Org. Agr. (2021) 11:285–300
https://doi.org/10.1007/s13165-020-00292-5

Landless animal and poultry production prospects: an overview on feeding and sustainability with special reference to fruit and vegetable wastes (FVWs)

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Received: 26 March 2020 / Accepted: 7 April 2020 / Published online: 24 April 2020

Abstract To overcome malnutrition and hunger, people need to be fed well, for which they need required quantities of animal source foods (ASFs) like milk, meat, fish and eggs. This is often difficult, due to feed and fodder scarcity especially in developing countries like India. The scarcity is more acute in landless animal and poultry production. Studies indicate potential of using fruit and vegetable wastes (FVWs) as feed, citing its nutritional value. On the other hand, FVWs are a burden and threat to environment. Unexplored areas of FVW research need to be studied for neutralizing threat by processing and recycling FVWs into animal and poultry feed. This paper gives an overview of the potential of FVWs as animal and poultry feed. Also, it describes the way forward and strategies to confront the constraints and challenges, highlights social marketing on waste disposal with special reference to FVWs and emphasizes collaborative involvement of stakeholders involved in fruit and vegetable value chain. As animals and poultry do directly and indirectly contribute to many of the sustainable development goals (SDGs), farmers and stakeholders of fruit and vegetable value chain need to be intervened with strategic extension and research initiatives to propagate and utilize the potential of FVWs as animal and poultry feed.

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Keywords Landless livestock and poultry production · Fruit and vegetable waste (FVW) · Feeding · Sustainability

Introduction

Trends reveal that livestock production will become increasingly consolidated into landless systems in the future. Currently, landless systems account for 72% of poultry, 55% of pork and over 66% of eggs in world's livestock production (EC undated). Promoting landless and smallholder animal and poultry production is a substitute for land to accomplish policy objectives for agricultural transformation (Byerlee et al. 2008). Landless animal and poultry production systems rely on purchased inputs (FAO 2013) and external feed resources (Teufel et al. 2010) and, in the ideal case, help to face the twin challenge of ensuring sufficient food and employment (CTA 1993). Feeding animals and poultry sustainably under the landless production system is a challenge to landless farmers, prompting them to explore low-cost or no-cost feeds and feed sources.

To overcome malnutrition and hunger, people need to be fed well, for which they need required quantities of animal source foods (ASFs) like milk, meat, fish and eggs that add much needed nutritional value (FAO 2018a) and determine human health (Opio et al. 2012). ASF can provide a variety of micronutrients that are difficult to obtain in adequate quantities from plant source foods alone (Murphy and Allen 2003). Animals and poultry, the sources of ASF, rely primarily on

forages, crop residues and by-products that are not edible to human (FAO 2018b; Van Zanten et al. 2019). But it is a challenge for the global food and agriculture system to accommodate the continued global demand for ASFs with finite availability of natural resources such as land and water (Steinfeld and Opio 2010). Therefore, it is important to explore resources of alternative feed ingredients (Crute et al. 2010; Groot et al. 2010). Recent studies (Wadhwa et al. 2006; Ramli et al. 2009; Angulo et al. 2012; Bakshi and Wadhwa 2013) show that fruit and vegetable wastes (FVWs), produced after harvesting and processing, are alternative feed resources for animals and poultry.

Fruits and vegetables (FVs), plus roots and tubers, have the highest wastage rates of any food with a global quantitative food loss of about 40–50% (FAO 2019). The loss and waste from FVs alone may reach up to 60% and processing operation of FVs produce significant by-products as waste which constitutes about 25–30% of a whole commodity group (FAO 2011). An estimate of FAOSTAT (2013) revealed that in 2011, almost 640 million tonnes of fruit and more than 1 billion tonnes of vegetables were gathered throughout the world. WHO and FAO recommend intake of a minimum of 400 g of fruit and vegetables per day, excluding starchy root crops, for the prevention of chronic diseases especially in less developed countries (WHO 2003; FAOSTAT 2013). Day-by-day, global food demand is shifting from grains and other staple crops to processed food and high-value agricultural products, such as vegetables, fruits, meat and dairy (FAO undated). This indicates that higher quantities of FVW will be generated in the future. Recycling of FVWs as animal food could avoid discharge of a large amount of waste to landfills (Angulo et al. 2012), which would minimize feed cost and alleviate environmental problems associated with these wastes (Wadhwa and Bakshi 2013).

Zero waste to zero hunger

Agricultural and food industry residues constitute almost 30% of worldwide agricultural production (Ajila et al. 2012). Feeding animals and poultry with foods which are not fit for human consumption is the most desirable endpoint (Dou et al. 2016; Garcia-Garcia et al. 2017). By-products of fruit and vegetable industry are organic residues (Russ and Meyer-Pittroff 2004) and commonly used in animal feed production (Elferink and Nonhebel 2007). Although not classified as such, their physical properties are comparable to fruit and vegetable food waste. Among the recommended management practices in waste hierarchy, recycling of FVWs into animal feed is appropriate for waste that is no longer suitable for human consumption (Teunissen undated). Profit motivation and economies of scale are influencing adoption of such practices (Dou et al. 2016). The food recovery hierarchy developed by the U.S. Environmental Agency also recommends diverting food waste that is beyond recovery for humans to animal feed (EPA undated). Animals and poultry fed with recovered food wastes including FVWs enrich food supply for humans by providing ASF such as meat, milk and eggs. This option contributes to accomplish zero waste and zero hunger challenges.

Material and methods

Agriculture is continuously transforming. Fruits and vegetables are international goods. Therefore, literature search was carried out without any restriction on geographical study area and research period. The keywords viz. adverse effects, agriculture and food processing, animal sourced food, anti-nutritional factor (ANF), balanced ration, challenges, commercial feed, constraints, environmental impact, extension, farm women, farmers start-up, feeding behaviour, fruits and vegetables, fruit and vegetable wastes (FVWs), inclusion level, landfilling, landless animal and poultry production, on-farm waste generation, organic agriculture, outreach intervention, recycling, research initiative, social marketing, sustainable development goal, sustainability, technology innovation, un-conventional animal and poultry feed, waste disposal, waste management and zero waste principle were used individually and in combination with other keywords through PubMed, Google Scholar and Semantic scholar search engines and ScienceDirect database to scout research findings on FVWs and their significance in animal and poultry production.

The research findings published on- and off-line in the field of agriculture, animal bioscience, animal sciences, animals, bioresources, dairy science, extension, environment, feed science and technology, food chemistry, food science, food security, health, livestock, meat science, nutrition, organic agriculture, poultry, recycling waste, rural development and veterinary science were

Table 1 FVWs commonly used as animal and poultry feed

S. no.	Fruit and vegetable wastes used to feed animal and poultry
1.	Apple (*Malus domestica*)
	• Apple pomace to ruminants (Ghoreishi et al. 2007) and broilers (Zafar et al. 2005)
2.	Baby corn (*Zea mays* Linn)
	• Fresh and ensiled form of baby corn husk with silk and fodder to ruminants (Bakshi and Wadhwa 2012; Bakshi et al. 2007)
3.	Bakery waste
	• As starter in broiler diet (Stefanello et al. 2016)
4.	Banana (*Musa acuminata*)
	• Banana leaf meal to growing pigs (Garcia et al. 1991) and rabbit (Rohilla and Bujarbaruah 2000)
	• Banana peel to ruminants (Dormond et al. 1998) and ducks (Ulep and Santos 1995)
	• Banana root to chicken and pigs (Rodríguez et al. 2006)
	• Banana stem to dairy cattle (Sruamsiri 2007)
	• Dried banana peel to growing pigs (Rios et al. 1975)
	• Dried plantain leaves to broiler (Marin et al. 2003)
	• Sundried ripe plantain peel to rabbit (Wadhwa and Bakshi 2013)
5.	Cannery waste
	• As alternate feed resource to ruminants (Bakshi and Wadhwa 2013)
	• As concentrate feed replacement in dairy cattle ration (Sruamsiri 2007)
6.	Carrot (*Daucus carota* subsp. *sativus*)
	• Carrot tops to growing boiler rabbits (Klinger et al. 2017)
	• Dehydrated carrot and carrot flakes to horses and pet animals (Bakshi et al. 2016)
	• Dried ground carrot (Ayanwale and Aya 2006) and tops hay (Bakshi et al. 2016) in layer ration
7.	Citrus peel
	• Citrus molasses to cattle (Bampidis and Robinson 2006) and pigs (Hendrickson and Kesterson 1965)
	• Citrus pulp to cattle (Göhl 1978), goats (Salvador et al. 2014) and broiler (Mourão et al. 2008)
	• Dried pulps to cattle (Bocco et al. 1998; Wing 2003; Assis et al. 2004), lambs (Gravador et al. 2014; Inserra et al. 2014) lactating ewes (Fegeros et al. 1995), pigs (O'sullivan et al. 2003) and rabbit (Hon et al. 2009)
	• Ensiled sweet lime waste to cattle (Bakshi et al. 2007) and growing pigs (Cerisuelo et al. 2010).
	• Sweet orange peel extract to broiler chicken (Pourhossein et al. 2015)
8.	Corn (*Zea mays*)
	• As starter in broiler diet (Ayanwale and Aya 2006)
	• Husk, silk and peel as roughage and supplemented roughage (Sruamsiri 2007)
9.	Dates (*Phoenix dactylifera*)
	• Date seed in sheep diet (El-Shazly et al. 1963)
	• Date waste in broiler diet (Al-Hiti and Rous 1978)
10.	Grapes (*Vitis vinifera* L.)
	• Fermented grape pomace to finishing pigs (Yan and Kim 2011)
	• Grape pomace to broilers (Goñí et al. 2007; Brenes et al. 2008) and laying hen Kara et al. 2016)
	• Grape seed / grape seed extract to laying hens (Kaya et al. 2014) and broilers (Smet et al. 2008)
	• Winery waste and by-products viz. grape stalks, grape pomace, grape seeds and yeast lees to ruminants (Nicolini et al. 1993)
11.	Mango (*Mangifera indica* L.)
	• Deoiled mango kernel meal to ruminants (Göhl 1982), broiler (Joseph and Abolaji 1997; Diarra and Usman 2008) and layers (Odunsi 2005)

Table 1 (continued)

S. no.	Fruit and vegetable wastes used to feed animal and poultry
	• Fresh, dried and ensiled mango peels to ruminants (Sruamsiri and Silman 2009) and pigs (Rao et al. 2003)
12.	Olive (*Olea europaea*)
	• Olive leaves (Abbeddou et al. 2011) and cake (Vargas-Bello-Pérez et al. 2013) to ewes
	• Olive pomace to rabbits (Dal Bosco et al. 2012) and pigs (Doyle et al. 2006)
13.	Oyster mushroom waste
	• As starter, grower and finisher in broiler diet (Fard et al. 2014)
14.	Palm (*Elaeis guineensis*)
	• Kernel meal to ruminants (Nair 2010), broilers (Sundu et al. 2006), starter and grower pullets (Onwudike 1986) and growing-finishing pigs (Adesehinwa et al. 2010; Boateng et al. 2010)
15.	Pea (*Pisum sativum*)
	• Empty pea pods ensiled with wheat straw and sundried pods in concentrate mixture to ruminants (Wadhwa et al. 2006, 2017)
	• Pea pods to ruminants (Wadhwa et al. 2006)
	• Peas to high-producing dairy cows (Corbett et al. 1995)
16.	Pineapple (*Ananas comosus*)
	• Dried pineapple bran to pigs (Göhl 1982) and chicks (Hutagalung et al. 1973)
	• Ensiled pineapple waste to ruminants (Muller 1978; Sruamsiri 2007; Gowda et al. 2016)
	• Fermented pineapple waste to ruminants (Sruamsiri 2007)
17.	Pomegranate (*Punica granatum*)
	• By-product silage to lambs (Kotsampasi et al. 2014)
	• By-products to broiler (Ahmed et al. 2015)
	• Peel extract to cow (Abarghuei et al. 2014)
18.	Tomato (*Solanum lycopersicum*)
	• Dried tomato pomace in layer rations and starter and finisher broiler rations (Bakshi et al. 2016) and to hogs, cows and chicks (Esselen Jr. and Fellers 1939)
	• Dried tomato pulp in diets of laying hens (Jafari et al. 2006)
	• Tomato extract to broilers (Smet et al. 2008)
	• Tomato pomace to ewes (Abbeddou et al. 2011)
	• Tomato powder (Karadas et al. 2006; Sahin et al. 2008) and pulp (Botsoglou et al. 2004) to quails
	• Tomato pulp in diets of laying hens (Yannakopoulos et al. 1992)
	• Tomato waste to dairy cattle (Sruamsiri 2007) and goats (Romero-Huelva et al. 2012)
19.	Vegetables
	• Cull vegetables to beef cattle (Davis et al. 2012)
	• Processed vegetable waste to bull (Das et al. 2019)
	• Tomato and cucumber feed block to dairy goats (Romero-Huelva et al. 2012)
20.	Vegetable leaves
	• Cabbage leaves and cauliflower leaves to ruminants (Wadhwa et al. 2006)

reviewed. Reports and publications of Technical Centre for Agrciultural and Rural Cooperation (CTA), Wageningen, the Netherlands; European Commission (EC); Food and Agriculture Organization (FAO), Rome; International Federation of Organic Agriculture Movements (IFOAM—Organics International), Germany; International Livestock research Institute (ILRI), Nairobi, Kenya; National Research Centre on

Pig (NRCP), Guwahati, India; World Bank Group, Washington, DC; and Wold Health Organization (WHO), Geneva were also reviewed to supplement the content. The collected documents were scrutinized for ensuring content suitability. Finally, a total of 138 studies including research articles, reports and publications were found suitable and reviewed to study the prospects of landless animal and poultry production using FVWs. A presentation on the topic was made by the first author at the International Workshop at Morocco on 2019.

FVWs for feeding animals and poultry

FVWs are used as ingredients or fed as such in animal and poultry ration. Feedipedia (2019) has listed 166 feeds under plant products and by-products category, including 43 feeds under fruits and by-products category. Various research studies reveal that vegetable wastes of both households and marketplace, due to the chemical compositions and nutritional potential, could be used as a feed ingredient for cattle (Gupta et al. 1993; Das et al. 2018). Some of the scientifically validated FVWs are listed below, in Table 1.

Way forward

In agriculture and allied farming practices, the waste generated is intrinsically linked with sustainability. Environment, one of the pillars of sustainability, reveals the priority of eco-friendly disposal of waste. The effort needed for proper disposal is not limited to one actor of fruit and vegetable value chain that involves core actors viz. farmers, trader, wholesaler, retailer and vendors and other stakeholders such as government departments, research institutes and extension functionaries. With participation of all the stakeholders, such efforts might lead to successful impact. International trade of fruits and vegetables envisages the potential of FVW generation throughout the world. Therefore, a global level initiative with a holistic contribution and coordinated efforts at local and regional level from all the stakeholders only can make it possible to utilize the full potential of FVWs as animal and poultry feed. Institutions involved in research and development activities need multi- and trans-disciplinary approaches for the transformation from current FVW disposal practices to sustainable practices of feeding animals and poultry using FVWs. The way forward must aim the following strategies:

Regulations

Government should frame appropriate policies integrating gender-perspective and develop required infrastructures considering the benefits of stakeholders in fruit and vegetable value chain and environment. The policies should enable utilizing the full potential of FVWs as animal and poultry feed by implementing the practices viz., awareness creation among public and other actors involved in fruit and vegetable value chain; segregated collection of waste from households, markets, offices, restaurants, factories and other FVW-generating places; monitoring FVW generation point to make it free from contamination and other health hazards; timely transport to collection point or dump yard; on-farm and centralized eco-friendly recycling process; distribution of processed FVWs to farmers; and information service on FVWs through toll free helpline around the clock. Government should consider that society needs support in terms of policy, research, innovation and technology development for meaningful progress in the zero waste challenge (Dou et al. 2018).

FVW generation to recycling

How far and how best the waste can be managed is one the challenges before world. The value of waste determines its ownership. Greater the value of waste more will be the interest in its ownership. Conversely, due to greater supply and magnitude of FVW disposal problems, there will be less desire for ownership (Harris et al. 2001).

Proper disposal aids collection

Maintaining waste dump points within the market ease traders to dispose and farmers and agripreneurs to collect the FVWs (Hassan and Kikisagbe 2001). To ease the processing and enhance the keeping quality, duly-labelled containers need to be kept for segregated disposal of FVWs with high, medium and low moisture contents in places where fruits and vegetables are sold, processed, handled and consumed. It aids timely and segregated collection which in turn helps to decide on recycling FVWs and species to be fed with.

Proper collection aids recycling

FVWs have a high-water content (Dou et al. 2016). It mandates collection of waste on daily basis (Maxwell and Zziwa 1992). High moisture content and the possibility of presence of contaminants such as pesticides and pesticide residues (Bakshi et al. 2016) pose a threat in using FVWs. Drying and ensiling help to improve the shelf-life quality and make vegetable waste suitable for feeding livestock (Ako et al. 2016; Bakshi et al. 2016). Segregated collection is required to avoid animal by-products, plastic bags and broken glass for making FVWs free from contamination (Rischkowsky et al. 2006). Therefore, it is mandate to implement stringent regulation for controlling residues of pesticide and other hazardous material in FVWs by monitoring usage of pesticide and other hazardous materials from production of fruits and vegetables to their sale and disposal of FVWs. All these help to enhance the suitability of FVWs as animal and poultry feed as such or recycling by appropriate practices which in turn helps in making FVWs appropriate, adequate, available, accessible and affordable. As a Corporate Social Responsibility (CSR) initiative, agricultural and food processing companies need to be clearly directed to recycle FVWs as animal and poultry feed.

Role of stakeholders

The actors of fruit and vegetable value chain must understand their moral and social responsibility in proper disposal of FVWs. Particularly, they must segregate the edible and inedible waste for proper disposal. Local bodies such as *panchayats* and municipalities need to establish local FVW bank in the FVW generation places for collecting FVWs. Trained workers in sufficient numbers need to be assigned for collection of FVWs at these places regularly.

On-farm FVWs

Demotivating forces such as lack of labour to harvest fruits and vegetables and market price which fails to generate any profit are responsible for on-farm FVW generation. Due to both the forces, farmers tend to leave the FV as such in farm and in the latter case, farmer may dispose FV improperly. Besides on-farm composting (Sall et al. 2016), converting FVWs into animal and poultry feed can help the farmers to protect from profound loss. Establishing FVW bank in areas where more FV are produced is also beneficial at village level.

Organic agriculture: an emerging source of FVWs

Organic agriculture can play an important role in solving future food challenges (Rahmann et al. 2017) with its ability to produce higher nutritional values products and lower environmental impact. It yields 20% lower than conventionally produced crops (Rembiałkowska 2007). However, in developed countries, organic agricultural systems yield equal or even higher than the current conventional agricultural systems (Scialabba and Müller-Lindenlauf 2010). Though landless animal husbandry systems are prohibited in organic farming (IFOAM 2012), there is no prohibition for feeding animals and poultry reared under landless production system with FVWs derived from organic agriculture. All these show the potential of organic agriculture in generating FVWs. It emphasizes the importance of collaborative research to utilize and convert organic FVWs as animal and poultry feed. Therefore, research institutions must foresee the future potential of organic agriculture, include utilizing or converting FVWs produced from organic agriculture as animal and poultry feed in their thrust areas and carryout collaborative research.

Benefits sharing

Animal and poultry feed prepared from FVWs is cost-effective, and it can be sold at cheaper rate than the commercial feed (Balaji 2019). By estimating profit generation from selling those feed, the feed manufacturers can pay the value chain actors at the time of procuring FVWs to encourage proper segregation and disposal of FVWs. In large scale, processing and converting FVWs into animal feed need permanent structures and machineries. Fruits and vegetables processing companies have to come forward to take such responsibility or sponsor farmers' start-up under their CSR.

Farmers' start-up

Nikhil Bohra, a biotech engineer, found improvement in quality milk in dairy animals after feeding them with carrot, papaya and *mosambi* waste collected from warehouses and *mandis*. With this field level solution for feed scarcity, he incubated a start-up in 2017. As a

result, he can produce feed at 10% cheaper rate than the market price (Balaji 2019). Season- and region-wise variations in fruits and vegetables production are seen universally everywhere. An entrepreneur originated from an area with significant knowledge on animals and local production and consumption of fruits and vegetables is the potential source for farmers' start-up. The programmes and schemes on farmers' start-up programmes need to incubate such entrepreneurs with a collaborative contribution from institutes involved in FVWs and animal feeds.

Research initiatives

FVWs have its own merits, i.e. potential to be used as animal and poultry feed and demerits, i.e. posing environmental problems. Appropriate research initiatives on characterization, limiting factors and adverse effects of FVWs and technology innovation are vital to utilize the full potential of FVWs as animal and poultry feed.

Characterization of FVWs

FVWs can be generated anywhere from production to consumption of FVWs. A rational strategy for a stepwise procedure includes quantitative and nutritional waste characterization, output definition, process design and feasibility study to explore the full potential of FVWs as animal and poultry feeds and minimize the environmental impact (Mirabella et al. 2014).

Technological innovation

Diverting more or all the FVWs to animal feed will require more technological innovation (Dou et al. 2016). Research institutes intensify their efforts in evaluating and validating the suitability using locally available FVWs as animal and poultry feed involving local farmers considering the high moisture content and variation in nutrient content and seasonal production. One such effort is that National Institute of Animal Nutrition and Physiology (NIANP), Bengaluru, India scientifically evaluated and validated pineapple fruit residue (PFR) silage as fodder source for livestock (Gowda et al. 2016). Guru Angad Dev Veterinary and Animal Sciences University (GADVASU), Ludhiana, Punjab, India has experimented on recycling FVWs into animal feed (Wadhwa and Bakshi 2013). National Research Centre on Pig, Guwahati, India identified locally available feed resources like root crop (tapioca, sweet potato, etc.), brewery waste, used tea leaves and other vegetable wastes like cabbage and collocassia could be used for developing economic ration for pig. The institute also identified various alternate energy sources viz., rice polish, molasses, tamarind seed, wheat bran, tea waste, pine apple waste, jackfruit waste and cashew apple and protein sources viz., silk worm pupae and sunflower cake (NRCP 2014).

Distance determines the use of FVWs as livestock feed (Nalubwama et al. 2019). Cleanliness and composition determine acceptability of the feed by animal and poultry. Goats, for example, are fastidious with innate dietary preference (Fajemisin et al. 1996). Therefore, research institutes concerned should have developing species-suitable eco-friendly technologies for on-farm and centralized processing of FVWs as one of the thrust areas. Animals differ in their capacity to convert by-products and wastes into valuable food for human consumption. It intends research institutes to carryout comparative study on locally available FVWs for feeding different species of animal and poultry to maximize ASF production with sustainable resource-use efficiency (Van Zanten et al. 2019). Also, based on the research, animal nutritionists need to develop a formula for balanced ration including FVWs as feed ingredients.

Need of research on limiting factors and adverse effects

Besides the benefits, research revealed adverse effects caused by feeding FVWs and limiting factors in determining inclusion level of FVWs. Retarted growth in broiler fed on diets supplemented with grape seed extract was found by Chamorro et al. (2013). Reduced growth rate, poorer feed consumption and reduced feed efficiency in chicks fed on mango seed kernel at 10 or 20% substituting corn were recorded by El Alaily et al. (El-Alaily et al. 1976). Inclusion level is also a factor in determining occurrence of adverse effects. Chicks fed with a ration containing substitution of 141 g of mango seed kernel per kilogram diet for maize practically did not affect performance of chicks. However, adverse effects occurred with substitution of 282 g or more per kilogram (Patil et al. 1982). Benefits and adverse effects caused by FVWs vary among species. Cooked potato is appropriate for inclusion in pig diets, whereas, it associates with digestive disturbances in some instances in calves and increases moisture content of excreta in poultry (Whittemore 1977). There are certain factors

that can limit inclusion level of FVWs. In broilers, keeping litter dry (Whittemore et al. 1975) and feeding diets containing potato in smaller sized particles (Whittemore et al. 1974) were proposed to overcome the main factors limiting the proportion of cooked potato used in the diet. Eventually, research institutes need to carryout research on various inclusion levels of FVWs, factors limiting inclusion level and corresponding effects to study benefits and adverse effects. Also, if required, older research findings on FVWs need to be revalidated, since the agriculture is continuously under transformation.

Outreach intervention

The outreach or extension services explore scope and find entry point for disseminating sustainable FVW recycling practices to transform the farmers from the current practices to the desirable and sustainable practices. Public sector extension alone cannot make such transformation. To provide active support and complement the public sector extension services, extension initiatives of private and voluntary sector such as input agencies, agri-business firms, farmer organizations (FO), producers' co-operatives, non-governmental (voluntary) organizations, media, financial institutions and consultancy service should be utilized (Sulaiman 2012). Initiating specific public-private partnership (PPP) mode would ensure collaborative extension efforts in making use of the full potential of FVWs. The outreach/extension efforts should target enhancing stakeholders' and consumers' behaviour considering the below mentioned strategic interventions.

Social marketing on waste management practices

Citing the magnitude of the present and future problems of wasting FVWs and the potential of FVWs in animal feeding, actors and other stakeholders of fruit and vegetable value chain needs to be educated with waste management practices and zero waste principles. The efforts need to be made as a social marketing campaign using multi-approach strategy with an appropriate mix of extension methods involving agriculture and allied extension departments. Extending such efforts can help for achieving desirable perception changes and incremental growth in knowledge, intentions and behaviour of the stakeholders (Pollard et al. 2008).

Actors and other stakeholders to be educated

Farmers involved in production, traders, wholesaler, retailer and vendors involved in marketing, entrepreneurs in value addition and meal preparers in home and restaurants and ultimate consumers need to be targeted primarily and educated on FVWs and their role in recycling FVWs into animal and poultry feed. The efforts can be supplemented by educating them through input dealers, municipality and local body staffs, farming-related service providers such as agriculture officer and veterinary officers. All the actors have to be motivated to improve their supply chain communication. It helps them in preparatory arrangement for FVW collection and processing.

Technology dissemination and agribusiness incubation

The extension functionaries have the responsibility to disseminate technologies developed and practices recommended in using FVWs as feed. To speed up the dissemination, create public awareness and motivate farmer level innovation, policymakers must frame evidence-based FVW regulatory policies or refine support policies. The potential outcome of such dissemination must be utilized to develop entrepreneurship and incubate new start-ups for converting FVWs into valuable marketable feeds. Information on know-how, relative economic value, benefits and adverse effects of feeding FVWs is essential for farmers and other actors in fruit and vegetable value chain. The general public with an emphasis on women, youth and children should also be covered under the outreach activities to intensify the efforts and develop complementarity with stakeholders. Training institutes must realize the importance of FVWs and impart periodical training to stakeholders and incubate agripreneurs to harness FVW-related entrepreneurial opportunities.

Competency development by extension functionaries

Competency in FVW related technologies, practices and information is a quintessential attribute for the extension functionaries to offer needy information and carryout extension activities at field. Considering the importance of their competency, the training institutes need to impart them training on FVWs as animal and poultry feed, waste management and agribusiness incubation. The catalogue of information on chemical composition,

Table 2 Strategies to confront constraints and challenges in feeding animal and poultry with FVWs

S. no.	Constraints and challenges	Confronting strategies	Stakeholder responsible
i.	Inherent and intrinsic attributes		
1.	High moisture content (Wadhwa and Bakshi 2013)	• Early and recommended collection methods and adequate processing including drying, extraction and ensiling (Ako et al. 2016; Bakshi et al. 2016)	• Local bodies
2.	Perishability and rotten FVWs (Bakshi et al. 2016)		
3.	Composition and variations in nutrient content (Kasapidou et al. 2014)	• Developing balanced ration formula based on variations in nutrient content of FVWs and heterogeneity, seasonal availability and production of fruits and vegetables	• Researchers
4.	Anti-nutritional factors (ANF) (Soetan and Oyewole 2009)	• Educating people on ANF and disseminating processing technologies	• Extensionists
ii.	Man-made attribute		
1.	Presence of contaminants (Bakshi et al. 2016)	• Developing eco-friendly bio-refinery technology for transfer to end-users	• Researchers
		• Monitoring pesticide usage in fruits and vegetables production by implementing suitable regulations on pesticide usage and analysing pesticide residues in FVWs produced from different areas (Cesnik et al. 2003)	• Government, policymakers, food chemists, biochemists and extensionists
iii.	Availability and recycling		
1.	Lesser shelf life and incompatible availability of FVWs to animal and poultry (Ezeldin et al. 2016)	• Linking availability of FVWs and animal and poultry population by studying (i) quantitative characterization (Angulo et al. 2012) (ii) trend analysis in production and consumption of fruit and vegetable and generation of FVWs (iii) fruits and vegetables supply chain(iv) population growth in human and animals	• Researchers and social scientists
		• Research on silage-making using FVWs	
		• Commercial efforts to utilize the potential of FVWs (Gowe 2015; Bakshi et al. 2016)	• Extensionists and agripreneurs
		• Data collection on FVW generation, collection, disposal, processing/recycling and distribution	• Local bodies, agripreneurs, agri food processing companies
		Centralized processing of FVWs	
2.	Difficulty in recycling and distribution logistics of FVWs (Kasapidou et al. 2015)	• Enhancing consumer and stakeholder behaviour	• Extensionists
		• Developing and implementing rational strategies for waste characterization, output definition, process design and feasibility study (Mirabella et al. 2014)	• Researchers and social scientists
		• Technlogy innovation to make affordable and benefit-giving feed with significant shelf life from FVWs	
		• Disseminating proper FVW handling operations and feed making technologies through on-site demonstrations	• Extensionists
3.	Adverse effects besides benefits (Wadhwa and Bakshi 2013)	• Nutritional characterization of FVWs (Angulo et al. 2012)	• Researchers
		• Testing the effects of feeding FVWs at field to determine the maximum species-specific inclusion level of beneficial FVWs as animal feed and identify adverse effects causing FVWs.	• Extensionists and researchers
iv.	Mixed multitude of stakeholders		
1.	Multi-stakeholder involvement	• Multi-stakeholder initiative for partnership development, strengthening linkages, improving information exchange and ensuring mutual benefits among stakeholders to develop complementarity	• Government through policies and programmes involving local bodies and extensionists

Table 2 (continued)

S. no.	Constraints and challenges	Confronting strategies	Stakeholder responsible
		• Sensitization on current and near-future effect and future impact of "what if" and "what if not"	• Extensionists
2.	Varied objectives of extension and research institutes and extension service providers	• Like fruit logistica and symposium on fruit and vegetable processing, providing a common platform to the stakeholders by organizing annual specialized exhibition and conference at national and regional level	• Extensionists, researchers, farmers and actors in fruit and vegetable value chain
3.	Difficulty in implementing and monitoring regulations	• Social-marketing on eco-friendly disposal of FVWs	• Social scientists
		• Utilizing data collected on FVWs for regulatory initiatives	• Government involving concerned departments
v.	Extended responsibility beyond FV value chain		
1.	Difficulty in educating actors beyond FV value chain	• Group followed by individual approach in educating women including farm women	• Social scientists, local leaders, NGOs, Self-help groups (SHGs)
		• Educating youth and children on social role and responsibilities through formal and non-formal mode	• Social scientists, NGOs, youth icons and through educational institutions

conservation methods, nutritive value and guidelines for incorporation of FVWs in animal diets documented by Wadhwa and Bakshi (2013) can also be helpful for extension functionaries in educating the stakeholders of fruit and vegetable value chain.

Initiatives for farmers

Extensionists offer services at grassroots level. Policymakers need to develop and implement initiatives with the help of extensionist to educate farmers on feeding animals and poultry with FVWs. Extension institutes imparting training to farmers should organize training and other extension programmes periodically on FVWs. Emphasis and care should be taken on educating farmers on inclusion level of various locally available and accessible FVWs and managing adverse effects, if any due to feeding or overfeeding of FVWs. A benefitted farmer can act as a source and thereby a leader for farmer-to-farmer extension in propagating the usefulness of FVWs. The services of private and voluntary sectors involved in extension can also play a vital role in educating farmers on feeding animal and poultry with FVWs.

Priority to farm women

FVW-related intervention has a gender dimension. Women do two-thirds of the world's work (ILRI 2008). Women spend more time in growing fruits and vegetable and keeping animals and poultry despite their gender constraints besides household chores. Focusing on livestock-related tasks of women to reduce their workload focuses on women empowerment (Waters-Bayer and Letty 2010). If they realize the importance and potential of FVW, they adopt FVW recycling and feeding practices. No programme should be based on assumption. The actual gender dimension in the area of intervention studied must consider their contributions and constraints in farming to analyse status-quo by applying 5W1H (who, what, where, when, why and how) approach and plan for women-specific programme to educate them on recycling and use of FVWs as animal and poultry feed. More number of trained female extension workers is needed for extension intervention at individual farm women level. Lahai et al. (1999) found that women farmers, who are supervised by female agents, have more access to extension services than women farmers who work with male agents. Therefore, as an entry point for intervention, women's organizations in the intervention area should be strengthened and sensitized on recycling and using FVWs. Such group approach offers a conducive setting for male extension workers to work better with women farmers (Waters-Bayer and Letty 2010). Women farmers' participation needs to be

encouraged by imparting off-campus extension programmes for short duration during their convenient days.

Way forward states the strategies to succeed in using or converting FVWs as animal and poultry feed. However, there are constraints to be confronted by farmers and stakeholders.

Constraints and challenges in feeding animal and poultry with FVWs

The transformation from disposal to sustainable use of FVWs as animal and poultry feed needs more time and to confront the constraints and challenges with rational strategy as mentioned below (Table 2).

Fruits and vegetables undergo various stages from production to consumption and handled at various places by various people throughout its value chain. Therefore, collaborative involvement of stakeholders only can confront the constraints and challenges in using FVWs as animals and poultry feed.

Conclusions

FVW is a burden to actors of fruit and vegetable supply chain and threat to environment. Contrarily, FVWs have potential and scope for feeding animals and poultry especially in landless animal and poultry production system. Feeding FVWs to animal and poultry needs knowledge of nutritional value, inclusion level and anti-nutritional factors of FVWs. The research community should study quantification and characterization of FVWs and decide inclusion level of FVWs in feeding balanced ration to the animal and poultry. Such efforts should be extended to explore and invent new eco-friendly technologies suitable for on-farm and centralized processing and recycling of FVWs. Parallel extension efforts integrating women perspectives by public, private and voluntary sectors should educate the stakeholders involved in FV value chain, disseminate technologies among farmers through on-site demonstrations and motivate agripreneurs for new start-ups. As a result, environmental threat posed by FVWs would be neutralized and potential of FVWs as low-cost or no-cost animal and poultry feed would be utilized effectively and efficiently to meet global need of ASF. Thus, FVWs, as animal and poultry feed, can ensure animal food security, low-cost production of animal products and environmental protection and, thereby, contribute for a future with zero hunger.

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