids are the main classes of bioreceptors which are widely used in biosensor applications. Though the enzymes are one of the biorecognition elements, they are mostly used to function as labels than the actual bioreceptor.

The enzymes, antibodies and nucleic acids are the main classes of bioreceptors which are widely used in biosensor applications. Though the enzymes are one of the biorecognition elements, they are mostly used to function as labels than the actual bioreceptor.

4.1. Antibody bioreceptors

Antibodies are common bioreceptors used in biosensors. Antibodies may be polyclonal, monoclonal or recombinant, depending on their selective properties and the way they are synthesized. In any case, they are generally immobilized on a substrate, which can be the detector surface, its vicinity, or a carrier (Lazcka et al., 2007).

The way in which an antigen and an antigen-specific antibody interact is similar to a lock and key fit (Vo-Dinh and Cullum, 2000). An antigen-specific antibody fits its unique antigen in a highly specific manner, so that the three-dimensional structures of antigen and antibody molecules are matching. Due to this three-dimensional shape fitting, and the diversity inherent in individual antibody make-up, it is possible to find an antibody that can recognize and bind to any one of a large variety of molecular shapes. This unique property of antibodies is the key that makes the immunosensors a powerful analytical tool and their ability to recognize molecular structures allows one to develop antibodies that bind specifically to chemicals, biomolecules, microorganisms, etc. One can then use such antibodies as specific probes to recognize and bind to an analyte of interest that is present, even in extremely small amounts, within a large number of other chemical substances. The basic structure of an antibody and antigen–antibody lock and key fit is illustrated in Fig. 4.

Antibodies can be covalently modified in many ways to suit the purpose of a particular assay. Many immunological methods involve the use of labeled antibodies. Enzymes, biotin, fluorophores and radioactive isotopes are commonly used labels to provide a detection signal in biological assays. Covalently attaching such a label to an antibody combines the unique specificity of the antibody with a sensitive means for detection, thus creating an ideal probe molecule.

The antibodies can be labeled in two different ways. First, the *direct method* is a one-step method in which a labeled antibody directly reacts with the antigen of interest. This direct detection method was first introduced in the 1940s by Coons et al. when they labeled antibodies with a fluorescent tag to mark tissue antigens (Coons et al., 1942).

Second, the *indirect method* is a two-step method in which an unlabeled primary antibody (first layer) reacts with the antigen, and a labeled secondary antibody (second layer) which reacts with the primary antibody. The second layer antibody is mostly labeled with a fluorescent dye or an enzyme. This indirect detection was first described by Weller and Coons (1954) and is still a popular method. The advantages and disadvantages of direct and indirect labeling methods are given in Table 3.

Few examples of biosensors fabricated using antibodies as the sensing element for the detection foodborne pathogens includes, surface plasmon resonance (SPR) (Taylor et al., 2006; Waswa et al., 2007), evanescent wave fiber-optic biosensors (Lim, 2003), nanowire labeled direct-charge transfer biosensor (Pal et al., 2007), self-excited PZT-glass microcantilevers (Campbell and Mutharasan, 2005), magnetoelastic resonance sensors (Guntupalli et al., 2007) and immunosensors (Tokarskyy and Marshall, 2008).

4.2. Enzyme bioreceptors

Biosensors that make use of enzymes as the biorecognition elements are a well developed and widely studied area. Enzymes are chosen based on their specific binding capability and their catalytic activity and the chosen enzyme with a suitable substrate should provide sufficient electron transfer to the working electrode (Vo-Dinh and Cullum, 2000). Almost all enzymes are proteins with an exception of a few ribonucleoprotien enzymes, in which the catalytic activity is in the RNA rather than the protein part. In the field of pathogen detection, using enzymes as bioreceptors not only provides biosensors with a high degree of specificity, but their catalytic activity can amplify the pathogenic bacteria being detected and measured, allowing for sensitive analyses. In most of the cases enzymes are used to function as labels than the actual bioreceptor. Owing to the improvements in enzyme-labeling methods during the past decades, enzyme-labeled antigens and antibodies have been increasingly used.

The use of enzymes as labels has gained more popularity in immunoassay detection than other labeling methods such as radioisotope and fluorescent tag. Enzymes offer the advantages of high sensitivity, possibility of direct visualization and are stable for years. But there are some disadvantages found when using enzymes as labels, which include multiple assay steps and the possibility of

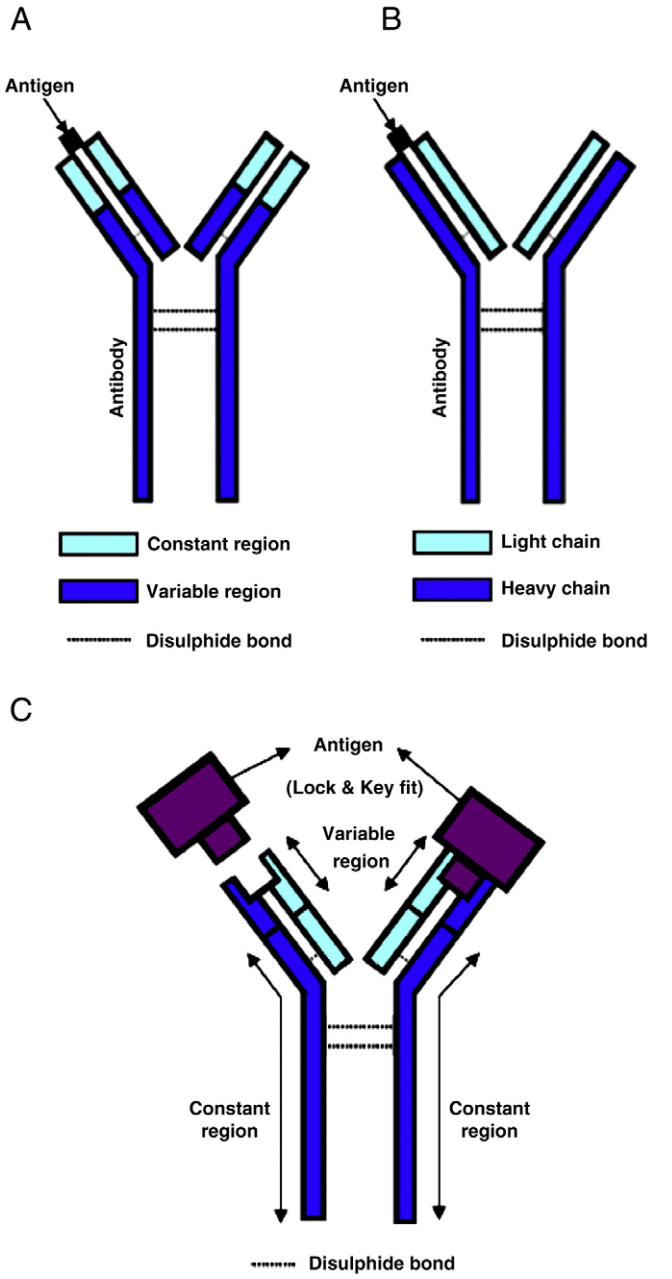

Fig. 4. (A) and (B): The basic structure of an antibody. (C): Antigen–antibody lock and key fit.

interference from endogenous enzymes. Using enzymes as labels offers several advantages over fluorescently labeled and radiolabeled substances. Enzyme immunoassay reagents are more stable, sensitive and there are no health hazards. Example, disposal of waste associated with radioisotopic labels. Many enzyme detection methods are visual, eliminating the need for expensive, complicated equipment. Antibodies/antibody fragments labeled to small enzymes can readily pass through cell membranes and by using light microscope it is then possible to localize and observe cellular antigens to tissue structures. Also, the tissue sections that have been developed with the appropriate substrate can be stable for years.

Whereas, in most immunofluorescent staining techniques, the fluorescent signal rapidly decreases due to exposure to light. There are three enzymes generally used with ELISA's. The earliest was alkaline phosphatase and the most commonly used now is horseradish peroxidase (HRP) and the third is beta-galactosidase. Many papers have been reported since the past 20 years, where immunosensor

Table 3
Comparison of direct and indirect antibody labeling methods.

Method	Advantages	Disadvantages
Direct	1. Simple and rapid method since only one antibody is used.	1. Immunoreactivity of the primary antibody may be reduced as a result of labeling.
	2. There is no cross-reaction since secondary antibody is eliminated.	2. Time-consuming and expensive since each and every primary antibody is to be labeled.
		3. Less sensitive and hence very small signal amplification.
Indirect	1. Immunoreactivity of the primary antibody is not affected.	1. Cross-reactivity may occur with the secondary antibody which results in nonspecific signal.
	2. Greater sensitivity allowing for signal amplification.	2. Procedure involves extra steps than the direct method.
	3. A wide variety of labeled secondary antibodies are available commercially.	

systems used enzymes as labels, for the detection of pathogens in food. For example, a report discussing the applications of highly dispersed carbon particles which utilized sandwich immunoassay format used horseradish peroxidase (HRP) enzyme to label the antibody for the detection of pathogenic bacteria's such as *L. monocytogenes*, *E. coli* and *C. jejuni* (Chemburu et al., 2005).

4.3. Nucleic acid bioreceptors

Recent advances in nucleic acid recognition have enhanced the power of DNA (deoxyribonucleic acid) biosensors and biochips. In the case of nucleic acid bioreceptors for pathogen detection, the identification of a target analyte's nucleic acid is achieved by matching the complementary base pairs that are often the genetic components of an organism. Since each organism has unique DNA sequences, any self-replicating microorganism can be easily identified. Biosensors based on nucleic acid as biorecognition element are simple, rapid, and inexpensive and hence it is widely used in pathogen detection. In contrast to enzyme or antibodies bioreceptors, nucleic acid recognition layers can be readily synthesized and regenerated. DNA damage is one of the most important factors to be considered when nucleic acid bioreceptor are used. Hundreds of compounds bind and interact with DNA. Detection of fcchemicals may cause irreversible damage to DNA by changing the structure of DNA and the base sequence, which in turn disturbs the DNA replication. Due to their wide range of physical, chemical and biological activities, nucleic acid based biosensors have been reported by many researchers for the detection of food pathogen like *E. coli* O157:H7 (Chen et al., 2008), *Salmonella* spp. (Lermo et al., 2007), *Cumpylohacter jejuni* (Uyttendaele et al., 1997) etc. DNA hybridization microarrays have been suggested as a platform for the parallel detection of multiple pathogenic microorganisms in food in a relatively short time.

DNA microarray techniques have been reported for the simultaneous detection of food-borne pathogens including *Listeria* spp., *Campylobacter* spp., *S. aureus* enterotoxin genes and *Clostridium perfringens* toxin genes and their virulence factors (Sergeev et al., 2004). Using single-stranded nucleic acid aptamer, Kim invented a rapid method for specific identification and quantification of food-borne pathogens (Kim, 2007). The single-stranded nucleic acid aptamer specifically binding to a food-borne pathogen had a nucleotide selected sequence wherein the food-borne pathogens were *E. coli*, *Salmonella* spp., *Listeria* spp. and *Staphylococcus* spp.

Recent advances in nucleic acid recognition, like the introduction of peptide nucleic acid (PNA) has opened up exciting opportunities for DNA biosensors. PNA is a synthesized DNA in which the sugar–phosphate backbone is replaced with a pseudopeptide. PNA as a probe molecule has several advantages like superior hybridization characteristics, detection

of single-base mismatches and improved chemical and enzymatic stability relative to nucleic acids. In addition, its different molecular structure enables new modes of label-free detection contributing significantly towards the establishment of rapid, stable and more reliable analytical processes. PNA based nucleic acid recognition have been reported by many researchers (Briones et al., 2004; Fan et al., 2007; Li et al., 2001; Mateo-Marti et al., 2007; Sawata et al., 1999; Steichen et al., 2007). PNA sensing can be utilized to detect desired pathogens with high stability and increased affinity for target sequences. But the main drawback of PNA is that synthesis is very expensive. The other disadvantages of PNAs are also becoming evident. For example, long PNA oligomers, depending on their sequence, are prone to aggregation, difficult to purify and difficult to characterize. In addition, purine-rich PNA oligomers tend to aggregate and are poorly soluble in aqueous media (Gall et al., 2003).

4.4. Cellular bioreceptors

In cellular structures/cells based bioreceptors biorecognition is either based on whole cell/microorganism or a specific cellular component that is capable of specific binding to certain species. The cellular systems, enzymes and non-enzymatic proteins are the three major sub-classes of this category. Since the biosensors based on enzyme bioreceptors have been discussed previously on their own classification, biorecognition based on the other two sub-classes are presented here.

4.4.1. (i) Cellular systems

The ability of cells to recognize and respond to stimuli has made them attractive components for incorporation into biosensors (Pancrazio et al., 1999). In cell-based biosensors (CBB), a whole cell serves as the molecular recognition element and requires two transduction phases. The cells serve as the primary transducer, converting the detected analyte into a cellular response. A second transducer is required to convert the cellular signal into an electronic signal that can be processed and analyzed. The second transduction is dependent on the type of cellular signal to be monitored. There are many reasons why living cells are well-suited for recognition. First, cells provide sensitivity to a wide range of biochemical stimuli since they contain many highly evolved biochemical pathways. Secondly, cells provide a functional assay for biochemical agents. Because CBB make use of direct measurements of physiologic function (and changes induced by toxins), they provide detection capability for previously unknown agents as well. The third major advantage associated with cells as bioreceptors for incorporation into biosensors, is that the detection limits can be very low, because of signal amplification. The above properties distinguish CBB from molecular biosensors that rely on the detection of molecular events such as antibody binding, DNA hybridization, or enzymatic reactions.

Though the CBB were reported by many researchers for the identification and quantification of the pathogenicity induced by various foodborne pathogens, they have some major difficulties as well. Because, the cells need a specific environment to function normally and also, as they are subject to biological variability, the cells duplicate which leads to the reproducibility of sensor responses. Moreover, their self-life is very short and preservation is not easy. In addition to the above disadvantages, it is difficult to classify the type of agent based on functional activity of the cells, because multiple biochemical pathways can lead to the same cellular response. However, due to the development of genetically-engineered cell-based biosensor (GECBB) this has been overcome.

A new approach using a GECBB for functional classification of agents was described by Alexander (Aravanis et al., 2001). The GECBB operates by examining for an agent's ability to differentially activate two populations of cells, wild-type (WT) cells and cells genetically engineered to lack a specific receptor, knockout (KO) cells. Any biological agent that targets the knocked out receptor will evoke a response in the WT but not in the KO. Thus, the GECBB is exquisitely sensitive to agents that affect the engineered pathway. This approach provides the benefits of an assay for specific functional activity while simplifying signal analysis. The use of GECBB for pathogen identification was reported by many researchers. Rider et al. (2003) demonstrated the use of genetically engineered B lymphocyte cells for a rapid identification of pathogens at very low levels. This sensor used B lymphocytes that have been engineered to emit light within seconds of exposure to specific bacteria and viruses. Because of its speed, sensitivity, and specificity, they suggested that this pathogen identification technology proves to be useful for food quality monitoring and other applications as well.

Biosensors incorporating mammalian cells to detect foodborne pathogens are drawing increasing interest because they respond in a manner that can offer insight into the physiological effect of an analyte. In addition, this type of cell-based biosensor has the unique potential of distinguishing between viable and nonviable bacterial cells, which is a critical determination for the food industry since nonviable bacterial cells in foods themselves are not considered to be potential threats (Bhunia et al., 2007). Recently, the first example of a cell-based sensing system using collagen-encapsulated mammalian cells for rapid detection of pathogenic bacteria or toxin was presented by Banerjee et al. (2008). A multi-well plate-based biosensor containing B-cell hybridoma, Ped-2E9, encapsulated in type I collagen matrix, was demonstrated for the rapid detection of viable cells of foodborne pathogens like *Listeria,* the toxin listeriolysin O, and the *enterotoxin* from *Bacillus* species. These pathogenic micro-organisms or toxins can infect and produce detectable cytotoxicity to Ped-2E9 cells, which release alkaline phosphatase when infected. It has been reported that, the pathogenic *L. monocytogenes* cells and toxin preparations from *L. monocytogenes* or *B. cereus* showed cytotoxicity ranging from 24 to 98% at 3–6 h postinfection. In contrast, nonpathogenic *L. innocua* (F4247) and *B. subtilis* induced minimal cytotoxicity, ranging only 0.4–7.6%.

Carlyle et al. (2002) demonstrated the application of chromatophore cell-based biosensor assay for the detection of foodborne and other microbial pathogens. Where, the chromatophores are pigmented cells derived from Betta splendens that undergo a vivid colour response, due to aggregation, when exposed to specific biologically active agents. The paper reported that, Chromatophore cells were exposed to purified bacterial toxins and live toxin producing bacterial strains to test the effect of bacterial toxins. Where, toxin producing strains of *E. coli, Salmonella, Shigella, Vibrio, B. cereus* and *Clostridium* induced aggregation of the pigmented organelles in the chromatophore cells and the non-toxin producing strains of *E. coli, Bacillus subtilis* and *Lactococcus lactis* did not induce aggregation. Therefore it indicates that the aggregation of the Chromatophore cells was toxin dependent and it is nonreversible.

Zhao et al. (2006) developed an artificial cell-based biosensor that used a liposome-doped silica nanocomposite, which mimics existing whole-cell assays for Listeriolysin O (LLO), a pore-forming hemolysin secreted by the foodborne pathogen *L. monocytogenes.* The liposomes were encapsulated in porous silica using alcohol-free sol–gel synthesis methods. The immobilized liposomes act as a cellular compartment containing the fluorescent dyes. The dye release due to the pore formation by LLO indicated the presence of the toxin. In contrast to the mammalian cell-based biosensors, the synthetic cell-based biosensors have very long self-life and preservation is easier, since these sensors are based on the “non-living” system.

4.4.2. (ii) Non-enzymatic proteins

Many proteins that are found within cells often serve the purpose of bioreception for intracellular reactions that will take place later or in another part of the cell (Vo-Dinh and Cullum, 2000). These proteins cab be used for transport of a chemical from one place to another, such

as a carrier protein or channel protein on a cellular surface. In any case, these proteins provide a means of molecular recognition through one or another type of mechanism specifically, active site or potential sensitive site. These proteins can be attached to various types of transducers for bacterial pathogen detection.

Ertl et al. (2003) reported an electrochemical, screen-printed biosensor array, where selective recognition was accomplished using lectins that recognize and bind to cell-surface lipopolysaccharides. Screen-printed sensor arrays in conjunction with factor analysis were used for the rapid identification of four *E. coli* subspecies (*E. coli* B, *E. coli* Neotype, *E. coli* JM105 and *E. coli* HB101) and their results suggested that identification of *E. coli* subspecies is possible within 40 min. Earlier work of this group showed the application of lectins to the recognition of distinct surface lipopolysaccharide structures on a broad range of microbial strains (Ertl and Mikkelsen, 2001). The lectin-based sensor array was exposed to viable cells of Gram-negative and Gram-positive as well as yeast, and chronocoulometric and they used principal component analysis to classify the chronocoulometric results for the different microbial strains. With this type of biosensor, they were able to distinguish between six microbial species such as *B. cereus, S. aureus, Proteus vulgaris, E. coli, Enterobacter aerogenes* and *Saccharomyces cerevisiae* (Ertl and Mikkelsen, 2001).

4.5. Biomimetic receptors

A receptor that is fabricated and designed to mimic a bioreceptor (antibody, enzyme, cell or nucleic acids) is often termed a biomimetic receptor. Though there are several methods, such as genetically engineered molecules and artificial membrane fabrication, the molecular imprinting technique has emerged as an attractive and highly accepted tool for the development of artificial recognition agents. Molecular imprinting is one of the techniques of producing artificial recognition sites by forming a polymer around a molecule which can be used as a template. Molecular imprinted polymers (MIPs) can, in principle, be synthesized for any analyte molecule and are capable of binding target molecules with affinities and specificities on a par with biological recognition elements (Haupt and Mosbach, 2000). However, MIPs possess many disadvantages as well. For example, it is hard to completely remove the template from MIPs, the imprinted polymer is insoluble, and although the polymer contains many imprinted cavities, only some are really good and match the template molecule.

Using biomimetic polymer sensor, Silbert et al. (2006) presented a new platform for visual and spectroscopic detection of bacteria. The detection scheme in their study was based on the interaction of membrane-active compounds secreted by bacteria with agar-embedded nanoparticles comprising phospholipids and the chromatic polymer polydiacetylene (PDA). PDA undergoes dramatic visible blue-to-red transformations together with an intense fluorescence emission that are induced by molecules released by multiplying bacteria. The chromatic transitions were easily identified by the naked eye and they suggested that since the chromatic technology is generic and simple, eliminating the need for prior identification of specific bacterial recognition elements, this can be applied for detection of both Gram-negative and Gram-positive bacteria. The bacteria used in their study were *S. enterica*, *B. cereus*, and *E. coli*. But the draw back of their bacterial detection was that the assay was incapable to facilitate specificity of detection among bacterial species. However, they explained that the nonspecificity of the chromatic platform can benefit in evaluating food freshness where, the presence of any type of bacteria can be reported.

Ma et al. (1998), demonstrated that glycolipids could be inserted into the polydiacetylene matrix based on noncovalent binding, where the polymerized vesicles using 2,4-tricosadiynoic acid (2,4-TCDA) as the matrix lipid and dioctadecyl glyceryl ether-β-glucoside (DGG) as the receptor could make a biosensor to detect *E. coli*. A major limitation of this method was the extravagant sensitivity of 2, 4-TCDA and there was no colour change when *E. coli* was added into the mixed PCDA/DGG vesicle solution. These obstacles have been overcome, when the same group of researchers reported that supramolecular assembly of phospholipid–polymerized diacetylene vesicles functionalized with glycolipid can provide a molecular recognition function (Su et al., 2005b). They demonstrated the fabrication of mixed phospholipid/polydiacetylene vesicles functionalized with glycolipid for the colorimetric detection of *E. coli*, where the direct coupling of a recognition event leads to a visible colour change from blue to red, readily seen with the naked eye and quantified by absorption spectroscopy.

Biochromic conjugated polymer (BCP) sensors are another type of biomimetic based biosensor for pathogen detection, demonstrated by Song et al. (2002). Biologically active cell membrane components were incorporated into conjugated polymers with desirable optical properties. Polydiacetylenic membrane-mimicking materials that mimic the cell membrane and conveniently report the presence of pathogens with a colour change were used for the colorimetric detection of bacterial toxins and influenza virus. It was suggested that the BCP sensors are convenient for microfabrication and use, since their molecular recognition and signal transduction functionalities are resident in a single functional unit (Song et al., 2002). Though many biomimetic-based biosensors for foodborne pathogen detection have been published in recent years, only very few applications to food samples have been reported to date.

4.6. Bacteriophages

From the past decades to todate, enzymes, antibodies, nucleic acids and biomimetic materials are used as biomolecular recognition elements and they have both merits and demerits when compared to one another. Recently, bacteriophages are employed as biorecognition elements for the identification of various pathogenic micro organisms. These powerful bacteriophages (phages) are viruses that bind to specific receptors on the bacterial surface in order to inject their genetic material inside the bacteria. These entities are typically of 20–200 nm in size (Singh et al., 2009). Phages recognize the bacterial receptors through its tail spike proteins. Since the recognition is highly specific it can be used for the typing of bacteria and hence opened the path for the development of specific pathogen detection technologies. Researchers have reported the application of phage as a biorecognition element for the detection of various pathogens such as *E. coli* (Singh et al., 2009), *S. aureus* (Balasubramanian et al., 2007) and *B. anthracis* spores (Huang et al., 2008; Xie et al., 2009) by using different sensing platforms.

5. Transducers

The transducer plays an important role in the detection process of a biosensor. Biosensors can also be classified based upon the transduction methods they employ. Wide varieties of transduction methods have been developed in the past decade for the detection of foodborne pathogens. Although there are new types of transducers constantly being developed for use in biosensors, the transduction methods such as optical, electrochemical and mass based are given importance here since these are the most popular and common methods. Each of these three main classes contains many different subclasses and they can be further divided into label and label-free (non-labeled) methods. Where, the labeled methods depend on the detection of a specific label and the label-free detection is based on the direct measurement of a phenomenon occurring during the biochemical reactions on a transducer surface.

5.1. Optical-based biosensors

Optical biosensors have received considerable interest for bacterial pathogen detection due to their sensitivity and selectivity. Optical-

based detection offers large number of subclasses based on absorption, reflection, refraction, dispersion, infrared, Raman, chemiluminescence, fluorescence, and phosphorescence. However, all the above subclasses require a suitable spectrometer to record the spectrochemical properties of the analyte. The most commonly employed techniques of optical detection are surface plasmon resonance and fluorescence due to their sensitivity. Optical techniques using fiberoptics, laser, prism and waveguides are also employed for pathogen detection.

5.1.1. Raman and Fourier transform infrared spectroscopy

Vibrational spectroscopies such as Raman scattering and Fourier transform infrared (FT-IR) are the more frequently reported whole-organism fingerprinting techniques. However, before any of these whole-organism fingerprinting techniques can be used to analyze sample of interest, the microorganisms must be cultured in order to isolate the analyte from other sample constituents and/or produce sufficient biomass for analysis.

Raman spectroscopy, an optical technique based on light scattering, has been investigated by many researchers as a means of rapid detection of bacterial pathogens. Schmilovitch et al. (2005) employed a dispersive system spectrophotometer, with a 785 nm diode laser to detect the presence of Gram-positive and Gram-negative bacteria. A clear distinction between samples containing bacteria and clean samples were obtained by this method. Also the system was able to determine bacterial concentrations within 2% of the level in the basic bacteria suspension. During the past decade, surface-enhanced spectroscopy technique based on employing the phenomenon that can enhance the normal signal by many orders of magnitude was developed to eliminate the need for culturing. In this approach the pathogens of interest are selectively isolated from the sample using capture biomolecules, which add an additional layer of specificity to the whole-organism fingerprinting, and the analysis is exceptionally specific, making it possible to differentiate among species/strains that cross-react with a given biomolecule.

Grow et al. (2003) developed a detection method that uses surface-enhanced Raman scattering microscopy for label-free transduction (SERS). Their initial studies have shown that the Gram-positive *Listeria* and Gram-negative *Legionella* bacteria, *Bacillus spores* and *Cryptosporidium oocysts* can often be identified at the subspecies/strain level on the basis of SERS fingerprints collected from single organisms. Therefore they demonstrated that pathogens can be individually identified by μSERS, even when organisms that cross-react with the capture biomolecules are present in a sample. Moreover, the SERS fingerprint reflects the physiological state of a bacterial cell, e.g., when pathogenic *Listeria* and *Legionella* were cultured under conditions known to affect virulence, their SERS fingerprints changed significantly (Grow et al., 2003).

Another report by Goeller and Riley (2007) demonstrated the analysis of pathogen detection using Raman spectroscopy without drying the microorganisms. Confocal Raman measurements of the bacterium *E. coli* and of two bacteriophages, MS2 and PRDI, were analyzed for characteristic peaks and to estimate detection limits using traditional Raman and SERS. With the obtained results they demonstrated that both Raman spectroscopy and SERS have a potential as a pathogen monitoring platform. Also Raman spectroscopy can be combined with other optical methods for pathogen detection. Recently, Kalasinsky et al. (2007) reported Raman chemical imaging spectroscopy (RCIS), which combines Raman spectroscopy, fluorescence spectroscopy, and digital imaging. Using this method, trace levels of pathogens were detected without the use of amplification or enhancement techniques.

Fourier transform infrared (FT-IR) spectroscopy is a non-destructive analytical technique with considerable potential for application in the foodborne pathogen detection. FT-IR spectrometry-based approach was developed by Yu et al. (2004a) for microbial differentiation and quantification of eight different microorganisms including *Salmonella*. FT-IR spectroscopy combined with chemometrics was able to differentiate the microorganisms studied at low concentration level of 10^3 colony-forming units (CFU)/mL in apple juice. Another report demonstrated the use of FT-IR spectrometry to differentiate *E. coli* O157: H7 from other bacteria inoculated into apple juice (10^9 CFU/mL) (Al-Holy et al., 2006). Lin et al. (2004) used FT-IR spectrometry to differentiate between intact and injured *Listeria* and to distinguish this strain from other selected *Listeria* strains.

Also it has been reported by Ellis et al. (2002) that FT-IR technique can be used directly on the surface of food to produce biochemically interpretable "fingerprints". FT-IR was exploited to measure biochemical changes within the meat substrate, enhancing and accelerating the detection of microbial spoilage. Quantitative interpretation of FT-IR spectra was possible using partial least-squares regression and allowed accurate estimates of bacterial loads to be calculated directly from the meat surface in 60 s. The same group of researchers recently reported the qualitative interpretation of FT-IR and Raman spectra for the identification and authentication of muscle foods (Ellis et al., 2005).

5.1.2. Surface plasmon resonance

A common method which uses reflectance spectroscopy for the pathogen detection is surface plasmon resonance (SPR). SPR is able to detect minor changes in the refractive index, which occur when cells binds to receptors immobilized on the transducer surface and it measures the change of the angle of the reflected light as a function of change of density of medium against time. Direct label-free detection of pathogens is also possible using this method. SPR based biosensors have been reported by many researchers for the detection of foodborne pathogens such as *L.monocytogenes*(Bhunia et al., 2004; Koubova et al., 2001; Taylor et al., 2006), *Salmonella* (Bhunia et al., 2004; Koubova et al., 2001; Oh et al., 2004; Taylor et al., 2006), *E. coli* O157:H7 (Meeusen et al., 2005; Oh et al., 2003; Subramanian et al., 2006; Taylor et al., 2006; Taylor et al., 2005; Waswa et al., 2007), and *C. jejuni* (Taylor et al., 2006). Also, commercially available optical biosensors that use SPR for monitoring and identifying pathogens were employed by many researchers for the detection of foodborne pathogens. Spreeta™ biosensor was used for the detection of *E. coli* 01 57: H7 (Meeusen et al., 2005; Waswa et al., 2007); BIACORE 3000 was used for the detection of *L. monocytogenes* (Leonard et al., 2004), and *Salmonella* (Bokken et al., 2003).

Recently, Waswa et al. (2007) demonstrated the use of the Spreeta (TM), SPR-based biosensor for the detection *E. coli* O157:H7. In the Spreeta™ biosensor light from an LED is reflected off a gold surface, and the angle and intensity corresponding to the SPR minimum is measured and represented as a refractive index change corresponding to the antigen–antibody coupling at the sensor surface. They conducted the assay at near real-time and results were obtained after about 30 min of sample injection. Sensitivity of the *E. coli* O157: H7 assay was 10^2–10^3 CFU/mL. The biosensor assay was also specific to *E coli* O157:H7 as other organisms (*E coli* K12 and *Shigella*) did not produce any appreciable change in the sensogram. The paper suggested that further experiments are needed to establish well-defined methods for detecting other food-borne pathogens in more complex and specific food matrices. Also, Wei et al. (2007) used the Spreeta™, SPR-based biosensor for the rapid identification of *C. jejuni.* Balasubramanian et al. (2007) reported the label-free detection of *S. aureus* using lytic phage as highly specific and selective biorecognition element and surface plasmon resonance-based SPREETA™ sensor as a detection platform. Lytic phage was immobilized on the gold surface of SPREETA sensor via trouble-free direct physical adsorption. The detection limit was found to be 10^4 CFU/mL. The paper reported that the preliminary results using lytic phage as a probe for bacterial detection, in combination with SPR platform were promising and hence can be employed for rapid and label-free detection of different bacterial pathogens.

A successful biosensor must distinguish a target analyte from a complex mixture. The work by Taylor et al. (2006) demonstrated the use of multi-channel SPR biosensor for the simultaneous discrimination of multiple target analytes from complex mixtures. A custom-built SPR sensor based on the Kretschmann geometry of the attenuated total reflection (ATR) method and wavelength modulation was used. The quantitative and simultaneous detection of the four species of bacteria, *E. coli* O157:H7, *Salmonella choleraesuis serotype typhimurium*, *L. monocytogenes*, and *C. jejuni*, using an eight-channel surface plasmon resonance (SPR) sensor based on wavelength division multiplexing was reported. Amplification using secondary antibodies allowed to achieve a lower detection limit, while assuring specific detection. The experiments, demonstrated the specificity of these secondary antibodies, which were tested after the exposure of a sensor surface to three non-target species of bacteria at concentrations of 10^7 CFU/mL (Taylor et al., 2006). The limit of detection for each of the four species of bacteria in the tested matrices ranged from 3.4×10^3 to 1.2×10^5 CFU/mL and the detection curves in buffer of individual bacteria in a mixture of all four species of bacteria correlated well with detection curves of the individual species of bacteria alone. The results suggested that specific detection of pathogens in a complex mixture of different species of bacteria can be achieved using secondary antibody amplification.

SPR-based immunosensor have been reported for the detection of foodborne pathogens (Oh et al., 2004; 2003; Subramanian et al., 2006). Self-assembled monolayers (SAM) based SPR immumosensor for the rapid and specific detection of *E. coli* O157:H7, using a sandwich assay has been reported by Subramanian et al. (2006). The paper investigated the effect of protein G based detection and the effect of concentrations of primary and secondary antibodies in sandwich assay. The sensor could detect as low as 10^3 CFU/mL of *E coli* O157:H7 in a sandwich assay, with high specificity against *S. enteritidis*. The detection limit using direct assay and protein G were 10^6 CFU/mL and 10^4 CFU/mL, respectively. Their results indicated that an alkanethiol SAM based SPR biosensor has the potential for rapid and specific detection of *E. coli* O157:H7, using a sandwich assay. Also, SPR-based immunosensor using self-assembled protein G for the detection of *Salmonella paratyphi* with a detection range of 10^2–10^7 CFU/mL has been reported by Oh et al. (2004). Previous work by the same group of researchers reported SPR-based immunosensors using self-assembled protein G for the detection of *E. coli* 01 57: H7 with detection limit of 102 CFU/mL (Oh et al., 2003).

5.1.3. Optical fibers

Based on the principle of total internal reflection (TIR), optical fibers transmit light. The fiber optic biosensor uses tapered fiber to send excitation laser light to the detection surface and receive emitted light. Propagation of light through a fiber or waveguide can be very sensitive to the surroundings, which makes the optical fibers excellent detectors for a variety of applications in foods such as identification and detection of pathogens. Also, it was highlighted that the detection limits of fiber optical biosensors are comparable to the sophisticated large bench-top instruments (Monk and Walt, 2004). The use of fiber optic biosensors and the combination of optical fiber with other optical techniques for the detection of foodborne pathogens, such as *Listeria* (Strachan and Gray, 1995), *Salmonella* (Ko and Grant, 2006; Morgan et al., 2006), *E. coli* O157:H7 (DeMarco and Lim, 2002; Simpson and Lim, 2005; Ye et al., 2002) and *Clostridium-botulinum* toxin (Ogert et al., 1992) were reported.

A fiber optic portable biosensor utilizing the principle of fluorescence resonance energy transfer (FRET) for fast detection of *Salmonella typhimurium* in ground pork samples was reported (Ko and Grant, 2006). A portable evanescent-wave fiber-optic biosensor to detect *E. coli* O157:H7 in seeded 10-g and 25-g ground beef samples was demonstrated by (DeMarco and Lim, 2002). A centrifugation method to obtain samples suitable for biosensor analysis from 10-g and 25-g ground beef samples was developed. The paper reported that the assay was sensitive and repeatable. One hundred percent correct identification of positive samples was obtained at 9.0×10^3 CFU/g for 25-g ground beef samples with silica waveguides and at 5.2×10^2 CFU/g for 10-g ground beef samples with polystyrene waveguides. With the obtained results they demonstrated that the reaction were highly specific.

The fiber-optic biosensors can also be used to reduce the impact of PCR inhibitors present in complex matrices in food. Though the fiber-optic biosensors can rapidly detect pathogens from complex matrices, confirmation tests may take up to several hours to complete. Simpson and Lim (2005) presented the methodologies to reduce the time necessary for confirmation from 10 to about 2 h in the detection of *E. coli* O157:H7 by direct PCR of bacteria from the fiber-optic waveguides without the need for culture or enrichment steps. A fiber-optic surface plasmon resonance biosensor for detection of Staphylococcal enterotoxin B (SEB) was reported (Slavik et al., 2002). For specific detection of SEB, the fiber-optic SPR sensor is functionalized with a covalently crosslinked double-layer of antibodies against SEB. It has been demonstrated that the fiber-optic SPR biosensor was able to detect ng/mL concentrations of SEB in less than 10 min.

Ye et al. (2002) developed a biosensor, consisting of a chemiluminescence reaction cell, a fiber-optic light guide, and a luminometer linked to a PC, in conjunction with immunomagnetic separation for rapid detection of *E. coli* O157:H7. The cell number of *E. coli* O157:H7 was determined by collecting the HRP-catalyzed chemiluminescence signal from the bead surface though a fiber-optic light guide and measuring the signal with a luminometer. The chemiluminescence biosensor was selective to *E. coli* O157:H7 in the presence of other bacteria in the sample, including *S. typhimurium*, *C. jejuni*, and *L. monocytogenes*. The detection limit of the biosensor was 1.8×10^2 CFU/mL within 1.5 h. By using the above method the same group of researchers demonstrated the detection of *E. coli* O157:H7 in ground beef, chicken carcass, and lettuce samples with the detection limits of 3.2×10^2, 4.4×10^2, and 5.5×10^2 CFU/mL, respectively and the detection was completed within 1.5 h without any enrichment (Liu et al., 2003). A fiber-optic immunosensor for the rapid and specific detection of *S. aureus* has been reported (Chang et al., 1996). A sensitive fiber-optic that produces evanescent waves was developed for the detection of protein A, a product secreted only by *S. aureus*. The principle of the detection involved a sandwich immunoassay with fluorescein isothiocyanate conjugated with anti-(protein A) immunoglobulin G to produce signals of the antigen–antibody reaction, and the detection limit obtained was 1 ng of protein A per millilitre. Also, commercially available fiber-optic biosensors have been used for food pathogen detection. RAPTOR, a portable and automated fiber-optic biosensor was used to detect *S. enteritidis* in food samples (Morgan et al., 2006).

5.1.4. Other optical techniques

Recently, Ramachandran et al. (2008) demonstrated the use of optical micro-ring resonators as a platform for quantitative and qualitative biosensing applications. Vertically coupled, high refractive index micro-ring resonators were used as sensing elements, fabricated on silicon chips by photolithographic techniques. An optical reader system consisting of a near-infrared broad band light source and an optical spectrum analyzer was employed for data acquisition. They modified the micro-ring resonator surfaces with specific target receptors, including antibodies and single-stranded DNA oligonucleotides. Also, the paper suggested that the system can be successfully used for label-free, specific, and rapid detection of whole bacterial cells, proteins and nucleic acids (Ramachandran et al., 2008). The use of terahertz time domain spectroscopy for determination of ligand binding for biomolecules has been reported by Markelz et al. (2004). Various optical-based techniques which were not discussed here are given in the Table 4.

Table 4
Different optical techniques employed for pathogen detection.

Optical techniques	Detected pathogen	Limit of detection	Assay time	References
Optic interferometer	*S. typhimurium*	10^5 CFU/mL	12 h	(Seo et al., 1999)
Resonant mirror detection	*E. coli*			(Kiba et al., 2006)
Evanescent wave	*E. coli* 01 57:H7	3 to 30 CFU/mL	4 h	(Varkey et al., 2002)
Turbidimetry (based on the optical density measurements)	*E. coli* 01 57:H7, *Staphylococcus aureus* and *Y. enterocolitica*			(Barco Alcala et al., 2000)
Automated optical method	*Salmonella* spp. and *L.monocytogenes*	10–50 cells each in 25 g sample	24 h	(Peng and Shelef, 2001)
Diffuse reflectance spectroscopy	*E. coli* O157:H7	5×10^5 to 5×10^8cells/mL	45 min	(Rahman et al., 2006)
Optical method using laser beam	*E. coli*	45 cells		(Acharya et al., 2006)
Surface-enhanced infrared absorption spectroscopy	*Salmonella*			(Brown et al., 1998; Seelenbinder et al., 1999)
Bidiffractive grating biosensor (BDG)	*Staphlococcus aureus* enterotoxin B, *Clostridium botulinum*, ricin toxin and *Francisella tularensis*			(O'Brien et al., 2000)
Near-infrared spectroscopy	Septicemia/toxemia (septox) in chickens			(Dey et al., 2003)
Imaging ellipsometry (IE)	*E. coli* O157:H7, *S. typhimurium*, *Y. enterocolitica*, and *Legionella pneumophila*	10^3 to 10^7 CFU/mL		(Choi and Oh, 2008)
Quantum dots	*E. coli* O157:H7	10^6 cells/mL		(Hahn et al., 2008)
Fluorescence microscopy	*E. coli* O157:H7, *S. typhimurium*, *Y. enterocolitica*, and *Legionella pneumophila*	10^2 CFU/mL		(Choi and Oh, 2008)
Chemiluminescence	*E. coli* O157:H7	10^2 to 10^5 CFU/mL	30 min	(Mathew et al., 2004)
Chemiluminescence enzyme immunoassay	*E. coli* O157:H7	10^1 to 10^2/g	24 h	(Kovacs and Rasky, 2001)
Chemiluminescent immunoassay	*E.* O157:H7, *Y. enterocolitica*, *S. typhimurium*, and *L. monocytogenes*	10^4 to 10^5 CFU/mL for all bacterial species		(Magliulo et al., 2007)
Bioluminescence	*E. coli*	$<10^3$ cells	1 and 2 h resp.	(Frank et al., 2007c; Lehtinen et al., 2006)
	E. coli and *Salmonella*			(Blasco et al., 1998)
Bacteriophage-based bioluminescene	*E. coli* O157:H7	10 CFU/mL	4 h	(Brigati et al., 2007)
	Salmonella	10^8 CFU/mL	1–3 h	(Chen and Griffiths, 1996)

5.2. Electrochemical biosensors

Electrochemical based detection methods are another possible means of transduction that has been used for identification and quantification of foodborne pathogens. Electrochemical biosensors can be classified into amperometric, potentiometric, impedimetric and conductometric, based on the observed parameters such as current, potential, impedance and conductance respectively. Different modes of electrochemical based foodborne pathogen detection are given in Table 5. Although the electrochemical detection has several advantages like low cost, ability to work with turbid samples and easy miniaturisation, their sensitivity and selectivity are slightly limited when compared to optical detection. However, electrochemical biosensors were found coupled with other biosensing techniques for enhanced detection.

5.2.1. Amperometric method

Amperometric transduction is the most common electrochemical detection method which has been used for pathogen detection and it

Table 5
Different modes of electrochemical based foodborne pathogen detection.

Mode of detection	Analyte	Limit of detection (CFU/mL)	Assay time	References
Amperometric	*E. coli* O157:H7	81	6 min	(Muhammad-Tahir and Alocilja, 2004)
Amperometric	*E. coli* O157:H7	7.8×10^1	10 min	(Muhammad-Tahir and Alocilja, 2003b)
Amperometric	*E. coli* O157:H7	6×10^2 cells/mL	2 h	(Ruan et al., 2002)
Amperometric	*S. typhimurium*	1.09×10^3	2.5 h	(Yang et al., 2001)
Amperometric	*Salmonella*	1–5	6 h	(Brooks et al., 1992)
Amperometric	*E. coli* O157:H7 without any enrichment after enrichment	1.6×10^1–7.2×10^7 8.0×10^0–8.0×10^1	15 min 6 h	(Varshney et al., 2005)
Amperometric	*E. coli* *L. monocytogenes*, and *C. jejuni*	50 cells/mL 10 cells/mL 50 cells/mL	30 min overall	(Chemburu et al., 2005)
Amperometric	*S. typhimurium*	5×10^3 cells/mL	2 h	(Che et al., 1999)
Amperometric	*E. coli* O157:H7 *Salmonella*	50 cells/mL 50 cells/mL	35 min overall	(Abdel-Hamid et al., 1999b)
Amperometric	*E. coli* O157:H7	100 cells/mL	30 min	(Abdel-Hamid et al., 1999a)
Potentiometric	*E. coli* O157:H7 heat-hided Live	7.1×10^2 cells/mL 2.5×10^4 cells/mL	45 min 30 min	(Gehring et al., 1998)
Potentiometric	*E. coli*	10 cells/mL	1.5 h	(Ercole et al., 2003a)
Cyclic voltammetry	*V. parahaemolyticus*	7.374×10^4		(Zhao et al., 2007)
Conductometric	*E. coli* O157:H7 and *Salmonella* spp.	7.9×10^1	10 min	(Muhammad-Tahir and Alocilja, 2003a)
Conductometric	*Bacillus cereus*	35–88	6 min	(Pal et al., 2008)
Impedimetric	*S. typhimurium*	4.8 and 5.4×10^5	9.3 and 2.2 h respectively.	(Yang et al., 2004)
Impedimetric	*L. monocytogenes* *Bacillus cereus*			(Susmel et al., 2003; Tully et al., 2008) (Susmel et al., 2003)
Impedimetric	*E. coli*	10^1 to 10^7		(Munoz-Berbel et al., 2008)

has superior sensitivity than potentiometic method. In amperometric based detection the sensor potential is set at a value where the analyte produces current. Thus, the applied potential serves as the driving force for the electron transfer reaction, and the current produced is a direct measure of the rate of electron transfer. Clark and Lyons, (1962) reported that oxygen electrodes, possibly represent the basis for the simplest forms of amperometric biosensors, in which current was produced in proportion to the oxygen concentration. Many researchers have reported amperometric detection of foodborne pathogens such as *E. coli* O157:H7 (Abdel-Hamid et al., 1999a,b; Chemburu et al., 2005; Ruan et al., 2002; Varshney et al., 2005), *Salmonella* (Abdel-Hamid et al., 1999b; Brooks et al., 1992; Che et al., 1999; Yang et al., 2001), *L. monocytogenes* (Chemburu et al., 2005; Crowley et al., 1999) and *C. jejuni* (Chemburu et al., 2005).

Reymond et al. (2007) developed an amperometric detection method for determining the presence, the amount, and/or the concentration of an analyte in a microfluidic sensor, where the sensor is a part of an integrated sample acquisition system and/or analyte measurement device. Microfluidic sensor was filled with sample to be analyzed, and amperometry was performed to detect the analyte by applying the potential required to directly or indirectly detect the analyte. The method was adapted to detect the presence, amount and/or concentration of analytes. Various analytes are detected by oxidation and/or reduction using different applied potentials. In the method, the potential was applied and the related current measured at the integrated working electrode for no more than 10 s, nearly 2 s and a relaxation time separating sequential amperometric measurements was longer than 1 s but shorter than 1 min.

In order to detect aflatoxin M1 in milk, Micheli et al. (2005) compared two pathogen detection procedures for better detection and shorter analysis. The first procedure involved spectrophotometric enzyme-linked immunosorbent assay (ELISA), which exhibited a working range between 30 and 160 ppt in a direct competitive format. Then electrochemical immunosensors were fabricated by immobilizing the antibodies directly on the surface of the screen-printed electrodes. The electrochemical technique chosen was the chronoamperometry, performed at −100 mV. Results showed that using screen-printed electrodes, aflatoxin M1 was measured with a detection limit of 25 ppt and with a working range between 30 and 160 ppt (Micheli et al., 2005). A comparison between the spectrophotometric and electrochemical procedure showed that a better detection limit and shorter analysis time could be achieved using electrochemical detection. Electrochemical biosensors based on amperometric detection were found coupled with other biosensing techniques. For example, a bienzyme electrochemical biosensor was found coupled with immunomagnetic separation technique for the detection of *E. coli* O157:H7 (Ruan et al., 2002), *S. typhimurium* (Yang et al., 2001).

5.2.2. Potentiometric detection

In potentiometric based detection the bio-recognition process is converted into a potential signal. Usually a high impedance voltmeter is used to measure the electrical potential difference or electromotive force (EMF) between two electrodes at near zero current. Since potentiometry generates a logarithmic concentration response, the technique allows the detection of extremely small concentration changes. Not many potentiometric biosensors were found for the detection of pathogens. Light-addressable potentiometric sensor (LAPS) for the detection of pathogens has been reported (Ercole et al., 2003a; Gehring et al., 1998; Mackay et al., 1991). LAPS is based on the coupling of a transient photocurrent to an insulated *n*- or *p*-doped silicon thin layer in contact with an electrolyte. This transient photocurrent is induced by the application of transient illumination by using an intensity modulated light source like, light emitting diodes (LEDs). The magnitude of the induced photocurrent depends on the applied potential to the silicon plate. Also it is possible to detect different physicochemical phenomena by using different light sources on different spatial regions. The control of several different parameters on a single device is possible if these regions differ structurally.

Ercole et al. (2003b) demonstrated the detection of *E. coli* cells in vegetable food using the potentiometric alternating biosensing (PAB) system based on LAPS. LAPS was used as a transducing element, for detecting pH variations due to NH3 production by a urease-*E. coli* antibody conjugate. The liquid phase was analyzed both by PAB system and conventional CFU methods. The paper reported, the PAB system appeared to be very sensitive and fast, in comparison with conventional methods and the concentration of 10 cells/mL was detected in an assay time of ca. 1.5 h, which was from 10 to 20 times shorter than the conventional CFU procedure. Gehring et al. (1998) developed an immunoligand assay (ILA) in conjunction with a light-addressable potentiometric sensor (LAPS) for the rapid detection of *E. coli* O157:H7 cells in buffered saline. The ILA protocol consists of "sandwiching" bacterial analyte between biotinylated and fluoresceinated antibodies. Using ILA with LAPS, a minimum detectable level of ca.7.1×10^2 cells/mL of heat-hided or ca. 2.5×10^4 cells/mL of Live *E. coli* O157:H7 bacteria were achieved in Tris-buffered saline in an assay time of ca.45 or ca.30 min, respectively.

5.2.3. Impedimetric detection

The integration of impedance with biological recognition technology for detection of pathogens has led to the development of impedance biosensors that are finding wide-spread use in the recent years (Yang and Bashir, 2008). Impedimetric transduction technique has been applied to detect and/or quantify variety of foodborne pathogens. Electrochemical impedance spectroscopy (EIS) is playing an important role in the biosensor development. In EIS measurements, a controlled AC electrical stimulus of between 5 and 10 mV is applied over a range of frequencies, and this causes a current to flow through the biosensor, depending on different processes. EIS is a widely used technique for probing bioaffinity interactions at the surfaces of electrically conducting polymers and can be employed to investigate 'labelfree' detection of analytes via impedimetric transduction (Tully et al., 2008). Though, EIS offers label-free detection compared to amperometry or potentiometry, its detection limits are inferior compared to traditional methods.

Yang et al. (2004) used interdigitated microelectrodes as impedance sensors for rapid detection of viable *Salmonella*. The impedance growth curves, impedance against bacterial growth time, were recorded at four frequencies (10 Hz, 100 Hz, 1 kHz, and 10 kHz) during the growth of *S. typhimurium*. It was observed that impedance did not change until the cell number reached 10^5–10^6 CFU/mL. The greatest change in impedance was observed at 10 Hz. An equivalent electrical circuit, consisting of double layer capacitors, a dielectric capacitor, and a medium resistor, was introduced and used for interpreting the change in impedance during bacterial growth. Bacterial attachment to the electrode surface was observed with scanning electron microscopy, and it had an effect on the impedance measurement. The paper reported that the detection times for 4.8×10^5 and 5.4×10^5 CFU/mL initial cell numbers were 9.3 and 2.2 h, respectively (Yang et al., 2004).

5.2.4. Conductometric detection

Conductometric-based biosensors bond the relationship between conductance and a bio-recognition technique. Most reactions involve a change in the ionic species concentration, which leads to a change in electrical conductivity or current flow. Normally, a conductometric biosensor consists of two metal electrodes separated by a certain distance and an AC voltage applied across the electrodes causes a current flow. During a bio-recognition event the ionic composition changes and the change in conductance between the metal electrodes are measured.

Muhammad-Tahir and Alocilja (2003a) developed a conductometric biosensor for detecting foodborne pathogens such as *E. coli*

O157:H7 and *Salmonella* spp. It has been reported that, the lower limit of detection was approximately 7.9×10^1 CFU/mL within a 10 minute process and the biosensor provided specific, sensitive, low volume, and near real-time detection mechanism. Recently, Pal et al. (2008) developed a direct-charge transfer conductometric biosensor for the detection of *B. cereus* in various food samples. The biosensor used the principle of a sandwich immunoassay, combined with an electron charge flow aided through conductive polyaniline, to generate an electronic signal. The biosensor was able to detect cell concentrations in the range of 35–88 CFU/mL in the food samples with a detection time of 6 min. The biosensor was found to be specific to the target pathogen in pure cultures of *Bacillus megaterium* and generic *E. coli.*

Also it has been reported that the speed, sensitivity and ease of use, of this biosensor make it a promising device for rapid field-based diagnosis toward the protection of the food supply chain.

5.3. Mass-sensitive biosensors

Mass-sensitive biosensors are suitable for very sensitive detection, in which the transduction is based on the small changes in mass. The principal means of mass analysis depends on the use of piezoelectric crystals, which can be made to vibrate at a specific frequency with the application of an electrical signal of a specific frequency. The frequency of oscillation is therefore dependent on the applied electrical frequency to the crystal as well as the mass of the crystal. Therefore, when the mass increases due to binding of chemicals, the frequency of oscillation of the crystal changes and the resulting change can be measured electrically which can be used to determine the additional mass of the crystal. Quartz is being used as a common piezoelectric material. The two main types of mass based sensors are (1) bulk wave (BW) or quartz crystal microbalance (QCM) and (2) surface acoustic wave (SAW).

When a piezoelectric sensor surface, which has been coated with an antibody, is placed in a solution containing pathogens, the attachment of the agent to the antibody coated surface results in an increase in the crystal mass, and this gives rise to a corresponding frequency shift. Mass based detection is relatively easy to use, cost effective, and offers direct label-free analysis with increased sensitivity and specificity.

But foodborne pathogen detection based on piezoelectric sensor found to be very less compared to electrochemical and optical-based biosensors. Su and Li (2005) demonstrated a quartz crystal microbalance (QCM) immunosensor for the detection of *S. typhimurium* with simultaneous measurements of the resonant frequency and motional resistance. The immunosensor was fabricated using protein A for the antibody immobilization. High-frequency impedance analysis indicated that the changes in resonant frequency and motional resistance of the QCM were significant while the changes in static capacitance, motional capacitance, and motional inductance were insignificant. In the direct detection of *S. typhimurium* in chicken meat sample, resonant frequency and motional resistance were proportional to the cell concentration in the range of 10^5–10^8 and 10^6–10^8 cells/mL, respectively. The detection limit was lowered to 10^2 cells/mL by using anti-*Salmonella*-magnetic beads; however, motional resistance was not related to the cell concentration.

QCM immunosensor for the detection of *L. monocytogenes* with a detection limit of 1×10^7 cells/mL was reported (Vaughan et al., 2001). Also rapid (80 s) detection of *S. typhimurium* (Chen and Barbaree, 2002), *E. coli* O157:H7 (Berkenpas et al., 2006) with a surface acoustic wave (SAW) sensor has been reported. Nanduri et al. (2007) developed a biosensor based on landscape phages immobilized by physical adsorption on the surface of a QCM for detection of β-galactosidase from *E. coli* and reported that phage can be used as a recognition element in biosensors.

Mutharasan and Campbell (2008) reported a sensor flow cell for receiving a piezoelectric-excited millimeter-sized cantilever (PEMC) sensor, which comprises a reservoir portion provided with a flow inlet aperture and a flow outlet aperture to allow a medium to flow into and out of the reservoir portion. The reservoir portion contains a sensing surface of the PEMC sensor, and at least a portion of the medium (liquid and/or a gas) exposable to the sensing surface. The method is found to be advantageous because, the exposure of the medium to the sensing surface of PEMC sensor is enhanced under the flow conditions as compared to a static medium. Thus, the ability of the sensor to detect the target material or analyte in the medium is superior under the flow conditions, as compared to stagnant conditions. The flow of medium enhances binding of analytes to the PEMC sensor surface, allowing detection of small concentration of analytes. It has been reported that, this method can be utilized for several biosensing applications including the detection of foodborne pathogens.

Recently, magnetoelastic sensor (ME) platform are gaining attention in chemical and biological sensing. ME sensors are constructed with amorphous ferromagnetic ribbons or wires which are analogous and complementary to piezoelectric acoustic wave sensors. ME sensors are excited with magnetic AC fields and in turn, they generate magnetic fluxes that can be detected with a sensing coil from a distance and hence these sensors are highly attractive for wireless biosensing. They have high tensile strength and are much more cost effective which makes them appealing for biosensor platform. The fundamental operating principle of the magnetoelastic sensors involves a change in sensor resonance frequency due to mass loading of the sensor. In biosensing, the change in mass is associated with the binding of a target analyte to a bioreceptor immobilized on the surface of the ribbon-like ME sensor. The ME sensor can be coated with various probe molecules to target analytes. A change in resonant frequency can be observed if an analyte binds to the magnetoelastic sensor which can be measured rapidly and accurately.

Ruan et al. (2004) have used ME sensors to detect staphylococcal enterotoxin Type B (SEB). The sensing configuration involves formation of a sandwich antigen–antibody complex by the primary affinity-purified anti-SEB antibody covalently immobilized on the surface of a mass-sensitive magnetoelastic sensor, the target SEB and the biotin-labeled secondary anti-SEB antibody. The study examined the response of the sensor by linearly varying the concentrations of SEB in the range of 0.5–5 ng/mL and demonstrated the sensitivity of magnetoelastic sensors. The detection limit was 0.5 ng/mL for a 1 h incubation period. Also the paper reported that, the cost of the sensor was approximately $0.001/sensor, therefore it can be easily utilized as a disposable sensor.

Ong et al. (2006) reported the fabrication and application of wireless, remote-query ME sensors for the quantification of multiple biological agents. A six-sensor array was fabricated for the simultaneous measurement of *E. coli* O157:H7, staphylococcal enterotoxin B, and ricin by immobilizing anti-bacterial or anti-biotoxin antibodies onto a gold-coated ME sensor through self-assembled monolayer modification cross-linking the antibody with a bifunctional binding agent. The paper reported that the telemetry of magnetoelastic sensor information is by magnetic flux; hence, no direct connections are needed between the sensor and monitoring electronic equipment making possible a variety of *in situ* and *in vivo* monitoring applications. Recently, Huang et al. (2008) and Xie et al. (2009) developed a ME biosensor by immobilizing bacteriophage as bio-recognition element for the real-time in vitro detection of *B. anthracis* spores.

6. Electronic nose sensor

The development of an 'electronic nose' for pathogen detection has received considerable attention in recent years. Balasubramanian et al. (2005) used a commercially available Cyranose-320™ electronic nose system to identify *S. typhimurium* in inoculated beef samples. An

electronic nose containing an array of 32 conducting polymer sensors was used to obtain the odour patterns of the headspace of the meat samples. The volatile organic compounds emanating from vacuum-packaged beef strip was analysed. Their results proved that the electronic nose system was able to identify meat samples contaminated with *S. typhimurium* at a population concentration level $\geq 0.7 \log_{10}$ CFU/g.

Conducting polymers has been used as detectors in electronic nose systems. When gas is adsorbed by the sensor, conducting organic polymer sensors exhibit a change in resistance, which is sensed and delivered as the output (Arshak et al., 2009). Conducting polymer based e-nose sensor for foodborne pathogen detection has been reported by many researchers. Magan et al. (2001) used Bloodhound™ BH114, an electronic nose unit including 14 conducting polymer sensors, to detect the volatile profiles produced by uninoculated skimmed milk media or that inoculated with bacteria (*Pseudomonas aureofaciens, P. fluorescens*, and *B. cereus*) or yeasts. It has been reported that using discriminant function analyses it was possible to separate unspoiled milk and that containing spoilage bacteria or yeasts. The sensor array used was a useful discriminator of microbial volatile profiles. The paper discussed the potential for using an electronic nose system for the early detection of microbial spoilage of milk-based products.

Muhammad-Tahir and Alocilja (2003b) fabricated a disposable biosensor based on an electrochemical sandwich immunoassay using polyaniline for detection of foodborne pathogen, *E. coli* O157:H7. Their results showed that the biosensor was able to detect approximately 7.8×10^1 CFU/mL of *E. coli* O157:H7 in 10 min. Minett et al. (2003) coupled conducting polymers and the electron mediators for the detection of *L. monocytogenes* and the sensor was capable to detect *L. monocytogenes* at levels of 10^5 cells mL^{-1} in 30 min. Also biosensors based on electronic conducting polymers were reported for the detection of fish freshness (Ghosh et al., 1998).

Recently, Arshak et al. (2007) reported the use of an array of conducting polymer composite sensors containing both carbon black and polyaniline to detect and identify the foodborne bacterial pathogens such as, *Salmonella* spp., *B. cereus* and *V. parahaemolyticus* through production of an individual response pattern for each bacterium. Their work demonstrates the potential application for the on site identification of food-borne pathogens where these sensors could be interfaced with handheld devices to quantify emissions emanating from samples of contaminated foods.

7. Summary and outlook

Though conventional pathogen detection methods are sensitive, they lag behind the analytical methods by detection time. However, the analytical techniques like optical and electrochemical detection have some disadvantages as well, considering sensitivity and cost. Therefore, new rapid methods are considered necessary for better performance. Optical techniques possibly provide better sensitivity relative to electrochemical detection, but they are expensive and complicated. In contrast, electrochemical techniques involve much simple procedures but for the detection of pathogens, it requires enhanced performance.

Though, numerous research efforts have been made during the past decades and in recent years for foodborne pathogen detection, in spite of everything it needs further improvement. Since foodborne pathogens are mostly present in very low numbers (<100 CFU/g) in the middle of millions of other bacteria, it is very difficult to detect them. So there are more chances for these microorganisms that may get lost during detection. Therefore a detection technique which is reliable, rapid, accurate, simple, sensitive, selective and cost effective has to be developed. In addition, it should be able to detect pathogens in very low concentrations of the samples and must be suitable for *in situ* real-time monitoring as well. Such a technique of detecting pathogens would offer a great commercial advantage to food processing and food manufacturing sector. By using a biosensor which is rapid in detecting microbial pathogens, the uncontaminated foodstuffs can be released within hours or even minutes, rather than several days, which further prevent the necessity for refrigerated storage.

Acknowledgement

This research work is funded by Science Foundation Ireland (SFI) Research Frontiers Programme, ID no: 07RPF-ENEF500.

References

Abadias M, Usall J, Anguera M, Solson C, Vinas I. Microbiological quality of fresh, minimally-processed fruit and vegetables, and sprouts from retail establishments. Int J Food Microbiol 2008;123:121–9.
Abdel-Hamid I, Ivnitski D, Atanasov P, Wilkins E. Flow-through immunofiltration assay system for rapid detection of *E-coli* O157: H7. Biosens Bioelectron 1999a;14:309–16.
Abdel-Hamid I, Ivnitski D, Atanasov P, Wilkins E. Highly sensitive flow-injection immunoassay system for rapid detection of bacteria. Anal Chim Acta 1999b;399: 99-108.
Acharya G, Chang CL, Savran C. An optical biosensor for rapid and label-free detection of cells. J Am Chem Soc 2006;128:3862–3.
Agle ME, Martin SE, Blaschek HP. Survival of *Shigella boydii* 18 in bean salad. J Food Prot 2005;68:838–40.
Aldus CF, van Amerongen A, Ariens RMC, Peck MW, Wichers JH, Wyatt GM. Principles of some novel rapid dipstick methods for detection and characterization of verotoxigenic *Escherichia coli*. J Appl Microbiol 2003;95:380–9.
Alexandre M, Prado V. Detection of Shiga toxin-producing *Escherichia coli* in food. Expert Rev Mol Diagn 2003;3:105–15.
Al-Holy MA, Lin M, Cavinato AG, Rasco BA. The use of Fourier transform infrared spectroscopy to differentiate *Escherichia coli* O157: H7 from other bacteria inoculated into apple juice. Food Microbiol 2006;23:162–8.
Alocilja EC, Radke SM. Market analysis of biosensors for food safety. Biosens Bioelectron 2003;18:841–6.
Aravanis AM, DeBusschere BD, Chruscinski AJ, Gilchrist KH, Kobilka BK, Kovacs GTA. A genetically engineered cell-based biosensor for functional classification of agents. Biosens Bioelectron 2001;16:571–7.
Arnold T, Neubauer H, Ganter M, Nikolaou K, Roesler U, Truyen U, et al. Prevalence of *Yersinia enterocolitica* in goat herds from northern Germany. J Vet Med B Infect Dis Vet Public Health 2006;53:382–6.
Arora S, Agarwal RK, Bist B. Comparison of ELISA and PCR vis-a-vis cultural methods for detecting *Aeromonas* spp. in foods of animal origin. Int J Food Microbiol 2006;106: 177–83.
Arritt FM, Eifert JD, Jahncke ML, Pierson MD, Williams RC. Effects of modified atmosphere packaging on toxin production by *Clostridium botulinum* in raw aquacultured summer flounder fillets (*Paralichthys dentatus*). J Food Prot 2007;70: 1159–64.
Arshak K, Adley C, Moore E, Cunniffe C, Campion M, Harris J. Characterisation of polymer nanocomposite sensors for quantification of bacterial cultures. Sens Actuators B Chem 2007;126:226–31.
Arshak K, Velusamy V, Korostynska O, Oliwa-Stasiak K, Adley C. Conducting polymers and their applications to biosensors: emphasizing on foodborne pathogen detection. IEEE Sensors J 2009;9:1942–51.
Artault S, Blind JL, Delaval J, Dureuil Y, Gaillard N. Detecting *Listeria monocytogenes* in food. Int Food Hyg 2001;12:23.
Atanassova V, Reich F, Klein G. Microbiological quality of sushi from sushi bars and retailers. J Food Prot 2008;71:860–4.
Ayçiçek H, Aydogan H, Küçükkaraaslan A, Baysallar M, Basustaoglu AC. Assessment of the bacterial contamination on hands of hospital food handlers. Food Control 2004;15:253–9.
Balasubramanian S, Panigrahi S, Logue CM, Marchello M, Sherwood JS. Identification of *Salmonella*-inoculated beef using a portable electronic nose system. J Rapid Methods Automation Microbiol 2005;13:71–95.
Balasubramanian S, Sorokulova IB, Vodyanoy VJ, Simonian AL. Lytic phage as a specific and selective probe for detection of Staphylococcus aureus — A surface plasmon resonance spectroscopic study. Biosens Bioelectron 2007;22:948–55.
Banerjee P, Lenz D, Robinson JP, Rickus JL, Bhunia AK. A novel and simple cell-based detection system with a collagen-encapsulated B-lymphocyte cell line as a biosensor for rapid detection of pathogens and toxins. Lab Invest 2008;88:196–206.
Barco Alcala E, Garcia Gimeno RM, Castillejo Rodriguez AM, Zurera Cosano G. Turbidimetry as a fast method to determine microorganisms in foods. Alimentaria 2000;37:109–12.
Batt CA. Food pathogen detection. Science 2007;316:1579–80.
Belson K, Fahim K. After extensive beef recall, Topps goes out of business. The New York Times [Newspaper]; 2007 [Issue: 6 October 2007], New York.
Bennett RW. Staphylococcal enterotoxin and its rapid identification in foods by enzyme-linked immunosorbent assay-based methodology. J Food Prot 2005;68:1264–70.
Berkenpas E, Millard P, da Cunha MP. Detection of *Escherichia coli* O157: H7 with langasite pure shear horizontal surface acoustic wave sensors. Biosens Bioelectron 2006;21:2255–62.

Beumer RR, Brinkman E. Detection of *Listeria*-spp with a monoclonal antibody-based enzyme-linked immunosorbent assay ELISA. Food Microbiol 1989;6:171–8.
Bhaduri S, Wesley IV, Bush EJ. Prevalence of pathogenic *Yersinia enterocolitica* strains in pigs in the United States. Appl Environ Microbiol 2005;71:7117–21.
Bhunia AK, Geng T, Lathrop A, Valadez A, Morgan MT. Optical immunosensors for detection of *Listeria monocytogenes* and *Salmonella enteritidis* from food. In: Bennedsen BS, Chen YR, Meyer GE, Senecal AG, Tu SI, editors. Monitoring food safety, agriculture, and plant health; 2004. p. 1–6.
Bhunia AK, Banada P, Banerjee P, Valadez A, Hirleman ED. Light scattering, fiber optic- and cell-based sensors for sensitive detection of foodborne pathogens. J Rapid Methods Automation Microbiol 2007;15:121–45.
Bialek SR, George PA, Xia GL, Glatzer MB, Motes ML, Veazey JE, et al. Use of molecular epidemiology to confirm a multistate outbreak of hepatitis A caused by consumption of oysters. Clin Infect Dis 2007;44:838–40.
Bianco MI, Luquez C, de Jong LIT, Fernandez RA. Presence of *Clostridium botulinum* spores in *Matricaria chamomilla* (chamomile) and its relationship with infant botulism. Int J Food Microbiol 2008;121:357–60.
Blasco R, Murphy MJ, Sanders MF, Squirrell DJ. Specific assays for bacteria using phage mediated release of adenylate kinase. J Appl Microbiol 1998;84:661–6.
Bokken G, Corbee RJ, van Knapen F, Bergwerff AA. Immunochemical detection of *Salmonella* group B, D and E using an optical surface plasmon resonance biosensor. FEMS Microbiol Lett 2003;222:75–82.
Borck B, Stryhn H, Ersboll AK, Pedersen K. Thermophilic *Campylobacter* spp. in turkey samples: evaluation of two automated enzyme immunoassays and conventional microbiological techniques. J Appl Microbiol 2002;92:574–82.
Bosilevac JM, Guerini MN, Brichta-Harhay DM, Arthur TM, Koohmaraie M. Microbiological characterization of imported and domestic boneless beef trim used for ground beef. J Food Prot 2007;70:440–9.
Brandl MT, Amundson R. Leaf age as a risk factor in contamination of lettuce with *Escherichia coli* O157: H7 and *Salmonella enterica*. Appl Environ Microbiol 2008;74:2298–306.
Breitling F, Dübel S. Recombinant antibodies. New York: John Wiley and Sons Inc; 1999. p. 154.
Brigati JR, Ripp SA, Johnson CM, Iakova PA, Jegier P, Sayler GS. Bacteriophage-based bioluminescent bioreporter for the detection of *Escherichia coli* O157: H7. J Food Prot 2007;70:1386–92.
Briones C, Mateo-Marti E, Gomez-Navarro C, Parro V, Roman E, Martin-Gago JA. Ordered self-assembled monolayers of peptide nucleic acids with DNA recognition capability. Phys Rev Lett 2004;93.
Brooks JL, Mirhabibollahi B, Kroll RG. Experimental enzyme-linked amperometric immunosensors for the detection of *Salmonellas* in foods. J Appl Bacteriol 1992;73: 189–96.
Brooks BW, Devenish J, Lutze-Wallace CL, Milnes D, Robertson RH, Berlie-Surujballi G. Evaluation of a monoclonal antibody-based enzyme-linked immunosorbent assay for detection of *Campylobacter* fetus in bovine preputial washing and vaginal mucus samples. Vet Microbiol 2004;103:77–84.
Brown CW, Li Y, Seelenbinder JA, Pivarnik P, Rand AG, Letcher SV, et al. Immunoassays based on surface enhanced infrared absorption spectroscopy. Anal Chem (Wash) 1998;70:2991–6.
Cabedo L, Barrot LPI, Canelles ATI. Prevalence of Listeria monocytogenes and *Salmonella* in ready-to-eat food in Catalonia, Spain. J Food Prot 2008;71:855–9.
Cahill D, Roben P, Quinlan N, O'Kennedy R. In: Townsend A, editor. Production of antibodies. Encyclopedia analytical scienceNew York: Academic Press; 1995. p. 2057–66.
Campbell GA, Mutharasan R. Detection of pathogen *Escherichia coli* O157: H7 using self-excited PZT-glass microcantilevers. Biosens Bioelectron 2005;21:462–73.
Camps N, Dominguez A, Company M, Perez M, Pardos J, Llobet T, et al. A foodborne outbreak of *Salmonella* infection due to overproduction of egg-containing foods for a festival. Epidemiol Infect 2005;133:817–22.
Carlin F, Broussolle V, Perelle S, Litman S, Fach P. Prevalence of *Clostridium botulinum* in food raw materials used in REPFEDs manufactured in France. Int J Food Microbiol 2004;91:141–5.
Carlyle CA, Svejcar M, Skinner MM, Preston RR, Jamerson NS, Fisher C, et al. A cell-based biosensor assay for toxin activity detection of bacterial origin. Abstr Gen Meet Am Soc Microbiol 2002;102:369.
Casas N, Amarita F, de Maranon IM. Evaluation of an extracting method for the detection of hepatitis A virus in shellfish by SYBR-green real-time RT-PCR. Int J Food Microbiol 2007;120:179–85.
CDC. Foodborne illness: frequently asked questions. Atlanta: Centers for Disease Control and Prevention; 2005.
Cereser ND, Costa FMR, Junior ODR, da Silva DAR, Sperotto VD. Foodbourne botulism. Cienc Rural 2008;38:280–7.
Chai LC, Robin T, Ragavan UM, Gunsalam JW, Abu Bakar F, Ghazali FM, et al. and Kumar, M.P., Thermophilic *Campylobacter* spp. in salad vegetables in Malaysia. Int J Food Microbiol 2007;117:106–11.
Chan SF, Chan ZCY. A review of foodborne disease outbreaks from 1996 to 2005 in Hong Kong and its implications on food safety promotion. J Food Saf 2008;28:276–99.
Chanachai K, Pittayawonganon C, Areechokchai D, Suchatsoonthorn C, Pokawattana L, Jiraphongsa C. A food borne outbreak of gastroenteritis due to *Shigella* and possibly *Salmonella* in a school. Southeast Asian J Trop Med Public Health 2008;39:297–302.
Chang YH, Chang TC, Kao EF, Chou C. Detection of protein a produced by *Staphylococcus aureus* with a fiber-optic-based biosensor. Biosci Biotechnol Biochem 1996;60:1571–4.
Che YH, Yang ZP, Li YB, Paul D, Slavik M. Rapid detection of *Salmonella typhimurium* using an immunoelectrochemical method coupled with immunomagnetic separation. J Rapid Methods Automation Microbiol 1999;7:47–59.
Che YH, Li YB, Slavik M. Detection of *Campylobacter jejuni* in poultry samples using an enzyme-linked immunoassay coupled with an enzyme electrode. Biosens Bioelectron 2001;16:791–7.
Chemburu S, Wilkins E, Abdel-Hamid I. Detection of pathogenic bacteria in food samples using highly-dispersed carbon particles. Biosens Bioelectron 2005;21:491–9.
Chen H, Barbaree JM. Effects of physiologic conditions on the rapid detection of *Salmonella typhimurium* with an acoustic wave sensor. Abstr Gen Meet Am Soc Microbiol 2002;102:361.
Chen CS, Durst RA. Simultaneous detection of *Escherichia coli* O157: H7, *Salmonella* spp. and *Listeria monocytogenes* with an array-based immunosorbent assay using universal protein G-liposomal nanovesicles. Talanta 2006;69:232–8.
Chen J, Griffiths MW. *Salmonella* detection in eggs using Lux(+) bacteriophages. J Food Prot 1996;59:908–14.
Chen Y, Knabel SJ. Multiplex PCR for simultaneous detection of bacteria of the genus *Listeria*, *Listeria monocytogenes*, and major serotypes and epidemic clones of *L-monocytogenes*. Appl Environ Microbiol 2007;73:6299–304.
Chen SH, Wu VCH, Chuang YC, Lin CS. Using oligonucleotide-functionalized Au nanoparticles to rapidly detect foodborne pathogens on a piezoelectric biosensor. J Microbiol Methods 2008;73:7-17.
Choi SH, Lee SB. Development of reverse transcriptase–polymerase chain reaction of fimA gene to detect viable *Salmonella* in milk. J Anim Sci Technol 2004;46:841–8.
Choi J-W, Oh B-K. Optical detection of pathogens using protein chip. Adv Environ Monit 2008:348–62.
Christison CA, Lindsay D, von Holy A. Microbiological survey of ready-to-eat foods and associated preparation surfaces in retail delicatessens, Johannesburg, South Africa. Food Control 2008;19:727–33.
Churchill RLT, Lee H, Hall JC. Detection of *Listeria monocytogenes* and the toxin listeriolysin O in food. J Microbiol Methods 2006;64:141–70.
Clark LC, Lyons C. Electrode systems for continuous monitoring in cardiovascular surgery. Ann N Y Acad Sci 1962;102:29–45.
Cohen N, Karib H, Saied JA, Lemee L, Guenole A, Quilici ML. Occurrence of potentially pathogens *Vibrio* from sea products marketed in Casablanca (Morocco). Rev Med Vet 2007;158:562–8.
Colakoglu FA, Sarmasik A, Koseoglu B. Occurrence of *Vibrio* spp. and *Aeromonas* spp. in shellfish harvested off Dardanelles cost of Turkey. Food Control 2006;17:648–52.
Cole K, Farnell MB, Donoghue AM, Stern NJ, Svetoch EA, Eruslanov BN, et al. Bacteriocins reduce *Campylobacter* colonization and alter gut morphology in turkey poults. Poult Sci 2006;85:1570–5.
Coons AH, Creech HJ, Jones RN, Berliner E. The demonstration of pneumococcal antigen in tissues by the use of fluorescent-antibody. J Immunol 1942;45:159–70.
Croci L, De Medici D, Di Pasquale S, Toti L. Resistance of hepatitis A virus in mussels subjected to different domestic cookings. Int J Food Microbiol 2005;105:139–44.
Crowley EL, O'Sullivan CK, Guilbault GG. Increasing the sensitivity of *Listeria monocytogenes* assays: evaluation using ELISA and amperometric detection. Analyst 1999;124:295–9.
Dao HTA, Yen PT. Study of *Salmonella*, *Campylobacter*, and *Escherichia coli* contamination in raw food available in factories, schools, and hospital canteens in Hanoi, Vietnam. Impact Emerg Zoonotic Dis Anim Health 2006;2006:262–5.
David ST, McIntyre L, MacDougal L, Kelly D, Liem S, Schallie K, et al. An outbreak of norovirus caused by consumption of oysters from geographically dispersed harvest sites, British Columbia, Canada, 2004. Foodborne Pathog Dis 2007;4:349–58.
Davis CR, Wingfield DL, Peak KK, Veguilla W, Amuso PT, Cannons AC, et al. Molecular characterization of *Vibrio parahaemolyticus* strains associated with foodborne illness in Florida. J Food Prot 2007;70:2396–401.
De Wit MAS, Widdowson MA, Vennema H, de Bruin E, Fernandes T, Koopmans M. Large outbreak of norovirus: the baker who should have known better. J Infect 2007;55: 188–93.
DeBoer E, Beumer RR. Methodology for detection and typing of foodborne microorganisms. Int J Food Microbiol 1999;50:119–30.
Deckenback J, Young CC, White JA. A sensitive method for the detection and differentiation of *Staphylococcus aureus* enterotoxins in an automated, electrochemiluminescent-based format. Abstr Gen Meet Am Soc Microbiol 2002;102: 368.
DeMarco DR, Lim DV. Detection of *Escherichia coli* O157: H7 in 10-and 25-gram ground beef samples with an evanescent-wave biosensor with silica and polystyrene waveguides. J Food Prot 2002;65:596–602.
Desai PT, Walsh MK, Weimer BC. Solid-phase capture of pathogenic bacteria by using gangliosides and detection with real-time PCR. Appl Environ Microbiol 2008;74: 2254–8.
Dey BP, Chen YR, Hsieh C, Chan DE. Detection of septicemia in chicken livers by spectroscopy. Poult Sci 2003;82:199–206.
Dickson JS, Chen JA. fast and accurate detection method of *E. coli* O157:H7 in beef. Abstr Gen Meet Am Soc Microbiol 2001;101:573.
Dressler D. Botulism caused by consumption of smoked salmon. Nervenarzt 2005;76: 763–6.
Dubois E, Hennechart C, Merle G, Burger C, Hmila N, Ruelle S, et al. Detection and quantification by real-time RT PCR of hepatitis A virus from inoculated tap waters, salad vegetables, and soft fruits: characterization of the method performances. Int J Food Microbiol 2007;117:141–9.
Eglezos S, Dykes GA, Huang B, Fegan N, Stuttard E. Bacteriological profile of raw, frozen chicken nuggets. J Food Prot 2008;71:613–5.
Ellis DI, Broadhurst D, Kell DB, Rowland JJ, Goodacre R. Rapid and quantitative detection of the microbial spoilage of meat by Fourier transform infrared spectroscopy and machine learning. Appl Environ Microbiol 2002;68:2822–8.
Ellis DI, Broadhurst D, Clarke SJ, Goodacre R. Rapid identification of closely related muscle foods by vibrational spectroscopy and machine learning. Analyst 2005;130:1648–54.
Ercole C, Del Gallo M, Mosiello L, Baccella S, Lepidi A. *Escherichia coli* detection in vegetable food by a potentiometric biosensor. Sens Actuat B Chem 2003a;91:163–8.

Ercole C, Del Gallo M, Mosiello L, Baccella S, Lepidi A. *Escherichia coli* detection in vegetable food by a potentiometric biosensor. Sens Actuat B Chem 2003b;91:163–8.
Ertl P, Mikkelsen SR. Electrochemical biosensor array for the identification of microorganisms based on lectin–lipopolysaccharide recognition. Anal Chem (Wash) 2001;73:4241–8.
Ertl P, Wagner M, Corton E, Mikkelsen SR. Rapid identification of viable *Escherichia coli* subspecies with an electrochemical screen-printed biosensor array. Biosens Bioelectron 2003;18:907–16.
Esteban JI, Oporto B, Aduriz G, Juste RA, Hurtado A. A survey of food-borne pathogens in free-range poultry farms. Int J Food Microbiol 2008;123:177–82.
Esteves A, Patarata L, Saraiva C, Martins C. Assessment of the microbiological characteristics of industrially produced Alheira, with particular reference to foodborne pathogens. J Food Saf 2008;28:88-102.
Fan Y, Chen XT, Kong JM, Tung CH, Gao ZQ. Direct detection of nucleic acids by tagging phosphates on their backbones with conductive nanoparticles. Angew Chem Int Ed 2007;46:2051–4.
FDA, Food Protection Plan. Department of health and human services. Maryland: U.S. Food and Drug Administration; 2007.
Feldsine PT, Lienau AH, Forgey RL, Calhoon RD. Assurance polyclonal enzyme immunoassay for detection of *Listeria monocytogenes* and related *Listeria* species in selected foods: collaborative study. J AOAC Int 1997a;80:775–90.
Feldsine PT, Lienau AH, Forgey RL, Calhoon RD. Visual immunoprecipitate assay (VIP) for *Listeria monocytogenes* and related *Listeria* species detection in selected foods: collaborative study. J AOAC Int 1997b;80:791–805.
Frank C, Buchholz U, Maass M, Schroder A, Bracht KH, Domke PG, et al. Protracted outbreak of *S. enteritidis* PT 21c in a large Hamburg nursing home. BMC Public Health 2007a;7.
Frank C, Walter J, Muehlen M, Jansen A, van Treeck U, Hauri AM, et al. Major outbreak of hepatitis A associated with orange juice among tourists, Egypt, 2004. Emerg Infect Dis 2007b;13:156–8.
Frank L, Markova S, Remmel N, Vysotski E, Gitelson I. Bioluminescent signal system: bioluminescence immunoassay of pathogenic organisms. Luminescence 2007c;22:215–20.
Fredriksson-Ahomaa M, Stolle A, Korkeala H. Molecular epidemiology of *Yersinia enterocolitica* infections. FEMS Immunol Med Microbiol 2006;47:315–29.
Fredriksson-Ahomaa M, Stolle A, Stephan R. Prevalence of pathogenic in pigs slaughtered *Yersinia enterocolitica* at a Swiss abattoir. Int J Food Microbiol 2007;119:207–12.
Freitas JA, Noronha GN. Occurrence of *Campylobacter* spp. in chicken meat and giblets exposed to consumption in Northern Brazil. Arq Bras Med Vet Zoo 2007;59:813–5.
Fricker M, Reissbrodt R, Ehling-Schulz M. Evaluation of standard and new chromogenic selective plating media for isolation and identification of *Bacillus cereus*. Int J Food Microbiol 2008;121:27–34.
FSAI. Annual report, 2006. Dublin: Food Safety Authority of Ireland; 2006.
Gadaga TH, Samende BK, Musuna C, Chibanda D. The microbiological quality of informally vended foods in Harare, Zimbabwe. Food Control 2008;19:829–32.
Gall, A.A., Kutyavin, I.V., Vermeulen, N.M.J., and Dempcy, R.O., 2003. Non-aggregating, non-quenching oligomers comprising nucleotide analogues; methods of synthesis and use thereof. Official Gazette of the United States Patent and Trademark Office Patents. [Patent Number: US 6660845], 1277(2), 2003.
Gallay A, Bousquet V, Siret V, Prouzet-Mauleon V, de Valk H, Vaillant V, et al. Risk factors for acquiring sporadic *Campylobacter* infection in France: results from a national case-control study. J Infect Dis 2008;197:1477–84.
Gangar V, Curiale MS, D'Onorio A, Schultz A, Johnson RL, Atrache V. VIDAS((R)) enzyme-linked immunofluorescent assay for detection of *Listeria* in foods: collaborative study. J AOAC Int 2000;83:903–18.
Gdynia HJ, Huber R, Kastrup A, Riecker A. Atypical botulism sparing palsy of extraocular muscles. Eur J Med Res 2007;12:300–1.
Gehring AG, Patterson DL, Tu SI. Use of a light-addressable potentiometric sensor for the detection of *Escherichia coli* O157: H7. Anal Biochem 1998;258:293–8.
Gehring AG, Irwin PL, Reed SA, Tu SI. Enzyme-linked immunomagnetic chemiluminescence incorporating anti-H7 and anti-O157 antibodies for the detection of *Escherichia coli* O157: H7. J Rapid Methods Automation Microbiol 2006;14:349–61.
Gellynck X, Messens W, Halet D, Grijspeerdt K, Hartnett E, Viaenei J. Economics of reducing *Campylobacter* at different levels within the Belgian poultry meat. J Food Prot 2008;71:479–85.
Ghafir Y, China B, Dierick K, De Zutter L, Daube G. A seven-year survey of *Campylobacter* contamination in meat at different production stages in Belgium. Int J Food Microbiol 2007;116:111–20.
Ghosh S, Sarker D, Misra TN. Development of an amperometric enzyme electrode biosensor for fish freshness detection. Sens Actuat B Chem 1998;53:58–62.
Ghosh M, Wahi S, Kumar M, Ganguli A. Prevalence of enterotoxigenic *Staphylococcus aureus* and *Shigella* spp. in some raw street vended Indian foods. Int J Environ Health Res 2007;17:151–6.
Gillespie BE, Mathew AG, Draughon FA, Jayarao BM, Oliver SP. Detection of *Salmonella enterica* somatic groups C1 and E1 by PCR-enzyme-linked immunosorbent assay. J Food Prot 2003;66:2367–70.
Girish R, Broor S, Dar L, Ghosh D. Foodborne outbreak caused by a Norwalk-like virus in India. J Med Virol 2002;67:603–7.
Goeller LJ, Riley MR. Discrimination of bacteria and bacteriophages by Raman spectroscopy and surface-enhanced Raman spectroscopy. Appl Spectrosc 2007;61:679–85.
Gonc S, Kinik O, Akalin S, Karagozlu C. Isolation of *Yersinia enterocolitica* in Turkish cheese varieties. Indian Vet J 2007;84:1062–3.
Gopal S, Otta SK, Kumar S, Karunasagar I, Nishibuchi M. The occurrence of *Vibrio* species in tropical shrimp culture environments; implications for food safety. Int J Food Microbiol 2005;102:151–9.
Gormley FJ, MacRae M, Forbes KJ, Ogden ID, Dallas JF, Strachan NJC. Has retail chicken played a role in the decline of human campylobacteriosis? Appl Environ Microbiol 2008;74:383–90.
Gottlieb SL, Newbern EC, Griffin PM, Graves LM, Hoekstra RM, Baker NL, et al. Multistate outbreak of listeriosis linked to Turkey deli meat and subsequent changes in US regulatory policy. Clin Infect Dis 2006;42:29–36.
Gounadaki AS, Skandamis PN, Drosinos EH, Nychas GJE. Microbial ecology of food contact surfaces and products of small-scale facilities producing traditional sausages. Food Microbiol 2008;25:313–23.
Grahek-Ogden D, Schimmer B, Cudjoe KS, Nygard K, Kapperud G. Outbreak of *Yersinia enterocolitica* serogroup O: 9 infection and processed pork, Norway. Emerg Infect Dis 2007;13:754–6.
Greening GE. Enteric viruses — a new hazard in our food? Food Aust 2006;58:589–92.
Grow AE, Wood LL, Claycomb JL, Thompson PA. New biochip technology for label-free detection of pathogens and their toxins. J Microbiol Methods 2003;53:221–33.
Guntupalli R, Hu J, Lakshmanan RS, Huang TS, Barbaree JM, Chin BA. A magnetoelastic resonance biosensor immobilized with polyclonal antibody for the detection of *Salmonella typhimurium*. Biosens Bioelectron 2007;22:1474–9.
Gupta SK, Nalluswami K, Snider C, Perch M, Balasegaram M, Burmeister D, et al. Outbreak of *Salmonella* Braenderup infections associated with Roma tomatoes, northeastern United States, 2004: a useful method for subtyping exposures in field investigations. Epidemiol Infect 2007;135:1165–73.
Hagens S, Loessner MJ. Application of bacteriophages for detection and control of foodborne pathogens. Appl Microbiol Biotechnol 2007;76:513–9.
Hahm BK, Bhunia AK. Effect of environmental stresses on antibody-based detection of *Escherichia coli* O157: H7, *Salmonella enterica* serotype *enteritidis* and *Listeria monocytogenes*. J Appl Microbiol 2006;100:1017–27.
Hahn MA, Keng PC, Krauss TD. Flow cytometric analysis to detect pathogens in bacterial cell mixtures using semiconductor quantum dots. Anal Chem 2008;80:864–72.
Hasegawa Y, Matsumoto F, Tanaka C, Ouchi Y, Hayashi K. Outbreak of hepatitis A virus infection caused by food served in a restaurant. Jpn J Infect Dis 2007;60:150–1.
Haupt K, Mosbach K. Molecularly imprinted polymers and their use in biomimetic sensors. Chem Rev 2000;100:2495–504.
Hibi K, Abe A, Ohashi E, Mitsubayashi K, Ushio H, Hayashi T, et al. Combination of immunomagnetic separation with flow cytometry for detection of *Listeria monocytogenes*. Anal Chim Acta 2006;573:158–63.
Hochel I, Slavickova D, Viochna D, Skvor J, Steinhauserova I. Detection of *Campylobacter* species in foods by indirect competitive ELISA using hen and rabbit antibodies. Food Agric Immunol 2007;18:151–67.
Hoffman AD, Wiedmann M. Comparative evaluation of culture- and BAX polymerase chain reaction-based detection methods for *Listeria* spp. and *Listeria monocytogenes* in environmental and raw fish samples. J Food Prot 2001;64:1521–6.
Huang S, Li S-Q, Yang H, Johnson M, Wan J, Chen I, et al. Optimization of phage-based magnetoelastic biosensor performance. Sens Transducers 2008;3:87–96.
Hudson JA, Lake RJ, Savill MG, Scholes P, McCormick RE. Rapid detection of *Listeria monocytogenes* in ham samples using immunomagnetic separation followed by polymerase chain reaction. J Appl Microbiol 2001;90:614–21.
Hussain I, Mahmood MS, Akhtar M, Khan A. Prevalence of *Campylobacter* species in meat, milk and other food commodities in Pakistan. Food Microbiol 2007;24:219–22.
Iqbal SS, Mayo MW, Bruno JG, Bronk BV, Batt CA, Chambers JP. A review of molecular recognition technologies for detection of biological threat agents. Biosens Bioelectron 2000;15:549–78.
Jayarao BM, Donaldson SC, Straley BA, Sawant AA, Hegde NV, Brown JL. A survey of foodborne pathogens in bulk tank milk and raw milk consumption among farm families in Pennsylvania. J Dairy Sci 2006;89:2451–8.
Jechorek RP, Johnson RL. Evaluation of the VIDAS (R) staph enterotoxin II (SET 2) immunoassay method for the detection of *Staphylococcal enterotoxins* in selected foods: collaborative study. J AOAC Int 2008;91:164–73.
Jin SS, Zhou J, Ye J. Adoption of HACCP system in the Chinese food industry: a comparative analysis. Food Control 2008;19:823–8.
Josefsen MH, Jacobsen NR, Hoorfar J. Enrichment followed by quantitative PCR both for rapid detection and as a tool for quantitative risk assessment of food-borne thermotolerant *campylobacters*. Appl Environ Microbiol 2004;70:3588–92.
Juneja VK, Fan XT, Pena-Ramos A, Diaz-Cinco M, Pacheco-Aguilar R. The effect of grapefruit extract and temperature abuse on growth of *Clostridium* perfringens from spore inocula in marinated, sous-vide chicken products. Innov Food Sci Emerg Technol 2006;7:100–6.
Jung YS, Frank JF, Brackett RE. Evaluation of antibodies for immunomagnetic separation combined with flow cytometry detection of *Listeria monocytogenes*. J Food Prot 2003;66:1283–7.
Jung EY, Kim DW, Lee DW, Cho HS, Chang SH, Park DJ. Vibrio vulnificus peritonitis after eating raw sea fish in a patient undergoing continuous ambulatory peritoneal dialysis (CAPD). Nephrol Dial Transplant 2007;22:1487-1487.
Kalasinsky KS, Hadfield T, Shea AA, Kalasinsky VF, Nelson MP, Neiss J, et al. Raman chemical imaging spectroscopy reagentless detection and identification of pathogens: signature development and evaluation. Anal Chem 2007;79:2658–73.
Kasalica A, Miocinovic D. Technical note: isolation of *Yersinia enterocolitica* from raw milk. Milchwissensch Milk Sci Int 2004;59:381–3.
Kawamura O, Emoto A. Production of monoclonal antibodies against zearalenone. Kagawa Daigaku Nogakubu Gakujutsu Hokoku 2006;58:7-11.
Kay D, Crowther J, Fewtrell L, Francis CA, Hopkins M, Kay C, et al. Quantification and control of microbial pollution from agriculture: a new policy challenge? Environ Sci Policy 2008;11:171–84.
Kegode RB, Doetkott DK, Khaitsa ML, Wesley IV. Occurrence of *Campylobacter* species, Salmonella species and generic *Escherichia coli* in meat products from retail outlets in the Fargo metropolitan area. J Food Saf 2008;28:111–25.

Khaitsa ML, Kegode RB, Doetkott DK. Occurrence of antimicrobial-resistant *Salmonella* species in raw and ready to eat Turkey meat products from retail outlets in the midwestern United States. Foodborne Pathog Dis 2007;4:517–25.
Kiba A, Toyoda K, Yoshioka K, Tsujimura K, Takahashi H, Ichinose Y, et al. A pea NTPase, PsAPY1, recognizes signal molecules from microorganisms. J Gen Plant Pathol 2006;72:238–46.
Kiess AS, Kenney PB, Nayak RR. *Campylobacter* detection in commercial turkeys. Brit Poult Sci 2007;48:567–72.
Kim, S.C., 2007. Single-stranded nucleic acid aptamer specifically binding to food-borne pathogens including *Escherichia coli*, *Salmonella* sp., listeria sp. and *Staphylococcus* sp. useful for identification and quantification of food-borne pathogens [Patent Number: KR2007054485-A; KR730359–B1], 2007.
Kim JK, Harrison MA. Transfer of *Escherichia coli* O157: H7 to romaine lettuce due to contact water from melting ice. J Food Prot 2008;71:252–6.
Kim HJ, Lee DS, Paik HD. Characterization of *Bacillus cereus* isolates from raw soybean sprouts. J Food Prot 2004;67:1031–5.
Kim JS, Lee GG, Park JS, Jung YH, Kwak HS, Kim SB, et al. A novel multiplex PCR assay for rapid and simultaneous detection of five pathogenic bacteria: *Escherichia coli* O157: H7, *Salmonella*, *Staphylococcus* aureus, *Listeria monocytogenes*, and *Vibrio parahaemolyticus*. J Food Prot 2007a;70:1656–62.
Kim S, Choi YG, Eom JW, Oh TJ, Lee KS, Kim SH, et al. An outbreak of *Salmonella enterica* serovar Othmarschen at a funeral service in Guri-si, South Korea. Jpn J Infect Dis 2007b;60:412–3.
Kimura T, Inoue A, Kawakami Y, Shirai C. Shigellosis in Kobe City, Japan, after school excursion to Malaysia and Singapore. Jpn J Infect Dis 2006;59:274-274.
Kimura B, Kimura R, Fukaya T, Sakuma K, Miya S, Fujii T. Growth and toxin production of proteolytic *Clostridium botulinum* in aseptically steamed rice products at pH 4.6 to 6.8, packed under modified atmosphere, using a deoxidant pack. J Food Prot 2008;71:468–72.
King NJ, Whyte R, Hudson JA. Presence and significance of *Bacillus cereus* in dehydrated potato products. J Food Prot 2007;70:514–20.
Kisla D, Uzgun Y. Microbiological evaluation of stuffed mussels. J Food Prot 2008;71:616–20.
Kissani N, Najib J, Amine M, Slassi I, Abid A. Food-born botulism in infants in Morocco: apropos of 5 cases. Arch Pediatr 2007;14:1324–7.
Kivaria FM, Noordhuizen J, Kapaga AM. Evaluation of the hygienic quality and associated public health hazards of raw milk marketed by smallholder dairy producers in the Dar es Salaam region, Tanzania. Trop Anim Health Prod 2006;38:185–94.
Kivi M, Hofhuis A, Notermans DW, Wannet WJB, Heck M, De Giessen AWV, et al. A beef-associated outbreak of *Salmonella typhimurium* DT104 in The Netherlands with implications for national and international policy. Epidemiol Infect 2007;135: 890–9.
Knutson HJ, Carr MA, Branham LA, Scott CB, Callaway TR. Effects of activated charcoal on binding *E-coli* O157: H7 and *Salmonella typhimurium* in sheep. Small Rum Res 2006;65:101–5.
Ko SH, Grant SA. A novel FRET-based optical fiber biosensor for rapid detection of *Salmonella typhimurium*. Biosens Bioelectron 2006;21:1283–90.
Kohler G, Milstein C. Continuous cultures of fused cells secreting antibody of predefined specificity. Nature 1975;256:495–7.
Koubova V, Brynda E, Karasova L, Skvor J, Homola J, Dostalek J, et al. Detection of foodborne pathogens using surface plasmon resonance biosensors. Sens Actuat B Chem 2001;74:100–5.
Kovacs HD, Rasky K. Testing of a chemiluminescence enzyme immunoassay for selective detection of *E-coli* O157 from ground beef samples. Acta Vet Hung 2001;49:377–83.
Kudaka J, Itokazu K, Taira K, Nidaira M, Okan S, Nakamura M, et al. Investigation and culture of microbial contaminants of *Caulerpa lentillifera* (sea grape). J Food Hyg Soc Jpn 2008;49:11–5.
Kumar S, Balakrishna K, Tuteja U, Batra HV. Application of monoclonal antibodies to flagellin of *Salmonella typhi* for its rapid detection in foods. Indian J Microbiol 2003;43:193–7.
Kumar R, Surendran PK, Thampuran N. Evaluation of culture, ELISA and PCR assays for the detection of *Salmonella* in seafood. Lett Appl Microbiol 2008;46:221–6.
Kuplulu O, Goncuoglu M, Ozdemir H, Koluman A. Incidence of *Clostridium botulinum* spores in honey in Turkey. Food Control 2006;17:222–4.
Kvenberg JE. Outbreaks of listeriosis *Listeria*-contaminated foods. Microbiol Sci 1988;5:355–8.
Lapidus A, Goltsman E, Auger S, Galleron N, Segurens B, Dossat C, et al. Extending the *Bacillus cereus* group genomics to putative food-borne pathogens of different toxicity. Chem Biol Interact 2008;171:236–49.
Lazcka O, Del Campo FJ, Munoz FX. Pathogen detection: a perspective of traditional methods and biosensors. Biosens Bioelectron 2007;22:1205–17.
Le Guyader FS, Bon F, DeMedici D, Parnaudeau S, Bertone A, Crudeli S, et al. Detection of multiple noroviruses associated with an international gastroenteritis outbreak linked to oyster consumption. J Clin Microbiol 2006;44:3878–82.
Lee EJ, Kim SG, Yoo SR, Oh SS, Hwang IG, Kwon GS, et al. Microbial contamination by *Bacillus cereus*, *Clostridium perfringens*, and *Enterobacter sakazakii* in sunsik. Food Sci Biotechnol 2007;16:948–53.
Lehtinen J, Jarvinen S, Virta M, Lilius EM. Real-time monitoring of antimicrobial activity with the multiparameter microplate assay. J Microbiol Methods 2006;66:381–9.
Leonard P, Hearty S, Brennan J, Dunne L, Quinn J, Chakraborty T, et al. Advances in biosensors for detection of pathogens in food and water. Enzyme Microb Technol 2003;32:3-13.
Leonard P, Hearty S, Quinn J, O'Kennedy R. A generic approach for the detection of whole *Listeria monocytogenes* cells in contaminated samples using surface plasmon resonance. Biosens Bioelectron 2004;19:1331–5.
Lermo A, Campoy S, Barbe J, Hernandez S, Alegret S, Pividori M. *In situ* DNA amplification with magnetic primers for the electrochemical detection of food pathogens. Biosens Bioelectron 2007;22:2010–7.
Lhafi SK, Kuhne M. Occurrence of *Vibrio* spp. in blue mussels (*Mytilus edulis*) from the German Wadden Sea. Int J Food Microbiol 2007;116:297–300.
Li J, Wang H, Cheng L, Zhao YJ, Liu HP, He NY, et al. Peptide nucleic acid (PNA) biosensors for DNA recognition. In: Tien NC, Huang QA, editors. Micromachining and microfabrication process technology and devices; 2001. p. 417–21.
Lim DV. Detection of microorganisms and toxins with evanescent wave fiber-optic biosensors. Proc IEEE 2003;91:902–7.
Lin MS, Al-Holy M, Al-Qadiri H, Kang DH, Cavinato AG, Huang YQ, et al. Discrimination of intact and injured *Listeria monocytogenes* by Fourier transform infrared spectroscopy and principal component analysis. J Agric Food Chem 2004;52: 5769–72.
Little CL, Barrett NJ, Grant K, McLauchlin J. Microbiological safety of sandwiches from hospitals and other health care establishments in the United Kingdom with a focus on *Listeria monocytogenes* and other *Listeria* species. J Food Prot 2008a;71:309–18.
Little CL, Rhoades JR, Sagoo SK, Harris J, Greenwood M, Mithani V, et al. Microbiological quality of retail cheeses made from raw, thermized or pasteurized milk in the UK. Food Microbiol 2008b;25:304–12.
Little CL, Richardson JF, Owen RJ, de Pinna E, Threlfall EJ. Campylobacter and Salmonella in raw red meats in the United Kingdom: prevalence, characterization and antimicrobial resistance pattern, 2003–2005. Food Microbiol 2008c;25:538–43.
Liu YC, Ye JM, Li YB. Rapid detection of *Escherichia coli* O157: H7 inoculated in ground beef, chicken carcass, and lettuce samples with an immunomagnetic chemiluminescence fiber-optic biosensor. J Food Prot 2003;66:512–7.
Loessner MJ. The enemys enemy is our friend: phageborne tools for detection and control of foodborne pathogens. Mitt Lebensmitt Hyg 2005;96:30–8.
Lofstrom C, Knutsson R, Axelsson CE, Radstrom P. Rapid and specific detection of *Salmonella* spp. in animal feed samples by PCR after culture enrichment. Appl Environ Microbiol 2004;70:69–75.
Loisy F, Atmar RL, Guillon P, Le Cann P, Pommepuy M, Le Guyader FS. Real-time RT-PCR for norovirus screening in shellfish. J Virol Methods 2005;123:1–7.
Ma ZF, Li JR, Liu MH, Cao J, Zou ZY, Tu J, et al. Colorimetric detection of *Escherichia coli* by polydiacetylene vesicles functionalized with glycolipid. J Am Chem Soc 1998;120:12678–9.
Macaluso A, Petrinca A, Lanni L, Saccares S, Amiti S, Gabrieli R, et al. Identification and sequence analysis of hepatitis A virus detected in market and environmental bivalve molluscs. J Food Prot 2006;69:449–52.
Macdonald KL, Eidson M, Strohmeyer C, Levy ME, Wells JG, Puhr ND, et al. A multistate outbreak of gastrointestinal illness caused by entero-toxigenic *Escherichia-coli* in imported semisoft cheese. J Infect Dis 1985;151:716–20.
Mackay RA, Goode MT, Stopa PJ, Zulich AW. Light addressable potentiometric sensor based detection of toxins and pathogens. Abstr Pap Am Chem Soc 1991;201 ENVR 69.
Maekawa F, Miura Y, Kato A, Takahashi KG, Muroga K. Norovirus contamination in wild oysters and mussels in Shiogama Bay, northeastern Japan. J Shellfish Res 2007;26:365–70.
Magan N, Pavlou A, Chrysanthakis I. Milk-sense: a volatile sensing system recognises spoilage bacteria and yeasts in milk. Sens Actuat B Chem 2001;72:28–34.
Magistrado PA, Garcia MM, Raymundo AK. Isolation and polymerase chain reaction-based detection of *Campylobacter jejuni* and *Campylobacter coli* from poultry in the Philippines. Int J Food Microbiol 2001;70:197–206.
Magliulo M, Simoni P, Guardigli M, Michelini E, Luciani M, Lelli R, et al. A rapid multiplexed chemiluminescent immunoassay for the detection of *Escherichia coli* O157: H7, *Yersinia enterocolitica*, *Salmonella typhimurium*, and *Listeria monocytogenes* pathogen bacteria. J Agric Food Chem 2007;55:4933–9.
Mahmud ZH, Neogi SB, Kassu A, Wada T, Islam MS, Nair GB, et al. Seaweeds as a reservoir for diverse *Vibrio parahaemolyticus* populations in Japan. Int J Food Microbiol 2007;118:92–6.
Makino SI, Kawamoto K, Takeshi K, Okada Y, Yamasaki A, Yamamoto S, et al. An outbreak of food-borne listeriosis due to cheese in Japan, during 2001. Int J Food Microbiol 2005;104:189–96.
Malorny B, Anderson A, Huber I. *Salmonella* real-time PCR-Nachweis. J Verbrauchersch Lebensmitt J Consum Prot Food Saf 2007;2:149–56.
Malorny B, Lofstrom C, Wagner M, Kramer N, Hoorfar J. Enumeration of *Salmonella* bacteria in food and feed samples by real-time PCR for quantitative microbial risk assessment. Appl Environ Microbiol 2008;74:1299–304.
Manges AR, Smith SP, Lau BJ, Nuval CJ, Eisenberg JNS, Dietrich PS, et al. Retail meat consumption and the acquisition of antimicrobial resistant *Escherichia coli* causing urinary tract infections: a case-control study. Foodborne Pathog Dis 2007;4: 419–31.
Manning SD, Motiwala AS, Springman AC, Qi W, Lacher DW, Ouellette LM, et al. Variation in virulence among clades of *Escherichia coli* O3157: H7, associated with disease outbreaks. Proc Natl Acad Sci U S A 2008;105:4868–73.
Markelz AG, Knab JR, Chen JY, Cerne J, Cox WA. Tagless and universal biosensor for point detection of pathogens. In: Hwu RJ, Woolard D, editors. Terahertz for military and security applications Ii; 2004. p. 182–6.
Maslanka SE, Kerr JG, Williams G, Barbaree JM, Carson LA, Miller JM, et al. Molecular subtyping of *Clostridium perfringens* by pulsed-field gel electrophoresis to facilitate food-borne-disease outbreak investigations. J Clin Microbiol 1999;37:2209–14.
Matar GM, Hayes PS, Bibb WF, Swaminathan Bala. Listeriolysin O-based latex agglutination test for the rapid detection of *Listeria monocytogenes* in foods. J Food Prot 1997;60:1038–40.
Mateo-Marti E, Briones C, Pradier CM, Martin-Gago JA. A DNA biosensor based on peptide nucleic acids on gold surfaces. Biosens Bioelectron 2007;22:1926–32.

Mathew FP, Alagesan D, Alocilja EC. Chemiluminescence detection of *Escherichia coli* in fresh produce obtained from different sources. Luminescence 2004;19:193–8.
Mattingly JA, Butman BT, Plank MC, Durham RJ, Robison BJ. Rapid monoclonal antibody-based enzyme-linked immunosorbent-assay for detection of *Listeria* in food-products. J Assoc Offic Anal Chem 1988;71:679–81.
Meeusen CA, Alocilja EC, Osburn WN. Detection of *E-coli* O157: H7 using a miniaturized surface plasmon resonance biosensor. Trans ASAE 2005;48:2409–16.
Meirelles PG, Ono MA, Ohe MCT, Maroneze DM, Itano EN, Garcia GT, et al. Detection of *Fusarium* sp contamination in corn by enzyme-linked immunosorbent assay. Food Agric Immunol 2006;17:79–89.
Melly H, Al-Emadi MA, Arwana AE, Alter T, Hamedy A, Fehlhaber K. Prevalence of *Campylobacter* spp. in Syrian poultry. Archiv Lebensmitt hyg 2007;58:180–3.
Mena C, Rodrigues D, Silva J, Gibbs P, Teixeira P. Occurrence, identification, and characterization of *Campylobacter* species isolated from Portuguese poultry samples collected from retail establishments. Poult Sci 2008;87:187–90.
Meng JH, Doyle MP. Introduction. Microbiological food safety. Microb Infect 2002;4: 395–7.
Messelhausser U, Fricker M, Ehling-Schulz M, Ziegler H, Elmer-Englhard D, Kleih W, et al. Real-time-PCR-System for detection of *Bacillus cereus* (emetic type) in the food. J Verbrauchersch Lebensmittelsich J Consum Prot Food Saf 2007;2:190–3.
Micheli L, Grecco R, Badea M, Moscone D, Palleschi G. An electrochemical immunosensor for aflatoxin M1 determination in milk using screen-printed electrodes. Biosens Bioelectron 2005;21:588–96.
Minett AI, Barisci JN, Wallace GG. Coupling conducting polymers and mediated electrochemical responses for the detection of *Listeria*. Anal Chim Acta 2003;475: 37–45.
Mitzscherling A, Kuhne M. Studies on the microbial and viral contamination status of prawns from aqua-culture. J Verbrauchersch Lebensmittelsich J Consum Prot Food Saf 2008;3:54–60.
Monk DJ, Walt DR. Optical fiber-based biosensors. Anal Bioanal Chem 2004;379:931–45.
Moore JE, Millar BC, Kenny F, Lowery CJ, Xiao LH, Rao JR, et al. Detection of *Cryptosporidium parvum* in lettuce. Int J Food Sci Technol 2007;42:385–93.
Morgan MT, Kim G, Ess D, Kothapalli A, Hahm BK, Bhunia A. Binding inhibition assay using fiber-optic based biosensor for the detection of foodborne pathogens. Advanced Nondestructive Evaluation I, Pts 1 and 2, Proceedings; 2006. p. 1145–50.
Mucchetti G, Bonvini B, Francolino S, Neviani E, Carminati D. Effect of washing with a high pressure water spray on removal of *Listeria innocua* from Gorgonzola cheese rind. Food Control 2008;19:521–5.
Muhammad-Tahir Z, Alocilja EC. A conductometric biosensor for biosecurity. Biosens Bioelectron 2003a;18:813–9.
Muhammad-Tahir Z, Alocilja EC. Fabrication of a disposable biosensor for *Escherichia coli* O157: H7 detection. IEEE Sens J 2003b;3:345–51.
Muhammad-Tahir Z, Alocilja EC. A disposable biosensor for pathogen detection in fresh produce samples. Biosys Eng 2004;88:145–51.
Mukhopadhyay A, Mukhopadhyay UK. Novel multiplex PCR approaches for the simultaneous detection of human pathogens: *Escherichia coli* O157: H7 and *Listeria monocytogenes*. J Microbiol Methods 2007;68:193–200.
Munoz-Berbel X, Vigues N, Jenkins ATA, Mas J, Munoz FJ. Impedimetric approach for quantifying low bacteria concentrations based on the changes produced in the electrode-solution interface during the pre-attachment stage. Biosens Bioelectron 2008;23:1540–6.
Murphy NM, McLauchlin J, Ohai C, Grant KA. Construction and evaluation of a microbiological positive process internal control for PCR-based examination of food samples for *Listeria monocytogenes* and *Salmonella enterica*. Int J Food Microbiol 2007;120:110–9.
Mutharasan R, Campbell GA. Flow cell for receiving piezoelectric-excited millimeter-sized cantilever sensor, to detect e.g. pathogens, in media, comprises reservoir portion having flow inlet and outlet apertures to allow flow of media across sensing surface of sensor [Patent Number: US2008034840-A1; WO2008021187-A2].
Najand LM, Ghanbarpour R. A study on enteropathogenic *Escherichia coli* isolated from domestic Iranian soft cheese. Veterinarski Arhiv 2006;76:531–6.
Nanduri V, Sorokulova IB, Samoylov AM, Simonian AL, Petrenko VA, Vodyanoy V. Phage as a molecular recognition element in biosensors immobilized by physical adsorption. Biosens Bioelectron 2007;22:986–92.
Nenonen NP, Hannoun C, Horal P, Hernroth B, Bergstrom T. Tracing of norovirus outbreak strains in mussels collected near sewage effluents. Appl Environ Microbiol 2008;74:2544–9.
Neves E, Silva AC, Roche SM, Velge P, Brito L. Virulence of *Listeria monocytogenes* isolated from the cheese dairy environment, other foods and clinical cases. J Med Microbiol 2008;57:411–5.
Nordstrom JL, Vickery MCL, Blackstone GM, Murray SL, DePaola A. Development of a multiplex real-time PCR assay with an internal amplification control for the detection of total and pathogenic *Vibrio parahaemolyticus* bacteria in oysters. Appl Environ Microbiol 2007;73:5840–7.
Normanno G, Parisi A, Addante N, Quaglia NC, Dambrosio A, Montagna C, et al. *Vibrio parahaemolyticus*, *Vibrio vulnificus* and microorganisms of fecal origin in mussels (*Mytilus galloprovincialis*) sold in the Puglia region (Italy). Int J Food Microbiol 2006;106:219–22.
Nygard K, Lassen J, Vold L, Andersson Y, Fisher I, Lofdahl S, et al. Outbreak of *Salmonella* Thompson infections linked to imported rucola lettuce. Foodborne Pathog Dis 2008;5:165–73.
O'Grady J, Sedano-Balbas S, Maher M, Smith T. and Barry, T., Rapid real-time PCR detection of *Listeria monocytogenes* in enriched food samples based on the SSR A gene, a novel diagnostic target. Food Microbiol 2008;25:75–84.
O'Beirne D. Microbial safety of fresh-cut vegetables. In: Kanlayanarat S, Toivonen PMA, Gross KC, editors. Proceedings of the international conference on quality management of fresh cut produce; 2007. p. 159–72.
O'Brien T, Johnson LH, Aldrich JL, Allen SG, Liang LT, Plummer AL, et al. The development of immunoassays to four biological threat agents in a bidiffractive grating biosensor. Biosens Bioelectron 2000;14:815–28.
Oermeci E, Oezdemir H. Prevalence of thermophilic *Campylobacter* spp. in raw milk. Milchwissenschaft 2007;62:264–5.
Ogert RA, Brown JE, Singh BR, Shriverlake LC, Ligler FS. Detection of *Clostridium-botulinum* toxin-a using a fiber optic-based biosensor. Anal Biochem 1992;205: 306–12.
Oh BK, Lee W, Lee WH, Choi JW. Nano-scale probe fabrication using self-assembly technique and application to detection of *Escherichia coli* O157: H7. Biotechnol Bioprocess Eng 2003;8:227–32.
Oh BK, Lee W, Kim YK, Lee WH, Choi JW. Surface plasmon resonance immunosensor using self-assembled protein G for the detection of *Salmonella paratyphi*. J Biotechnol 2004;111:1–8.
Ong KG, Zeng K, Yang X, Shankar K, Ruan C, Grimes CA. Quantification of multiple bioagents with wireless, remote-query magnetoelastic microsensors. IEEE Sens J 2006;6.
Oravcova K, Kuchta T, Kaclikova E. A novel real-time PCR-based method for the detection of *Listeria monocytogenes* in food. Lett Appl Microbiol 2007;45:568–73.
Pal S, Alocilja EC, Downes FP. Nanowire labeled direct-charge transfer biosensor for detecting *Bacillus* species. Biosens Bioelectron 2007;22:2329–36.
Pal S, Ying W, Alocija EC, Downes FP. Sensitivity and specificity performance of a direct-charge transfer biosensor for detecting *Bacillus cereus* in selected food matrices. Biosys Eng 2008;99:461–8.
Palumbo JD, Borucki MK, Mandrell RE, Gorski L. Serotyping of *Listeria monocytogenes* by enzyme-linked immunosorbent assay and identification of mixed-serotype cultures by colony immunoblotting. J Clin Microbiol 2003;41:564–71.
Pancrazio JJ, Whelan JP, Borkholder DA, Ma W, Stenger DA. Development and application of cell-based biosensors. Ann Biomed Eng 1999;27:697–711.
Peck MW. *Clostridium botulinum* and the safety of minimally heated, chilled foods: an emerging issue? J Appl Microbiol 2006;101:556–70.
Peng H, Shelef LA. Automated simultaneous detection of low levels of listeriae and salmonellae in foods. Int J Food Microbiol 2001;63:225–33.
Perry L, Heard P, Kane M, Kim H, Savikhin S, Dominguez W, et al. Application of multiplex polymerase chain reaction to the detection of pathogens in food. J Rapid Methods Automation Microbiol 2007;15:176–98.
Piatek, D.R. and Ramaen, D.L.J., 2001. Method for controlling the freshness of food products liable to pass an expiry date, uses a barcode reader device that reads in a conservation code when a product is opened and determines a new expiry date which is displayed [Patent Number: FR2809519-A1], 2001.
Pinu FR, Yeasmin S, Bar ML, Rahman MM. Microbiological conditions of frozen shrimp in different food market of Dhaka city. Food Sci Technol Res 2007;13:362–5.
Porter J, Edwards C, Pickup RW. Rapid assessment of physiological status in *Escherichia coli* using fluorescent probes. J Appl Bacteriol 1995;79:399–408.
Portnoy BL, Goepfert JM, Harmon SM. Outbreak of *Bacillus-cereus* food poisoning resulting from contaminated vegetable sprouts. Am J Epidemiol 1976;103: 589–94.
Quinones B, Parker CT, Janda JM, Miller WG, Mandrell RE. Detection and genotyping of *Arcobacter* and *Campylobacter* isolates from retail chicken samples by use of DNA oligonucleotide arrays. Appl Environ Microbiol 2007;73:3645–55.
Ragazani AVF, Schoken-Iturrino RP, Garcia GR, Delfino TPC, Poiatti ML, Berchielli SP. *Clostridium botulinum* spores in honey commercialized in Sao Paulo and other Brazilian states. Cienc Rural 2008;38:396–9.
Rahman S, Lipert RJ, Porter MD. Rapid screening of pathogenic bacteria using solid phase concentration and diffuse reflectance spectroscopy. Anal Chim Acta 2006;569:83–90.
Ramachandran A, Wang S, Clarke J, Ja SJ, Goad D, Wald L, et al. A universal biosensing platform based on optical micro-ring resonators. Biosens Bioelectron 2008;23: 939–44.
Ramaswamy HS, Zaman SU, Smith JP. High pressure destruction kinetics of *Escherichia coli* (O157: H7) and *Listeria monocytogenes* (Scott A) in a fish slurry. J Food Eng 2008;87:99-106.
Rasooly A, Rasooly RS. Detection and analysis of *Staphylococcal enterotoxin* A in food by Western immunoblotting. Int J Food Microbiol 1998;41:205–12.
Refseth UH, Hoidal HK, Kolpus T, Mathiesen S, Nesbakken T, Eckner K, et al. Evaluation of a new diagnostic system utilizing magnetic beads for rapid detection of *Salmonella* in food samples. Abstr Gen Meet Am Soc Microbiol 2001;101:576.
Regulation (EC) No 2073/2005 of the European Parliament and of the Council of 15 November 2005, on microbiological criteria for foodstuffs, 2005.
Reymond F, Rossier JS, Morier P. Amperometric detection method for determining presence, amount, or concentration of analyte in microfluidic sensor by filling microfluidic sensor with sample to be analyzed, and performing amperometry to detect the analyte [Patent Number: WO2007115694-A2; WO2007115694-A3].
Rider TH, Petrovick MS, Nargi FE, Harper JD, Schwoebel ED, Mathews RH, et al. A B cell-based sensor for rapid identification of pathogens. Science 2003;301:213–5.
Riyaz-Ul-Hassan S, Verma V, Qazi GN. Evaluation of three different molecular markers for the detection of *Staphylococcus aureus* by polymerase chain reaction. Food Microbiol 2008;25:452–9.
Ronner AC, Lindmark H. Quantitative detection of *Campylobacter jejuni* on fresh chicken carcasses by real-time PCR. J Food Prot 2007;70:1373–8.
Ruan C, Wang H, Li Y. A bienzyme electrochemical biosensor coupled with immunomagnetic separation for rapid detection of *Escherichia coli* O15: H7 in food samples. Trans ASAE 2002;45:249–55.
Ruan CM, Zeng KF, Varghese OK, Grimes CA. A staphylococcal enterotoxin B magnetoelastic immunosensor. Biosens Bioelectron 2004;20:585–91.
Sallam KI. Prevalence of *Campylobacter* in chicken and chicken by-products retailed in Sapporo area, Hokkaido, Japan. Food Control 2007;18:1113–20.

Sanchez G, Bosch A, Pinto RM. Hepatitis A virus detection in food: current and future prospects. Lett Appl Microbiol 2007;45:1–5.
Sanders SQ, Boothe DH, Frank JF, Arnold JW. Culture and detection of *Campylobacter jejuni* within mixed microbial populations of biofilms on stainless steel. J Food Prot 2007;70:1379–85.
Sawata S, Kai E, Ikebukuro K, Iida T, Honda T, Karube I. Application of peptide nucleic acid to the direct detection of deoxyribonucleic acid amplified by polymerase chain reaction. Biosens Bioelectron 1999;14:397–404.
Schimmer B, Nygard K, Eriksen HM, Lassen J, Lindstedt BA, Brandal LT, et al. Outbreak of haemolytic uraemic syndrome in Norway caused by stx(2)-positive *Escherichia coli* O103: H25 traced to cured mutton sausages. BMC Infect Dis 2008;8.
Schlosser G, Kacer P, Kuzma M, Szilagyi Z, Sorrentino A, Manzo C, et al. Coupling immunomagnetic separation on magnetic beads with matrix-assisted laser desorption ionization-time of flight mass spectrometry for detection of staphylococcal enterotoxin B. Appl Environ Microbiol 2007;73:6945–52.
Schmilovitch Z, Mizrach A, Alchanatis V, Kritzman G, Korotic R, Irudayaraj J, et al. Detection of bacteria with low-resolution Raman spectroscopy. Trans ASAE 2005;48: 1843–50.
Schneid AD, Ludtke CB, Diel C, Aleixo JAG. Production and caracterization of monoclonal antibodies for the detection of *Salmonella enterica* in chicken meat. Braz J Microbiol 2005;36:163–9.
Schneid AD, Rodrigues KL, Chemello D, Tondo EC, Ayub MAZ, Aleixo JAG. Evaluation of an indirect ELISA for the detection of *Salmonella* in chicken meat. Braz J Microbiol 2006;37:350–5.
Seelenbinder JA, Brown CW, Pivarnik P, Rand AG. Colloidal gold filtrates as metal substrates for surface-enhanced infrared absorption spectroscopy. Anal Chem (Wash) 1999;71:1963–6.
Sehgal R, Kumar Y, Kumar S. Prevalence and geographical distribution of *Escherichia coli* O157 in India: a 10-year survey. Trans R Soc Trop Med Hyg 2008;102:380–3.
Selma MV, Beltran D, Chacon-Vera E, Gil MI. Effect of ozone on the inactivation of *Yersinia enterocolitica* and the reduction of natural flora on potatoes. J Food Prot 2006;69:2357–63.
Selma MV, Beltran D, Allende A, Chacon-Vera E, Gil MI. Elimination by ozone of *Shigella sonnei* in shredded lettuce and water. Food Microbiol 2007;24:492–9.
Seo KH, Brackett RE, Hartman NF, Campbell DP. Development of a rapid response biosensor for detection of *Salmonella typhimurium*. J Food Prot 1999;62:431–7.
Sergeev N, Distler M, Courtney S, Al-Khaldi SF, Volokhov D, Chizhikov V, et al. Multipathogen oligonucleotide microarray for environmental and biodefense applications. Biosens Bioelectron 2004;20:684–98.
Sewell AM, Warburton DW, Boville A, Daley EF, Mullen K. The development of an efficient and rapid enzyme linked fluorescent assay method for the detection of *Listeria* spp. from foods. Int J Food Microbiol 2003;81:123–9.
Shearer AEH, Strapp CM, Joerger RD. Evaluation of a polymerase chain reaction-based system for detection of *Salmonella enteritidis*, *Escherichia coli* O157: H7, *Listeria* spp., and *Listeria monocytogenes* on fresh fruits and vegetables. J Food Prot 2001;64: 788–95.
Shieh YC, Khudyakov YE, Xia G, Ganova-Raeva LM, Khambaty FM, Woods JW, et al. Molecular confirmation of oysters as the vector for hepatitis A in a 2005 multistate outbreak. J Food Prot 2007;70:145–50.
Shim WB, Choi JG, Kim JY, Yang ZY, Lee KH, Kim MG, et al. Production of monoclonal antibody against *Listeria monocytogenes* and its application to immunochromatography strip test. J Microbiol Biotechnol 2007;17:1152–61.
Shuler C, Drenzek C, Lance S, Gonzalez G, Miller J, Tohin-Dangelo M, et al. Botulism associated with commercial carrot juice — Georgia and Florida, September 2006. Morb Mortal Wkly Rep 2006;55:1098–9.
Silbert L, Ben Shlush I, Israel E, Porgador A, Kolusheva S. and Jelinek, R., Rapid chromatic detection of bacteria by use of a new biomimetic polymer sensor. Appl Environ Microbiol 2006;72:7339–44.
Simpson JM, Lim DV. Rapid PCR confirmation of *E. coli* 0157: H7 after evanescent wave fiber optic biosensor detection. Biosens Bioelectron 2005;21:881–7.
Sincero TCM, Levin DB, Simoes CMO, Barardi CRM. Detection of hepatitis A virus (HAV) in oysters (*Crassostrea gigas*). Water Res 2006;40:895–902.
Singh A, Glass N, Tolba M, Brovko L, Griffiths M, Evoy S. Immobilization of bacteriophages on gold surfaces for the specific capture of pathogens. Biosens Bioelectron 2009;24:3645–51.
Siragusa GR, Line JE, Schutz AR. Fluorescent detection of *Campylobacter* spp. on colony immunoblots. Abstr Gen Meet Am Soc Microbiol 2001;101:577.
Sireli UT, Gucukoglu A. Prevalence and antibiotic resistance of *Listeria* spp. isolated from ready-to-eat foods in Ankara. Turkish Journal of Veterinary & Animal. Sciences 2008;32:131–5.
Siriken B. The presence of *Yersinia enterocolitica* and other *Yersinia* species in ground beef in Aydin, Turkey. Turk J Vet Anim Sci 2004;28:489–95.
Slavik R, Homola J, Brynda E. A miniature fiber optic surface plasmon resonance sensor for fast detection of staphylococcal enterotoxin B. Biosens Bioelectron 2002;17:591–5.
Solve M, Boel J, Norrung B. Evaluation of a monoclonal antibody able to detect live *Listeria monocytogenes* and *Listeria innocua*. Int J Food Microbiol 2000;57:219–24.
Song J, Cheng Q, Zhu SM, Stevens RC. "Smart" materials for biosensing devices: cell-mimicking supramolecular assemblies and colorimetric detection of pathogenic agents. Biomed Microdev 2002;4:213–21.
Stark R, Made D. Detection of *Salmonella* in foods — experience with a combination of microbiological and molecular biological methods. Fleischwirtschaft 2007;87: 98-101.
Steichen M, Decrem Y, Godfroid E, Buess-Herman C. Electrochemical DNA hybridization detection using peptide nucleic acids and [Ru(NH3)(6)](3+) on gold electrodes. Biosens Bioelectron 2007;22:2237–43.
Stephan R, Schumacher S, Zychowska MA. The VITR technology for rapid detection of *Listeria monocytogenes* and other *Listeria* spp. Int J Food Microbiol 2003;89:287–90.
Stoyanchev T, Vashin I, Ring C, Atanassova V. Prevalence of *Campylobacter* spp. in poultry and poultry products for sale on the Bulgarian retail market. Antonie Van Leeuwenhoek Int J Gen Mol Microbiol 2007;92:285–8.
Strachan NJC, Gray DI. A rapid general-method for the identification of PCR products using a fiberoptic biosensor and its application to the detection of *Listeria*. Lett Appl Microbiol 1995;21:5–9.
Su XL, Li YB. A QCM immunosensor for *Salmonella* detection with simultaneous measurements of resonant frequency and motional resistance. Biosens Bioelectron 2005;21:840–8.
Su H-P, Chin S-I, Tsai J-L, Lee C-L, Pan T-M. Bacterial food-borne illness outbreaks in northern Taiwan, 1995–2001. J Infect Chemother 2005a;11:146–51.
Su YL, Li JR, Jiang L, Cao J. Biosensor signal amplification of vesicles functionalized with glycolipid for colorimetric detection of *Escherichia coli*. J Colloid Interface Sci 2005b;284:114–9.
Subramanian A, Irudayaraj J, Ryan T. A mixed self-assembled monolayer-based surface plasmon immunosensor for detection of *E-coli* O157: H7. Biosens Bioelectron 2006;21:998-1006.
Sulonen J, Karenlampi R, Holma U, Hanninen ML. *Campylobacter* in Finnish organic laying hens in autumn 2003 and spring 2004. Poult Sci 2007;86:1223–8.
Sumner J, Ross T. A semi-quantitative seafood safety risk assessment. Int J Food Microbiol 2002;77:55–9.
Sunwoo HH, Wang WW, Sim JS. Detection of *Escherichia coli* O157:H7 using chicken immunoglobulin Y. Immunol Lett 2006;106:191–3.
Susmel S, Guilbault GG, O'Sullivan CK. Demonstration of labeless detection of food pathogens using electrochemical redox probe and screen printed gold electrodes. Biosens Bioelectron 2003;18:881–9.
Taylor E. A new method of HACCP for the catering and food service industry. Food Control 2007;19:126–34.
Taylor AD, Yu QM, Chen SF, Homola J, Jiang SY. Comparison of *E-coli* O157: H7 preparation methods used for detection with surface plasmon resonance sensor. Sens Actuat B Chem 2005;107:202–8.
Taylor AD, Ladd J, Yu QM, Chen SF, Homola J, Jiang SY. Quantitative and simultaneous detection of four foodborne bacterial pathogens with a multi-channel SPR sensor. Biosens Bioelectron 2006;22:752–8.
Thongsawad S, Baumann M, Graubaum D, Hildebrandt G, Khattiya R, Zessin KH, et al. Research about the prevalence of norovirus in Pacific White Shrimps (*Litopeneaus vannamei*) in Thailand. Archiv Lebensmitt hyg 2007;58:86–90.
Tokarskyy O, Marshall DL. Immunosensors for rapid detection of *Escherichia coli* O157: H7 — perspectives for use in the meat processing industry. Food Microbiol 2008;25: 1-12.
Tokuzaki S, Takahashi M. An outbreak of nalidixic acid-resistant *Salmonella enterica serovar enteritidis* at a nursery school in Kitakyushu City, Japan. Jpn J Infect Dis 2007;60:62-62.
Touron A, Berthe T, Pawlak B, Petit F. Detection of *Salmonella* in environmental water and sediment by a nested-multiplex polymerase chain reaction assay. Res Microbiol 2005;156:541–53.
Toze S. PCR and the detection of microbial pathogens in water and wastewater. Water Res 1999;33:3545–56.
Tsai TY, Lee WJ, Huang YJ, Chen KL, Pan TM. Detection of viable enterohemorrhagic *Escherichia coli* O157 using the combination of immunomagnetic separation with the reverse transcription multiplex TaqMan PCR system in food and stool samples. J Food Prot 2006;69:2320–8.
Tully E, Higson SP, Kennedy RO. The development of a 'labeless' immunosensor for the detection of *Listeria monocytogenes* cell surface protein, Internalin B. Biosens Bioelectron 2008;23:906–12.
Umali-Deininger D, Sur M. Food safety in a globalizing world: opportunities and challenges for India. Agric Econ 2007;37:135–47.
Unicomb LE, Dalton CB, Gilbert GL, Becker NG, Patel MS. Age-specific risk factors for sporadic *Campylobacter* infection in regional Australia. Foodborne Pathog Dis 2008;5:79–85.
Urabe Y, Minai Y, Haga M, Sugita-Konishi Y, Ishiguro A, Hara-Kudo Y. Survival of *Salmonella* in spices and growth in cooked food. J Food Hyg Soc Jpn 2008;49:70–5.
Uyttendaele M, Bastiaansen A, Debevere J. Evaluation of the NASBA® nucleic acid amplification system for assessment of the viability of *Campylobacter jejuni*. Int J Food Microbiol 1997;37:13–20.
Valdivieso-Garcia A, Desruisseau A, Riche E, Fukuda S, Tatsumi H. Evaluation of a 24-hour bioluminescent enzyme immunoassay for the rapid detection of *Salmonella* in chicken carcass rinses. J Food Prot 2003;66:1996–2004.
Valentin-Bon I, Jacobson A, Monday SR, Feng PCH. Microbiological quality of bagged cut spinach and lettuce mixes. Appl Environ Microbiol 2008;74:1240–2.
Van TTH, Moutafis G, Istivan T, Tran LT, Coloe PJ. Detection of *Salmonella* spp. in retail raw food samples from Vietnam and characterization of their antibiotic resistance. Appl Environ Microbiol 2007;73:6885–90.
Varkey S, Cannons AC, Lim DV. Enhanced detection of DNA fragments with an evanescent biosensor using a signal amplification system. Abstr Gen Meet Am Soc Microbiol 2002;102:145.
Varshney M, Yang LJ, Su XL, Li YB. Magnetic nanoparticle-antibody conjugates for the separation of *Escherichia coli* 0157: H7 in ground beef. J Food Prot 2005;68: 1804–11.
Vasavada PC. Pathogens and public-health concerns in ice cream. In: Tharp B, editor. Ice Cream Ii; 2004. p. 312–25.
Vaughan RD, O'Sullivan CK, Guilbault GG. Development of a quartz crystal microbalance (QCM) immunosensor for the detection of *Listeria monocytogenes*. Enzyme Microb Technol 2001;29:635–8.

Vindigni SM, Srijan A, Wongstitwilairoong B, Marcus R, Meek J, Riley PL, et al. Prevalence of foodborne microorganisms in retail foods in Thailand. Foodborne Pathog Dis 2007;4:208–15.
Vo-Dinh T, Cullum B. Biosensors and biochips: advances in biological and medical diagnostics. Fresenius J Anal Chem 2000;366:540–51.
Vojdani JD, Beuchat LR, Tauxe RV. Juice-associated outbreaks of human illness in the United States, 1995 through 2005. J Food Prot 2008;71:356–64.
Warminska-Radyko I, Laniewska-Trokenheim L, Miks M. Microbiological contamination of vegetable salads. Polish J Nat Sci 2007;22:733–41.
Warren BR, Parish ME, Schneider KR. Shigella as a foodborne pathogen and current methods for detection in food. Crit Rev Food Sci Nutr 2006;46:551–67.
Warren BR, Yuk HG, Schneider KR. Survival of *Shigella sonnei* on smooth tomato surfaces, in potato salad and in raw ground beef. Int J Food Microbiol 2007;116: 400–4.
Warren RE, Ensor VM, O'Neill P, Butler V, Taylor J, Nye K, et al. Imported chicken meat as a potential source of quinolone-resistant *Escherichia coli* producing extended-spectrum beta-lactamases in the UK. J Antimicrob Chemother 2008;61:504–8.
Waswa J, Irudayaraj J, DebRoy C. Direct detection of *E-Coli* O157: H7 in selected food systems by a surface plasmon resonance biosensor. Lwt-Food Sci Technol 2007;40:187–92.
Weagant SD. A new chromogenic agar medium for detection of potentially virulent *Yersinia enterocolitica*. J Microbiol Methods Feb 2008;72:185–90.
Webby RJ, Carville KS, Kirk MD, Greening G, Ratcliff RM, Crerar SK, et al. Internationally distributed frozen oyster meat causing multiple outbreaks of norovirus infection in Australia. Clin Infect Dis 2007;44:1026–31.
Wei D, Oyarzabal OA, Huang TS, Balasubramanian S, Sista S, Simoman AL. Development of a surface plasmon resonance biosensor for the identification of *Campylobacter jejuni*. J Microbiol Methods 2007;69:78–85.
Weller TH, Coons AH. Fluorescent antibody studies with agents of varicella and herpes zoster propagated *in vitro*. Proc Soc Exp Biol Med 1954;86:789–94.
Wheeler C, Vogt TM, Armstrong GL, Vaughan G, Weltman A, Nainan OV, et al. An outbreak of hepatitis A associated with green onions. N Engl J Med 2005;353:890–7.
WHO, international health regulations. The fifty-eighth world health assembly. Geneva: World Health Organization; 2005.
WHO. Food safety & food-borne illness. fact sheet no. 237 (reviewed March 2007). Geneva: World Health Organization; 2007a.
WHO. The world health report, 2007. Global public health security in the 21st century. Geneva: World Health Organization; 2007b.
Whyte P, Fanning S, O'Mahony M, O'Mahony R, Drudy D. Public health and economic burden of infectious food-borne diseases in Ireland. Ir Vet J 2005;58:279–83.
Wichmann-Schauer H, Kirschfeld R, Alpers K, Malorny B, Krokotsch B, Geuss-Fosu U, et al. Investigation of a foodborne outbreak caused by *Salmonella enteritidis* in confectionery during a sports event in Berlin, July 2006. Archiv Lebensmitt hyg 2006;57:172–9.
Wiwanitkit V. Ecology of *Clostridium botulinum* causing food-borne botulism in Thailand. Southeast Asian J Trop Med Public Health 2006;37:1160–2.
Wolf S, Williamson WM, Hewitt J, Rivera-Aban M, Lin S. Ball, A, Scholes, P., Greening, G.E., Sensitive multiplex real-time reverse transcription-PCR assay for the detection of human and animal noroviruses in clinical and environmental samples. Appl Environ Microbiol 2007;73:5464–70.
Wong HC, Liu SH. Characterization of the low-salinity stress in *Vibrio vulnificus*. J Food Prot 2008;71:416–9.
Wong TL, Hollis L, Cornelius A, Nicol C, Cook R, Hudson JA. Prevalence, numbers, and subtypes of *Campylobacter jejuni* and *Campylobacter coli* in uncooked retail meat samples. J Food Prot 2007;70:566–73.
Workman SN, Mathison GE, Lavoie MC. An investigation of sources of *Campylobacter* in a poultry production and packing operation in Barbados. Int J Food Microbiol 2008;121:106–11.
WTO. International trade statistics. Geneva: World Trade Organization; 2007.
Xie F, Yang H, Li S, Shen W, Wan J, Johnson ML, et al. Amorphous magnetoelastic sensors for the detection of biological agents. Intermetallics 2009;17:270–3.
Xu HS, Roberts N, Singelton FL, Attwell RW, Grimes DJ, Colwell RR. Survival and viability of non-culturable *Escherichia coli* and *Vibrio cholerae* in the estuarine and marine environment. Microb Ecol 1982;8:313–23.
Yang L, Bashir R. Electrical/electrochemical impedance for rapid detection of foodborne pathogenic bacteria. Biotechnol Adv 2008;26:135–50.
Yang LJ, Ruan CM, Li YB. Rapid detection of Salmonella typhimurium in food samples using a bienzyme electrochemical biosensor with flow injection. J Rapid Methods Automation Microbiol 2001;9:229–40.
Yang LJ, Li YB, Griffis CL, Johnson MG. Interdigitated microelectrode (IME) impedance sensor for the detection of viable *Salmonella typhimurium*. Biosens Bioelectron 2004;19:1139–47.
Yaron S, Matthews KR. A reverse transcriptase–polymerase chain reaction assay for detection of viable *Escherichia coli* O157:H7: investigation of specific target genes. J Appl Microbiol 2002;92:633–40.
Ye J, Liu Y, Li Y. A chemiluminescence fiber-optic biosensor coupled with immunomagnetic separation for rapid detection of *E-coli* O15: H7. Trans ASAE 2002;45:473–8.
Yoda K, Uchimura M. An outbreak of *Campylobacter jejuni* food poisoning caused by secondary contamination in cooking practice at a high school. Jpn J Infect Dis 2006;59:408–9.
Yokoyama K, Ito M, Agata N, Isobe M, Shibayama K, Horii T, et al. Pathological effect of synthetic cereulide, an emetic toxin of *Bacillus cereus*, is reversible in mice. FEMS Immunol Med Microbiol 1999;24:115–20.
Yu CX, Irudayaraj J, Debroy C, Schmilovtich Z, Mizrach A. Spectroscopic differentiation and quantification of microorganisms in apple juice. J Food Sci 2004a;69:S268–72.
Yu KY, Noh Y, Chung MS, Park HJ, Lee N, Youn M, et al. Use of monoclonal antibodies that recognize p60 for identification of *Listeria monocytogenes*. Clin Diagn Lab Immunol 2004b;11:446–51.
Yucel N, Ulusoy H. A Turkey survey of hygiene indicator bacteria and *Yersinia enterocolitica* in raw milk and cheese samples. Food Control 2006;17:383–8.
Zhao ZJ, Liu XM. Preparation of monoclonal antibody and development of enzyme-linked immunosorbent assay specific for *Escherichia coli* O157 in foods. Biomed Environ Sci 2005;18:254–9.
Zhao JX, Jedlicka SS, Lannu JD, Bhunia AK, Rickus JL. Liposome-doped nanocomposites as artificial-cell-based biosensors: detection of listeriolysin O. Biotechnol Prog 2006;22:32–7.
Zhao GY, Xing FF, Deng SP. A disposable amperometric enzyme immunosensor for rapid detection of *Vibrio parahaemolyticus* in food based on agarose/nano-Au membrane and screen-printed electrode. Electrochem Commun 2007;9:1263–8.
Zimmerman AM, DePaola A, Bowers JC, Krantz JA, Nordstrom JL, Johnson CN, et al. Variability of total and pathogenic *Vibrio parahaemolyticus* densities in northern Gulf of Mexico water and oysters. Appl Environ Microbiol 2007;73:7589–96.