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The role of food science and technology in humanitarian response

Dominique Bounie[a,*], Jayashree Arcot[b], Martin Cole[c], Florence Egal[d], Pablo Juliano[e], Carla Mejia[f], Donna Rosa[g], Jay Sellahewa[b,h]

[a] GBA Department/Institut Charles Violette, Polytech Lille, University of Lille, 59655, Villeneuve d'Ascq Cedex, France
[b] Food and Health Cluster, School of Chemical Engineering, UNSW Sydney, NSW, 2052, Australia
[c] School of Agriculture, Food and Wine, University of Adelaide, Glen Osmond, SA, 5064, Australia
[d] Independent Expert, Sustainable Food Systems, Rome, Italy
[e] CSIRO Agriculture and Food, Werribee, VIC, 3030, Australia
[f] World Food Programme, Lumpini, Pathumwan, 10330, Bangkok, Thailand
[g] EFour Enterprises LLC, Miami, FL, USA
[h] CSIRO Agriculture and Food, North Ryde, NSW, 2154, Australia

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ABSTRACT

Background: In humanitarian contexts, ensuring access to safe, nutritious, good quality and culturally appropriate food in the right quantity at the right time and place during an emergency or a protracted crisis is an enormous challenge, which is likely to increase given uncertainties such as climate change, global political and economic instability and emerging pandemics like COVID-19. Several international organizations and non-government organizations have well established systems to respond to food security emergencies. However, the role of food science and technology in humanitarian response is not well understood and is seldom considered in humanitarian circles.

Scope and approach: The role of food science and technology in humanitarian response and the importance of addressing the requirements of the local consumers within the local food systems are discussed.

Key findings and conclusions: Humanitarian food aid policies focus on immediate and short-term assistance to save lives. The implementation of emergency programs and projects tends to induce dependency on aid, rather than strengthening local food systems and ensuring resilience. Transformative change must embrace innovation across the whole food system with an increased emphasis on food science and technology that addresses local food security, generates employment and contributes to the local economy. There needs to be a move beyond rehabilitating and increasing agricultural production to addressing the whole food system with a view to link humanitarian assistance and longer-term support to sustainable livelihoods and resilience.

1. Introduction

1.1. Humanitarian context and key concepts

Many people around the world are affected by natural disasters, internal or cross-boundary conflicts or large-scale economic turmoil (Reliefweb, 2019). Providing these people with sufficient quantities of safe foods necessary for healthy and sustainable diets at the right time, in the right place, and on a consistent basis, is challenging. Furthermore, with emerging pandemics such as COVID-19, there will be a significant impact on local and global food systems and food security with the poorest people being the most affected. Therefore, urgent action must be taken by all stakeholders in mitigating this impact (CFS-HLPE, 2020).

The Right to Food Guidelines (Food and Agriculture Organisation (FAO, 2005) sharply extended this notion by linking humanitarian assistance to conditions where emergency interventions account for longer-term rehabilitation and development objectives, as well as for concerns for food security, food safety, food culture, local production of food and recipient needs.

The 2018 Report on the State of Food Security and Nutrition in the World (FAO et al., 2018), illustrates the scale of the problem. The report shows that the key drivers for a severe food crisis leading to food insecurity were climate-related shocks and conflicts. Hunger and undernutrition are significantly worse where conflicts are prolonged and local institutional capacities are weak. It therefore requires a conflict-sensitive approach that aligns actions, immediate humanitarian assistance, long-term development and sustained peace.

* Corresponding author.
E-mail address: Dominique.Bounie@univ-lille.fr (D. Bounie).

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In the Sahel region in Africa, the worst humanitarian crisis since World War 2 has seen more than 30 million people in four countries facing starvation and famine in 2017 with 3.8 million children under five years of age suffering from severe acute malnutrition and 5.6 million suffering from moderate acute malnutrition. More than 2 billion people worldwide were affected by micronutrient deficiencies mostly due to changes in diets related to economic development (e.g., changes in food production).

The World Food Programme (WFP) of the UN has been very active in delivering food assistance to 91.4 million people in more than 83 countries in 2017, with 80% of WFP resources being allocated to conflict environments; 3 million metric tonnes (Mt) of food were purchased from 101 countries; 3.8 Mt of in-kind food donations were received by WFP from donor countries and 3.5 Mt of food were delivered to more than 70 countries by WFP.

Although many international organizations such as the WFP and various non-government organizations (NGOs) are well equipped to source and distribute food aid to those affected by food security related crises, very often this food is procured from different countries. As such, this food may not conform to the local sensory and cultural preferences or food habits and/or risks potentially undermining local food systems. Food science and technology (FST) can play a key role in the production of foods for affected populations using local raw materials with context appropriate robust technologies while fulfilling nutritional, microbiological, sensory, cultural, environmental and quality requirements.

However, it is important to highlight that a multidisciplinary approach is required so that humanitarian activities remain human-centred rather than technology-driven (Passino, 2016). Here, we suggest that 'humanitarian' be understood as *'concerns and behaviours that translate into human-centred activities aimed at mitigating the short- and long-term adverse effects of shocks on individuals and communities and promoting their lasting recovery'*. This will apply to both emergencies and development contexts and, therefore, could also help to support the prevention-relief-rehabilitation-development-peace nexus. In this regard, humanitarian food science and technology (HFST) should be considered as a people-centric approach aimed at applying FST to prepare for, respond to and sustainably recover from any external shocks. In this context we can define HFST as *'the application of food science and technology to enhance food security, health, and economic prosperity for global humanitarian purposes'*.

However, the role of FST in humanitarian response is still not well understood or addressed (sections 2.1). It is also important to recognise that food systems in affected areas are often not sustainable and that FST could contribute to strengthening local resilience (i.e. *'ability to prevent and mitigate disasters and crises as well as to anticipate, absorb, accommodate or recover and adapt from them in a timely, efficient and sustainable manner. This includes protecting, restoring and improving livelihood systems in the face of threats that impact agriculture, nutrition, food security and food safety*', FAO, 2013a) and increasing the adaptability of such systems, by creating short to long-term opportunities, in particular for the employment of youth and women.

Although some evidence on the relevance of post-harvest interventions as a source of livelihoods and revitalisation of local economies is available (Hodges et al., 2011), no systematic attention has been given so far to elicit guiding principles for their adoption, adaptation, replication and/or upscaling, especially for agro-food processing.

There are opportunities to develop HFST-based solutions and responses to enhance the effectiveness of current humanitarian response as well as contributing to lasting food security in the context of internal conflicts, climate change, other natural hazards, increasing poverty, accelerated urbanisation, widespread migration and pandemics. To find effective, innovative, long term solutions to such incidences of food-related shocks across the globe, it is important that industry, NGOs, the research community, consumers, aid organizations and donors work together. It is also important that adequate training is given to those engaged in HFST activities in order to develop the required skills. We present here the current status of the role of FST in humanitarian response, together with current gaps.

1.2. Methodology

Literature specifically addressing the role of HFST is very limited. There is extensive literature on food sustainability and food policy and some literature in the use of technology in disaster management and the use of innovation in humanitarian responses. Moreover, effects of food systems disruption due to conflict and climate-related disasters on food insecurity and malnutrition have been addressed in the Global Report on Food Crises (FSIN, 2018). However, the published work rarely refers to the use of innovation or the role of FST in humanitarian response. Most of the published work in food security focuses on agriculture to increase on-farm production and productivity and there is less focus on the importance of post-farm processing. Eade and Williams (1995) of Oxfam provide a good analysis of the situation regarding development and relief operations.

One of the main limitations in effectively using FST expertise in addressing global humanitarian feeding situations is the lack of awareness and adequate information and training of personnel from different stakeholders working in humanitarian preparedness and response. This limitation, together with the limited published information on HFST, prompted the organisation of an international symposium on HFST in Sydney, Australia in 2017, where key stakeholders from seven countries representing UN agencies, NGOs, academia, research institutes, the private sector and governments participated (AIFST, 2017). This symposium was followed by a workshop where contributors to the symposium and other experts in HFST discussed current problems and identified potential opportunities where FST could contribute to humanitarian response. Following this workshop, a global HFST group, representing key stakeholders was formed and this group (which includes the authors) has disseminated relevant information to increase awareness of HFST (AIFST, 2017).

The framework that we used for making our recommendations is based on a literature review, the outcomes from the international HFST symposium and workshop and the expertise and experience of the global HFST Group (Fig. 1).

2. Contribution of food science and technology in improving humanitarian food security

There are three factors that are not clearly understood by policy makers and by most humanitarian actors. i.e:

a) How FST could contribute to go beyond nutritional requirements by developing foods that are 'fit for purpose', i.e., satisfying consumer expectations in terms of convenience, taste, shelf life, enjoyment, preparation, cultural appropriateness, acceptability and value
b) How the application of FST could better control the quality and safety of diets and food during processing and along the humanitarian supply chain, while minimizing wastes and energy losses, and
c) How FST could contribute to strengthen food systems in disrupted environments and make them more resilient to shocks and inclusive by bringing value to destitute and vulnerable communities

As a prerequisite, it is important to recognise that the implementation of any new FST solution, especially in fragile food systems, should be preceded by a careful needs assessment in the affected areas. Some of the issues to consider are: What is the targeted population? What are their nutritional needs and what are their food habits (What and when do people eat? Where and how is food produced/procured/processed? What local foods should be considered? What FST related experiences, skills and resources exist and who should be supported to do what?).

Some examples on how FST has contributed or might contribute to

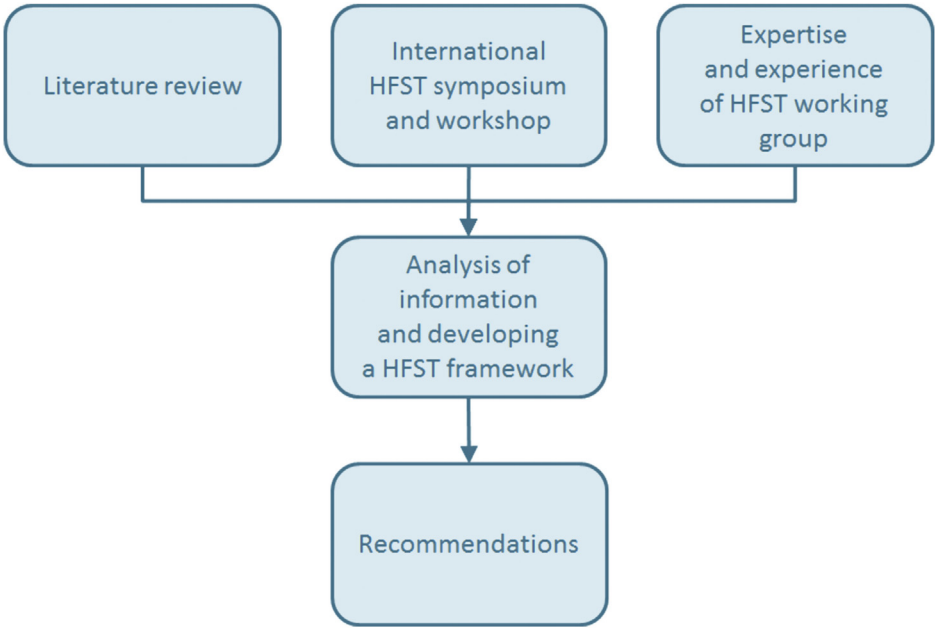

Fig. 1. Methodology used in making the recommendations in this study.

Table 1
Contribution of Food Science and Technology in the development of nutritious local foods.

Objectives	Examples of local adaptability	References
Development of new nutritious foods/improving existing foods	Reformulation: ● Replacing peanut paste in ready-to-use supplementary foods (RUSF) with locally available nuts or pulses (almonds or chickpea - WFP, Pakistan); cashew nuts (Ivory Coast) and Bambara nuts. ● Replacing soy proteins or animal proteins with under-exploited plant proteins (chickpea - WFP RUSF 'Wawa Mum'); leaf proteins ● Evaluating plant proteins; pseudocereals (quinoa, teff and amaranth grains, leaves)	UNICEF-WFP-USAID (2016); WFP (2011) Bounie et al. (in AIFST, 2017); WFP (2011) Akande et al. (2017); Michaelsen et al. (2009); Shumoy and Raes (2017); Rathore (2010)
Adapting to local food habits and varying the taste of common Ready to Use Supplementary Foods (RUSFs) and blended flours; adding aroma and spices	● Equinut project; Nutriset '(Plumpynut'); developing new textures (extruded pillows filled with nutritious paste made by Nutriset; gellified bars) ● Producing locally RUSF adapted to local resources and tastes ● Developing RUSFs with intermediate water activity and improved osmolality, minimizing diarrheal side effects; decrease need to drink safe water when eating lipid-based RUSFs	AKDN (2016) and Seye (in AIFST, 2017) Sheeran (2009) Webb et al. (2011)
Improving the nutritional and health value of Special Nutritious Foods (SNFs)	Improving bioavailability by reducing phytase activity; improving nutrient density of fortified blended flours using appropriate processes (extrusion cooking, germination, use of alpha-amylase) to reduce consistency improving swallowing ability to achieve fullness in the stomach in infants Adding functional ingredients (probiotics, anti-diarrheal constituents e.g. new products developed by Nutriset)	Harvestplus (2019); Van Hoan et al. (2010); Webb et al. (2011) Nutriset (2018)
Improving shelf-life of SNFs using traditional antioxidant products or antioxidant rich natural ingredients or new combined processes	Kemin Industries Inc. operates in more than 60 countries with manufacturing facilities in Belgium, Brazil, China, India, Singapore, South Africa, Thailand and the United States providing advice on health and nutritional solutions to agrifoods, food ingredients, pet food and human health and pharmaceutical industries	WFP (2008)
Improving convenience of SNFs i.e. reduced re-humidification during storage, auto heating products, design of more ready-to-use foods	WFP has provided 'Specialized Nutritious foods' sheet as a reference for the various types of formulated foods made available to address undernutrition.	WFP (2013)
Understanding and better control of the operating conditions when producing SNFs locally	Control and optimisation of degree of cooking (which affects digestibility) when producing precooked extruded blended flours; selecting the appropriate process for efficiently cooking blended flours; extrusion cooking vs. drum drying or Infra-Red roasting	Van Hoan et al. (2010); WFP (2019)
Designing and developing appropriate equipment (low cost, easy to operate and maintain, resistant to wear)	Containerized food processing units, using alternative energy (solar energy, biogas from waste, biochar)	Bounie (2018); Fellows (in AIFST, 2017)
Improving the safety and quality of foods: Use of Hazard Analysis Critical Control Points (HACCP) methodology, traceability systems, rapid-analysis system for on-site quality assessment	The 'Blue Box' to assess in the field the aflatoxin content of maize developed for WFP	Webb et al. (2011); WFP (2012)

the development of foods that fulfil these requirements are outlined in Table 1 and discussed further in sections 2.1, 2.2. and 2.3.

2.1. Innovation and the use of technology

Although there has been some activity recently on innovation and the use of new technologies and systems in humanitarian response, the focus of innovation in humanitarian processes and practices has been on incremental improvements and it appears that the application of FST in humanitarian response is limited. Ramalingam et al. (2009) point out that in innovations within existing humanitarian practices, policies and processes, there is some reluctance to change because of a potential conflict with pre-defined practices and methods.

In a policy paper by the UN Office for the Coordination of Humanitarian Affairs (OCHA), Betts and Bloom (2014) discuss the role of innovation in a humanitarian context. They discuss the challenges in introducing innovation, the innovation cycle for products, processes and technologies, and the importance of collaboration (the human ecosystem). They claim that a better understanding of the potential and purpose of the innovation cycle and developing an innovative mindset could bring significant benefits to the humanitarian system.

In the WFP publication *Revolution: From Food Aid to Food Assistance - Innovations in Overcoming Hunger* (Omamo, Gentilini, & Sandstrom 2010), several papers discuss innovation in a humanitarian context, including the role of information and communications technology and logistics to deliver innovations in complex environments in food assistance.

Several recent initiatives have put innovation at the heart of humanitarian action, including the Global Alliance for Humanitarian Innovation (GAHI) (GAHI, 2016) and WFP's 'Innovation Accelerator' (WFP, 2018).

Although innovation has been acknowledged as important in the humanitarian agenda through these initiatives, it should be noted that some of them are no longer operating, are not scalable or are poorly addressing specific HFST concerns. This is unfortunate because Research and Development (R&D) has always been strong in the food industry and the academic sector and therefore, resources for R & D should be solicited more by HFST to these stakeholders with the aim of finding new solutions to existing problems (Webb et al., 2011).

A report from the World Economic Forum (2018) has identified 12 key technology applications that may accelerate food systems transformation "to sustainably and nutritiously feed more than 9 billion people while providing economic opportunities in both rural and urban communities". These pioneering technologies, using digital tools, robotics, biotechnologies and genomics, are presented as having, until now, poorly disseminated into current food systems but offering promising results. Their application in humanitarian contexts is not addressed, which once again demonstrates that humanitarian situations are not considered as a potential beneficiary from such a transformative program.

2.2. Optimizing product and process development in humanitarian response

FST plays a key role in product and process development in humanitarian response. Sheeran (2009) discusses the importance of FST in the preparation of convenient to consume, non-perishable foods and examples given to produce ready-to-eat fortified sweet paste in India (with chickpeas and milk powder), high energy biscuits in Thailand, and fortified date bars in Egypt. The importance of public-private partnerships and WFP's role in humanitarian feeding is also highlighted.

Guimon and Guimon (2012) discuss how ready-to-use therapeutic foods (RUTFs) changed the treatment of child malnutrition since the turn of the 21st century and explore the historical development of RUTFs with respect to technological innovations in the 1980s to testing and large-scale dissemination in the late 1990s. RUTFs are now routinely used to treat malnutrition in children and have many advantages over the use of fortified milk powder. However, this paper does not discuss the vital role played by FST in the development of RUTFs.

Ryan et al. (2014) discuss the optimisation of formulation of low cost RUTFs from locally available raw materials using linear programming and De Pee et al. (in Omamo et al., 2010) highlight the importance of nutrition when developing new food products for food assistance. The paper by Michaelsen et al. (2009) was one of the first instances where nutritionists referred to the importance of food technology when choosing foods and ingredients for moderately malnourished children.

The most relevant publication with respect to HFST that is in the public domain is by Bounie et al. (in Omamo et al., 2010). This paper discusses how food technology is used at WFP to support different corporate units and country offices to enable the production of safe and nutritious food for humanitarian aid to comply with WFP's mandate and strategy. Several examples of producing such food in different countries are given and processes used to produce nutritious, convenient, safe food are explained (including the use of containerized food production units). This paper also outlines the methods used by WFP at that time to manage product safety and quality as well as traceability.

2.3. Managing food safety and quality through the humanitarian food supply chain

The improvement of the safety and quality of foods is an important factor in reducing hunger. Food that is safe and of good quality results in improved access to markets, reduced food loss and waste, improved food security and reduced burden of foodborne diseases. This issue disproportionally affects the least developed and developing nations, namely in Africa and Asia. The World Health Organisation (WHO) estimated that the global burden of foodborne diseases by the main foodborne hazards was 33 million Disability-Adjusted Life Years (DALYs) in 2010 and 40% of this burden was among children under five years of age (WHO, 2015). Despite these figures and its effects on socio-economic development, ensuring food safety and quality in developing countries with poor public-sector regulatory enforcement remains a challenge that is only exacerbated by climate change, conflict and other external shocks, such as pandemics.

Much work in quality control systems in the supply chain of humanitarian feeding systems has been carried out by WFP, UNICEF and Médecins Sans Frontières (MSF). Relevant technical and other information is available in the dedicated WFP Food Quality and Safety web site (WFP, 2019) and the publication '*Managing the Supply Chain of Specialized Nutritious Foods*' (WFP, 2013). The topics covered in this publication include determining the demand, food quality, procurement, logistics and distribution to the identified population.

Although there have been some problems in the past with respect to maintaining the quality of food in such a complex supply chain, WFP has taken the lead by introducing a 'quality culture' in the supply chain by changing the approach at WFP to moving from a procurement only (at lower price) approach to a modern 'Food Quality and Safety' approach (Menage & Salvignol, 2010). However, there were some product quality incidents and possible causes for quality problems in the supply chain which have been listed (WFP, 2013). A major food safety concern in 2012 led to a multi-stakeholder collaboration for clarifying specifications and to facilitate process changes by suppliers in order to comply with these new specifications (FAO-WHO, 2016). This also highlighted that the main distributors of these products were not ready to handle major food incidents.

The actions taken by WFP include the implementation of a corporate FSQMS (Food Safety and Quality Management System) and proactive FIMS (Food Incident Management System) decision making process (i.e. Initiate-Detect-Estimate-Act-Learn (IDEAL), (Bounie, 2012; WFP, 2013). This approach has significantly increased the reporting of incidents and over time reduced the number of food safety and quality incidents. These actions require a committed food safety culture, the

full and coordinated effort of every stakeholder along the whole food supply chain and the provision of appropriate resources. Therefore, it is recommended that donors should do more to support and advocate the maintenance of product quality and safety throughout the supply chain. In addition, quality control should be an independent function from procurement and logistics, in order to avoid any conflict of interest or misunderstanding on quality requirements.

3. The design of new humanitarian food science and technology solutions

3.1. Humanitarian food science and technology solutions for enhancing resilience to shocks

3.1.1. Long term development and sustainability

The emphasis of most current aid policies is on immediate and short-term assistance where the focus is on coping mechanisms. The implementation of these policies in protracted emergency environments tends to induce dependency on aid (Alonso et al., 2012). Instead, aid policies should go much further and foster sustainable self-reliance. In this regard, solutions should help the beneficiaries, not only by the provision of relief foods that they need, but also by strengthening local food systems and supporting sustainable interventions. Some examples have recently been published showing the link between sustainable energy and food security in humanitarian contexts (Caniato et al., 2017).

Humanitarian interventions are often a result of significant disruption of daily life that affects food security and nutrition in the population and needs a timely and targeted response. Depending on the severity of the situation and whether the event is considered acute or chronic (FAO, 2018), available resources are mobilized with a focus more on immediate relief rather than post-emergency recovery. Local food systems, already weakened or disrupted, may be affected for a long time by interruption of external drivers that may bring additional disruptive blows.

Today there is a consensus that humanitarian interventions should be included into a larger prevention-relief-rehabilitation-development continuum, which would result in mitigating future crises by building longer term sustainable solutions. This should be based more on the resilience capacity of the population concerned than on their coping mechanisms. Therefore, the FST components of any humanitarian response should account as much as possible, on the main recommendations by FAO (2017) for 'increasing availability, affordability, and consumption of diverse, safe, nutritious foods and diets, aligned with dietary recommendations and environmental sustainability'. Some of these issues have also been addressed by Keding et al. (2013).

3.1.2. Assessing economic feasibility

Only a few documents are available that evaluate the economic feasibility of FST projects implemented in humanitarian contexts. Most technical and economic feasibility assessment reports that are available are internal reports, produced by international agencies or NGOs submitting their projects to donors. When investing in humanitarian projects, there should be a balance between avoiding 'white elephants' that have so often resulted in undesirable outcomes from humanitarian interventions (e.g. not adapted to local market requirements, local resources not used, not scalable beyond localized pilots), while still promoting local initiatives that would foster the recovery and longer term development of affected communities.

Harper et al. (2015) have shown that in development contexts, such demand-based and inclusive value chains may be developed and directly benefit the poorest by increased incomes while increasing their resilience capacities and access to safe, nutritious, convenient foods that are available locally. Ritchie, 2018 has shown that promoting entrepreneurship in refugee settings may boost self-resilience and female empowerment while fostering new socio-cultural dynamics and human security. In such fragile and conflict-affected settings, the 5 years research program 'Human Security in Fragile States' at the IS Academy, Wageningen has attempted to understand the socio-economic recovery at the intersection of strategies to rebuild people's lives, institutional change and aid interventions (IS Academy, 2014).

Transferring such initiatives to humanitarian contexts would require a shift in aid interventions from relief-only to recovery and rehabilitation activities aiming at seeding incentives that would have a leveraging effect on sustainable development schemes. This is an exciting outlook where food scientists and micro, small, and medium enterprises could collaborate to develop new and appropriate processes and use technologies that are accessible to local communities, resulting in positive economic and social outcomes. It should be mentioned, however, that there are significant challenges in setting up and operating local food processing operations, including:

- Little to no access to sufficient financing for start-up businesses
- Lack of reliable power
- High cost of production equipment
- Need for intensive management and employee training in both technical and business skills
- Potential lack of adequate and continuous local sources of some raw materials, packaging and spare parts, necessitating imports
- Distribution problems due to poor transport infrastructure

In a humanitarian context, it is not always possible to quantify the economic feasibility of FST interventions, especially when only short-term impact factors are used. However, such interventions could often be justified because of significant social benefits and of the expected long-term decline in aid dependency. Overall feasibility should be assessed in terms of multi-dimensional cost-benefit analyses, while existing good FST practices in the field should be identified, reviewed, supported and utilized.

3.2. Multi stakeholder partnerships

As the world becomes more complex, the best solutions are often planned and delivered through multi stakeholder partnerships and participatory approaches. A good example in a humanitarian context is public-private partnerships because the private sector has significant expertise and resources in food processing, quality control and management, food safety, nutrition, packaging, logistics and R & D that the humanitarian sector could adapt. Therefore, there is potential for the humanitarian agencies and NGOs to develop partnerships with the private sector and utilise its expertise and the private sector could benefit from the untapped demand and potential commercial opportunities of the humanitarian sector. Even though such partnerships are largely encouraged today by major humanitarian agencies and are well documented in development media, there is not much information in the literature on private-public partnerships in emergency situations, except the conference in Australia in 2009, organised by the Crawford Fund (Sheeran, 2009).

Two other sectors where the humanitarian sector could develop partnerships with and transfer knowledge for mutual benefit are the military and space programs. R&D undertaken in the development of foods for combat forces, astronauts and for populations in humanitarian feeding systems has many similarities with respect to issues of quality, nutrition, safety, stability, shelf-life and packaging. However, a key difference between the applications in military and space programs and the humanitarian sector is that the food for humanitarian feeding must be significantly more cost effective. Another difference is that target groups are much more diverse in the humanitarian sector, requiring tailoring to a wider range of nutritional and cultural needs.

The U.S. Army's Combat Feeding Directorate at the Natick Soldier Research, Development and Engineering Center (NSRDEC) and the

Defence Science and Technology Group in Australia (DSTG) are addressing the possibility of using the expertise that they have in FST and logistics for humanitarian purposes. At NSRDEC, a first comprehensive study (Briggs et al., 2007) was funded by USAID for developing an emergency food product with a focus on product and packaging specifications. Barrett and Cardello (2012) published a systematic review of U.S. military's approach to the development of ready-to-eat self-heating foods with respect to processing, packaging, testing, and distribution methods with in-depth information on reducing weight, nutrient optimisation and shelf-life extension. Beagley (in AIFST, 2017) has reported the link made by DSTG between combat rations and humanitarian feeding.

The National Aeronautics and Space Administration in the United States has extensive expertise in developing foods for astronauts on long-range space missions and this expertise may be relevant for humanitarian feeding (e.g. extended shelf life, nutritional density of low weight rations, sensory acceptability over long-time consumption). The development of food for astronauts and its multifaceted nutritional and processing challenges, has been reported by Cooper et al. (2011).

Thus, it is important that the humanitarian agencies have closer indirect collaborations with the military through scientific institutions and with space research agencies so that expertise in food science, technology and nutrition could be transferred from these agencies to the humanitarian sector. Sakai et al. (2014) highlight different multi-stakeholder initiatives (civil society, military, state institutions and media) that have been developed in the Asia-Pacific region for responding to disasters. Corresponding mechanisms of coordination in such contexts at central, regional and local levels are described by OCHA (2013). These examples advocate for improved multidisciplinary coordination, but the FST dimension is still poorly addressed. It is also very important that effective partnerships are developed between national and local governments.

3.3. Reshaping humanitarian food systems

FAO and CFS (Committee on World Food Security) were among the first to highlight the importance of the concept of a food system for understanding the many drivers and interactions that contribute to the incremental shaping of our foods, from field to plate: '*A food system encompasses all the people, institutions and processes by which agricultural products are produced, processed and brought to consumers*' (FAO, 2013b). In 2014, CFS sharpens this definition by integrating the inputs and outputs of such activities as well, '*including socioeconomic and environmental outcomes*' (CFS-HLPE, 2014). In a recent report, CFS also highlights the importance of agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition (CFS-HLPE, 2019). This holistic approach clearly outlines the different levels where FST may contribute in improving food safety, quality and acceptability.

In humanitarian contexts, where food insecurity is at its highest, it is crucial to look at all local foods and every level of the value chain (from production, processing and delivery to consumption and end-of-life). This goes far beyond looking at the impact of food systems on the nutritional value of foods alone and advocates for investigating how to account for other attributes of food quality (safety, taste, convenience) that may affect food availability, acceptability, utilization and stability. In the same way, inclusive nutrition-sensitive value chains should include representatives not only of smallholders but of all the stakeholders involved in the value chain: producers, processors, transporters and retailers (CFS, 2016). Through the direct benefit that they may find in maintaining the value chain, they all bring their own contribution to strengthening local food security and the sustainability of the concerned Humanitarian Food Systems (HFS), an emerging concept that we propose to define as described in Fig. 2.

HFSs require specific attention because they operate quite differently from traditional food systems, some of the main differences being their fragile and disruptive environment and being driven by donors rather than beneficiaries. This has often been a conflicting issue when it questions the competition among NGOs for funding and the inclusiveness of beneficiaries. However, this should not justify why HFSs have been so poorly studied. This opens promising perspectives for using the need for inclusive and resilient HFSs as a comprehensive conceptual framework for studying the potential interest of FST in humanitarian contexts.

HFSs should not be abstract concepts which evolve aside traditional food systems: both systems should benefit from each other. Humanitarian situations foreshadow those that industrialized countries may soon encounter due to the upsurge in climatic, environmental, economic and migratory crises they regularly face today as well as emerging pandemics such as COVID-19 and this could be best addressed by challenging the current HFSs. It is interesting to note the current revival of small and decentralized food systems that are revitalizing local food production through processing, with the objective of optimizing better the 'local unused capacities' (Gwin & McCain, 2017). This so-called 'missing link in sustainable food systems' could inspire and benefit HFSs on how they too should invest more in food processing and how these initiatives could be financially viable.

Most of these key issues of HFST could be captured under the categories of 'products', 'processes' and 'people and systems', encapsulating different attributes in each category, as summarised in Fig. 3.

4. Conclusions and recommendations

As a result of natural disasters and economical and political unrest, the world is facing a humanitarian crisis in an unprecedented scale and millions of people are food insecure and this problem is likely to worsen with emerging pandemics such as COVID-19.

UN agencies and a range of NGOs are well equipped to source and distribute food to those in need in current humanitarian situations, resulting in significant benefits to affected people. However, the role of FST and the contribution that it could make in addressing some of the problems within the global humanitarian food system is not well understood by relief workers, NGOs, donors, governments, academia or the R&D community because this topic has not been sufficiently or methodically explored. In addition, the FST community is not aware of the challenges and opportunities in humanitarian feeding. It is also apparent that the vast expertise of the private sector in the food supply chain is not used to its full potential in current humanitarian supply chains.

It is important to take an innovative, multidisciplinary, multi-stakeholder partnership approach in humanitarian food systems not only to cope with emergencies in the short term, but also to build resilience of local communities so that they could secure sufficient, safe and nutritious food in the long term. Food scientists and technologists could make a significant contribution to this initiative. Such an approach will enable less dependency on food aid from donors and more reliance on local sources of agricultural commodities, post-harvest processing and inclusive human capacities.

The proper implementation of innovative solutions for humanitarian systems through multi stakeholder partnerships involving relevant UN agencies, donor organizations and NGOs, together with the research community and the private sector, is likely to result in tangible outcomes to affected people with significant positive economic, social and environmental impact to the local communities.

It is recommended:

1) To increase awareness of the critical role and importance of FST in humanitarian response among humanitarian stakeholders and conversely of the challenges and opportunities of humanitarian issues among food scientists and technologists.
2) That policy makers, donors, governments, NGOs and other

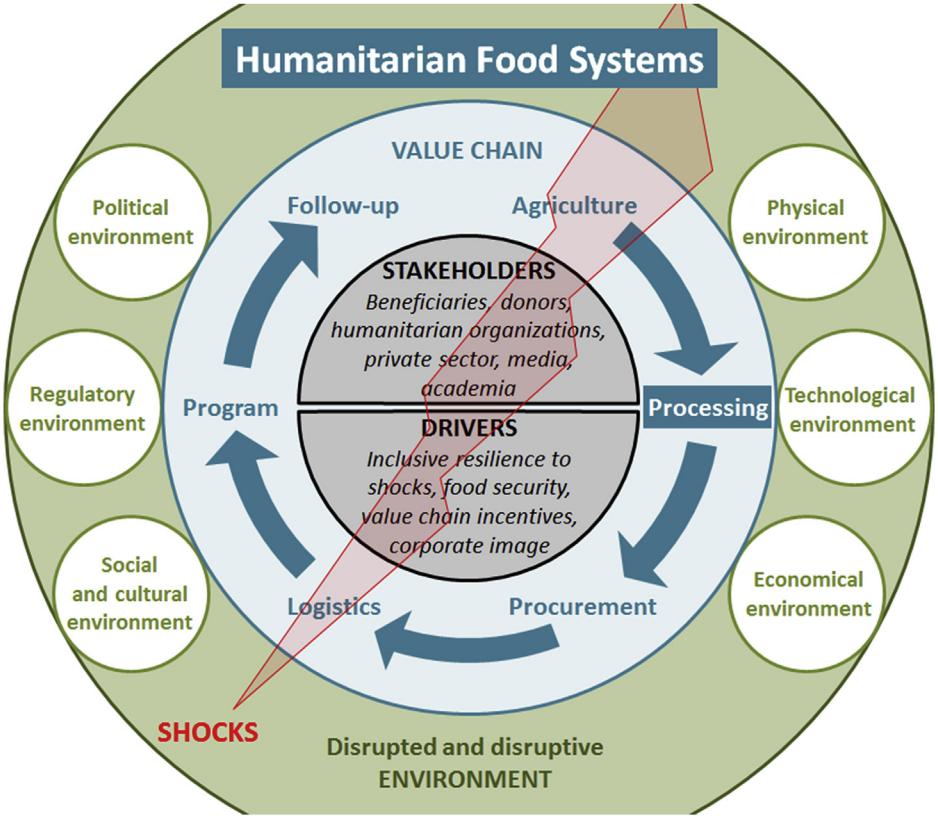

Fig. 2. Conceptual framework for Humanitarian Food Systems.

humanitarian stakeholders recognise that FST plays a key role in food systems and it should be systematically included in relief and rehabilitation strategies aiming at sustainable and resilient food systems. Furthermore, food security interventions need to go beyond food aid and support to farmers and be expanded throughout the whole value chain. Such an approach will enable local food security issues to be addressed in humanitarian response, as well as reducing food waste, creating local employment and increasing local resilience through the application of FST.

3) That adequate resources are allocated, and investments made in capability strengthening focused on the application of FST to address humanitarian response problems with appropriate, innovative solutions.
4) That HFST is recognized as a new academic sub-discipline that should be investigated to build comprehensive multi-disciplinary curricula and new teaching programs. These programs should be taught at a high level to train humanitarian stakeholders implicated in the design and implementation of resilient and inclusive humanitarian food systems, with a strong focus on low-cost, robust and appropriate food technologies.

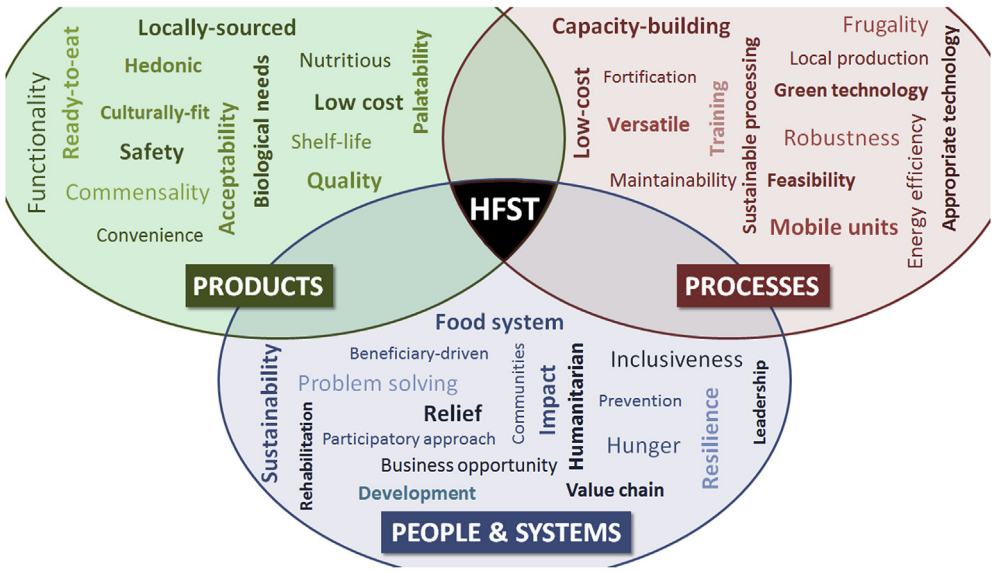

Fig. 3. HFST at the intersection of Products, Processes, People and Systems.

Declaration of competing interest

The authors declare no conflict of interest and no competing financial interest.

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References

AIFST (2017). Oral presentations at the AIFST humanitarian food science and technology symposium, Sydney, Australia; HFST working group summary and briefing paper. https://www.aifst.asn.au/humanitarian-food-science-and-technology, Accessed date: 15 April 2020https://www.aifst.asn.au/AIFST-Humanitarian-Food-Science-&-Technology-Symposium-Presentations.

Akande, O. A., Nakimbugwe, D., & Mukisa, I. M. (2017). Optimization of extrusion conditions for the production of instant grain amaranth-based porridge flour. *Food Sciences and Nutrition, 5*, 1205–1214. https://doi.org/10.1002/fsn3.513.

AKDN (2016). Mali-Health. https://www.akdn.org/where-we-work/west-africa/mali/health-mali, Accessed date: 15 April 2020.

Alonso, J. A., Garcimartín, C., & Martin, V. (2012). Aid, institutional quality and taxation: Some challenges for the international cooperation system. In J. A. Alonso, & J. A. Ocampo (Eds.). *Development cooperation in times of crisis* (pp. 172–247). New York: Columbia University Press ISBN: 9780231159661.

Barrett, A. H., & Cardello, A. V. (2012). *Military food engineering and ration technology.* Lancaster: DEStech Publications Inc ISBN-13: 978-1605950495.

Betts, A., & Bloom, L. (2014). Humanitarian innovation: The state of the art. OCHA policy and studies series No: 9. https://www.unocha.org/sites/unocha/files/Humanitarian%20Innovation%20The%20State%20of%20the%20Art_0.pdf, Accessed date: 15 April 2020.

Bounie, D. (2012). *Food incident management - proposal for setting-up an integrated process for securing the decision-making process at WFP in case of food incident. Rome: WFP, consultancy report*.

Bounie, D. (2018). *Containerised Food Production Units (CFPU) for the local production of food in humanitarian (and non-humanitarian) context. s.* IFT webinarhttps://www6.ift.org/Ecommerce/Meetings/MeetingDetail?productId=41460228, Accessed date: 15 April 2020.

Briggs, J., Maguire, P., Sherman, P., Davis, B., Barrett, A., Mahon, J., & Doucette, J. (2007). *Final report on development of an emergency food product - product and packaging specifications, shelf life study and drop test synopsis*USAID & NSRDEChttp://pdf.usaid.gov/pdf_docs/Pnads423.pdf, Accessed date: 15 April 2020.

Caniato, M., Carliez, D., & Thulstrup, A. (2017). Challenges and opportunities of new energy schemes for food security in humanitarian contexts: A selective review. *Sustainable Energy Technologies and Assessments, 22*, 208–219. https://doi.org/10.1016/j.seta.2017.02.006.

CFS (2016). Inclusive value chains for sustainable agriculture and scaled-up food security and nutrition outcomes. Rome: FAO, 43rd session "making a difference in food security and nutrition. http://www.fao.org/3/a-mr587e.pdf, Accessed date: 15 April 2020.

CFS-HLPE (2014). *Ood losses and waste in the context of sustainable food systems. Rome: FAO, HLPE report n° 8. F*http://www.fao.org/3/a-i3901e.pdf, Accessed date: 15 April 2020.

CFS-HLPE (2019). Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. Rome: FAO, HLPE Executive Summary no 14 http://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE_Briefs-Flyers/HLPE_Report_14-Executive-Summary-A5_WebRes_DEF.pdf, Accessed date: 15 April 2020.

CFS-HLPE (2020). Impact of COVID-19 on food security and nutrition. Rome: FAO, HLPE interim issues paper (version 1). http://www.fao.org/fileadmin/templates/cfs/Docs1920/HLPE_2020/New_HLPE_paper_COVID_EN.pdf, Accessed date: 4 May 2020.

Cooper, M., Douglas, G., & Perchonok, M. (2011). Developing the NASA food system for long-duration missions. *Journal of Food Science, 76*(2), R40–R48. https://doi.org/10.1111/j.1750-3841.2010.01982.x.

Eade, D., & Williams, S. (1995). *The Oxfam handbook of development and relief.* Oxford: Oxfam0 85598 274 8.

FAO (2005). *Voluntary guidelines to support the progressive realization of the right to adequate food in the context of national food security.* Rome: FAO978-92-5-105336-2http://www.fao.org/docrep/pdf/009/y7937e/y7937e00.pdf, Accessed date: 15 April 2020.

FAO (2013a). *Resilient livelihoods: Disaster risk reduction for food and nutrition security.* Rome: FAO978-92-5-107625-5http://www.fao.org/docrep/015/i2540e/i2540e00.pdf, Accessed date: 15 April 2020.

FAO (2013b). *The state of food and agriculture: Food systems for better nutrition.* Rome: FAO978-92-5-107671-2http://www.fao.org/3/i3300e/i3300e.pdf, Accessed date: 9 July 2019.

FAO (2017). *Nutrition-sensitive agriculture and food systems in practice - options for intervention.* Rome: FAO978-92-5-109945-2http://www.fao.org/3/a-i7848e.pdf, Accessed date: 15 April 2020.

FAO (2018). Integrated food security phase classification - evidence and standards for better food security. http://www.ipcinfo.org/fileadmin/user_upload/ipcinfo/docs/1_IPC_Brochure_2017.pdf, Accessed date: 15 April 2020.

FAO-WHO (2016). *Microbial safety of lipid-based ready-to-use foods for management of moderate acute malnutrition and severe acute malnutrition. Vol. 28*Rome: FAO, Microbiological Risk Assessment Series n°978-92-5-109062-6http://www.fao.org/3/a-i5347e.pdf, Accessed date: 15 April 2020.

FAO, I. F. A. D., UNICEF, W. F. P., & WHO (2018). *The state of food security and nutrition in the world 2018. Building climate resilience for food security and nutrition.* Rome: FAO978-92-5-130571-3https://docs.wfp.org/api/documents/WFP-0000074343/download/?_ga=2.235013825.1901618707.1557349353-1970116371.1551780093, Accessed date: 15 April 2020.

FSIN (2018). *Global report on food crises. Rome*WFP/FAO/IFPRI/European Unionhttp://fsinplatform.org/sites/default/files/resources/files/GRFC_2018_Full_report_EN_Low_resolution.pdf, Accessed date: 15 April 2020.

GAHI (2016). *Building a global alliance for humanitarian innovation.* World Humanitarian Summit. Istanbul 2016 https://app.box.com/shared/spsyw7c1eiaeeuvlmazbtoxca7jlt3vw/1/7759703669/74960003102/1, Accessed date: 15 April 2020.

Guimon, J., & Guimon, P. (2012). How ready-to use therapeutic food shapes a new technological regime to treat child malnutrition. *Technological Forecasting and Social Change, 79*(7), 1319–1327. https://doi.org/10.1016/j.techfore.2012.04.011.

Gwin, L., & McCain, N. (2017). Use it or lose it: Local food, regional processing and the perils of unused capacity. In A. Dumont, (Ed.). *Harvesting opportunity: The power of regional food system investments to transform communities* (pp. 151–171). St Louis: Federal Reserve Bank of St. Louis and the Board of Governors of the Federal Reserve System. https://www.thecommonmarket.org/assets/uploads/reports/Harvesting_Opportunity.compressed.pdf, Accessed date: 15 April 2020.

Harper, M., Belt, J., & Roy, R. (2015). *Commercial and inclusive value chains - doing good and doing well.* Rugby: Practical Action Pub.

Harvestplus (2019). Nutrition. https://www.harvestplus.org/what-we-do/nutrition, Accessed date: 15 April 2020.

Hodges, R. J., Buzby, J. C., & Bennett, B. (2011). Postharvest losses and waste in developed and less developed countries: Opportunities to improve resource use. *The Journal of Agricultural Science, 149*(S1), 37–45. https://doi.org/10.1017/S0021859610000936.

IS Academy. (2014). Facing fragilities: People, aid and institutions in socio-economic recovery. Conference report. The Hague, September 11 2014 https://www.wur.nl/en/newsarticle/Facing-Fragilities.htm, Accessed date: 15 April 2020.

Keding, G. B., Schneider, K., & Jordan, I. (2013). Production and processing of foods as core aspects of nutrition-sensitive agriculture and sustainable diets. *Food Security, 5*(6), 825–846. https://doi.org/10.1007/s12571-013-0312-6.

Menage, N., & Salvignol, B. (2010). *Note to the executive policy council: WFP food safety and quality management system.* Rome: WFP Policy Paper No: EPC10/2010/A.

Michaelsen, K. F., Hoppe, C., Roos, N., Kaestel, P., Stougaard, M., Lauritzen, L., Mølgaard, C., Girma, T., & Friis, H. (2009). Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age. *Food and Nutrition Bulletin, 30*(Suppl), S343–S404. https://doi.org/10.1177/15648265090303S303.

Nutriset (2018). Treatment and prevention of diarrhea: ZinCfant. https://www.nutriset.fr/products/en/zincfant, Accessed date: 15 April 2020.

OCHA (2013). Disaster response in Asia and the pacific - a guide to international tools and services. Bangkok: OCHA-ROAP. https://www.unocha.org/sites/unocha/files/dms/ROAP/Promotional%20Materials/The%20Guide-Web-FINAL.pdf, Accessed date: 15 April 2020.

Omamo, S. W., Gentilini, U., & Sandström, S. (2010). Innovations in food assistance: Issues, lessons and implications. In S. W. Omamo, U. Gentilini, & S. Sandström (Eds.). *Revolution: From food aid to food assistance - innovations in overcoming hunger* (pp. 1–16). Rome: WFP. http://documents.wfp.org/stellent/groups/public/documents/newsroom/wfp228797.pdf, Accessed date: 15 April 2020.

Passino, K. M. (2016). *Humanitarian engineering: Advancing technology for sustainable development.* Columbus: Bede Publishing. ISBN-10: 0692394222 https://hebook.engineering.osu.edu/sites/hebook.engineering.osu.edu/files/uploads/Edition3/humanitarian-engineering-3rdedition.pdf, Accessed date: 15 April 2020.

Ramalingam, B., Scriven, K., & Foley, C. (2009). Innovations in international humanitarian action, active learning network for accountability and performance. *ALNAP's 8th review of humanitarian action (chapter 3)*London: ALNAPhttps://www.alnap.org/system/files/content/resource/files/main/alnap-rha-2009.pdf, Accessed date: 15 April 2020.

Rathore, M. (2010). Leaf protein concentrate as food supplement from arid zone plants. *Journal of Dietary Supplements, 7*(2), 97–103. https://doi.org/10.3109/

19390211003766777.
Reliefweb (2019). https://reliefweb.int/, Accessed date: 15 April 2020.
Ritchie, H. A. (2018). Gender and enterprise in fragile refugee settings: Female empowerment amidst male emasculation - a challenge to local integration? *Disasters, 42*(S1), S40 − S60. https://doi.org/10.1111/disa.12271.
Ryan, K. N., Adam, K. P., Vosti, S. A., Ordiz, M. I., Cimo, E. D., & Manary, M. J. (2014). A comprehensive linear programming tool to optimize formulations of ready-to-use therapeutic foods: An application to Ethiopia. *American Journal of Clinical Nutrition, 100*(6), 1551–1558. https://doi.org/10.3945/ajcn.114.090670.
Sakai, M., Jurriëns, E., Zhang, J., & Thornton, A. (2014). *Disaster relief in the Asia pacific.* London: Routledge ISBN-10: 0415711770.
Sheeran, J. (2009). The UN world food program. *Proceedings of the 15th annual international conference: World food security – can private sector R & D feed the poor?* (pp. 97–100). Canberra, Australia: Crawford Fund. In: *https://www.crawfordfund.org/wp-content/uploads/2014/02/CrawfordFund2009ConferenceProceedings.pdf*, Accessed date: 15 April 2020.
Shumoy, H., & Raes, K. (2017). Teff: The rising ancient cereal: What do we know about its nutritional and health benefits? *Plant Foods for Human Nutrition, 72*(4), 335–344. https://doi.org/10.1007/s11130-017-0641-2.
UNICEF-WFP-USAID (2016). Harmonization of lipid-based products. http://nutritionuat.kelltontech.net/sites/default/files/2020-01/Harmonization-of-lipid-based-products-UNICEF-WFP-USAID.pdf, Accessed date: 15 April 2020.
Van Hoan, N., Mouquet-Rivier, C., Eymard-Duvernay, S., & Trèche, S. (2010). Effect of extrusion cooking and amylase addition to gruels to increase energy density and nutrient intakes by Vietnamese infants. *Asia Pacific Journal of Clinical Nutrition, 19*(3), 308–315. http://apjcn.nhri.org.tw/server/APJCN/19/3/308.pdf, Accessed date: 15 April 2020.
Webb, P., Lorge Rogers, B., Rosenberg, I., Schlossman, N., Wanke, C., Bagriansky, J., Sadler, K., Johnson, Q., Tilahun, J., Reese Masterson, A., & Narayan, A. (2011). *Improving the nutritional quality of U.S. Food aid: Recommendations for changes to products and programs.* Boston, MA: Tufts University. https://pdf.usaid.gov/pdf_docs/pnadz841.pdf, Accessed date: 15 April 2020.
WFP (2008). Kemin industries to provide food quality and shelf life stability expertise to WFP. https://reliefweb.int/report/world/kemin-industries-provide-food-quality-and-shelf-life-stability-expertise-united-nations, Accessed date: 15 April 2020.
WFP (2011). Wawa Mum: From the factory to the field. https://www.wfp.org/videos/wawa-mum-factory-field, Accessed date: 15 April 2020.
WFP (2012). Blue box training. https://documents.wfp.org/stellent/groups/public/documents/manual_guide_proced/wfp254693.pdf, Accessed date: 15 April 2020.
WFP (2013). *Managing the supply chain of specialized nutritious foods.* Rome: WFP. http://documents.wfp.org/stellent/groups/public/documents/manual_guide_proced/wfp259937.pdf, Accessed date: 15 April 2020.
WFP (2018). WFP innovation accelerator. http://innovation.wfp.org/, Accessed date: 15 April 2020.
WFP (2019). Food quality and safety in WFP. http://foodqualityandsafety.wfp.org/, Accessed date: 15 April 2020.
WHO (2015). *WHO estimates of the global burden of foodborne diseases: Foodborne disease burden epidemiology reference group 2007-2015.* Geneva: World Health Organization978 92 4 156516 5https://apps.who.int/iris/bitstream/handle/10665/199350/9789241565165_eng.pdf;jsessionid=8EF0538ADBBBAC999A369BE3146E5514?sequence=1, Accessed date: 15 April 2020.
World Economic Forum (2018). Innovation with a Purpose: The role of technology innovation in accelerating food systems transformation. Report developed in collaboration with McKinsey & Company. http://www3.weforum.org/docs/WEF_Innovation_with_a_Purpose_VF-reduced.pdf, Accessed date: 15 April 2020.