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REVIEW PAPER

Involvement of Egyptian Foods in Foodborne Viral Illnesses: The Burden on Public Health and Related Environmental Risk Factors: An Overview

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Abstract
Foodborne viral diseases are a major public health threat and pose a huge burden on the economies of both developed and developing countries. Enteric viruses are the causative agents of most foodborne illnesses and outbreaks. Egypt is classified by WHO among the regions with intermediate to high endemicity for various enteric viruses. This is manifested by the high prevalence rates of different enteric virus infections among Egyptian population such as Hepatitis A and E viruses, human rotaviruses, human noroviruses, human astroviruses, and human adenovirus. Recently, a number of foodborne gastroenteritis and acute hepatitis outbreaks have occurred in the US, Canada, Australia, and the European Union countries. Some of these outbreaks were attributed to the consumption of minimally processed foods imported from Egypt indicating the possibility that Egyptian foods may also be partially responsible for high prevalence of enteric virus infections among Egyptian population. In the absence of official foodborne-pathogen surveillance systems, evaluating the virological safety of Egyptian foods is a difficult task. In this review, we aim to provide a preliminary evaluation of the virological safety of Egyptian foods. A comprehensive review of prevalence studies on enteric virus infections shows hyperendemicity of several enteric viruses in Egypt and provides strong evidence of implication of Egyptian foods in these infections. We also address possible environmental risk factors that may lead to the contamination of Egyptian foods with enteric viruses. In addition, we describe potential obstacles to any plan that might be considered for improving the virological safety of Egyptian foods.

Keywords Acute gastroenteritis · Acute hepatitis · Astrovirus · Egyptian foods · Enteric viruses · Foodborne viral diseases · Hepatitis A virus · Hepatitis E virus · Human norovirus · Rotavirus

Introduction

Microbial contamination of food is one of the most important routes of illness worldwide (Odeyemi and Bamidele 2016). More than 250 sources of foodborne diseases have been identified globally, most of them being caused by microbial pathogens including bacteria, viruses, protozoans, and fungi (CDC 2018b). Of these pathogens, foodborne viruses, such as human noroviruses (HuNoVs), are responsible for more than 50% of foodborne illnesses in the US (Scallan et al. 2011). A majority of viruses implicated in foodborne diseases are enteric viruses that infect the gastrointestinal tract of humans, excreted in human feces, and transmitted by the fecal–oral route (Greening and Cannon 2016). Five enteric viruses [Human Norovirus (HuNoVs), Hepatitis A virus (HAV), Human Rotaviruses (HRVs), Human Astroviruses (HAstVs), and Human sapovirus] are included among the 31 pathogens identified as the major foodborne pathogens in the US (Scallan et al. 2011).

Because of the increasing number of foodborne outbreaks, several countries such as the US, Canada, the European Union, and Australia have imposed stricter food-quality regulations. In addition, some of these countries have established several surveillance systems for viral contaminants in foods. This information is available to enforcement authorities to take all possible actions to control disease and prevent

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public health problems. However, such systems do not exist in a vast majority of developing countries, and hence, there is dearth of information regarding foodborne diseases in these countries (Grace 2015; Odeyemi and Bamidele 2016).

In Egypt as well, information on foodborne outbreaks, number of cases, causative agent, point of infection, and implicated food is not available. However, an increasing number of enteric virus outbreaks are linked with minimally processed vegetables and fruits exported from Egypt (Swinkels et al. 2014; CDC 2016c; Franklin et al. 2019). Thus, a number of importing countries have banned the import of some Egyptian crops (Beach 2016; Coveny 2016; Gulf News 2017; Reuters 2017), which will ultimately hurt the Egyptian economy. The Egyptian authorities have denied these reports and claimed that Egyptian fruits and vegetables are free of viral pathogens (Flynn 2016). In the absence of a surveillance system, this official reaction does not appear logical. Instead, these authorities should devise executive action toward improving the virological safety of Egyptian foods. This review is a preliminary evaluation of the virological quality of Egyptian foods using the limited data available on this subject. Our hope is that the information provided herein would spur the Egyptian authorities to adopt comprehensive strategies for monitoring and improving the virological safety of foods in Egypt.

Global Burden of Foodborne Viral Diseases

Gastroenteritis results in approximately 1.8 million deaths (17% of all deaths) in children below the age of 5 years worldwide. In a large number of these cases, the causative agent is transmitted through contaminated food and water (WHO 2004, 2007), which are an important cause of morbidity and mortality, and a significant impediment to socioeconomic development in the world (WHO 2015). It has been estimated that consumption of contaminated food results in one illness per 10 people (~ 600 million) and leads to 420,000 deaths each year, 30% of which are in children < 5 years of age (WHO 2015). It has been estimated that 76 million people in the U.S. suffer each year from foodborne illnesses (Mead et al. 1999; Newell et al. 2010). The estimated number of annual foodborne illnesses in the Europe is 23 million cases, including 3 million children < 5 years of age (WHO 2015). In the WHO African region, the estimated annual foodborne illnesses is > 91 million cases with 137,000 deaths (WHO 2015). The annual cost of foodborne illnesses in the U.S. is approximately $77.7 billion USD (Scharff 2012). In Europe, $171 million and $2 million USD were the estimated annual costs to Sweden and Croatia, respectively (Razem and Katusin-Razem 1994; Toljander et al. 2012). The costs in Australia and New Zealand were approximately 1.3 billion and $86 million USD each year, respectively (McPherson et al. 2011; Lake et al. 2010).

Human enteric viruses are increasingly recognized as a major cause of foodborne outbreaks of gastroenteritis. These viruses infect the human gastrointestinal tract followed by being shed in human feces. They are transmitted by the fecal–oral route and consumption of contaminated foods. In the US, viruses were responsible for 35% and 11% of total hospitalization and death cases linked to foodborne illnesses, respectively (Scallan et al. 2011). In 2012 and 2017, viruses were responsible for 14% and 7.8% of all reported foodborne outbreaks in the European Union, respectively (EFSA 2014, 2019). Enteric viruses include human noroviruses (HuNoVs), sapoviruses (SAV), enteroviruses (EVs), human adenoviruses (HAdV), hepatitis A virus (HAV), hepatitis E virus (HEV), human rotaviruses (HRVs), and human astroviruses (HAstVs). Most of these viruses have been associated with foodborne disease outbreaks (Greening and Cannon 2016) but human norovirus and HAV are considered as the leading causes of viral foodborne illnesses (Koopmans and Duizer 2004; Ahmed et al. 2014b). The characteristics and global burden of some of the important foodborne viruses are described below.

Human Norovirus (HuNoVs)

Noroviruses are small (28–35 nm), nonenveloped viruses belonging to the family *Caliciviridae*. Their genome is composed of a linear, ~ 7.6 kb single-stranded positive-sense RNA (+ssRNA) (Buesa and Rodriguez-Díaz 2016). They are the cause of "winter-vomiting disease" or "stomach-flu" (ECDC 2013b). In the U.S. alone, HuNoVs cause 19–21 million cases of acute gastroenteritis annually; including 1.7–1.9 million outpatient visits, 400,000 emergency room visits, 56,000–71,000 hospitalizations, and 570–800 deaths (CDC 2016a). The highest rate of death associated with HuNoVs occurs in adults aged ≥ 65 years (Hall et al. 2012a) while children aged < 5 years have the highest rates of HuNoVs-associated medical care visits (Gastañaduy et al. 2013; Hall 2016; Lopman et al. 2011). About 48% of all foodborne disease outbreaks due to a single known cause from 2009 to 2012 in the US were due to HuNoVs (CDC 2016a). In the EU, HuNoVs were responsible for 97 of 104 foodborne viral outbreaks in 2012 (EFSA 2014). In addition, HuNoVs were responsible for 5.7 million infections, 800,000 medical visits, 53,000 hospitalizations, and 102 deaths among children less than 5 years old between 2003 and 2013 in Europe (Kowalzik et al. 2015). In 2017 alone, HuNoVs were responsible for 211 foodborne and waterborne outbreaks (6550 cases) in the EU (EFSA 2019). Globally, HuNoVs are responsible for 685 million gastroenteritis cases including 200 million among children < 5 years old

(CDC 2016a). Over 200,000 deaths annually are caused by HuNoVs in developing countries (Lopman et al. 2016). The annual global economic burden of HuNoVs is estimated to be $4.2 billion as direct health system costs and $60.3 billion as societal costs (Bartsch et al. 2016). HuNoVs are transmitted mainly by close personal contact with an infected person or through the fecal–oral route when a person consumes contaminated food or water (CDC 2016a).

Hepatitis A Virus (HAV)

The HAV is a 27–32 nm nonenveloped, positive-sense, single-stranded RNA virus with a 7.5 kbp genome. The virus is classified in the Heptovirus genus under the family *Picornaviridae* (Greening and Cannon 2016). Hepatitis A is a serious foodborne infection and hence is a notifiable disease in most of the developed countries (Todd and Grieg 2015; Greening and Cannon 2016). Transmission occurs by the fecal–oral route, by direct contact with an infected person or by ingestion of HAV-contaminated food or water (CDC 2017a). In the developed countries, the number of HAV cases has declined due to good sanitary infrastructure and because of routine immunization of children and adults traveling to endemic regions (Fiore et al. 2006). For instance, the prevalence of hepatitis A in the U.S. has declined by 95% since a vaccine became available in 1995 (NNDSS 2017). In 2016, only 2007 cases of HAV were reported in the US (CDC 2017b). In the EU, only 591 cases traced to 90 HAV foodborne and waterborne outbreaks were reported in 2017 (EFSA 2019).

Worldwide, more than 46 million HAV cases including 13.7 million foodborne HAV illnesses and 27,700 deaths annually have been estimated by WHO (2015). In addition, 200 million asymptomatic carriers are estimated annually worldwide (WHO, 2014). In recent years, the incidence of HAV infection in many countries has been declining because of the progressive improvement in sewage treatment and hygiene practices. Unfortunately, this has also led to a lowering of the immunity in these populations and has consequently led to an increase in susceptibility to the disease (Greening and Cannon 2016). As a result, the risk of contracting HAV infection from foods imported from regions of the world where HAV is endemic is increasing.

Human Rotaviruses (HRVs)

Human rotaviruses (HRVs) belong to the genus Rotavirus under the *Reoviridae* family (Carstens 2010) and were the leading cause of severe diarrhea among infants and young children in the U.S. before rotavirus vaccine became available in 2006 (Todd and Grieg 2015). Prior to vaccine availability, almost all the U.S. children were infected with rotavirus before their 5th birthday. The Centers for Disease Control and Prevention (CDC) report over three million cases of HRV annually in the US, of which 15,433 cases are foodborne (Todd and Grieg 2015). Globally, rotavirus is still one of the leading causes of severe diarrhea in infants and young children (CDC 2016b) and was responsible for more than 258 million episodes of diarrhea among children younger than 5 years of age in 2016. The HRVs are responsible for an estimated 128,500 deaths every year among children younger than 5 years of age throughout the world (Troeger et al. 2018).

Hepatitis E Virus (HEV)

Hepatitis E virus is classified under the family *Hepeviridae,* genus Hepevirus (Van Regenmortel 2000). It is a small, nonenveloped, single stranded RNA virus having four different genotypes. Genotypes 1 and 2 are associated with human epidemics in developing countries and are transmitted by the fecal–oral route. Genotypes 3 and 4, on the other hand, are transmitted zoonotically from animal reservoirs and as sporadic foodborne cases (Cattoir et al. 2018). Although several studies reveal a high prevalence of HEV antibodies in the general population, this virus is believed to be uncommon in the US. However, HEV is very common in developing countries with inadequate water supply and low environmental sanitation. Large epidemics of HEV have been reported in Asia, the Middle East, Africa, and Central America (CDC 2018a). In endemic regions of the world, HEV causes 20 million infections, 3.4 million symptomatic illnesses, 70,000 deaths, and 3000 stillbirths (Dalton et al. 2013).

Human Astroviruses (HAstVs)

Astroviruses belong to the family *Astroviridae.* They are 28–30 nm, nonenveloped positive-sense single-stranded RNA viruses with a genome of about 6.8–7.8 kb (Bosch et al. 2014; Greening and Cannon 2016). The astrovirus infection in humans is usually a self-limiting gastroenteritis. This virus causes up to 20% of all sporadic and 0.5–15% of epidemic cases of nonbacterial gastroenteritis in humans, with most cases of infection being detected in young children under 2 years of age (De Benedictis et al. 2011). Consumption of contaminated food has been associated with several large outbreaks of HAstVs (Bosch et al. 2014).

Other Viruses

The burden of other enteric foodborne viruses that cause gastroenteritis (e.g., sapovirus, aichi virus, torovirus, and

parvovirus) is limited as compared to the above-mentioned viruses.

Burden of Enteric Virus Infections on Egyptian Public Health

In Egypt, there are no published estimates of economic and public health burdens of infectious diseases, especially enteric virus illnesses, because of the lack of comprehensive surveillance systems. However, a few published studies are available that provide some insight on this issue. In general, diarrheal illnesses are the major cause of morbidity in children under 3 years of age (Kamel et al. 2009). The institute for Health Metrics and Evaluation (IHME) of the University of Washington reported that intestinal infectious diseases were responsible for 8.21% of all deaths in Egyptian children (age range 5–14 years) from 1990 to 2013 (IHME 2015). In its most recent World Fact Book, the US Central Intelligence Agency (CIA) classified Egypt as "intermediate" in terms of the degree of risk of major infectious diseases, particularly foodborne and waterborne diseases. Bacterial diarrhea, HAV, and typhoid fever were reported as the most important foodborne and waterborne diseases (CIA World Factbook 2018).

Kamel et al. (2009) collected 230 fecal samples from patients in Cairo and Giza hospitals and found that 50% of the samples had at least one enteric virus. Positive samples were from 1-month-old to 18-year-old patients who visited the clinics for acute gastroenteritis. Table 1 summarizes the results of the available prevalence studies on the major enteric viruses in Egypt during 1986–2019.

Prevalence of HuNoVs in Egypt

Only seven studies are available on the prevalence of HuNoVs in Egypt (Table 1). HuNoVs were detected in 5.4% (7 of 129) of stool samples collected from US military personnel who participated in a military exercise (i.e., Operation Bright Star, 2001) in northwestern Egyptian desert (Sanders et al. 2005). In another study, HuNoVs were detected in ~ 13.5% (31 of 230) of fecal specimens collected from children with acute gastroenteritis who visited clinics in Cairo and Giza from March 2006 through February 2007; half of the HuNoVs belonged to the predominant GII.4 cluster. Phylogenetic analysis of the capsid gene suggested the emergence of new GGII.4 variants that were not associated with any previously known GII.4 viruses (Kamel et al. 2009). El-Mohammady et al. (2012) found 9% (191 of 2112) of stool specimens positive for HuNoVs in children with acute gastroenteritis who visited three hospitals in Cairo and Al-Beherah Governorates from 2005 to 2007. In another study, HuNoVs were detected in 16.2% (81 of 500) of 500 stool specimens from diarrheic children < 15 years of age (Zaghloul et al. 2013). El-Nady et al. (2014) detected HuNoVs in 25.58% (22 of 86) fecal samples collected from infants and children < 3 years old presenting with acute gastroenteritis; of the 22 positive samples, 19 were GII, and 3 were GI.

In a recent review, Mans et al. (2016) reported 12 GII.4 variants in Africa between 1998 and 2013, while Osaka 2007 strain was detected in Egypt between 2006 and 2008. Genogroups I and II of HuNoVs were detected in 27% (54 of 200) of stool specimens from pediatric patients with acute gastroenteritis in the Zagazig University Hospitals (Sharaf et al. 2016). In a cross-sectional observational study, 30% (30 of 100) of stool samples from diarrheic children from Dakahlia Governorate were found positive for HuNoVs (Zaki and El Kheir 2017). In a systematic review of 46 prevalence studies in middle east and North African region including Egypt, Shaheen (2019) found that the mean overall prevalence of HuNoV was 11.8% in in-patients with gastroenteritis, and HuNoV GII.4 is the predominant serotype.

Prevalence of HAV in Egypt

Viral hepatitis constitutes a major public health issue in Egypt because the burden of this disease in Egypt is one of the highest in the world (Divizia et al. 1999; Kamel et al. 2011). In fact, Egypt is located within the HAV-infected intermediate-to-high endemicity regions of the world (Fig. 1, Table 1: Kroneman et al. 2018; Tahaei et al. 2012). For instance, a seroprevalence study conducted in Cairo from June to Nov 1990 showed that HAV was the causative agent in 33% (85 of 261) of children (1–11 years of age) with symptoms of acute hepatitis (El-Zimaity et al. 1993). Between August and December 1993, HAV was identified as the causative etiology in 99.5% (201 of 202) of patients with acute hepatitis at the Fever Hospital of Alexandria; the highest level of infection was in < 9 year-old children (Divizia et al. 1999). In 2001, a sentinel surveillance of five hospitals in diverse areas of Egypt (i.e., Cairo, Alexandria, Mahalla, Qena, and Aswan) was carried out; it was found that 40.2% (1684 of 5909) of the cases were positive for HAV (Talaat et al. 2010). Unpublished reports from the Egyptian Ministry of Health and Population (MOHP) indicate that approximately 20,000 cases of HAV are reported annually by a network of 108 infectious disease hospitals (Talaat et al. 2010). However, there are limitations in the interpretation of these data due to limited laboratory confirmation of the disease, lack of a standardized case definition, and inconsistency in reporting from diverse reporting sources.

Another indicator of HAV hyperendemicity in Egypt is the incidence of HAV outbreaks in European tourists who visit Egypt (Table 2). In August–September 2004, a large

Table 1 Prevalence of human enteric viruses in Egyptian population

Study period	City/Governorate	Age	Type of infection	Samples type	Setting (origin of samples)	Detection Method	% (positive/total)	Predominant Genogroup/Genotype	References
(A) Noroviruses (HuNoVs)									
Fall 2001	Northwestern Egypt	Adults (19–63 years)	Outbreak	Stool	Military base (Outpatients)	ELISA	5.4 (7/129)		Sanders et al. (2005)
Mar 2006 to Feb 2007	Grater Cairo (Cairo and Giza)	Children (1 month to < 18 years)	Sporadic	Stool	Urban (in and outpatients)	RT-PCR	13.5 (31/230)	GII.4	Kamel et al. (2009)
2005 to 2007	Cairo and Al-Beherah Governorates	Children (< 5 years)	Sporadic	Stool	Rural/urban (outpatients)	EIA	9 (191/2112)		El-Mohammady et al. (2012)
Feb 2012 to Jan 2013	Cairo	Children (< 15 years)	Sporadic	Stool	Urban (outpatients)	RT-PCR	16.2 (81/500)		Zaghloul et al. (2013)
NA	El-Mansoura (Dakahlia Governorate)	Children (1 months to < 3 years)	Sporadic	Stool	Rural (in and outpatients)	RT-PCR	25.58 (22/86)	GII > GI	El-Nady et al. (2014)
Nov 2014 to June 2015	Zagazig	Children (1 months to 12 years)	Sporadic	Stool	Rural/Urban (Outpatients)	RT-PCR	27 (54/200)	GII > GI	Sharaf et al. (2016)
Jan 2015 to Jan 2017	El-Mansoura (Dakahlia Governorate)	Children (< 5 years)	Sporadic	Stool	Rural (outpatients)	RT-PCR	30 (30/100)		Zaki and El Kheir (2017)
(B) Hepatitis A virus (HAV)									
Feb to Nov 1983	Cairo	Adults (> 16 years)	Sporadic	Serum	Urban (in and outpatients)	EIA	2.7 (8/295)		Bassily et al. (1986)
June to Nov 1990	Cairo	Children (1–11 years)	Sporadic	Serum	Urban (outpatient)	EIA	32.6 (85/261)		El-Zimaity et al. (1993)
Aug 1993 to Dec 1993	Alexandria	Children/adults (1–73 years)	Sporadic	Serum	Rural/urban (inpatients)	ELISA	99.5 (201/202)		Divizia et al. (1999)
Aug 2004	Hurghada	Children/Adults (2–67 years)	Outbreak	Serum	Urban (in and outpatients)	ELISA	100 (200/351)		Frank et al. (2007)
Dec 2001 to Sept 2002	Embaba (Giza)	Children/adults (4–65 years)	Sporadic	Serum	Rural/urban (inpatients)	EIA	34 (68/200)		Zakaria et al. (2007)
Sept 2002 to Nov 2003	Cairo	Children (2.5 to 18 years)	Sporadic	Serum	Urban (outpatients)	ELISA	61.4 (181/296)		Abdal Aziz and Awad (2008)
Mar 2007 to Aug 2008	Assiut Governorate	Children/adults (1 to 65 years)	Sporadic	Serum	Rural (outpatients)	ELISA	8.1 (19/235)		Eldin et al. (2010)
2001 to 2004	Cairo, Alexandria, Mahalla, Qena, Aswan	Children/adults (> 1 year)	Sporadic	Serum	Urban/rural (outpatients)	ELISA	40.2 (1684/5909)		Talaat et al. (2010)
Apr 2002 to Dec 2007	Greater Cairo (Cairo, Giza, Qalyoubia)	Children/adults (> 5 years)	Sporadic	Serum	Rural/urban (outpatients)	EIA	44 (858/1950)		Delarocque-Astagneau et al. (2012)

Table 1 (continued)

Study period	City/Governorate	Age	Type of infection	Samples type	Setting (origin of samples)	Detection Method	% (positive/total)	Predominant Genogroup/Genotype	References
(C) Rotaviruses (HRVs)									
May 1982 to Apr 1983	Cairo	Children (< 1.5 years)	Sporadic	Stool	Rural/urban (inpatient)	EIA	32.8 (88/268)		Shukry et al. (1986)
Feb 1995 to Feb 1996	Al-Beherah Governorate (Abu homos)	Children (< 3 years)	Sporadic	Stool	Rural (outpatients)	ELISA	0.24 (481,270)	G1 and G2	Naficy et al. (1999)
Fall 2001	Northwestern Egypt	Adults (19 to 63 years)	Outbreak	Stool	Military base (outpatients)	EIA	1.55 (2/129)		Sanders et al. (2005)
May 2000 to May 2002	Cairo (Benha) and Al-Beherah Governorate	Children (< 6 years)	Sporadic	Stool	Rural (inpatients)	EIA	16 (204/1275)		Wierzba et al. (2006)
Aug to Sept 2003	Fayoum Governorate	Children (< 5 years)	Sporadic	Stool	Rural (inpatients)	ELISA	21 (54/356)		El-Mohamady et al. (2006)
Jan to Dec 2006	Alexandria Governorate	Children (< 5 years)	Sporadic	Stool	Urban (inpatients)	RT-PCR	33 (33/100)	G4 > G1 > G9	Amer et al. (2007)
Mar 2006 to Feb 2008	Grater Cairo (Cairo and Giza)	Children (1 months to < 18 years)	Sporadic	Stool	Urban (in and outpatients)	RT-PCR	30.4 (70/230)	G1P > G2P > G12P	Kamel et al. (2009)
May 2009 to Apr 2010	Cairo, Fayoum, and Sharkia Governorates	Children (< 5 years)	Sporadic	Stool	Rural/Urban (Outpatients)	ELISA and RT-PCR	35 (158/450)	G1 > G3 > G4 > G9	Hashem et al. (2012)
Jan 2004 to Apr 2007	Abu Homos (Al-Beherah Governorate)	Children (birth to 2 years)	Sporadic	Stool	Rural (outpatients)	RT-PCR	40 (140/348)	G2 > G1 > G9	Ahmed et al. (2014a)
Feb 2012 to Jan 2013	Cairo	Children (< 15 years)	Sporadic	Stool	Urban (outpatients)	RT-PCR	39 (195/500)		Zaghloul et al. (2013)
May 2011 to April 2012	Greater Cairo	Children (< 5 years)	Sporadic	Stool	Urban (outpatients)	Rt-PCR	45.4 (50/110)	A and C	El-Senousy et al. (2015)
Aug 2011 to Aug 2012	Cairo	Children (< 2 years)	Sporadic	Stool	Rural/urban (in and outpatients)	ELISA and RT-PCR	36.7 (97/264)	G3P > G1P > G9P	Shoeib et al. (2015)
Oct 2014 to Mar 2015	Zagazig (Sharkia Governorate)	Children (2.3 to 9 years)	Sporadic	Stool	Rural (inpatients)	RT-PCR	76.9 (50/65)		Ibrahim et al. (2015)
NA	Greater Cairo	Children	Sporadic	Stool	NA	RT-PCR	56.9 (53/93)	G3P > G2P > G4P	Elnady et al. (2016)
May 2015 to Apr 2016	Cairo	Children (< 5 years)	Sporadic	Stool	Rural/urban (in and outpatients)	ELISA	28.3 (56/198)	G3 > G1 > G9 > G10	Shaheen et al. (2017)
Jan 2015 to Jan 2017	El-Mansoura (Dakahlia Governorate)	Children (< 5 years)	Sporadic	Stool	Rural (outpatients)	ELISA	44 (44/100)		Zaki and El Kheir (2017)

Table 1 (continued)

Study period	City/Governorate	Age	Type of infection	Samples type	Setting (origin of samples)	Detection Method	% (positive/total)	Predominant Genogroup/Genotype	References
NA	Cairo	Children (< 5 years)	Sporadic	Stool	Urban (inpatients)	EIA and RT-PCR	31 (37/119)		Allayeh et al. (2018)
(D) Astroviruses (HAstVs)									
Feb 1995 to Feb 1998	Abu Homos (Al-Beherah Governorate)	Children (< 2 years)	Sporadic	Stool	Rural (outpatients)	EIA	31 (123/397)	Type 1 > 5 > 8 > 3 > 6	Naficy et al. (2000)
Mar 2006 to Feb 2009	Grater Cairo (Cairo and Giza)	Children (1 months to < 18 years)	Sporadic	Stool	Urban (in and outpatients)	RT-PCR	2.17 (5/230)		Kamel et al. (2009)
Sept 2006 to Sept 2007	Abu Homos (Al-Beherah Governorate)	Children (< 5 years)	Sporadic	Stool	Rural (inpatients)	RT-PCR	6.3 (23/364)	Type 1	Ahmed et al. (2011)
2005 to 2007	Cairo and Al-Beherah	Children (< 5 years)	Sporadic	Stool	Rural/urban (outpatients)	EIA	2.65 (56/2112)		El-Mohammady et al. (2012)
Sept. 2012 to May 2013	Cairo	Children (< 6)	Sporadic	Stool	Rural (outpatients)	ELISA and RT-PCR	2.5 (2/79)		Raouf et al. (2014)
Jan 2015 to Jan 2017	El-Mansoura (Dakahlia Governorate)	Children (< 5 years)	Sporadic	Stool	Rural (outpatients)	RT-PCR	14 (14/100)		Zaki and El Kheir (2017)
(E) Hepatitis E Virus (HEV)									
June to Nov 1990	Cairo	Children (1 to 11 years)	Sporadic	Serum	Urban (inpatients)	EIA	22.2 (58/261)		El-Zimaity et al. (1993)
NA	NA	Adults (NA)	Sporadic	Serum	NA (blood donors and hemodialysis)	ELISA	42.4 (81/191)		Abdel et al. (1998)
Aug 1993 to Dec 1993	Alexandria	All ages (1 to 73 years)	Sporadic	Serum	Rural/urban (inpatients)	ELISA	44.6 (90/202)		Divizia et al. (1999)
1997 to 1998	South Cairo and Nile Delta	Children/adults (10 to < 50 years)	Sporadic	Serum	Rural (outpatients)	EIA	67.7 (6790/10,026)		Fix et al. (2000)
Aug 1997 Sept 2003	(Menoufia) Nile Delta	Pregnant women (16 to 48 years)	Sporadic	Serum	Rural (outpatients)	EIA	84.3 (2046/2428)		Stoszek et al. (2006)
2006 to 2008	NA	NA	Sporadic	Serum	NA	ELISA and RT-PCR	20.2 (58/287)	Genotype 1	Blackard et al. (2009)
NA	Ismailia Governorate	Adults (33 to 53 years)	Sporadic	Serum	Rural (inpatients)	ELISA	2.3 (5/214)		Youssef et al. (2009)
Mar 2007 to Aug 2008	Assiut Governorate	Children/adults (1 to 65 years)	Sporadic	Serum	Rural (outpatients)	ELISA	16 (42/235)		Eldin et al. (2010)

Table 1 (continued)

Study period	City/Governorate	Age	Type of infection	Samples type	Setting (origin of samples)	Detection Method	% (positive/total)	Predominant Genogroup/Genotype	References
Apr 2002 to Dec 2007	Greater Cairo (Cairo, Giza, and Qalyoubia)	Children/adults (> 5 years)	Sporadic	Serum	Urban and rural (outpatients)	EIA	0.87 (17/1950)		Delarocque-Astagneau et al. (2012)
May 2010 to Apr 2011	Kafrelsheikh Governorate	Adults (20 to 40 years)	Sporadic	Serum	Rural (outpatients)	EIA	38.1 (51/134)		El-Tras et al. (2013)
Apr 2016 to Oct 2016	El-Mansoura (Dakahlia Governorate)	Children (1 to < 18 years)	Sporadic	Serum	Rural (outpatients)	ELISA	27.15 (38/140)		Abdelmawla et al. (2019)
(F) Adenovirus (HAdV)									
Mar 2006 to Feb 2010	Grater Cairo (Cairo and Giza)	Children (1 month to < 18 years)	Sporadic	Stool	Urban (in and outpatients)	PCR	12.2 (14/230)		Kamel et al. (2009)
2005 to 2007	Cairo and Al-Beherah Governorates	Children (< 5 years)	Sporadic	Stool	Rural/urban (outpatients)	EIA	2 (34/2112)		El-Mohammady et al. (2012)
Feb 2012 to Jan 2013	Cairo	Children (< 15 years)	Sporadic	Stool	Urban (outpatients)	Nested-PCR	6.8 (34/500)		Zaghloul et al. (2013)
Jan 2015 to Jan 2017	El-Mansoura (Dakahlia Governorate)	Children (< 5 years)	Sporadic	Stool	Rural (outpatients)	Multiplex-RT-PCR	20 (20/100)		Zaki and El Kheir (2017)
NA	Cairo	Children (< 5 years)	Sporadic	Stool	Urban (inpatients)	EIA and nested-PCR	6.7 (8/119)		Allayeh et al. (2018)
NA	Cairo	Children	Sporadic	Stool	Urban (inpatients)	PCR	28.3 (17/60)		Elmahdy et al. (2019)
(G) Sapovirus (HSV)									
NA	El-Mansoura (Dakahlia Governorate)	Children (< 1 to 9 years)	Sporadic	Stool	Rural (outpatients)	RT-PCR	18 (18/100)		El-Daker et al. (2012)

NA not available

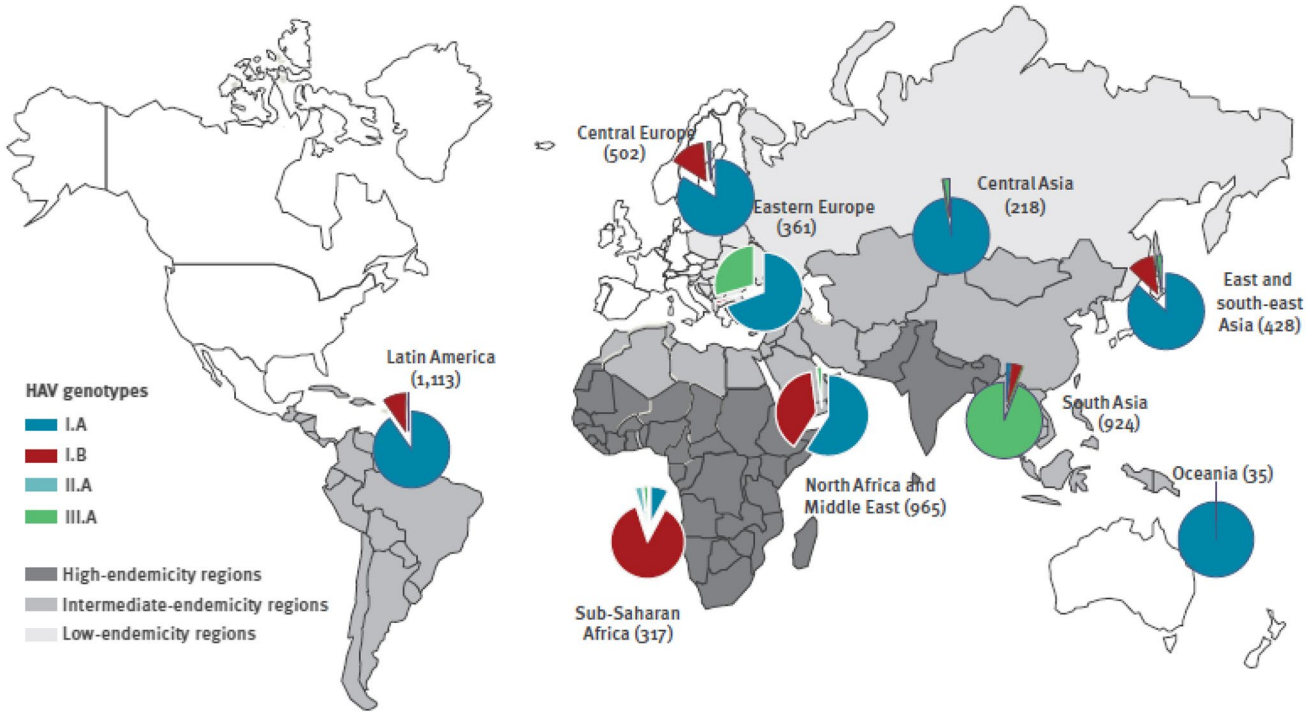

Fig. 1 Distribution of human hepatitis A virus genotypes over the endemic Global Burden of disease regions, pre-2010–2017 ($n = 4863$). *Source* Kroneman et al. (2018)

Table 2 Hepatitis A outbreaks in travelers to Egypt

Date of the outbreak	Number of cases	Citizenship of traveling patients	Age range (years)	Egyptian region visited	References
August and September 2004	351	Germany (278), Austria (18), Sweden (10), Denmark (9), the Netherlands (9), Belgium (6), the United Kingdom (5), Italy (2) and Switzerland (1)	2–67	Hurghada resort	Frank et al. (2005)
September 2008 to January 2009	26	France	10–65	Cairo hotel and cruise on the Nile	Couturier et al. (2009)
August to December 2008	34	Germany	11–69	Cairo (cruise on the Nile)	Bernard and Frank, (2009)
Nov 2012 to April 2013	80	Germany (39), England (11), Netherlands (11), Denmark (7), Norway (6), Sweden (6)	3–76	Sharm-El-Sheik and Hurghada resorts	MacDonald et al. (2013)

outbreak of HAV occurred in tourists staying at a hotel in the Hurghada resort. Of the 351 cases reported, 278 were from Germany and the remaining 73 were from eight other European countries (Frank et al. 2005). In France, a cluster of 26 HAV cases was detected in tourists returning from Cairo during September 2008 to January 2009 (Couturier et al. 2009). From September to December 2008, 34 cases of HAV in Germany were most likely linked to Nile river cruises (Bernard and Frank 2009). From November 2012 to April 2013, 80 acute HAV cases were reported in tourists from six European countries (i.e., Germany, England, Netherlands, Denmark, Norway, and Sweden). All of them had stayed in Sharm-El-Sheik and Hurghada resorts in Eastern Egypt (MacDonald et al. 2013).

Prevalence of HRVs in Egypt

Human rotavirus is the most frequently studied virus in prevalence studies, which indicates that HRVs are a prime cause of acute gastroenteritis in Egyptian children (Table 1). For example, HRV was responsible for 33% of all episodes of diarrhea in Egyptian children under 5 years of age during May 1982 to April 1983 (Shukry et al. 1986). Several studies during the past two decades showed HRVs as the most identified cause of diarrhea in children living in the Delta of Nile River (Abu-Elyazeed et al. 1999; Naficy et al. 1999; Rao et al. 2003; Wierzba et al. 2006). From March 2006 to Feb 2008, a study conducted in Greater Cairo found 30.4% (70 of 230) of fecal samples from diarrheic children to be HRVs positive (Kamel et al. 2009). In a recent study, 37 of 119 (31%) stool specimens from children (< 5 years old) with acute diarrhea at Abou Elreesh Children's hospital, Cairo were HRVs positive (Allayeh et al. 2018).

Prevalence of HAstVs in Egypt

Human astroviruses are a common cause of gastroenteritis in children, the elderly, and immunocompromised persons (Bosch et al. 2014). However, the number of reported cases of HAstVs in Egypt is small (Table 1). For example, HAstVs were detected in 2.17% (5 of 230) of fecal samples collected from children (1.0 to < 18 years old) with acute gastroenteritis in Greater Cairo region between March 2006 and Feb 2008 (Kamel et al. 2009). In a recent study (January 2015 to January 2017), 14 of 100 (14%) diarrheic children (< 5 years old) in Dakahlia Governorate were positive for HAstVs (Zaki and El Kheir 2017).

Prevalence of HEV in Egypt

Although HEV infects liver and causes acute hepatitis, it is an enteric virus, which is shed in feces and can be transmitted by food and water (Greening and Cannon 2016). The prevalence of HEV is high in Egypt (Fig. 2; CDC 2018a). The seroprevalence of anti-HEV antibodies in most countries of North Africa/Middle east region was up to 20%, but in Egypt it was up to 80% (WHO 2010). This is supported by many seroprevalence studies conducted between 1990 and 2016 (Table 1). For example, a large seroprevalence study on 10,026 villagers from two south Cairo and Nile delta villages, showed the presence of HEV antibodies in 6790 (67.7%) (Fix et al. 2000). From August 1997 to September 2003, serum samples collected from 2428 pregnant women (16–48 years old) living in Menoufia (Nile Delta region) were tested; antibodies to HEV were detected in 84.3% ($n = 2046$) of the samples (Stoszek et al. 2006). On the other hand, another study between April 2002 and Dec 2007 found HEV antibodies in serum of only 0.87% (17 of 1950) of acute hepatitis

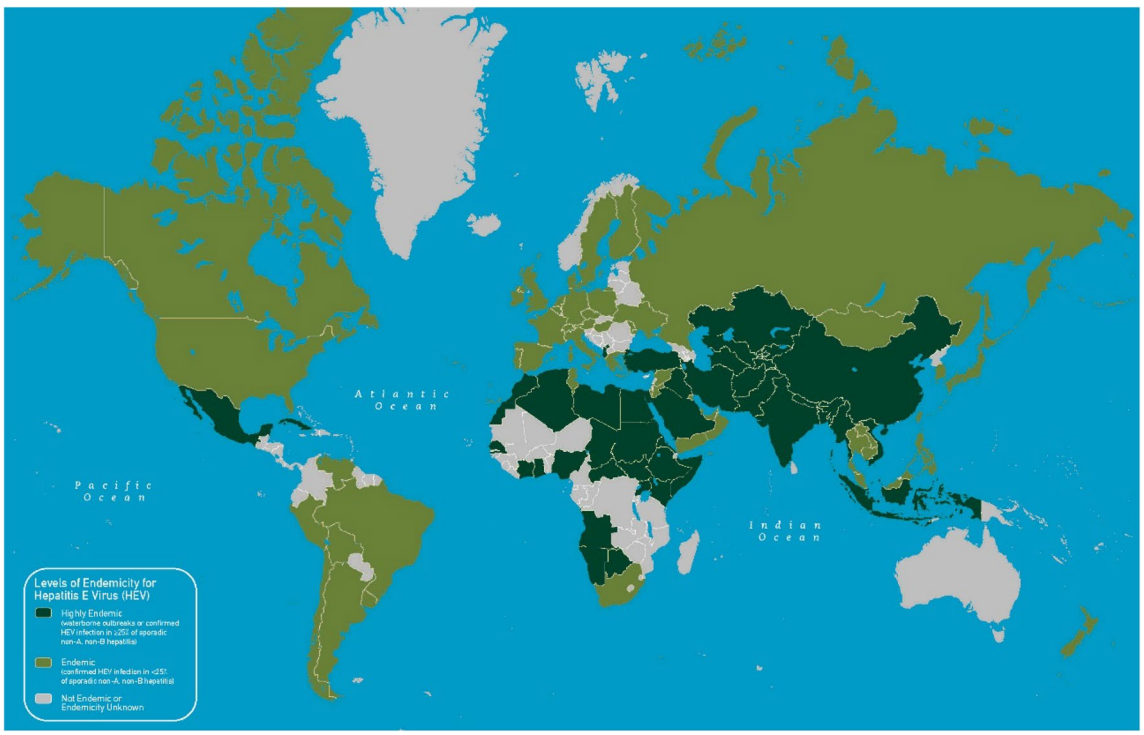

Fig. 2 Worldwide levels of endemicity for hepatitis E virus (HEV) *Source* CDC (2018a)

patients (> 5 years old) at Abbassia and Imbaba Fever Hospitals (Greater Cairo region) (Delarocque-Astagneau et al. 2012).

Prevalence of Other Foodborne Viruses

In addition to the above viruses, HAdV and human sapovirus (HSV) have also been detected in Egyptian children with acute gastroenteritis (Table 1; Allayeh et al. 2018; El-Daker et al. 2012; El-Mohammady et al. 2012; Kamel et al. 2009; Zaghloul et al. 2013; Zaki and El Kheir 2017).

Implication of Food in Global Outbreaks of Viral Illnesses

As a result of advances in methodologies for detection and identification of viruses in foods, the extent and role of viruses in foodborne disease outbreaks is increasingly being clarified. New molecular methods, including real-time quantitative PCR for the detection of nonculturable or difficult-to-culture viruses, frequently show the presence of viruses in the environment, shellfish, and fresh produce (Goyal and Aboubakr 2016). Numerous studies have assessed the fate of foodborne viruses in the environment and their transfer to foods during preparation and handling (Kotwal and Cannon 2014). Many studies have demonstrated that shellfish, soft berry fruits, herbs and salad greens are at the greatest risk of virus contamination at the pre-harvest, during harvest or post-harvest processing (Table 3, Shieh et al. 2007; Yu et al. 2015; Chatziprodromidou et al. 2018).

Foods that are subject to much handling and are subsequently consumed cold or uncooked (minimally-processed and ready-to-eat-foods) are also at a risk of contamination from food handlers (Koopmans and Duizer 2004). Such foods include bread and bakery goods, lightly cooked or raw shellfish, sandwiches, salads, herbs, fresh fruits, cold meats and cold desserts. Poor food handling was shown to be a key risk factor in the transmission of HuNoVs in New Zealand and of HuNoVs and HRVs in the Netherlands (De Wit et al. 2007; Thornley et al. 2013). In the U.S., infected food handlers are the source of over 50% of all foodborne HuNoVs outbreaks (Hall et al. 2012b). It is possible that the current trend for the consumption of raw or lightly cooked ready-to-eat (RTE) foods, especially salads and sandwiches, has increased the risk of foodborne viral disease.

Key factors influencing contamination of fresh produce are water quality and food worker hand hygiene. Thus, sewage contamination and poor hygiene practices play a major role in the contamination of produce. In some cases, more than one pathogen or strain of virus was associated with an outbreak, suggesting that sewage-contaminated irrigation or vegetable wash water may have been involved

Table 3 Fresh Produce implicated in viral outbreaks. *Source* Chatziprodromidou et al. (2018)

Vehicle	Scientific literature		ProMED mail	
	Frequency	Percent	Frequency	Percent
Frozen raspberries	36	27.7	4	18.2
Frozen berries	31	23.9	2	9.1
Salad	26	20.1	3	13.6
Lettuce	7	5.3		
Frozen strawberries	7	5.3	4	18.2
Green onion	3	2.3		
Orange juice	2	1.5	1	4.5
Tomatoes	2	1.5	2	9.1
Pomegranate arils	2	1.5		
Frozen fruit blend	2	1.5		
Frozen semi-dried tomatoes	2	1.5		
Mixed (salad fruits, etc.)	2	1.5	4	18.2
Salad dressing	1	0.8		
Fresh strawberries	1	0.8		
Semi-dried tomatoes	1	0.8	2	9.1
Frozen mango	1	0.8		
Fresh mango	1	0.8		
Dried fruit	1	0.8		
Pumpkin salad	1	0.8		
Orange mousse	1	0.8		
Total	130	100	22	100

(Le Guyader et al. 2008; Greening and Cannon 2016). Fresh produce may become contaminated with disease-causing enteric viruses if irrigated with or washed in water containing human fecal material or if handled by field-workers or food-handlers with poor hygiene practices. Similarly, the quality of shellfish growing waters is important; pre-harvest virus contamination occurs when filter-feeding bivalve shellfish are grown in waters contaminated with sewage or fecal material. A single shellfish filters about 20 to 40 L of water per hour in order to sieve out and accumulate food particles. Bacterial and viral particles that might contaminate water can be entrapped in the mucus of the gills, which is then pushed into the digestive gland where viruses concentrate at levels that are 100 to 1000 times greater than in the surrounding waters (Gerba and Goyal 1978; Greening and Cannon 2016).

The globalization of food supply has increased the circulation of fresh produce with anonymous sources and with uncontrolled quality. Although fresh produce is usually considered “clean, green and healthy” by customers, it might not be so especially when imported from countries where general hygiene practices do not meet international standards (Gaulin et al. 1998). Thus, there have been numerous outbreaks of HuNoVs and HAV associated with contaminated

fresh produce imported into Europe, Australia, and North America (CDC 2013; Carvalho et al. 2012; Donnan et al. 2012; Ethelberg et al. 2010; Made et al. 2013; Maunula et al. 2013).

Implication of Egyptian Foods in Enteric Virus Illnesses

To date, there is no official reporting system for foodborne viral disease outbreaks in Egypt and systematic surveillance studies on foodborne viral pathogens are also lacking. Hence, data on the role of Egyptian foods in enteric disease outbreaks are meager. A few studies have confirmed the contamination of some Egyptian foods with enteric viruses and some other studies have implicated Egyptian foods in enteric virus outbreaks as discussed below:

Egyptian Foods Contaminated with Enteric Viruses

Only three studies are available on the detection of enteric viral contaminants in Egyptian foods (Table 4). In a surveillance study of 2400 Egyptian meat and dairy products

Table 4 Egyptian foods contaminated with enteric viruses

Type of food	Detected viral contaminant[a]	Genotype	No. positive/no. tested samples (percentage)	Study period	City/Governorate	References
Green onion	HNoVs	GI	49/144 (34%)	Dec 2008 to Nov 2009	Dakahlia Governorate (Nile delta)	El-Senousy et al. (2013b)
Green onion	HadV, HAV, HRV, HuNoV	NI, NI, NI, GI	19/23 (59%), 8/32 (25%), 6/32(18.7%), 13/32 (40.6%)	Sept 2017 to Dec 2017	Cairo and Dakahlia (Nile delta)	Shaheen et al. (2019)
Watercress	HNoVs	GI	45/144 (31.3%)	Dec 2008 to Nov 2009	Dakahlia Governorate (Nile delta)	El-Senousy et al. (2013b)
Watercress	HadV, HAV, HRV, HuNoV	NI, NI, NI, GI	18/32 (56%), 9/32 (28%), 7/32 (21.9%), 11/32 (34.4%)	Sept 2017 to Dec 2017	Cairo and Dakahlia (Nile delta)	Shaheen et al. (2019)
Radish	HNoVs	GI	37/144 (25.7%)	Dec 2008 to Nov 2009	Dakahlia Governorate (Nile delta)	El-Senousy et al. (2013b)
Lettuce	HNoVs	GI	35/144 (24.3%)	Dec 2008 to Nov 2009	Dakahlia Governorate (Nile delta)	El-Senousy et al. (2013b)
Lettuce	HadV, HAV, HRV, HuNoV	NI, NI, NI, GI	17/32 (53%), 10/32 (31%), 8/32 (25%), 10/32 (31%)	Sept 2017 to Dec 2017	Cairo and Dakahlia (Nile delta)	Shaheen et al. (2019)
Leek	HNoVs	GI	30/144 (20.8%)	Dec 2008 to Nov 2009	Dakahlia Governorate (Nile delta)	El-Senousy et al. (2013b)
Leek	HadV, HAV, HRV, HuNoV	NI, NI, NI, GI	15/32 (46.8%), 6/32 (18.7%), 4/32 (12.5%), 9/32 (28%)	Sept 2017 to Dec 2017	Cairo and Dakahlia (Nile delta)	Shaheen et al. (2019)
Minced meat	HAV, HRVs	NI	27/400 (6.75%) and 28/400 (7%)	Jan 2007 to Dec 2007	Cairo Governorate	Zaher et al. (2008)
Beef burger	HAV, HRVs	NI	20/400 (5%) and 27/400 (75%)	Jan 2007 to Dec 2007	Cairo Governorate	Zaher et al. (2008)
Sausage	HAV, HRVs	NI	22/400 (5.5%) and 26/400 (6.5%)	Jan 2007 to Dec 2007	Cairo Governorate	Zaher et al. (2008)
Milk	HAV, HRVs	NI	19/400 (4.75%) and 24/400 (6%)	Jan 2007 to Dec 2007	Cairo Governorate	Zaher et al. (2008)
Ice-cream	HAV, HRVs	NI	22/400 (5.5%) and 29/400 (7.25%)	Jan 2007 to Dec 2007	Cairo Governorate	Zaher et al. (2008)
Cottage cheese	HAV, HRVs	NI	18/400 (4.5%) and 28/400 (7%)	Jan 2007 to Dec 2007	Cairo Governorate	Zaher et al. (2008)

GI Genogroup I, *NI* not Identified

[a]Detected by RT-PCR

(i.e., minced meat, beef burger, sausage, milk, ice-cream, and cottage cheese) conducted from January to December 2007, HAV and HRVs were found in 5.33% and 6.75%, respectively (Zaher et al. 2008). These foods, intended for human consumption, were collected randomly from four markets in the Egyptian Capital, Cairo. El-Senousy et al. (2013b) reported natural contamination by HuNoV GI in 34% ($n=49$), 31.3% ($n=45$), 25.7% ($n=37$), 24.3% ($n=35$), and 20.8% ($n=30$) of green onion ($n=144$), watercress ($n=144$), radish ($n=144$), lettuce ($n=144$), and leek ($n=144$), respectively. The tested samples were collected from farms around El Mansoura city, Dakahlia Governorate (Nile delta), during Dec 2008 to Nov 2009. Recently, Shaheen et al. (2019) detected HuNoV GI in 40.6% (13/32), 34.4% (11/32), 31% (10/32), and 28% (9/32), respectively, of green onion, watercress, lettuce, and leek samples collected from two locations in Nile delta (i.e., Cairo and El Mansoura). In the same study, HAV was found contaminating 25% (8/32), 28% (9/32), 31% (10/32), and 18.7% (6/32) of the same fresh vegetable samples mentioned above, respectively. The results of these three studies indicate contamination of a wide variety of Egyptian foods—including fresh produce, meat products (processed and unprocessed) and dairy products. The results of the most recent study (Shaheen et al. 2019) reveals an increase in incidence rate of viral contamination of Egyptian food as compared to that of the first two studies conducted approximately a decade ago (Zaher et al. 2008; El-Senousy et al. 2013b). This indicates that the sanitation measures in pre- and post-harvest processes of Egyptian vegetables and fruits is getting worse.

Frequent detection of enteric viruses in Egyptian food products imported by the European countries support the aforementioned conclusion. For instance, many countries (Denmark, Austria, Portugal, Germany, Switzerland, Spain, and Hungary) detected HuNoV GII in frozen strawberries imported from Egypt (RASFF 2015). On March 13, 2018, HuNoV GI was found in frozen strawberries imported from Egypt into Italy (RASFF 2018a). On May 29, 2018, frozen strawberries imported from Egypt into Greece were contaminated by HAV (RASFF 2018b). In addition to the confirmed detection of enteric viruses in Egyptian foods, a study confirmed the infection of Egyptian food animals with zoonotic viruses. For instance, 21.6% (11 out of 51), 14% (8 out of 57), 4.4% (2 out of 45), and 9.4% (3 out of 32) of examined Egyptian cows, buffaloes, sheep, and goats, respectively, were seropositive for HEV. Interestingly, the HEV detected in food animals had a very high genotypic similarity with the circulating HEV infection among humans living in the same geographical locations (Kafr El-Sheikh Governorate, Nile delta, Egypt). These data indicate a high risk of zoonotic viral infections in humans who might consume or handle products from infected food animals (El-Tras et al. 2013).

Egyptian Foods Implicated in Enteric Virus Outbreaks

Although there is no reported viral gastroenteritis or acute hepatitis outbreak in Egypt linked with consumption of contaminated foods, this is not a true reflection of the virological safety status of Egyptian foods because no official records of foodborne viral outbreaks are kept. However, many foodborne viral outbreaks have been reported in several countries that imported Egyptian foods or their citizens have consumed Egyptian foods during their visit to Egypt (Table 5). For instance, Egyptian orange juice was identified in a case–control study as the most likely infection vehicle of an HAV-Genotype 1B outbreak among 351 tourists from nine European countries (i.e., Germany, Austria, Sweden, Denmark, Netherlands, Belgium, United Kingdom, Italy, and Switzerland) returning from Hurghada, Egypt during August and September 2004 (Frank et al. 2007). Pomegranate arils imported from Egypt were linked to nine cases of nontravel HAV-Genotype 1A and 1B outbreak in British Columbia, Canada, between February and May 2012 (Swinkels et al. 2014). More recently, frozen pomegranate arils imported from Egypt were implicated in 30 cases (25 hospitalizations and 1 death) of HAV-genotype 1A and 1B in a multistate outbreak in Australia. (Franklin et al. 2019).

Frozen strawberries imported from Egypt were the most likely vehicle of a 103-case HAV outbreak in Nordic countries (i.e., Denmark, Finland, Norway, and Sweden) during October 2012 to June 2013 (Nordic 2013). Similarly, fresh strawberries consumed locally at Sharm-El-Sheikh and Hurghada resorts in Northeastern Egypt, were implicated in a 107-case multistate HAV-1B outbreak in tourists from 14 European Union countries during November 2012 to April 2013; 2 deaths and 11 hospitalizations were reported (ECDC 2013a; Sane et al. 2015). On August 2016, 143 cases (56 hospitalized) of acute HAV-Genotype 1B infection were reported from nine states in the U.S. Of these, 129 cases reported drinking a smoothie from different locations of Tropical Smoothie Café. Trace back investigation implicated frozen strawberries imported from Egypt (CDC 2016c). This incident resulted in a recall of the product from US markets (FDA 2016) and a series of bans by U.S., Russia, UAE, KSA, Bahrain, and Sudan on the importation of strawberries from Egypt (Beach 2016; Coveny 2016; Gulf News 2017; Reuters 2017). These bans have huge economic burden on the Egyptian economy, which depends in a significant part on exporting agricultural products.

Table 5 Outbreaks of hepatitis A linked to foods imported from Egypt

Occurrence date	Genotype	Implicated food	Affected country/ies	Total number of cases	Patient age range (year)	Number of deaths	Number of hospitalizations	References
[a]Aug and Sept 2004	HAV Genotype 1B	Orange juice	Germany, Austria, Sweden, Denmark, the Netherlands, Belgium, the United Kingdom, Italy and Switzerland	351	2–67	0	170	Frank et al. (2007)
Feb to May 2012	HAV Genotype 1A and 1B	Pomegranate arils	Canada	9	19–49	0	2	Swinkels et al. (2014)
[a]Oct 2012 to June 2013	HAV	Frozen strawberries	Denmark, Finland, Norway and Sweden	103	4–76	NA	NA	Nordic (2013)
[a]Nov 2012 and April 2013.	HAV Genotype 1B	Fresh strawberries	Denmark, Estonia, Finland, France, Germany, Ireland, Latvia, Lithuania, Norway, Slovak Republic, Sweden, Switzerland, The Netherlands, The United Kingdom	107	4–76	2	11	ECDC (2013a) and Sane et al. (2015)
[a]Aug 2016 to Oct 2016	HAV Genotype 1B	Frozen strawberries	USA (Arkansas, California, Maryland, New York, North Carolina, Oregon, Virginia, West Virginia, and Wisconsin)	143	NA	0	56	CDC (2016c)
[a]Jan to June 2018	HAV Genotype 1A and 1B	Frozen pomegranate arils	Australia	30	4–74	1	25	Franklin et al. (2019)

NA not available

[a]Multistate outbreak

Environmental Risk Factors That May Lead to Viral Contamination of Egyptian Foods

The Egyptian rural areas are inhabited by approximately half the population of Egypt and do not have access to sewer systems or wastewater treatment facilities. The "septic tank" is the most common disposal facility where excreta and a limited amount of sludge can be collected for biological digestion. The digested excreta leach into the soil surrounding the tank and may result in shallow groundwater pollution. An increase in the discharge of municipal and domestic wastes renders the occasional primary treatment of urban sewage insufficient to prevent deterioration of vital water streams (Parker 1987; Abdel-Shafy and Aly 2002). In addition, Egypt as well as most of the countries of the Middle East and North African regions, are either arid or semi-arid. Therefore, reuse of marginal water (secondarily treated wastewater and blended drainage water) for irrigation has been adopted for many years as an economically attractive means to increase the utilization rate of water in Egypt (El-Mowelhi et al. 2006).

Egypt produces an estimated 3.5 billion m^3 of sewage every year (Okubo et al. 2019). Because of the poor sewer infrastructure, a large portion is discharged into agricultural drainage channels (Fig. 3). Although this water is not officially allowed for irrigation without pretreatment, approximately 2.7 billion m^3 is unofficially used by farmers along the drainage channels (El-Mowelhi et al. 2006; Okubo et al. 2019). Considering these facts, the risk of waterborne viral contamination of agricultural products in Egypt is very high. Therefore, the use of sewage-contaminated water for irrigation is one of the major environmental risk factors of Egyptian food contamination with enteric viruses. Indeed, many studies have described the detection of enteric viruses in Egyptian tap water, irrigation waters, and sewage (Table 6).

The Nile is the main source of drinking and irrigation water in Egypt and 95% of the population lives in the River's delta and banks (UNDP 2015). However, many studies have revealed pollution of this river with several enteric viruses. For instance, El-Senousy et al. (2013a) detected HRVs and HAdV in 29.2% and 66.7%, respectively, of untreated Nile water samples ($n=24$) collected from El- Giza water treatment plant located in Greater Cairo region. In another study, HRVs were detected in 41.7%, 20.8%, and 20.8% of raw Nile River water samples ($n=24$) collected from Meet-Kames, Shoha, and Mahalet Damana drinking water treatment facilities, respectively, which are fed directly from the Nile in Dakahlia Governorate. In addition, HEV was detected in 1.4% of samples collected from Meet-Kames water treatment facility (El-Senousy and El-Gamal 2014). Rotavirus groups A and C were detected in 41% (10/24) and 12.5% (3/24) of raw and treated Nile water, respectively, collected from El-Giza water treatment plant over a 2-year period from Nov 2009 to Oct 2011 (El-Senousy et al. 2015). Recently, Shaheen and Elmahdy (2019) detected HAstV and HuNoV in 25% and 16.6% ($n=12$), respectively of Nile water collected from Rosetta branch in a location after mixing with wastewater from El-Rahawy drain.

Furthermore, enteric viruses have been recovered from treated and chlorinated drinking water collected from several Egyptian water treatment facilities. For instance, HuNoVs, HAV, and HEV were detected in treated water collected from Abo El-Nomros and El-Hawamdia (southern Egypt) in 2004 (Ali et al. 2004). During Oct 2006 to Sept 2008, HRVs were detected in 4.2–29.2% of treated drinking water samples ($n=72$) collected from three compact and traditional water treatment facilities (i.e., Mahalet Damana, Meet Kames, and Shoha) located in Dakahlia Governorate (El-Senousy and

Fig. 3 Representative images showing a farmer collecting water from the Dishody drain Kafr El-Dawar, Al-Beherah Governorate (**a**) and using polluted agricultural drainage wastewater for paddy rice cultivation (**b**). *Source* Okubo et al. (2019)

Table 6 Viruses in Egyptian waters

Sample type	Facility type	Name of facility	Region	Date of study	Detected virus/s	No. positive/no. tested samples (percentage)	Reference
Drinking water	Compact drinking water treatment facilities fed from Nile river	Abo El-Nomros and El-Hawamdia	South Cairo	NA	HuNoVs, HAV, HEV	NA	Ali et al. (2004)
Drinking water (treated)	Compact drinking water treatment facilities	Mahalet Damana	Dakahlia governorate (Nile delta)	Oct 2006 to Sept 2008	HRVs	1/24 (4.2%)	El-Senousy and El-Gamal (2014)
Drinking water chlorinated (treated)	Traditional water treatment plant fed by Nile water	Meet Kames	Dakahlia governorate (Nile delta)	Oct 2006 to Sept 2008	HRVs	7/24 (29.2%)	El-Senousy and El-Gamal (2014)
Drinking water chlorinated (treated)	Compact drinking water treatment facilities	Shoha	Dakahlia governorate (Nile delta)	Oct 2006 to Sept 2008	HRVs	4/24 (16.7%)	El-Senousy and El-Gamal (2014)
Drinking tap water	Homes	–	Giza Governotrate	June 2016 to My 2017	HRVs G1	6/72 (8.3%)	Rizk and Allayeh (2018)
Drinking tap water	Public café, restaurants and homes	–	Cairo, Giza, Helwan, Qalyubia and Faiyum Governorates	Dec 2016 to Nov 2017	HRVs and HAdV	28/180 (15.6%) and 16/180 (8.9%)	Gad et al. (2019)
Nile river water (untreated)	Drinking water treatment facility	EL-Giza water treatment plant	Greater Cairo	July 2009 to June 2011	HRVs and HAdV	7/24 (29.2%) and 16/24 (66.7%)	El-Senousy et al. (2013a)
Nile river water (untreated)	Traditional water treatment plant fed by Nile water	Meet Kames	Dakahlia governorate (Nile delta)	Oct 2006 to Sept 2008	HRVs and HEV	10/24 (41.7%) and 3/24 (1.4%)	El-Senousy and El-Gamal (2014)
Nile river water (untreated)	Compact drinking water treatment facilities	Shoha	Dakahlia governorate (Nile delta)	Oct 2006 to Sept 2008	HRVs	5/24 (20.8%)	El-Senousy and El-Gamal (2014)
Nile river water (untreated)	Compact drinking water treatment facilities	Mahalet Damana	Dakahlia governorate (Nile delta)	Oct 2006 to Sept 2008	HRVs	5/24 (20.8%)	El-Senousy and El-Gamal (2014)
Nile river water Raw and treated	Drinking water treatment facilities	El-Giza water treatment plant	Greater Cairo	Nov 2009 to Oct 2011	– Raw: HRVs – Treated: HRVs	Raw:10/24 (41.7%) Treated: 3/24 (12.5%)	El-Senousy et al. (2015)
Nile river water	River	Rosetta River Nile branch	Dakahlia governorate (Nile delta)	April 2017 to March 2018	– Before mixing point with wastewater: HAstVs – After mixing point with wastewater: HAstVs and HuNoVs	Before: 2/24 (8.3%) After: 6/24 (25%) and 4/24 (16.6%)	Shaheen and Elmahdy (2019)

Table 6 (continued)

Sample type	Facility type	Name of facility	Region	Date of study	Detected virus/s	No. positive/no. tested samples (percentage)	Reference
Nile river water	River	Rosetta River Nile branch	Cairo and Dakahlia governorate (Nile delta)	Sept 2017 to Dec 2017	HAdV, HRVs, HAV, HuNoV GI	30/32 (93.75); 16/32 (50%); 11/32 (34.4%); 10/32 (31.25%)	Shaheen et al. (2019)
Irrigation water	Private Farms		Dakahlia governorate (Nile delta)	Dec 2008 to Nov 2009	HuNoVs GI and GII	46/144 (31.9%)	El-Senousy et al. (2013b)
Irrigation water and wastewater	Agricultural drainage canal	Ummom drainage canal and its tributaries (Dishody, hares, Truga Nubarya, and Maryout drains) Pour in Maryout lake and Mediteraninan sea	Elbeheira and Alexandria Governorates (west Nile delta region)	NA	HAdV; HAV; HEV; HuNoVs GI; GII; GIV; HRVs; Aichi virus (AIV); and enterovirus (EV) (all viruses detected in 100% of samples)	NA	Okubo et al. (2019)
Wastewater	Agricultural drainage canal	Zenin wastewater treatment plant	Greater Cairo	Nov 2009 to Oct 2011	– Raw: HRVs – Treated: HRVs	Raw: 6/24(25%) Treated: 4/24 (16.7%)	El-Senousy et al. (2015)
Wastewater	Agricultural drainage canal	El-Rahawy drainage canal pors in Rositta River Nile branch	Dakahlia governorate (Nile delta)	April 2017 to March 2018	HAstVs and HuNoVs	29/72 (40.2%) and 18/72 (25%)	Shaheen and Elmahdy (2019)
Sewage water (treated and untreated)	Sewage treatment plant	Zenin and El-berka wastewater treatment plats	Greater Cairo	April 2006 to Feb 2007	EV; HuNoVs GI and GII; HRVs	16/72 (22%); 13/72 (18%); 6/72 (8.3%)	Kamel et al. (2010)
Sewage water (treated and untreated)	Sewage treatment plant	Zenin and El-berka wastewater treatment plats	Greater Cairo	July 2006 to Aug 2007	– Raw: HAV, EV – Treated: HAV; EV	Raw: 8/38 (21.1%) and 15/38 (39.5%) Treated: 3/38 (7.9%) and 6/38 (15.8%)	Kamel et al. (2011)
Sewage water (treated and untreated)	Sewage treatment plant	Zenin and El-Giza water treatment plants	Greater Cairo	July 2009 to June 2011	– Raw: HRVs and HAdV – Treated: HRVs and HAdV	Raw: 11/13 (84.6%) and 22/24 (91.7%) Treated: 7/13 (53.8%) and 11/24 (45.8%)	El-Senousy et al. (2013a)
Sewage water (treated and untreated)	Sewage treatment plant	Zenin, El-berka, and Balaks wastewater treatment plants	Greater Cairo	2014	HAV 1B	43/68 (63.2%)	Hamza et al. (2017)
Sewage water	Sewage treatment plant	Zenin wastewater treatment plat	Greater Cairo	June 2015 to Aug 2017	– Raw: HRVs – Treated: HRVs	Raw: 8/27 (29.9%) Treated: 2/27 (7.4%)	Abd El-Daim et al. (2019)
Sewage water	Sewage treatment plant	Zenin wastewater treatment plant	Greater Cairo	NA	– Raw: HAdV – Treated: HAdV	Raw: 27/32 (84.4%) Treated: 16/32 (50%)	Elmahdy et al. (2019)
Sea water	Sea	Mediterranean Sea	Alexandria, Egypt	NA	Enteric viruses	3/24 (12.5%)	Divizia et al. (1997)

NA not available

El-Gamal 2014). In recent studies, HRV and HAdV were detected in 8.3% to 15.6% of tap water samples collected from homes, cafés and restaurants from four Egyptian Governorates (Cairo, Giza, Kalyoubia, and Fayoum) (Rizk and Allayeh 2018; Gad et al. 2019).

Irrigation water in Egypt was also found contaminated with enteric viruses. El-Senousy et al. (2013b) detected HuNoVs GI and GII in 31.9% (46/144) of irrigation water samples collected from private farms in Dakahlia Governorate during Dec 2008 and Nov 2009. In 2017/2018, HAdV, HAV, HEV, HuNoVs GI and GII and GIV, HRVs, Aichi virus (AIV), and enterovirus (EV) were detected in 100% ($n=16$) of water samples (used for irrigation) from Ummom Agricultural drainage canal and its tributaries (i.e., Dishody, hares, Truga Nubarya, and Maryout drains), which pour in Maryout lake in the Alexandria governorate (Okubo et al. 2019).

As expected, HRV and HAdV were detected in raw (untreated) sewage and wastewater in different Agricultural drainage canals and wastewater treatment plants in Egypt (Kamel et al. 2009/2011; El-Senousy et al. 2013a; El-Senousy et al. 2015; Shaheen and Elmahdy 2019). Even treated wastewater samples collected from several wastewater treatment plants were found to be contaminated with enteric viruses. For instance, several studies during 2006–2017 detected HAV, HuNoVs, HRVs, HAdV, and enterovirus (EV) in treated sewage waters samples; ranging from 8.3 to 63.2%. These samples were collected from Zeinin, El-berka, and Balaks wastewater treatment plants, located in Greater Cairo, after the final step of treatment and chlorination (Kamel et al. 2010, 2011; El-Senousy et al. 2013a; Hamza et al. 2017; Abd El-Daim et al. 2019). These results indicate that the treatment process used in most of wastewater treatment plants in Egypt is primary and is not adequate for complete elimination of enteric viruses from wastewaters before their discharge in rivers, canals and lakes, which are the main sources for irrigation, drinking, and food processing waters in Egypt. The data reviewed here strongly support our hypothesis that the major critical risk factor of viral contamination of Egyptian food is the virological quality of irrigation water used in farms and washing waters used in post-harvest processing stations. Moreover, different enteric viruses were recovered from water samples collected from Mediterranean Sea in Alexandria Governorate, northern Egypt (Divizia et al. 1997). Since the Mediterranean Sea is the main source of wild caught shellfish in Egypt, we expect high level of contamination of Egyptian shellfish with enteric viruses despite the nonavailability of studies on this subject.

General Discussion

It is obvious from these data that the virological safety of Egyptian foods, particularly shellfish, fresh produce, and frozen fruits is not completely clear. Only three surveillance studies on viral contaminants in Egyptian foods are available (Zaher et al. 2008; El-Senousy et al. 2013a, b; Shaheen et al. 2019), which makes it very difficult to comprehensively assess the status of virological safety of Egyptian foods. However, this review provides strong evidence that Egyptian foods are implicated in foodborne viral illnesses and that it may be a possible reason of the high prevalence of enteric virus infections among the Egyptian population. The confirmed implication of some exported Egyptian fruits in outbreaks in the importing countries is an evidence that cannot be refuted. Another evidence is the recovery of several enteric viruses from drinking water, which is used in post-harvest processes and in irrigation water, which is in direct contact with vegetable and fruits in the farm. An additional evidence is the detection of enteric viruses, in high numbers, in treated sewage sludge, which is sometimes used as organic fertilizer in agricultural farms with direct contact with vegetables and fruits (Abd El-Daim et al. 2019). High rate of prevalence of enteric viruses among Egyptian population indicates that the point of infection is not only the direct contact with infected persons but also through a common vehicle such as foods and water.

Lack of Information

Because of the inadequacy of the available data on virological safety of Egyptian foods, several research points need to be addressed to form a comprehensive understanding and assessment of this issue. These important points are discussed below:

- Although there is a considerable number of enteric virus prevalence studies in Egyptian communities, most of these studies are focused mainly on greater Cairo and Nile delta regions (Fig. 4). Similarly, all available surveillance studies on drinking and irrigation waters are concentrated in Greater Cairo and Nile delta religions, while the status of water in other regions is unknown (Fig. 4).
- There is a need to determine virological safety of the water sources of post-harvest stations and food processing plants in Egypt. This should be required by food producers and manufacturers to understand if they need to establish secondary water treatment units in their facilities. The assessment of pre- and post-harvest processes on vegetable and fruit production farms and the adequacy of minimal food processes (washing, freezing, and salt-

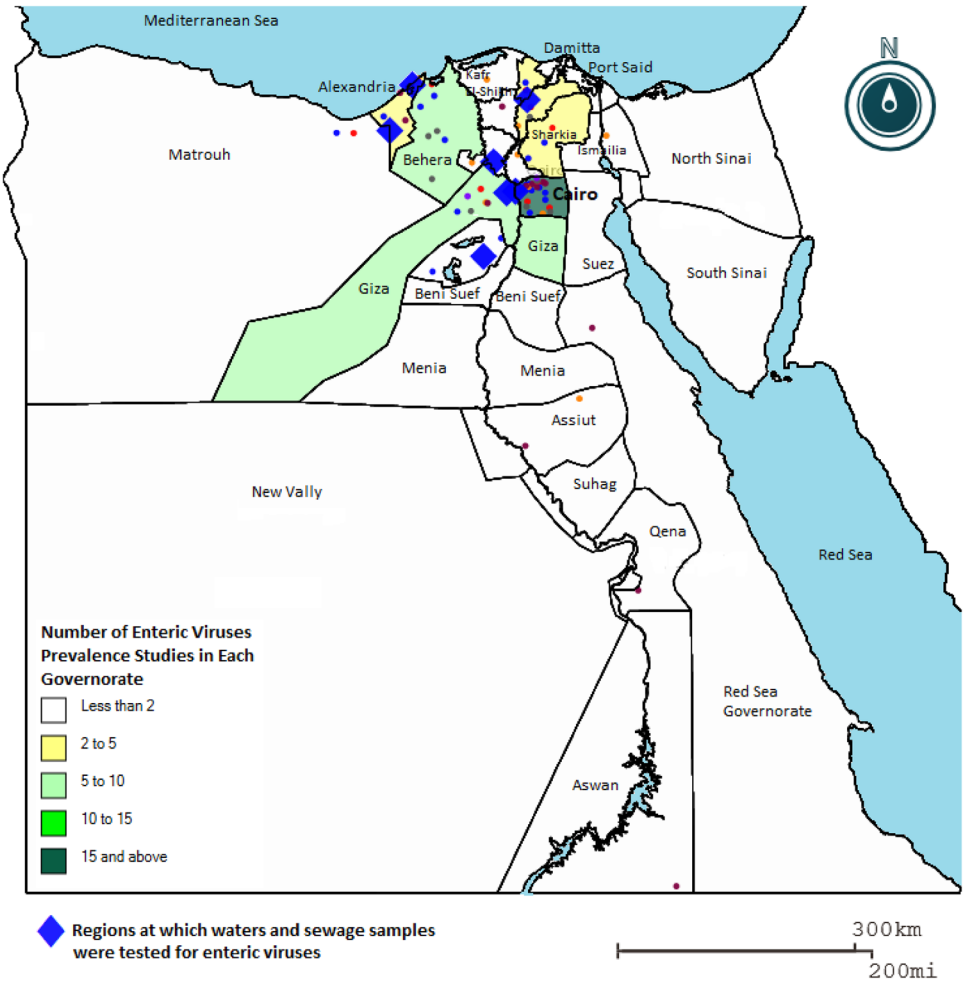

Fig. 4 Distribution of enteric virus prevalence studies in Egyptian regions. Each colored dot represents a study on one of enteric viruses. Red dots = HuNoVs; blue dots = HRVs; dark red dots = HAV; yellow dots = HEV; gray dots = HAstVs; purple dots = HAdVs (Color figure online)

ing) in food service facilities and food-processing factories are also important. This will help in formulating proper practices for efficient production of safe Egyptian foods, which is of mutual interest to both Egypt and importing countries.

- In the two studies that detected enteric viruses in Egyptian foods, PCR methods were used to detect HAV and HuNoV without regard to other enteric viruses that might be present. There is a pressing need to use modern molecular and metagenomics techniques such as next generation sequencing for detection, identification, and typing of foodborne viruses.
- To date, there are no studies on the virological safety of shellfish (clams, oyster, cockles, and mussels) in Egyptian markets. However, the detection of enteric viruses in seawater of Mediterranean Sea in Alexandria (Divizia et al. 1997) indicates high probability of contamination of Egyptian shellfish by enteric viruses. It is widely known that bivalve mollusks bioaccumulate waste contaminants and viral particles during their filter feeding activities. Although depuration process can rid shellfish of contaminants, this process is not widely practiced in Egypt. The fresh or salted shellfish eating is common in the coastal cities of Egypt, and this increases the risk of infection by viral disease in consumers. Therefore, there is a real need to investigate the virological safety of shellfish in Egypt.
- There are no traceback investigation studies to determine the point of infection for any outbreak of viral acute hepatitis or viral acute gastroenteritis in Egypt probably because there is no official surveillance system for these outbreaks in Egypt. To understand the burden of viral-contaminated Egyptian foods on public health and economy, it is necessary to conduct systematic surveillance and epidemiological studies to understand the correlation between viral contaminants of Egyptian foods and viruses responsible for outbreaks and sporadic cases of gastroenteritis and acute hepatitis.

Obstacles to Improving the Virological Safety Status of Egyptian Foods

Enhancing the virological safety of Egyptian foods should be one of the urgent objectives of the Egyptian Government to avoid huge burden on public health and economy. Here, we explain some of the challenges that might have led to the current situation and might pose obstacles in the future in developing such control programs. The microbiological quality control laboratories of most Egyptian food producers and manufacturers are designed for detecting bacterial pathogens and spoilage fungi only and not for routine testing of foodborne viruses. Therefore, we recommend that the Egyptian regulatory agencies make large food manufacturers and exporters responsible for establishing food virology laboratories as part of their quality control and quality assurance systems. Some Egyptian food exporters are required to report the virological safety status of their products to the importing countries. To fulfill this requirement, the Egyptian exporters usually send their samples to clinical/medical laboratories because of the lack of food virology laboratories. The clinical laboratories test food samples using the same testing protocols that they use for clinical samples. The negative results by these laboratories are mostly misleading because of the nonuse of the standard protocols for virus recovery from foods that are usually sophisticated, time consuming and different than those for clinical samples (Goyal and Aboubakr 2016). It should be noted that the number of viruses present in food samples is much lower than those present in clinical samples. However, these low numbers of virus particles are still infectious and may cause clinical disease in susceptible individuals because of low infectious dose of enteric viruses. Hence, it is difficult to detect viruses in foods unless specific methods for concentration and detection are used (Goyal and Aboubakr 2016).

Another challenge is the limited awareness of Egyptian personnel in the regulatory, food manufacturing, food service, and food safety sectors regarding characteristics, pathogenicity, contamination sources, methods of recovery and detection, and control strategies for foodborne viruses. The absence of didactic food virology in most Egyptian academic programs as well as the lack of expertise in this field might be a reason for the low awareness of this important public health and economical challenge. Therefore, establishing food virology programs in academic institution is important. The absence of any food and public safety outreach programs in the Egyptian media might also be a reason for the lack of awareness. Therefore, the establishment of sustainable outreach and awareness programs is urgent for overcoming this challenge. The establishment of an efficient outreach and training program should be inclusive to not only the food specialists but also to all Egyptians to work together toward mitigation of this problem.

Conclusions

Prevalence studies show hyperendemicity of enteric virus infections in Egypt. High prevalence of enteric infections indicates that infection from person-to-person may not be the only route of infection and that contaminated food and water may also be the culprit. Although the data are limited, the published literature strongly indicates the implication of Egyptian food in viral gastroenteritis and viral hepatitis. The data reviewed here indicate a huge burden of foodborne viral disease on Egyptian economy and not only Egyptian public health but also the public health of importing countries. The burden of foodborne viral diseases can be estimated in developed countries because of the existence of centers for disease control and official foodborne disease surveillance systems, which report directly to the enforcement authorities. Then, actions to control these diseases can be undertaken by the decision-makers. However, Egypt, as well as most of developing countries, lack such centers and official foodborne pathogen surveillance systems. Therefore, actual estimation of the burden of foodborne viral contaminants of Egyptian foods is not available. Consequently, no serious actions are taken by Egyptian decision-makers to overcome this challenge. Any future development plans in Egypt must include the establishment of a comprehensive official surveillance system for foodborne viral diseases. The limited awareness with this issue and lack of food virology expertise are two main obstacles to control this threat. The development of a national public awareness program is highly desirable to educate Egyptian people on this issue.

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