UTILIZATION OF FRUIT AND VEGETABLE WASTES AS LIVESTOCK FEED AND AS SUBSTRATES FOR GENERATION OF OTHER VALUE ADDED PRODUCTS

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Utilization of fruit and vegetable wastes as livestock feed and as substrates for generation of other value-added products

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Cover photographs:
Left image: Tomato pomace coming out of a processing plant
Right image: Buffaloes relishing baby corn fodder at GADVASU
All images: @FAO/M.P.S. Bakshi

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Foreword

By 2050 the world will need to feed an additional 2 billion people and require 70 percent more meat and milk. The increasing future demand for livestock products, driven by increases in income, population and urbanization will impose a huge demand on feed resources. Sustainability of feed production systems is being challenged due to bio-physical factors such as land, soil and water scarcity, food-fuel-feed competition, on-going global warming and frequent and drastic climatic vagaries, along with increased competition for arable land and non-renewable resources such as fossil carbon-sources, water and phosphorus. A key to sustainable livestock development is: efficient use of available feed resources including reduction in wastage, and enlargement of the feed resource base through a quest for novel feed resources, particularly those not competing with human food.

A huge quantity of fruit and vegetable wastes (FVW) and by-products from the fruit and vegetable processing industry are available throughout the world. For example fruit and vegetable processing, packing, distribution and consumption in the organized sector in India, the Philippines, China and the United States of America generate a total of approximately 55 million tonnes of FVW. A large proportion of these wastes are dumped in landfills or rivers, causing environmental hazards. Alternatives to such disposal methods could be recycling through livestock as feed resources and/or further processing to extract or develop value-added products.

This publication presents information on the chemical composition, conservation methods, nutritive value and guidelines for incorporation of FVW in animal diets. It also covers aspects related to utilization of such wastes as a substrate for the generation of value-added products. It is expected that this document will promote conversion of wastes to resources and help generate opportunities for development. The recycling of these resources will economise on animal feed and also alleviate the environmental pollution associated with disposal of FVW.

The document is intended for use by extension workers, researchers, feed industries, food processing industries, NGOs, farmers' associations, producers, policy-makers and science managers.

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Summary

Currently, livestock is one of the fastest growing agricultural subsectors in developing countries. The demand for livestock products is rapidly increasing in most developing countries. However, many developing countries have feed deficits. New unconventional alternate feed resources could play an important role in meeting this deficit. Fruit and vegetable processing, packing, distribution and consumption generate a huge quantity of fruit and vegetable wastes, for example, approximately 1.81, 6.53, 32.0 and 15.0 million tonnes of fruit and vegetable wastes (FVW) are generated in India, the Philippines, China and the United States of America, respectively and most of this is being disposed of either by composting or dumping in the landfills/rivers, causing environmental pollution. Such unconventional resources can act as an excellent source of nutrients and help to bridge the gap between demand and supply of feedstuffs for livestock. In addition their use can also reduce the cost of feeding, giving higher profits to farmers.

Fresh banana foliage can be fed as such or after ensiling with broiler litter (40:60) or with wheat straw (75:25) to levels of up to 15 percent in the rations of lactating animals without altering milk production. Banana peels can be incorporated at levels of 15 to 30 percent in the diet without affecting palatability and performance of lactating cows. Dried ripe banana peels can be fed to growing pigs at levels up to 20 percent and to rabbits up to 30 percent of the diet without having any adverse effect on the performance. Dried citrus pulp is used as a cereal substitute in concentrate mixture due to its high net energy, NE (1.66–1.76 Mcal/kg DM) value for lactating dairy cows. It can replace 20 percent concentrate in the diets of dairy cattle and up to 30 percent in lactating ewes without affecting palatability, nutrient utilization, milk yield or its composition. It can also be used up to 50 percent in the diet of gestating and lactating sows, 20–30 percent in rabbit diets and 5–10 percent in poultry diets. Citrus pulp ensiled with wheat or rice straw in a ratio of 70:30 produces excellent silage. Mango seed kernels can be incorporated in the concentrate mixture up to 50 percent. Tannins and cyanide in mango seed kernels can be removed by soaking or boiling in water and then the kernels can be incorporated at 5–10 percent in the diet of broilers. Mango peels can be fed fresh, dried or ensiled with wheat or rice straw. Due to their high sugar content (13.2 percent) they are highly palatable. Pineapple juice waste can replace the roughage portion in the diets of ruminants completely and cereals partly. Ensiled pineapple waste with straw can replace up to 50 percent of roughage in the total mixed ration of dairy cattle. Fresh baby corn husk, a waste after removing cob for human consumption can be fed fresh, ensiled after wilting or after mixing with cereal straw. These are more acceptable and palatable as compared with conventional maize fodder. After taking 3–4 baby corn picks, the leftover plant baby corn fodder can be used as fodder for livestock. The fresh or ensiled baby corn fodder and conventional maize fodder, fed exclusively or in complete feed, have comparable nutritional worth for ruminants. Bottle gourd is extensively used as a vegetable and its juice has many medicinal properties. Sun dried ground pomace can be incorporated up to 50 percent in the concentrate mixture of ruminants without affecting nutrient utilization or the health of animals. Fresh cauliflower and cabbage leaves with stems are a rich source of proteins, soluble sugars, both macro- and micro- elements and have

good digestibility and dry matter intake. These can be fed either as such, after drying or ensiling with cereal straws, without affecting the palatability, nutrient utilization, health or performance of livestock. Fresh carrot contains 88 percent water, 10 percent crude protein (CP), up to 60 percent sugars, mostly sucrose and high levels of vitamin C and β-carotene. The cull carrots are palatable and can be fed up to 20–25 kg/day to dairy cows, leading to improved reproductive performance. Dehydrated carrots and carrot flakes are common commercial treats for horses. From 4 to 8 percent of dried carrot meal in the diet of laying hens significantly improved yolk colour and did not affect egg production. Carrot pomace is a rich source of soluble sugars (64.3 percent). Pea vines can be fed fresh or after ensiling. The pea straw, with a high protein content and low fibre, has a higher nutritive value than cereal straws. The empty pea pods are rich in CP (19.8 percent), soluble sugars, phenolics, and macro- and micro-elements. The empty pea pods are relished by ruminants, and can be fed exclusively. Cull potatoes, a rich source of starch (60–70 percent), can be fed up to 15–20 kg/day in the raw form, without any adverse effect on health of lactating dairy cows. Potato tubers can also be chopped with forage and ensiled. Cooked potatoes are efficiently used by fattening and breeding sows, and can be fed up to 6 kg a day. Cooked potatoes can be used up to 40 percent in poultry rations. Sarson saag waste (SSW) contains 14.5 percent protein and is a good source of water-soluble sugars (6 percent). An adult cow can consume 50–55 kg of fresh SSW/day and is highly palatable. Cull snow peas, excellent source of protein, can be fed fresh or after drying to ruminants. Sun dried tomato pomace (TP) is a good source of lycopene. The dried TP can completely replace concentrate mixture without any adverse effect on nutrient utilization in adult buffaloes; while in lactating animals it can include up to 35 percent of the concentrate mixture without any adverse effect on milk yield. In the diet of rabbits it can be incorporated up to 20–30 percent, while in broiler and layer diets it should be added up to 5 and 10 percent respectively. Tomato pomace and spent sugar syrup from amla (*Phyllanthus emblica*) preserve (murabba) industries can be effectively used in the preparation of urea molasses multinutrient blocks without affecting their quality or utilization by livestock.

Peels, pomace and seeds are a rich source of bio-active compounds, which can be extracted and utilized for food and pharmaceutical applications. The citrus peel is a potential source of essential oil and yields 0.5 to 3.0 kg oil/tonne of fruit. These essential oils are used in alcoholic beverages, confectioneries, cosmetics, pharmaceuticals and for improving the shelf-life and safety of foodstuffs. Peels, pomace and seeds are also a rich source of poly-phenols and their concentration in these fractions is more than twice that in edible tissue. These exhibit anti-cancer, anti-microbial (pathogens), anti-oxidative and immune-stimulating effects in vertebrates and reduce the incidence of cardiovascular diseases. The fat in mango seed kernel is a promising source of edible oil and its fatty acid and triglyceride profiles are similar to those of cocoa butter. Pigments can also be isolated from fruit and vegetable wastes (FVW) e.g. carotenoids from tomato peel and carrot pomace, anthocyanin from banana bracts and beet root pulp (betalains). The antioxidant compounds from waste products of the food industry could be used for protecting the oxidative damage in living systems by scavenging oxygen free radicals. These compounds can also be used for increasing the stability of foods by preventing lipid peroxidation. Hydrolytic products of glucosinolates present in brassica extracts could act as anti-carcinogenics. FVW also acts as a source of dietary fibre (non-starch polysaccharides: pectin) for addition to refined foods. These compounds increase the bulk of the food, prevent constipation, and bind to toxins and bile salts. Enzymes such as bromelain from pineapple; papain from papaya, α-amylase, hemicellulase; cellulase from banana waste and kinnow pulp; lignin, manganese peroxidase and laccase from apple pomace and onion waste; and pectinase from sapota and citrus peels can also be isolated for various applications. The FVW peels and pomaces or pulps have been used in the production of bioethanol, biomethane, biodegradable plastic, single cell proteins and sweeteners.

Introduction

Livestock play an integral role in the livelihood of poor farmers by providing economic, social and food security. Taking 2010 as the base year, the world would need 73 percent more meat and 58 percent more milk in 2050, while these values for developing countries will be 109 percent and 116 percent, respectively (FAO, 2011). To meet this demand, huge quantity of feed resources will be required; challenging sustainability of the feed production systems. Already there is a considerable shortage of feed availability in most developing countries. Taking some examples from Asian countries, Bangladesh faces a deficit of 49.4 and 81.9 percent of roughages and concentrates (Uddin, 2013), while in Pakistan a shortage of 43.9, 49.7 and 44.2 percent of dry matter (DM), crude protein (CP) and total digestible nutrients (TDN), respectively has been recorded (Habib, 2008). In China, there was a deficit of 10, 30 and 20 million tonnes of protein feed, energy feed, and aquatic feed, respectively (Jie Chen, 2012), and in India a shortage of 25, 159 and 117 million tonnes of concentrates, green forages and crop residues, constituting respectively a shortage of 32, 20 and 25 percent of the requirement has been estimated (Ravi Kiran *et al*., 2012). The area under fodder production can not be increased due to increasing human population and urbanization and the industrial intensive model of livestock production has severe limitations due to increasing cost of fossil fuels, competition for food-feed-fuel and other biophysical limiting factors. The global price of feed ingredients such as maize, wheat, fish meal and soybean meal has increased by 160, 118, 186 and 108 percent, respectively in the last decade, while the price rise in livestock products such as poultry meat, pork and lamb was only 59, 32 and -37 percent respectively, while that of beef was 142 percent (Index Mundi, 2013). Under these conditions, to meet the nutrient requirements of livestock and to sustain their productivity and profitability seem only possible if non-conventional, alternate feed resources are explored.

The ongoing shift in the cropping pattern from cereals to more remunerative fruit and vegetable crops in many Asian countries will lead to decreased supply of cereals and crop residues for animal feeding. A strong shift in this direction has already been observed in north India, for example. This change has resulted in generation of huge quantities of fruit and vegetable byproducts and wastes. For example, fruit and vegetable processing, packing, distribution and consumption in the organized sector in India, the Philippines, China and the USA generate approximately 1.81, 6.53, 32.0 and 15.0 million tonnes of fruit and vegetable wastes (Table 1). These are either composted or dumped in landfills or rivers, causing environmental hazards. Alternatives to such disposal methods could be recycling through livestock as feed resources and/ or further processing to extract or develop value-added products. Such an approach will convert "wastes to opportunities for development" in addition to contributing to sustainable intensification of livestock industry.

TABLE 1

Fruit (F) and vegetable (V) wastes generated after processing, packing, distribution and consumption in organized sector

Country	Production[1] (million tonnes)			F and V processed[2] (percent)	Processed F and V (million tonnes)	Losses and wastage[3] (percent*)			Waste generated (million tonnes)
	F	V	Total			Processing	Distribution	Consumption	
India	74.88	146.55	221.43	2.2	4.87	25	10	7	1.81
China	122.19	473.06	595.25	23.0	136.91	2	8	15	31.98
Philippines	16.18	6.30	22.48	78.0	17.53	25	10	7	6.53
Malaysia	1.07	1.21	2.28	80.0	1.82	25	10	7	0.68
Thailand	10.27	3.81	14.08	30.0	4.22	25	10	7	1.57
USA	25.38	35.29	60.67	65.0	39.43	2	12	28	14.95

[1]ICAR. 2012, NHB. 2011, FAO. 2011; [2]MOFPI. 2007-08; [3]Gustavsson *et al.,* 2011(FAO. 2011); *of what enters at each step; Author's calculations

Fruit wastes as livestock feed

Apple *(Malus domestica)*

Out of the total world production (Table 2), 30–40 percent of apples are damaged and therefore not marketed, and 20–40 percent are processed for juice extraction. The residue left after extraction of the juice, called **apple pomace**, could be used as a livestock feed.

Ruminants: The dried apple pomace (Box 1) contains 7.7 percent crude protein (CP) and 5.0 percent ether extract (EE) (Table 3). It has 1.86 Mcal metabolizable energy (ME)/kg DM and 1.06–1.12 Mcal net energy (NE)/kg DM for lactating dairy cows (NRC, 2001). The ensiled apple pomace, incorporated up to 30 percent in the diet of lactating multiparous Holstein cows, did not show any adverse effects on milk yield or its composition. However, the best feed conversion ratio was observed at 15 percent incorporation in the diet (Ghoreishi, Pirmohammadi and Yansari, 2007).

BOX 1
Conservation of fruit and vegetable wastes by drying

1. Fruit and vegetable wastes such as fresh apple pomace, tomato pomace, bottle gourd pomace (muddy in texture), pineapple bran and carrot pulp contain about 90 percent water.
2. Keep the fresh waste in a heap on a slant till the excess water is drained out.
3. Press mechanically by using filter press.
4. Dry the waste by thermal drying: by blowing hot air or by using a solar drier.
5. In case a mechanical press or thermal drying facilities are not available, then the waste may be spread in a 5–7 cm thick layer on a concrete floor under direct sunlight for sun drying. Wastes such as chaffed banana foliage, pea pods, tomato pomace and snow peas can be easily sun dried.
6. Turn the material upside down with a fork, 2–3 times a day, till the dry matter reaches around 90 percent. In peak summer (40–45 ^{o}C), the desired dry matter is achieved within 2–3 days.
7. Ground the dried waste in a Willey mill using 1–2 mm screen.
8. Store the ground waste in polythene bags and use as and when required.

Non-ruminants: The dried apple pomace can be used as an energy source in broiler rations replacing maize by 10 percent (w/w), without adversely affecting the broiler production. Incorporation at >10 percent leads to production of wet litter and depresses feed efficiency, mainly due to higher fibre content. The ME of apple pomace for broilers is 2.6–2.8 Mcal/kg DM. Matoo *et al*. (2001) have reported better performance of broilers fed on apple pomace diets supplemented with a commercial enzyme preparation (α-amylase, hemicellulase, protease and β-glucanase) compared with those that were not supplemented. The dried, ground damaged apple can replace 20 percent maize in broiler ration without any harmful effect and thus decreasing the feed cost.

Banana *(Musa acuminata)*

There are two main types of bananas: i) when ripe consumed as a fruit and ii) "plantains" used for cooking or making beer, vinegar, chips or starch. These two types of bananas represent 56 and 44 percent of the world banana production, respectively. The underground stem and male flowers of both the types can be eaten as a vegetable. About 30–40 percent of the total banana production (Table 2) is rejected for failing to meet quality standards and is potentially available for feeding to livestock (Babatunde, 1992). Banana wastes include small-sized, damaged bananas, banana peels, leaves, young stalks and pseudo stems, which can be fed to livestock. Fresh plantain and banana fruits may be ensiled with molasses, grass, legumes, rice bran etc. Green fruits are easier to ensile than ripe fruits.

Leaves, young stalks and pseudo stems

Whole, fresh banana leaves, stalks and pseudo stems are chopped and directly fed either fresh, sun-dried or ensiled (Boxes 2 and 3) with molasses in many tropical countries. Pseudo stems are easily ensiled if chopped and mixed with molasses or rice bran.

Composition: Banana leaves contain about 15 percent DM and 10–17 percent CP, while pseudo stems contain 5–8 percent DM and 3–5 percent CP. The NDF and ADF vary between 50–70 percent and 30–40 percent, respectively. Banana leaves contain 8 percent polyphenols, but very few condensed tannins (Marie-Magdeleine *et al.,* 2010).

Ruminants: The organic matter (OM) digestibility of pseudo stems is higher than that of leaves (Ffoulkes and Preston, 1978) mainly because the erectness of pseudo stems is primarily due to the presence of water in the cells, and not because of the presence of lignin in the cell wall. The high tannin content of leaves may also be responsible for low digestibility (Marie-Magdeleine *et al.,* 2010). Banana leaf meal (leaves chopped and sun dried) up to 40 percent in the forage based ration on DM basis increased weight gains and feed efficiency of Zebu cattle and sheep (Garcia, Chicco and Carnevali, 1973). Fresh banana foliage up to 15 percent (El-Ghani, 1999); dried foliage ensiled with dried broiler litter in a 40:60 ratio and rehydrated with either molasses or whey (Box 4), included at 15 percent (Khattab *et al.,* 2000), foliage and wheat straw (75:25) ensiled with molasses and urea (Baloch *et al.,* 1988) could replace 50 percent of green maize in the rations of lactating cows/buffaloes without altering milk production. Dried banana pseudostems have been fed to goats and sheep at levels of 20–50 percent in diets with no adverse effects, but daily weight gains were depressed (Poyyamozhi and Kadirvel, 1986). Its nutritional value was comparable to that of poor quality crop residues like rice straw or sugarcane tops (Viswanathan, Kadirvel and Chandrasekran, 1989).

Non-ruminants: Banana leaf meal could be used up to 15 percent in the diet of growing pigs, resulting in satisfactory average daily gain and feed conversion efficiency (García, Ly and Dominguez, 1991). However, plantain leaf meal at a 20 percent level had a significant detrimental effect on ileal and faecal digestibility of most nutrients, including protein, but it may be used at low levels in pig diets (Ly, García and Dominguez, 1997). Rabbits can be fed up to 40 percent banana leaves without adverse effects on growth, feed intake and digestibility (Rohilla and Bujarbaruah, 2000). After weaning, young rabbits were fed diets containing either 30 percent dry banana leaves or plantain leaves, fresh leaves or a mixture of dry and fresh leaves (1:1). Dry leaves were more effective with respect to increase in weight gain. Net returns over feed costs were highest in rabbits fed dried leaves (Fomunyam, 1985). Dried plantain leaves replacing 10 percent of a standard conventional diet in broilers did not affect feed efficiency or feed conversion (Marin *et al.,* 2003).

Banana peels

Banana peel constitutes about 30 percent of fresh banana by weight. These can be fed to livestock as fresh green, ripe or dried.

Composition: Ripe banana peels contain up to 8 percent CP and 6.2 percent EE (Table 3), 13.8 percent soluble sugars and 4.8 percent total phenolics (Table 4) (Bakshi and Wadhwa, 2013). Banana peels are rich in trace elements, but Fe, Cu and Zn contents are much higher than the maximum tolerance limit for ruminants (Table 7), suggesting that these should not be fed *ad libitum*, but should be supplemented in the ration of ruminants as source of organic minerals. Green peels have approximately 15 percent starch which gets converted to sugars as the fruit ripens and the ripened peel has approximately 30 percent free sugars. Green plantain peels contain 40 percent starch. Lignin content also increases from 7 to 15 percent with ripening. Tannins mostly present in the peels are responsible for the astringent taste of immature fruits, which adversely affect their palatability in monogastric animals, while there is no palatability problem with peels of the mature/ripened fruit. Ripening causes migration of tannins to the pulp or they get degraded by polyphenol oxidases and peroxidases (Emaga *et al.,* 2007).

BOX 2
Conservation of fruit and vegetable wastes by ensiling in bunker or pit silo

1. The green leafy wastes can be conserved in bunker- trench or pit (Photo 1) silo, depending on the quantity of the material to be ensiled.
2. Environment temperature should be between 10 and 38 °C, the optimum being 32 °C.
3. The size of the pit should be length 10 m × width 3 m × depth 1.5 m. One cubic meter can accommodate approximately 0.5 tonnes green waste; and accordingly keeping in view the availability of waste, the size can be adjusted.
4. Wilt the wastes like banana foliage, cabbage and cauliflower leaves with stem, baby corn husk or baby corn forage for 1–2 days in the open, then chaff to 3–5 cm.
5. Mix the wilted, chaffed wastes with either chaffed wheat straw, rice straw or maize stovers in a 70:30 ratio.
6. Spread on the floor of the trench or pit (Photo 2) a 5–7 centimeter layer of any poor quality crop residue to absorb the effluents released during fermentation.
7. Fill the pit with uniformly mixed waste and straw/stover layer after layer in batches of 40 to 60 kg by trampling.
8. Ensure that no air is trapped in the chaffed waste, till the pit is filled. In case of large silos, the pit is filled directly with the help of chaff cutter cum blower (Photo 3) followed by pressing or packing with a tractor (Photo 4).
9. Seal the silo pit/trench properly with polyethylene sheet and a layer of mud. Allow it to ferment for 42 days. As the mud sealing dries up cracks may appear which need to be sealed.
10. Open the trench/pit after 42 days; remove silage as per the daily requirement (Photo 5) and cover the pit again with a polyethylene sheet.

Photo 1. Silo pits

Photo 2. Spreading wheat straw onthe floor of silo

Ruminants: Banana peels are widely used by small, marginal and landless farmers as complementary feeds for ruminants in the tropics. Their nutritive value is similar to that of cassava or citrus peels. Dairy cows fed 14–21 kg of fresh ripe banana peels increased milk production (Dormond, Boschini and Rojas, 1998). In grass-fed Zebus, the addition of 15–30 percent banana peels in the diet increased weight gain significantly without causing health problems or affecting palatability (Hernan Botero, Enrique Toro and Rios, 2000). In goats, dry ripe plantain peels can replace up to 100 percent maize without adversely affecting growth performance, and were found to be an economical source of carbohydrates (Aregheore, 1998).

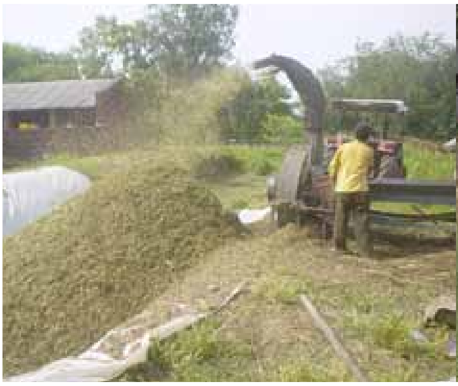

Photo 3. Chaffing and loading in the silo

Photo 4. Pressing trench silo with a tractor

Photo 5. Silage being taken out of silo pit

Non-ruminants: Dried ripe banana peels can be fed to growing pigs up to 20 percent in the diet without depressing growth (Rios, Abernathy and Nicholas, 1975). The ripe banana peels had higher ME (14.0 vs. 11.6 MJ/kg DM) than green peels (Tartrakoon *et al.,* 1999). Sun dried ripe plantain peels could replace 75–100 percent of maize in weaned rabbit diets with positive economic returns. Inclusion rates beyond 30 percent in the diet adversely affected daily weight gain and feed conversion efficiency (Fanimo and Odu, 2006).

BOX 3
Conservation of fruit and vegetable wastes by ensiling in tube silo

1. The green leafy material can also be conserved in a 10 to 12 feet long, 60–80 µ thick, low density polyethylene (LDPE) tube of 6 feet diameter. It can accommodate 0.5 tonnes of green waste.
2. Environment temperature should be between 10 and 38 °C, the optimum being 32 °C.
3. Tie one end of the tube tightly with nylon string.
4. Wilt the wastes (banana foliage, cabbage and cauliflower leaves with stem, baby corn husk or baby corn forage) for 1–2 days in the open, then chaff to 3–5 cm.
5. Mix the wilted, chaffed wastes with either chaffed wheat straw, rice straw or maize stovers in a 70:30 ratio and ensile for 42 days.
6. Before ensiling, spread a 5–7 centimeter layer of any poor quality crop residue at the bottom of the LDPE tube (to absorb the effluents released during fermentation).
7. About 40–60 kg is transferred each time; then after manual pressing (Photo 6) transfer another batch and again press (so as to ensure that no air is trapped in the waste material) till the LDPE tube is filled.
8. After packing, seal the tube tightly at the top end with a nylon string (Photo 7).
9. After 42 days, take out the silage from the tube as per the daily requirement and again seal the tube at the top end with a string.
10. Ensiling in an LDPE tube is preferred over trench silo by landless, marginal and small dairy farmers because it reduces the initial infrastructure investment and it is easy to handle.

Dried banana peels incorporated up to 10 percent in broiler diets improved the live weight gain and feed conversion efficiency. However, inclusion beyond 10 percent in the diet depressed the growth. An equal mixture of banana peels and golden snail (*Pomacea canaliculata*) meat could replace up to 90 percent of a commercial diet for ducks (Ulep and Santos, 1995).

Citrus

Brazil processes 47 percent of the world's citrus fruits (the main citrus processing country in the world), followed by the United States of America (29 percent). About 30 percent of the production of citrus fruits (and 40 percent of orange production) is processed (USDA-FAS, 2010) principally to make juice.

Citrus pulp

The residue left after extraction of the juice is called citrus pulp (50–70 percent of the fruit by weight). It contains 60–65 percent peel, 30–35 percent internal tissues and up to 10 percent seeds (Crawshaw, 2004). Citrus pulp is usually made from oranges (60 percent), grapefruits and lemons. Adult crossbred cattle can consume 50–60 kg fresh citrus pulp daily. But it is perishable due to the presence of high contents of water and soluble sugars and may cause environmental pollution. It should be sun dried (Box 1) and pelleted to increase density or should be ensiled (Boxes 2 and 3). While drying, lime is added to neutralize the free acids, bind the fruit pectins and release water (Wing, 2003).

Photo 6. Baby corn fodder being pressed in an LDPE tube silo

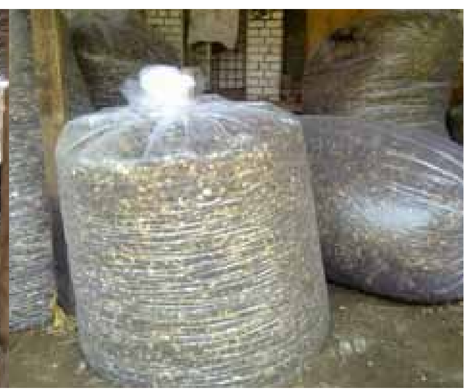

Photo 7. Baby corn fodder ensiled in an LDPE tube silo

TABLE 2

Production of fruits and vegetables (million tonnes) in India and world in 2010–11

	India[1]	World[2]	Contribution (Percent)	Rank in world
Fruits				
Apple	2.89	70.30	4.10	3
Banana	29.78	100.00	29.80	1
Citrus	7.8	119.7	6.50	4
Grapes	1.24	67.32	2.00	10
Mango & guava	17.65	39.98	44.00	1
Pineapple	1.42	19.41	7.30	6
Vegetables				
Cabbage	7.95	59.55	13.40	2
Carrot & turnip	0.49	33.79	1.45	7
Cauliflower	6.75	18.93	36.70	2
Peas	3.52	15.97	22.04	2
Potato	42.34	330.05	12.80	2
Tomato	16.83	150.51	11.00	2

[1]NHB (2011); [2]FAO (2012)

Composition: It contains 5–10 percent CP and 6.2 percent EE (Table 3), 10–40 percent soluble fibre (pectins) and 54 percent water soluble sugars (Table 4), 1–2 percent calcium due to the addition of lime and 0.1 percent phosphorus (Crawshaw, 2004; Bakshi and Wadhwa, 2013). Citrus pulp is a rich source of trace elements and their concentration is much below the maximum tolerance limit for ruminants (Table 7). The composition of dried citrus pulp is variable and depends mainly on the relative proportions of skins and seeds, which varies according to the citrus species, variety and the harvesting season. It is much less valuable to pigs and poultry due to the fibre content and to the presence of limonin in the seeds, which is toxic to monogastrics (Göhl, 1982).

Ruminants: Dried citrus pulp is used as a cereal substitute in concentrate diets due to its high OM digestibility (85–90 percent) and energy availability (2.76–2.9 Mcal ME/kg DM and 1.66–1.76 Mcal NE/kg DM) for lactating dairy cows. The ME availability is 85–90 percent that of maize and comparable to barley (NRC, 2001; Bampidis and Robinson, 2006). Unlike cereals, its energy is not based on starch but on soluble carbohydrates and digestible fibre. Citrus pectins are easily and extensively degraded, producing acetic acid, which is less likely than lactic acid to cause a pH drop and result in acidosis (Wing, 2003). Due to its high fibre content, the long rumination of citrus pulp produces large quantities of saliva that has a buffering effect on rumen pH. Citrus pulp is therefore considered as a safer feed than cereals for animals fed high-concentrate, low-roughage diets as in high-yielding dairy cows (Crawshaw, 2004). Dried citrus pulp can replace 20 percent concentrate in dairy cattle (Assis *et al.,* 2004) and up to 30 percent in lactating ewes (Fegeros *et al.,* 1995) without adversely affecting DM intake, rumen metabolites, digestibility, milk yield or milk protein and fat contents. Animals should be adapted gradually because it contains limonin in the seeds and peels, which has a bitter taste. At higher levels in diets (>40 percent), it lowered palatability (Bhattacharya and Harb, 1973) and overall performance with ruminal parakeratosis (Martinez Pascual and Fernandez Cormona, 1980). Large amounts of butyric acid produced as a result of the high-level feeding cause rumen papillae to become enlarged and keratisined, restricting nutrient absorption and impairing animal performances (Brugère-Picoux, 2004).

BOX 4
Conservation of banana waste with broiler litter

1. Dried banana waste (B) and dried broiler litter (40:60) were ensiled using 2 rehydration media (RM).
2. Rehydration media (RM) can be either (i) molasses (25 percent moisture) diluted with water (1:9), or (ii) whey (93 percent moisture).
3. Mix 200 kg dried banana waste and 300 kg dried broiler litter with 1 tonne of the rehydration media on a plastic sheet.
4. Pack the above mixture in a bunker silo (length 10 m × width 3 m × height 1.5 m) lined with paddy straw, as explained earlier with thorough pressing done in a manner stated in previous Boxes.
5. Seal the silos with plastic cover to ensure anaerobic conditions and store for eight weeks.
6. After completion of the stipulated period, the required quantity of the silage can be taken out from one side of the silo.
7. Cover the silos again with a plastic sheet.

Non-ruminants: The presence of limonin in the seeds of citrus pulp may be a limiting factor. Dried citrus pulp may be included up to 5 percent in the diet of growing pigs. Higher rates (>10 percent) can adversely affect growth rates, feed conversion efficiency and carcass yield. Dried citrus pulp may be included up to 20 percent and 15 percent in the diets of pregnant and lactating sows respectively, without affecting reproductive and productive performance (O'Sullivan *et al.,* 2003). Sotto *et al.* (2009) used citrus pulp up to 50 percent in the diets of gestating and lactating sows without deleterious effects on performances and productive indices. Dried citrus pulp can be incorporated in diets of rabbit at 20–30 percent levels (Hon, Oluremi and Anugwa, 2009).

The level of citrus pulp in the diets of poultry should not exceed 5–10 percent because of the presence of non-starch polysaccharides which impaired growth rates, lowered feed efficiency and reduced carcass yields (Mourao *et al.,* 2008). But within these limits (up to 10 percent) it did not affect feed intake, egg production, and egg weight in laying hens (Yang and Chung, 1985).

Ensiled citrus pulp

Before ensiling, the fresh citrus pulp should be mixed either with grass, hay, sugarcane bagasse or cereal straw in order to increase DM content. Fruit juice waste (mainly sweet lime) without peels can be mixed with wheat or rice straw in a 70:30 ratio and ensiled (Box 5) to give an excellent silage (Bakshi *et al.,* 2007). Ensiled citrus pulp has a pleasant odour and is readily eaten by cattle. Citrus pulp enhances overall silage quantity and quality.

Ruminants: A silage mixture containing 70 percent fresh citrus pulp had no adverse effect on milk yield or composition, but increased fat content (6.85 vs. 5.85 percent) when offered to primiparous dairy ewes in late lactation (Volanis *et al.,* 2006). Ensiled fresh citrus pulp and wheat straw (80:20) with only 70 percent of the concentrate mixture normally offered to lambs in oat hay-concentrate based diets had no effect on daily weight gain or dressing percentage. The feed cost per kg of body weight gain was lower with the citrus pulp silage diet as compared with the control diet. Carcass and meat quality were not affected by treatments (Scerra *et al.,* 2001).

BOX 5
Conservation of densified/intermingled fibrous fruit and vegetable wastes

1. Fruit and vegetable wastes like tomato pomace, bottle gourd pomace, citrus pulp, pineapple waste and pineapple bran, carrot pulp, which have either a highly densified/muddy texture or intermingled fibre and cannot be mixed uniformly with the straw should be ensiled in alternate layers.
2. In such cases, spread a layer of poor quality crop residue in the trench/pit or LDPE tube silo, then a layer of the fruit/vegetable waste (Photo 8) and press it manually as explained in Box 2. Repeat the procedure by spreading alternate layers of straw (30 percent) and waste (70 percent) with thorough pressing.
3. Follow the rest of the procedure explained in Boxes 2 and 3.

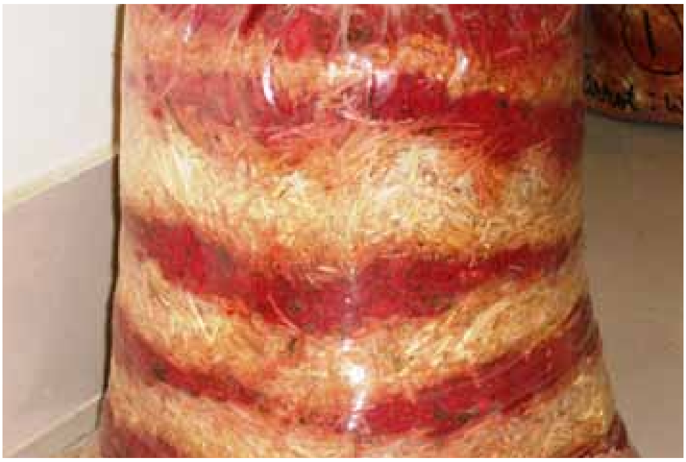

Photo 8. Alternate layers of carrot pomace and wheat straw ensiled in an LDPE tube silo

Non-ruminants: Citrus pulp silage can be included at 5–10 percent in the diet of growing pigs, which reduced the feeding cost. Pigs offered citrus pulp showed significantly lower *Enterobacteria* counts in faeces compared with pigs in the control group. However, no difference was observed in the *Lactobacilli* count (Cerisuelo *et al.,* 2010). Generally, increasing the amount of fermentable fibre in the diet stimulates microbial fermentation in the hindgut of pigs and fermentation generates lactic acid and volatile fatty acids, which are capable of inhibiting some intestinal pathogens e.g. *Escherichia coli* and *Salmonella* spp. (Montagne *et al.,* 2003). Feeding ensiled citrus pulp improved meat quality, without affecting growth performance (Cerisuelo *et al.,* 2010).

Citrus molasses

It is a by-product of citrus juice extraction. The fresh pulp mixed with lime is pressed to remove moisture. The resulting liquid (press juice) is screened to remove the larger particles, sterilized and concentrated. It is a thick, viscous dark brown to almost black liquid, and is called citrus molasses. It has bitter taste due to the presence of naringin, a flavonoid (Hendrickson and Kesterson, 1965). Its composition (60–65 percent sugars and 4–5 percent CP) is comparable to sugarcane molasses. It can be fed to animals, or added to grass silage.

Ruminants: In spite of the bitter taste, it is readily accepted by beef and dairy cattle and is as palatable as sugarcane molasses. It may be mixed with pressed pulp prior to drying, which increases the total digestible nutrient (TDN) content in the dried product without affecting the keeping quality of the pulp. Cattle can consume up to 3 kg/day when offered *ad libitum* (Göhl, 1978). It could replace 50 percent of ground maize in the diet of fattening steers without reducing body weight gain, quality and carcass yield (Hendrickson and Kesterson, 1965).

Non-ruminants: Citrus molasses is not palatable to pigs, but pigs can be adapted in 3–7 days and it can subsequently replace 10–40 percent of maize depending on the age of the pig (Hendrickson and Kesterson, 1965).

Grapes *(Vitis vinifera L)*

China is the highest producer followed by Italy, contributing 13 and 12 percent of world production. Grapes are mainly used for wine making. Winery waste and by-products as percent of grapes include grape stalks (2.5–7.5 percent), grape pomace (~15 percent dry; wet up to 25–45 percent) and grape seeds (3–6 percent) and yeast lees (3.5–8.5 percent) [yeast lees are the residual yeast and other particles that precipitate at the bottom of a wine vat]. Grape pomace contains up to 15 percent sugars, 0.9 percent phenolics/pigments (red grape pomace), 0.05–0.08 percent tartarate and 30–40 percent fibre. Grape seeds contain 4–6 percent phenolics and 12–17 percent oil very rich in linoleic acid-omega-6 fatty acid (76 percent). The yeast lees contain 0.012 percent pigments, 0.1–0.15 percent tartrate and 6–12 percent β 1, 3-glucans.

The main by-products of a vineyard are the grape stalks rich in lignin, cellulose, nitrogen and potassium (vine prunings ~5 tonnes/ha/year). These can be used for producing compost. Grape stalk compost has a high agronomic value and is particularly suitable for the soils of the vineyards which have very low organic matter content. The use of grape stalks in the form of single cell protein, as ruminant feed or a component in the feed has also been proposed after solid state fermentation using fungal strains (Nicolini *et al.*, 1993). Results indicated that, after removal of lignin through the fungal treatment, the cellulose is better accessible to rumen micro-organisms. Since the fermented product has good protein value and low lignin content, it has DM digestibility similar to forages (54–60 percent). The grape pomace contains 9–12 percent CP and 5–7 percent EE (Table 3) and has very low ME (1.06 Mcal/kg DM) and NE (0.69 Mcal/kg DM) for lactating dairy cows (NRC, 1989).

Mango *(Mangifera indica L.)*

The edible pulp makes up 33–85 percent of the fresh fruit, while the peel and the kernel amount to 7–24 percent and 9–40 percent, respectively, on a fresh weight basis (Wu, Chen and Fang, 1993). The by-products/wastes available after processing of mango includes cull fruits (fresh fruits unsuitable for human consumption), mango kernel meal (containing 6–16 percent mango oil on DM basis), deoiled mango kernel meal and mango peels.

Antinutritional factors: Mango seed kernels are rich in tannins, which progressively lead to depression in growth rates and efficiency of feed utilization, when included as a major component in diets of pigs and poultry. They also contain 64 mg/kg DM cyanogenic glucosides, 42 mg/kg DM oxalates and 20 TIU (trypsin inhibiting unit)/g DM trypsin inhibitors (Ravindran and Sivakanesan, 1996). Amongst the different treatments, soaking in water was most effective, and it removed 61 percent of the tannins and 84 percent of hydrocyanic acid (HCN) (El Boushy and Vander Poel, 2000).

Mango seed kernels

Ruminants: Mango seed kernels can be incorporated in the concentrate mixture up to 50 percent without any adverse effects (Göhl, 1982). In sheep, DM digestibility of dried seed kernels was 70 percent but intake was low (1.2 percent of body weight), mainly due to the tannin content.

Non-ruminants: Raw mango seed kernel meal included at 5–10 percent in the diet depressed feed intake and growth in broiler chicks (El-Alaily, Anwar and El Banna, 1976). The recommendation for optimum growth is to use boiled mango seed kernels <5 percent in broiler chicks during the starter phase (0–28 days) and 10–20 percent in the diets of broilers during the finisher phase (28–63 days) on DM basis (Joseph and Abolaji, 1997; Diarra and Usman, 2008). The incorporation of 5 percent raw mango seed kernel meal in layers decreased laying rate and increased weight loss in layers (Odunsi, 2005).

Mango peels

Ruminants: Mango peels can be fed fresh, dried or ensiled. Due to the high sugar content (13.2 percent) they are palatable and considered as an energy feed, but the high moisture and acidity of fresh peels may limit their use in ruminants. Because of their low protein content, addition of a source of nitrogen or protein is necessary to allow efficient utilization of the energy in the diet. In order to produce good silage, mango peels were mixed with rice straw and legume to facilitate fermentation (Boxes 2 and 3). Ensiled mango peels and rice straw had 60 percent DM digestibility, which increased when *Leucaena* leaves were included in the diet (Sruamsiri and Silman, 2009).

Non-ruminants: Dried mango peels up to 10 percent in the diet of finishing pigs had no deleterious effect on feed conversion ratio or performance and economized feeding cost (Rao, Ravi and Yedukondalu, 2003).

Pineapple *(Ananas comosus)*

The post-harvest processing of pineapple fruits yields skins, crowns, and waste from fresh trimmings and the pomace after extracting the juice. Fresh pineapple cannery waste can be preserved either by drying (Box 1) or ensiling (Boxes 2 and 3) Pineapple bran is the solid residue of the pressed macerated skins and crowns. It can be fed either fresh, ensiled or after drying to the animals.

Composition: Raw pineapple waste (on DM basis) contains 4–8 percent CP, 60–72 percent NDF, 40–75 percent soluble sugars (70 percent sucrose, 20 percent glucose and 10 percent fructose) as well as pectin, but it is poor in minerals (Müller, 1978; Pereira *et al.,* 2009). Therefore, it should be supplemented with protein and minerals in order to prevent detrimental effects on productivity and health.

Ruminants: Pineapple wastes can replace the roughage portion in the diet partly or completely (Müller, 1978) and partly the cereals in the diet of meat animals (Geoffroy, 1985). Pineapple wastes are highly palatable and digestible (73–75 percent OM digestibility) in cattle, sheep and goats (Müller, 1978). Fermented pineapple waste is less acidic than fresh waste and animals prefer the former (Sruamsiri, 2007). Ensiled pineapple waste fed to steers up to 70 percent of the diet with a protein supplement and 2.5 kg fresh forage resulted in high daily weight gains (1 kg/day) and also decreased the cost of feeding (Geoffroy *et al.,* 1984). It could also replace up to 60 percent of maize silage without affecting daily weight gains (Prado *et al.,* 2003). Silage made of 80 percent pineapple wastes and 10 percent poultry litter with molasses and additives reduced the feed cost. Pineapple waste mixed with rice straw could replace up to 50 percent of roughage in the total mixed ration of dairy cattle without affecting milk production (Sruamsiri, 2007).

Non ruminants: Pigs did not relish dried pineapple bran offered *ad libitum* in the ration. The high crude fibre (CF) content (20 percent) limits its use in pigs of <27 kg BW. However, incorporation up to 50 percent in the ration of older pigs (57 kg BW) improved the body weight gain and feed conversion efficiency. Beyond 50 percent in the ration these parameters were depressed (Göhl, 1982). Inclusion of 15 percent pineapple bran in chick diets depressed the feed conversion ratio and 20 percent inclusion decreased weight (Hutagalung, Webb and Jalaludin, 1973).

Other fruit wastes and their comparative evaluation as livestock feed

The nutritional worth of banana peels (BP), musk melon peels (MMP) and water melon peels (WMP) revealed that MMP had the highest ($P<0.05$) CP and cell wall constituents (Table 3), except cellulose which was highest in BP (Bakshi and Wadhwa, 2013). The total sugars were highest ($P<0.05$) in MMP, the true protein ($P<0.05$) in WMP and total phenolics in BP (Table 4).

The fractionation of the true proteins revealed that BP had the highest ($P<0.05$) proportion of albumin and globulins, MMP had that of prolamin, while WMP had that of glutelin fraction (Table 5). Irrespective of protein supplements, the rumen degradability of globulin was highest, followed by albumin, glutelin and prolamin (Wadhwa, Kaur and Bakshi, 2010), reflecting the availability of bypass protein. All the tested fruit wastes were very rich in macro- (Table 6) and micro-elements (Table 7) and could meet the daily requirements of ruminants (NRC, 2001). However, the concentration of Mg in MMP, Fe in BP, Cu in BP and MMP and Zn in BP were higher than the maximum tolerance limit, and can be used as source of organic minerals. None of the fruit wastes contained the heavy metals above the maximum tolerance limit (Table 8). The in sacco DM degradability of different fruit wastes revealed that WMP had the highest effective degradability and lowest rumen fill value, which was responsible for higher DM intake potential and nutritive index value (Table 9).

It is concluded that most of the tested fruit wastes, especially banana foliage and peels, mango peels and seed kernels, citrus pulp and pineapple waste either fresh, dried or ensiled could serve as excellent alternate feed resources for livestock and poultry.

TABLE 3

Chemical composition (percent DM basis) of vegetable, cannery and fruit wastes

	Botanical name	DM	Ash	OM	CP	EE	NDF	NDS	ADF	HC	CEL
Vegetable wastes											
Sugar beet leaves[1]	*Beta vulgaris*	10.0	21.0^{d}	78.9^{c}	21.9^{g}	3.5^{d}	42.3^{c}	57.8^{c}	21.1^{b}	21.2^{e}	11.4^{a}
Cauliflower leaves[1]	*Brassica oleracea* B.	13.0	13.7^{b}	86.4^{e}	17.0^{d}	4.2^{e}	27.5^{a}	72.5^{f}	19.4^{a}	8.1^{c}	15.2^{c}
Black chick pea plant[1]	*Cicer arietinum*	14.2	9.8^{a}	90.2^{f}	13.6^{b}	3.4^{d}	46.4^{d}	53.6^{b}	38.2^{e}	8.3^{c}	25.3^{e}
Cabbage leaves[1]	*Brassica oleracea* C.	10.0	15.8^{c}	84.2^{d}	19.9^{f}	2.6a^{b}	33.7^{b}	66.3^{e}	22.6^{d}	11.1^{d}	13.7^{b}
Pea vines[1]	*Pisum sativum*	13.5	10.0^{a}	89.9^{f}	11.8^{a}	2.4^{a}	60.0^{e}	40.0^{a}	49.9^{g}	10.0^{d}	36.8^{f}
Radish leaves[1]	*Raphanus sativus*	8.8	22.1^{e}	77.9^{b}	19.4^{e}	4.5^{e}	27.9^{a}	72.1^{f}	21.9^{c}	5.9^{b}	14.9^{c}
Summer squash vines[1]	*Cucurbita pepo* L.	13.8	23.3^{f}	76.8^{a}	13.9^{c}	2.9^{b}	41.1^{c}	58.9^{d}	40.4^{f}	0.7^{a}	16.9^{d}
Pooled SE			1.09	1.30	0.08	0.11	0.21	0.47	0.96	0.42	1.14
Baby corn husk[2]	*Zea mays Linn*	10.0	5.2	94.8	11.6	1.8	60.9	39.1	28.8	32.1	24.4
Carrot[3]	*Daucus carota*	10.1	8.2	91.8	9.9	1.4	9.0	91.0	8.0	1.0	7.0
Ensiled pea vines[3]	*Pisum sativum*	25.0	9.0	91.0	13.1	3.3	59.0	41.0	49.0	10.0	34.0
Potato[3]	*Solanum tuberosum L.*	12.0	4.8	95.2	9.5	0.4	–	–	–	–	–
Snow peas[4]	*Pisum sativum var. saccharatum*	11.5	5.2	94.8	23.2	1.0	23.1	76.9	14.4	8.7	21.6
Cannery wastes											
Pea pods[5]	*Pisum sativum*	14.1	8.04^{b}	92.0^{a}	19.8^{d}	1.0^{a}	48.1^{c}	52.9^{b}	35.4^{c}	12.7^{b}	24.0^{c}
Carrot pulp[5]	*Daucus carota*	9.50	7.5^{b}	92.5^{a}	7.2^{a}	1.8^{b}	24.0^{a}	76.0^{c}	20.0^{a}	4.^{0a}	15.3^{b}
Citrus pulp[*5]	*Citrus limetta*	9.50	4.5^{a}	95.5^{b}	10.5^{b}	5.8^{c}	26.5^{b}	73.5^{c}	24.5^{b}	2.0^{a}	12.8^{a}
Sarson saag waste[5]	*Brassica campestris*	11.85	6.9^{b}	93.1^{a}	15.0^{c}	1.0^{a}	63.3^{d}	36.7^{a}	45.6^{d}	17.7^{c}	34.8^{d}
Pooled SE			0.27	0.27	0.10	0.08	0.12	0.12	0.63	0.67	0.16
Apple pomace[6]	*Malus domestica*	35.9	2.6	97.4	7.7	5.0	52.5	47.5	43.2	4.3	-
Bottle gourd pulp[7]	*Lagenaria siceraria*	12.3	9.3	90.7	24.3	2.4	50.6	49.4	40.2	10.4	10.5

Grape pomace[8]	*Namily vitaceae*	35.0	7.9	92.1	8.9–12.2	5.0–7.1	51.5–58.0	42.0–48.5	48.4–52.6	3.1–5.4	54.0
Pineapple bran[3]	*Ananas comosus*	9.9	3.5	96.5	4.6	1.5	73.0	27.0	37.0	36.0	–
Sugar beet pulp[6]	*Beta vulgaris*	10-15	7.3	92.7	10.0	1.1	45.8	54.2	23.1	22.7	
Tomato pomace[9]	*Solanum lycopersicum*	25.3	6.0	94.0	22.1	11.5	63.0	37.0	51.0	12.0	12.0
Fruit wastes											
Banana peels[5]	*Musa acuminata*	9.4	11.1[b]	88.9[b]	8.1[a]	6.2[b]	35.8[a]	64.2[b]	25.3[a]	10.5[b]	18.2[b]
Muskmelon peels[5]	*Cucumis melo*	12.6	14.9[c]	85.1[a]	9.5[b]	5.8[b]	59.3[b]	40.7[a]	35.7[c]	23.6[c]	14.8[a]
Watermelon peels[5]	*Citrullus lanatus*	10.5	7.9[a]	92.1[c]	7.9[a]	1.8[a]	33.8[a]	66.2[b]	30.7[b]	3.1[a]	26.4[c]
Pooled SE			0.24	0.24	0.14	0.07	0.11	0.11	0.09	0.10	0.10

*Without peels; OM- Organic matter; CP- Crude protein; EE- Ether extract; NDF- Neutral detergent fibre; NDS- Neutral detergent solubles; ADF- Acid detergent fibre; HC- Hemicellulose; CEL- Cellulose; SE- Standard error; [1]Wadhwa and Bakshi (2005); [2]Bakshi and Wadhwa (2012a); [3]NRC (1989); [4]Bakshi and Wadhwa (2012b); [5]Bakshi and Wadhwa (2013); [6]NRC (2001); [7]Wadhwa, Saini and Bakshi (2013); [8]Zalikaranab, Pirmohammadi and Teimuryansari (2007); [9]Bakshi, Kaur and Wadhwa (2012); Figures with different superscriptsa,b,c in a column (separately for vegetable, cannery and fruit wastes) differ significantly at $P<0.05$; OM=100-total ash; NDS=100-NDF; HC=NDF-ADF.

Vegetable wastes as livestock feed

Baby corn *(Zea mays Linn)*

Baby corn is eaten both raw and cooked and is used as a delicacy in Asian cuisine. Thailand is the major baby corn producing and exporting country in the world, while India has emerged as one of the potential baby corn producing countries because of the low cost of production as compared to many other countries. Major baby corn importing countries include the United States of America and other Asian and European countries. About 3–4 picks are taken from each baby corn plant. Keeping in view the increased demand, the cultivation of baby corn has increased remarkably in India. Average baby corn production is about 7.5–8.7 tonnes/ha. Only 15 percent is the edible baby corn cob, while 85 percent is constituted by outer peels with a silky thread like structure called baby corn husk (Photo 9), which is a waste material and is a source of environmental pollution. A number of other by-products are tassels and green plant material. The wastes/by-products, if used judiciously, can give additional income to the growers.

Photo 9. Chaffed baby corn husk

Baby corn husk

Ruminants: Fresh baby corn husk (BCH) contained 11.7 percent CP and 1.8 percent EE (Table 3). Fresh chaffed BCH, or BCH wilted for 2–3 days and ensiled for 42 days or fresh BCH mixed with chaffed rice straw in a 70:30 ratio (BCH-RS) and ensiled for 42 days were evaluated as livestock feed (Bakshi and Wadhwa, 2012a). The *in vitro* gas production studies revealed that NDF and true OM digestibility, and ME availability were highest ($P<0.01$) for fresh BCH followed by ensiled BCH and ensiled BCH-RS. The total and individual volatile fatty acid production were highest for fresh BCH, statistically comparable with those for ensiled BCH but higher ($P<0.05$) than those by BCH-RS silage. *In vivo* evaluation of fresh chaffed BCH and conventional green maize fodder fed *ad libitum* to male Murrah buffalo calves revealed higher ($P<0.05$) digestibility of nutrients, N-retention and apparent biological valve of protein for fresh BCH as compared with those for green maize fodder. In another experiment ensiled BCH was evaluated in total mixed ration (TMR) containing concentrate mixture, ensiled BCH and wheat straw in a 40:30:30 ratio on DM basis. The study revealed higher digestibility of nutrients and N-retention in animals fed TMR as compared with those offered fresh BCH. The higher digestibility of nutrient, N-retention, apparent biological valve and favourable rumen environment conclusively revealed that fresh or ensiled BCH was highly acceptable and palatable, comparable with conventional maize fodder.

Baby corn fodder

Ruminants: After taking 3–4 baby corn picks, the left over plant was harvested to be used as fodder for livestock. It was observed that the fodder yield of baby corn varieties was lower (P<0.05) than the conventional maize fodder variety. It contained 92.2 percent OM, 11.7 percent CP, 59.2 percent NDF, 30.4 percent ADF, 28.8 percent hemicellulose and 37.1 percent cellulose. The chemical composition was quite comparable with that of the conventional maize fodder. The in vitro evaluation revealed that baby corn fodder had higher (P<0.05) digestibility of nutrients, total volatile fatty acid (TVFAs) production and ME availability as compared with conventional maize fodder. Both the forages when fed *ad libitum* alone or with other feedstuffs as total mixed ration to adult buffaloes, the daily DM intake, nutrient utilization, purine nitrogen index and N-retention were comparable (Bakshi *et al.,* 2013). The baby corn fodder can also be ensiled in trench/pit or low density poly propylene tube. The studies on male buffalo calves revealed that ensiled baby corn fodder and ensiled maize fodder in complete feed had comparable DM intake, digestibility of nutrients and N-retention in male buffalo calves (Wadhwa, Kumar and Bakshi, 2013).

Bottle gourd *(Lagenaria siceraria)*

It is extensively used as vegetable. In addition, its juice has many medicinal properties and is being used in curing urinary disorders, insanity, epilepsy and other nervous diseases, stomach acidity, indigestion and ulcers, flatulence and even piles.

Bottle gourd ('lauki') pulp

Ruminants: The residue after extraction of juice is called bottle gourd pulp. It can be conserved by sun drying and then ground to pass through a 1 mm screen. It is a rich source of CP (24.3 percent) and has a low concentration of cell wall constituents (Table 3). The *in vitro* gas production studies revealed that the graded levels in the iso-nitrogenous and iso-caloric concentrate mixtures (0, 25, 50, 75 and 100 percent) depressed digestibility of nutrients, VFA production and ME availability. The *in vivo* studies on bucks fed with a diet containing 0, 25 and 50 percent bottle gourd pulp in iso-nitrogenous and iso-caloric concentrate mixtures supplemented with green fodder (50:50) revealed that fungal population in the rumen had increased (P<0.05), while that of bacterial and total protozoal population was depressed (P<0.05) with the increasing level of 'lauki' pulp in the diet. However, it did not affect the daily DM intake. The digestibility of CP was depressed, whereas that of ADF and cellulose improved (P<0.05), without affecting the N-retention in bucks. It was concluded that 'lauki' waste can be incorporated up to 50 percent in the concentrate mixture of adult ruminants (Wadhwa, Saini and Bakshi, 2013).

Carrot *(Daucus carota)*

Feed carrots are usually cull (grade-out) or surplus carrots obtained during glut season of production. These can be fed fresh (whole/chopped), ensiled or dehydrated. Other carrot products that occasionally are fed to livestock include the carrot tops and carrot pomace after extraction of juice.

Composition: Fresh carrot contains 10 percent CP, 1.4 percent EE (Table 3), up to 60 percent sugars, mostly sucrose (on DM basis). A rich source of vitamin C (300–700 mg/kg DM) and carotene, depending on the carrot variety; orange carrots contain 200–1000 mg/kg DM of β-carotene (ANSES, 2008). Carrots also contain harsh turpentine-like flavors associated with the presence of total volatiles especially γ-terpenine and elicit a negative organoleptic response and decrease in palatability when in high concentration (Simon, Peterson and Lindsay, 1980).

Ruminants: Carrots are highly palatable and readily consumed by cattle. Carrots are a rich source of ME (3.29 Mcal/kg DM) and NE (1.94 Mcal/kg DM) for lactating dairy cows (NRC, 1989). Fresh carrots can be fed up to 20 and 25 kg/day to young bulls and dairy cows (Morel d'Arleux, 1990) and can be included up to 40 percent in the diet of steers, without any adverse effects (Rust and Buskirk, 2008). Due to high fermentable sugars, fresh carrots should be combined with fibrous feeds to prevent acidosis and scouring, and should be introduced progressively in the diet (8–10 days). The mixture of carrots and concentrate feed should not exceed 50 percent of the diet DM and *ad libitum* feeding must be prevented (Morel d'Arleux, 1990). Prolonged use of carrots in the diet of dairy cows increased the carotene content of the milk and produced yellow coloured milk fat (Fuller, 2004). A significant improvement in the reproductive performance of high-yielding cows fed 10 kg/day fresh carrots in the diet was observed; a decrease in the calving interval from 167–185 days to 110–171 days, a decrease in the number of inseminations necessary for successful fertilization (1.8–2.7 to 1.0–1.8) and an increase in the calving rate (84.5 to 92 percent). The milk yield and fat content were not affected (Car, 1985). The gestating and lactating ewes fed 3.3 kg/day fresh carrots during the last month of gestation and 5 kg/day (27 percent of the dry matter intake, DMI) during lactation were well accepted by the animal. It could be included up to 80 percent in the diet of ewes at maintenance. Goats can be fed up to 2–4 kg/day of fresh carrots (Morel d'Arleux, 1990).

Non-ruminants: Carrot is a staple diet of horses. Dehydrated carrots and carrot flakes are common commercial treats for horses. Fresh carrots are used in low amounts (2–3 kg/day) for working horses, and these are mostly used to maintain appetite and facilitate the consumption of dry feeds. Clean and well-preserved carrots can be fed up to 10 kg/day to resting or convalescent horses (Wolter, 1999). They should be chopped into 5 mm thick rings (Kohnke, Lelleher and Trever-Jones, 1999) or sliced into long thin slivers (Vogel, 2011) before feeding to reduce the risk of choking.

TABLE 4

Water soluble nutrients in vegetable, cannery and fruit wastes (percent DM basis)

	Botanical name	Sugars			Total phenolics
		Total	Reducing	Non-reducing	
Vegetable wastes					
Sugar beet leaves[1]	*Beta vulgaris*	24.9[g]	1.5[d]	23.4[f]	2.9[a]
Cauliflower leaves[1]	*Brassica oleracea* B.	18.6[e]	3.6[e]	15.0[e]	5.9[e]
Black chick pea plant[1]	*Cicer arietinum*	14.0[d]	0.8b[c]	13.2[d]	3.2[b]
Cabbage leaves[1]	*Brassica oleracea* C.	20.6[f]	5.0[f]	15.6[e]	5.9[e]
Pea vines[1]	*Pisum sativum*	6.4[a]	1.0[c]	5.4[a]	4.5[d]
Radish leaves[1]	*Raphanus sativus*	9.5[c]	0.7a[b]	8.8[c]	6.9[f]
Summer squash vines[1]	*Cucurbita pepo* L.	7.8[b]	0.5[a]	7.3[b]	3.7[c]
Pooled SE		0.29	0.08	0.24	0.04
Cannery wastes					
Pea pods[2]	*Pisum sativum*	35.8[b]	3.2[b]	32.6[b]	9.4[c]
Carrot pulp[2]	*Daucus carota*	64.3[d]	6.2[d]	58.1[d]	4.3[b]
Citrus pulp[*2]	*Citrus limetta*	53.6[c]	5.8[c]	47.8[c]	10.3[d]
Sarson saag waste[2]	*Brassica campestris*	6.0[a]	0.2[a]	5.8[a]	0.4[a]
Pooled SE		1.28	0.03	1.30	0.15
Fruit wastes					
Banana peels[2]	*Musa acuminata*	13.8[a]	5.9[b]	7.9[a]	4.8[c]
Muskmelon peels[2]	*Cucumis melo*	24.5[c]	6.8[b]	17.7[b]	0.7[a]
Watermelon peels[2]	*Citrullus lanatus*	19.3[b]	3.5[a]	15.8[c]	1.4[b]
Pooled SE		0.14	0.21	0.22	0.02

*Without peels; [1]Wadhwa and Bakshi (2005); [2]Bakshi and Wadhwa (2013); Figures with different superscripts in a column (Separately for vegetable, cannery and fruit wastes) differ significantly at P<0.05.

TABLE 5

Different protein fractions (percent of the total) in vegetable, cannery and fruit wastes

Wastes	Botanical name	Albumin	Globulin	Prolamin	Glutelin
Vegetable wastes					
Sugar beet leaves[1]	*Beta vulgaris*	60.6^{cd}	12.7^{ab}	12.0^{c}	14.7^{ab}
Cauliflower leaves[1]	*Brassica oleracea* B.	62.4^{d}	12.9^{ab}	9.1^{b}	15.6^{b}
Black chick pea plant[1]	*Cicer arietinum*	43.5^{a}	13.5^{ab}	27.6^{d}	15.5^{ab}
Cabbage leaves[1]	*Brassica oleracea* C.	54.3^{b}	16.2^{c}	8.2^{b}	21.3^{c}
Pea vines[1]	*Pisum sativum*	56.9^{bc}	12.4^{a}	7.9^{b}	22.7^{c}
Radish leaves[1]	*Raphanus sativus*	61.0^{cd}	13.7^{ab}	11.4^{c}	13.8^{ab}
Summer squash vines[1]	*Cucurbita pepo* L.	69.8^{e}	14.8^{bc}	2.8^{a}	12.6^{a}
Pooled SE		1.48	0.71	0.52	0.88
Cannery wastes					
Pea pods[2]	*Pisum sativum*	59.3^{b}	15.6^{c}	7.3^{a}	17.8^{a}
Carrot pulp[2]	*Daucus carota*	61.3^{b}	11.9^{b}	7.9^{a}	18.9^{a}
Citrus pulp[*2]	*Citrus limetta*	38.4^{a}	12.4^{b}	14.0^{b}	35.2^{c}
Sarson saag waste[2]	*Brassica campestris*	63.8^{b}	8.3^{a}	8.2^{a}	21.0^{b}
Pooled SE		1.35	0.74	0.33	0.52
Fruit wastes					
Banana peels[2]	*Musa acuminata*	78.1^{b}	12.3^{b}	2.5^{a}	7.0^{a}
Muskmelon peels[2]	*Cucumis melo*	67.8^{a}	6.4^{a}	8.5^{c}	17.0^{b}
Watermelon peels[2]	*Citrullus lanatus*	64.4^{a}	8.1^{a}	4.8^{b}	22.8^{c}
Pooled SE		0.80	0.80	0.16	0.39

*Without peels; [1]Wadhwa and Bakshi (2005); [2]Bakshi and Wadhwa (2013); Figures with different superscripts in a column (separately for vegetable, cannery and fruit wastes) differ significantly at $P<0.05$.

Boiled, dehydrated and ground carrots have been tested successfully in the prophylaxis of diarrhea of weaning piglets (Jugl *et al.,* 2001). Silage containing 17 percent carrots (with fodder beets, sugar beets and potatoes) fed to replacement sows had a positive effect on live weight gain, reproductive parameters and on litter performance. Similar results were obtained on lactating and gestating sows fed silage containing 12 percent carrots with pumpkins and potatoes (Yushkova and Kertieva, 2010).

Carrots can provide carotenoids to laying hens. The yolk colour of the egg was improved significantly when 4–8 percent dried carrot meal was used in the diet of laying hens compared with a wheat-based control diet. Body weight gain, egg production and feed conversion were not affected (Sikder *et al.,* 1998). Giving egg-laying hens access to maize silage, barley-pea silage and carrots as forage materials decreased pecking behaviour, thus improving animal welfare (Steenfeldt, Kjaer and Engberg, 2007).

Carrot tops

Ruminants: Carrot tops contain 11–12 percent CP, 17 percent crude fibre and up to 18 percent ash due to residual dirt. Carrot top hay replacing 50 percent of berseem hay in the diet of Rahmani sheep increased nutrient digestibility (Bassiouni, Eweedah and Mohsen, 1999).

Non-ruminants: Carrot tops can be included up to 20–30 percent in diets of growing rabbits replacing *Trifolium alexandrium* hay with improved growth performance and feed conversion efficiency (Eleraky, 1996). However, higher levels (67 to 100 percent), replacing clover hay in the diet, depressed the performance of growing rabbits (Ibrahim, 2000). Carrot tops fed at 5 percent to laying hens improved ß-carotene content of egg yolk and did not affect egg weight, Haugh unit, egg-shape index and strength and thickness of the eggshell (Ishikawa *et al.,* 1999).

Carrot pomace

Ruminants: After extraction of juice, approximately one-third of the raw material remains as pomace. It contains 7–8 percent CP and 1.8 percent EE (Table 3). It is a rich source of total sugars (64.3 percent) and contains about 4.3 percent total phenolics (Table 4). The fractionation of true protein revealed that like other cannery wastes, it is rich in albumin, followed by glutelin, globulin and prolamin (Table 5). It is also a rich source of macro- and micro-elements (Tables 6 and 7). The digestion kinetic parameters for DM revealed that about 97 percent is degradable, with very high effective and true degradability and low rumen fill (Table 9) resulting in high potential DM intake (Bakshi and Wadhwa, 2013).

Non-ruminants: Dried carrot pomace could be used up to 50 percent in growing rabbit's diets without any adverse effects on the productive performance, nutrient digestibility and blood components (El-Medany, Hashem and Abdel-Azeem, 2008).

Peas *(Pisum sativum L.)*

Pea is one of the four most important legume crops next to soybean, groundnut, and beans. After harvesting garden/sweet peas, which are eaten as a vegetable, the left over plant is called **pea vine**. It can be fed fresh or ensiled. The pea vines contain 11.8 percent CP and 2.4 percent EE (Table 3). These contain 6.4 percent total sugars and 4.5 percent total phenols (Table 4). The fractionation of proteins revealed that, like other vegetable wastes, pea vines have the highest concentration of albumins, followed by that of glutelins, globulins and prolamins. The digestion kinetic parameters for DM of fresh pea vines revealed that it had 60.8 percent degradable fraction, with effective and true degradability of 52.3 and 75.1 percent. These have very high rumen fill value (Table 9), resulting in low potential DM intake. The in vitro gas production studies revealed that pea vines had 41.7 percent NDF digestibility, 64.1 percent OM digestibility and 7.1Mcal ME/kg DM (Table 10) (Wadhwa and Bakshi, 2005). The ensiled pea vines (Boxes 2 and 3) contained 13 percent CP and 3.3 percent EE with 2.09 Mcal ME/kg DM and 1.28 Mcal NE/kg DM for lactating dairy cows (NRC, 1989). The nutritive value of pea vines and that of clover were comparable for rabbits (Zaza *et al.,* 2009).

After harvesting sweet peas, the mature plant is left in the field for drying and is called 'pea straw'. It contains 5–10 percent CP, 53–63 percent NDF and 7–12 percent minerals, notably calcium (Leclerc, 2003). Pea straw intake as a percent of body weight is higher for small ruminants as compared to large ruminants (Bachchu *et al.,* 1994). With higher protein content and less fibre, pea straw has a higher nutritive value than cereal straws. Its quality is intermediate between cereal straw and good grass hay; and horses can consume daily up to 3–4 kg (Leclerc, 2003).

Empty pea pods

After shelling peas, the left over material is empty pea pods, which contain 19.8 percent CP and 1.0 percent EE (Table 3). These are rich in total soluble sugars, total phenolics, macro- and micro-elements. The fractionation of true proteins revealed that albumins had the highest concentration followed by glutelins, globulins and prolamins (Table 5) (Wadhwa, Kaushal and Bakshi, 2006). The digestion kinetic parameters for DM revealed that pea pods had 82.3 percent degradable fractions and 68–69 percent effective and true degradability (Table 9). Pea pods are relished by ruminants, are highly palatable with high nutritive value and can be fed exclusively.

Potato *(Solanum tuberosum L.)*

During the peak production season, it becomes a problem for the farmers to dispose of the surplus and the cull potatoes. These cannot be dumped, even in the waste land, because of the legal implications. Also, such potatoes cannot be kept in the cold stores because of the cost involved. The only option for the farmers is to feed them to the livestock. Raw potatoes are not very palatable and have a laxative effect and, therefore, should be introduced gradually in the diet of animals. To get the most value from the starch present in potatoes, these should be boiled or steamed. Potato sprouts contain an alkaloid, solanine, and it is advisable to remove the sprouts before the potatoes are fed to pigs or poultry. Fungal infested potatoes should never be used as feed.

Composition: The fresh potatoes contain 65–75 percent starch (depending on the variety), 9.5 percent CP and 0.4 percent EE on dry matter basis (Table 3). Potatoes contain negligible quantities of fibrous fractions like NDF, ADF and cellulose.

Ruminants: Potatoes have high ME (3.16 Mcal/kg DM) and NE (1.87 Mcal/kg DM) for lactating dairy cows (NRC, 1989). Dairy and beef cows can be fed up to 15–20 kg/day of raw potatoes without any adverse effects on the health of the animals (De Boever *et al.,* 1983). Potato tubers can be chopped with forage and ensiled. The heat generated during the fermentation is sufficient to cook the potatoes. The haulm can be ensiled for feeding to cattle.

Non-ruminants: Pigs are usually given only cooked potatoes, which are efficiently used by fattening and breeding animals. Pigs can be fed up to 6 kg a day. Potatoes produce firm pork. Cooked potatoes can be used for poultry up to 40 percent of the total ration (Edwards, Fairbairn and Capper, 1986).

TABLE 6

Macro mineral content (percent DM basis) of vegetable, cannery and fruit wastes

	Botanical name	Ca	P	Mg	Na	K	S
Vegetable wastes							
Sugar beet leaves[1]	*Beta vulgaris*	0.88[a]	0.20[ab]	0.82[c]	1.76[d]	0.54[bc]	0.31[b]
Cauliflower leaves[1]	*Brassica oleracea* B.	2.17[d]	0.34[c]	0.44[a]	0.39[b]	0.60[c]	0.56[c]
Black chick pea plant[1]	*Cicer arietinum*	1.13[b]	0.14[a]	0.51[a]	0.16[a]	0.47[ab]	0.20[a]
Cabbage leaves[1]	*Brassica oleracea* C.	2.38[e]	0.23[b]	0.68[b]	0.43[b]	0.44[a]	0.68[d]
Pea vines[1]	*Pisum sativum*	1.28[b]	0.22[ab]	0.49[a]	0.15[a]	0.45[ab]	0.28[a]
Radish leaves[1]	*Raphanus sativus*	1.79[c]	0.28[bc]	0.46[a]	1.01[c]	0.61[c]	0.89[e]
Pooled SE		0.04	0.02	0.03	0.03	0.02	0.01
Carrot[2]	*Daucus carota*	0.40	0.35	0.20	1.04	2.80	0.17
Ensiled pea vines[2]	*Pisum sativum*	1.31	0.24	0.39	0.01	1.40	0.25
Potato[2]	*Solanum tuberosum* L.	0.08	0.22	0.12	0.01	2.15	0.09
Snow peas[3]	*Pisum sativum var. saccharatum*	0.39	0.48	0.22	0.04	1.80	–
Cannery wastes							
Pea pods[4]	*Pisum sativum*	0.85[ab]	0.38[b]	0.38[b]	0.03[a]	0.63[b]	0.21
Carrot pulp[4]	*Daucus carota*	0.42[a]	0.23[ab]	0.17[a]	1.00[b]	0.45[a]	0.22
Citrus pulp*[4]	*Citrus limetta*	0.49[a]	0.14[a]	0.11[a]	0.02[a]	0.66[b]	0.14
Sarson saag waste[4]	*Brassica campestris*	1.42[b]	0.22[ab]	0.18[a]	0.14[a]	0.64[b]	0.29
Pooled SE		0.20	0.04	0.05	0.08	0.04	0.04
Apple pomace[5]	*Malus domestica*	0.20	0.14	0.09	0.04	0.73	0.07
Grape pomace[2]	*Namily vitaceae*	0.61	0.06	0.10	0.09	0.62	–
Pineapple bran[2]	*Ananas comosus*	0.23	0.13	–	–	–	–
Sugar beet pulp[5]	*Beta vulgaris*	0.91	0.09	0.21	0.31	0.96	0.30
Tomato pomace[5]	*Solanum lycopersicum*	0.22	0.47	0.28	0.12	0.98	0.15
Fruit wastes							
Banana peels[4]	*Musa acuminata*	0.29[a]	0.18[a]	0.30[a]	0.01[a]	1.11[c]	0.27
Muskmelon peels[4]	*Cucumis melo*	0.62[c]	0.44[b]	0.43[b]	0.49[c]	0.44[a]	0.29
Watermelon peels[4]	*Citrullus lanatus*	0.47[b]	0.43[b]	0.36[ab]	0.21[b]	0.74[b]	0.18
Pooled SE		0.01	0.02	0.02	0.03	0.03	0.01
Requirement		0.44–0.80	0.22–0.44	0.11–0.29	0.10–0.34	0.50–1.24	0.20
MTL		1.00	1.00	0.40	1.60	3.00	0.40

*Without peels; MTL- Maximum tolerance limit; [1]Wadhwa and Bakshi (2005); [2]NRC (1989); [3]Bakshi and Wadhwa (2012b); [4]Bakshi and Wadhwa (2013); [5]NRC (2001); Figures with different superscripts in a column (separately for vegetable, cannery and fruit wastes) differ significantly at $P<0.05$.

Sarson saag waste

Sarson saag, a vegetarian dish, is prepared by steam cooking of leaves of *Brassica campestris* (Mustard), *Spinacea oleracea* (Spinach) and *Trigonella foenum-graecum* (Fenugreek) in a 95:4:1 ratio. The chopped leaves are steam cooked after thorough washing (Photo 10). The contents are then transferred into a pulper for making pulp. The pulp is cooked with butter oil, condiments and then packed in sterilized cans while hot and is used as a delicacy for human consumption in India and abroad. The waste material left (Photos 11 and 12) after extracting the pulp (which constitutes about 50 percent of the original leafy vegetables) is called 'Sarson saag waste' (SSW). It is dumped on the waste land posing great threat to the environment. SSW contains 14.5 percent CP and is a good source of water-soluble sugars (6 percent). Adult buffalo can consume 50–55 kg fresh SSW/day. The nutrient digestibility of SSW in male Murrah buffaloes is comparable to that of conventional green fodder, *Avina sativa*, but significantly (P<0.05) higher than that of the isonitrogenous conventional total mixed ration (TMR) consisting of naturally fermented wheat straw (3.5 kg urea dissolved in 50 litre water, sprayed on 96.5 kg wheat straw, mixed and stacked for 9 days; Bakshi, Gupta and Langar, 1987), *Trifolium alexandrium*, solvent extracted mustard cake and rice bran in 65: 3: 21: 11 ratio (DM basis). The TMR had roughage to concentrate ratio of 68:32 (DM basis). The urinary excretion of total purine derivatives is comparable in animals fed SSW and the conventional green fodder but is higher (P<0.05) than that of animals fed conventional TMR. The low (P<0.05) purine nitrogen index (Makkar and Chen, 2004) in animals fed conventional TMR resulted in lower (P<0.05) microbial protein synthesis than that in animals fed SSW and the conventional green fodder. The N-excretion as percent of nitrogen intake was low (P<0.05) in animals fed SSW as compared with either of the conventional feeds tested, resulting in both higher (P<0.05) N-retention and apparent biological value (Bakshi, Kaushal and Wadhwa, 2005). Animals gained weight and their coat became shinier. It is concluded that SSW supplemented with mineral mixture is highly palatable, can serve as an excellent source of nutrients for ruminants and can be fed as a complete feed.

Photo 10. Chopped leaves are washed thoroughly 3-4 times prior to steam cooking

Photo 11. After removing pulp, Sarson saag waste (SSW) coming out of hopper

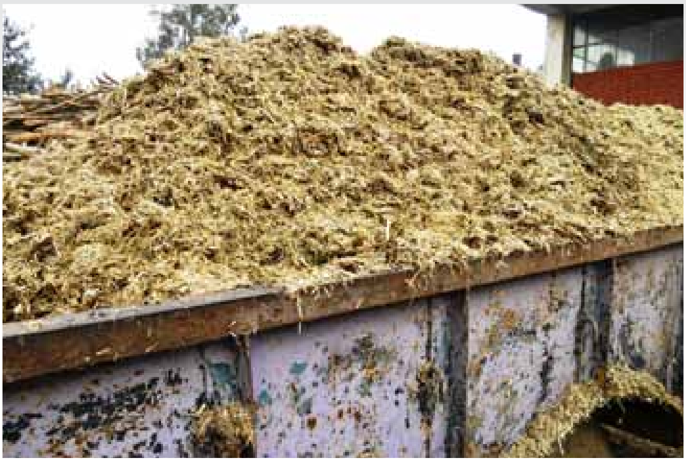

Photo 12. Sarson saag waste being transported by dairy farmer

Snow peas *(Pisum sativum var. saccharatum)*

It is a variety of pea. Unlike sweet peas, these are valued for their pods rather than just the beans inside and are eaten whole with pod as a salad. Snow peas are delicate and sweet in flavor. Frost affected snow peas are considered unfit for human consumption, fail the quality control test and are not exported.

Composition: Cull snow peas contain 23–25 percent CP, 1.0 percent EE (Table 3) and 35.8 percent total sugars on DM basis. These are an excellent source of vitamin A, B complex, C and vitamin K. Also, they are rich in pigments like lutein and zeaxanthin which help promote vision.

Ruminants: In a feeding trial on male buffaloes (424 kg body weight), the animals in the control group were offered 2 kg concentrate mixture with 7 kg wheat straw and 2 kg green fodder (C). While in the experimental group the animals were offered either 25 kg fresh snow peas and 6 kg wheat straw (SP1); or fresh snow peas were fed *ad libitum* exclusively (SP2). In the SP2 group the animals consumed 50–55 kg fresh snow peas/animal/day, indicating very high palatability. However, the DM intake was significantly lower than that of the control group mainly because of the very high moisture content in fresh snow peas. The digestibility of DM, OM and CP was significantly ($P<0.05$) high in the SP2 group as compared with the control group, but the digestibility of cell wall constituents was not affected. The N-retention was improved considerably, but the apparent biological value in the SP2 group as compared with the control group of animals was depressed significantly, mainly because of significantly higher N-excretion through faeces and urine. In another experiment, sun dried snow peas replaced 50 and 100 percent of iso-nitrogenous and iso-caloric concentrate mixture in the diet of male buffalo calves (168 kg body weight). The daily DM intake and digestibility of nutrients was comparable in all the groups, except that CP digestibility was depressed, while the ADF digestibility was improved. It was concluded that fresh or sun dried cull snow peas were highly palatable and can be effectively utilized in the diet of livestock, without effecting nutrient utilization or the health of the animals (Bakshi and Wadhwa, 2012b).

Sugar beet *(Beta vulgaris var. altissima)*

Sugar beet leaves

Composition: The sugar beet leaves contain 22 percent CP and 3.5 percent EE (Table 3). The leaves are rich in total soluble sugars (24.9 percent). The fractionation of true protein revealed that concentration was in the order: albumins > glutelins > globulins > prolamins (Table 5). The leaves are a rich source of both macro- and micro-elements (Table 6 and 7), except that the Mg and Na contents were higher than the maximum tolerance limit for ruminants (Table 6).

Ruminants: The digestion kinetic parameters for DM revealed that sugar beet leaves had 94 percent degradable fractions, and 81.9 percent and 75.9 percent effective and true degradability (Table 9) (Wadhwa and Bakshi, 2005). The *in vitro* studies revealed very high digestibility of nutrients. Cattle and sheep relish the wilted leaves and crowns of sugar beet. However, due to the presence of oxalic acid, which may cause scouring, fresh leaves and crowns should not be fed at levels >10 kg/day, while ensiled leaves should not be fed at levels >15 kg/day to cattle and >2 kg/day to sheep. The laxative effect of beet tops is not so pronounced in beet-top silage. The best results are obtained if the beet-top silage is fed together with lucerne hay. The ensiling of beet tops produces large amounts of seepage water during the first few weeks, which can be absorbed by spreading a 5–7 centimeter layer of wheat or rice straw on the floor of the pit before ensiling.

Non-ruminants: Due to the presence of oxalic acid, feeding of beet tops to pigs should be avoided.

Sugar beet pulp

The residue after juice extraction, known as sugar beet pulp, is dried and sold as dried sugar beet pulp or mixed with molasses to form dried molasses beet pulp.

Ruminants: The sugar beet pulp contains 10 percent CP and 1.1 percent EE (Table 3) with 2.36 Mcal ME/kg DM and 1.38–1.47 Mcal NE/kg DM for lactating dairy cows (NRC, 2001). Fresh pulp can be given to dairy cows and bullocks at levels up to 12 and 24 kg/day. The dried beet pulp can be fed up to 3.5 kg/day to milking animals, 5.5 kg/day to fattening cattle and 0.5 kg/day to 4 month old calves. As dried pulp readily absorbs water and swell, it should be soaked in two or three times its weight of water, especially if large amounts are to be fed to horses or calves.

Non-ruminants: Pigs digest the beet pulp fibre well, but the pulp is so bulky that total food consumption and performance will be depressed if >0.5 kg/day is fed to fattening pigs or >1 kg/day is fed to sows. Pigs relish the moist soaked pulp once they acquire a taste for it. Young pigs do not thrive on the pulp and may cause scouring because of the high oxalic acid content and contamination by the soil. Beet pulp has proved to be unsatisfactory for poultry.

Tomato *(Lycopersicon esculentum* Mill.*)*

Tomato waste is made up of culled tomatoes and tomato pomace. The culled fruits may be damaged, diseased, too small, misshapen etc. and do not meet the grading standards for sale in the fresh market or for processing. Tomato pomace (Photo 13) is a mixture of tomato peels, seeds and small amounts of pulp that remains after processing of tomato and is fed after sun drying and grinding. Unripe tomatoes and the green parts of ripe tomatoes contain a solanine-like alkaloid (saponin) called tomatine that may be toxic to insects, dogs and, to a lesser extent, herbivores (diarrhea, vomiting, intestinal irritation). However, it disappears as the tomato ripens and is not a problem in tomato pomace.

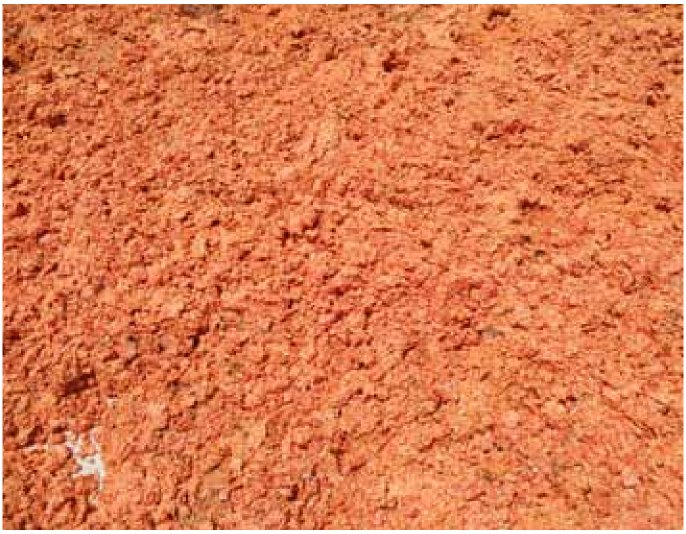

Photo 13. Tomato pomace being sun dried

Cull tomatoes

Fresh culled tomatoes contain 14–20 percent CP, 4–5 percent EE and 22 percent ADF. Tomatoes contain 40–60 percent non-structural carbohydrates; 90–95 percent of them are soluble sugars and 5–10 percent pectins (ANSES, 2008; Ventura, Pieltin and Castanon, 2009).

Ruminants: Cull tomatoes are slightly more digestible that tomato pomace as they contain all the highly digestible pulp and less fibre. The *in vitro* OM digestibility of fresh tomatoes was 63 percent, providing a DE value of 2.59 Mcal DE/kg DM. The low in sacco degradability of protein was due to the high acid detergent insoluble nitrogen (ADIN) content. Fresh cull tomatoes can be fed up to 1.5 kg to male goats with *ad lib* ryegrass hay without digestive disorders (Ventura, Pieltin and Castanon, 2009).

Non-ruminants: Dried cull tomatoes satisfactorily replaced alfalfa meal at 3 percent of the diet for broilers.

Tomato pomace

Ruminants: Tomato pomace (TP) can be fed fresh or can be preserved either by sun drying or by ensiling. Because of the high moisture content, it cannot be ensiled alone. Therefore, it is recommended to mix with wheat or rice straws or maize stovers in 70:30. TP contains 19–22 percent CP and 11–13 percent EE (Table 3), while acid detergent lignin (ADL) content varies between 7–13 percent (NRC, 1989; Bakshi, Kaur and Wadhwa, 2012). It is a good source of lycopene, a pigment that gives colour to meat, and is a known antioxidant. It has 2.37 Mcal ME/kg DM and 1.43–1.53 Mcal NE/kg DM for lactating dairy cattle (NRC, 1989). In multiparous dairy cows (26 kg milk/day) dried tomato pomace could be included up to 32.5 percent in the concentrate mixture

TABLE 7

Micro mineral content (ppm) of vegetable, cannery and fruit wastes

	Botanical name	Fe	Cu	Zn	Mn	Mo	Co
Vegetable wastes							
Sugar beet leaves[1]	*Beta vulgaris*	677.0[c]	8.5[d]	32.5[b]	67.8[e]	1.4[a]	2.3[a]
Cauliflower leaves[1]	*Brassica oleracea* B.	387.0[a]	4.0[a]	40.8[d]	40.8[a]	2.7[d]	3.7[b]
Black chick pea plant[1]	*Cicer arietinum*	838.0[d]	6.4[b]	21.5[a]	45.8[b]	5.5[f]	5.0[d]
Cabbage leaves[1]	*Brassica oleracea* C.	894.0[d]	9.4[e]	48.3[e]	54.6[d]	3.1[e]	5.9[e]
Pea vines[1]	*Pisum sativum*	1587.0[e]	10.9[f]	53.6[f]	49.8[c]	2.1[c]	6.7[f]
Radish leaves[1]	*Raphanus sativus*	638.0[b]	6.6[c]	34.0[c]	54.4[d]	1.7[b]	4.4[c]
Pooled SE		5.03	0.05	0.06	0.04	0.05	0.03
Carrot[2]	*Daucus carota*	120.0	10.0	–	31.0	–	–
Ensiled pea vines[2]	*Pisum sativum*	100.0	–	–	–	–	–
Potato[2]	*Solanum tuberosum* L.	39.0	5.5	14.5	7.5	–	–
Snow peas[3]	*Pisum sativum var. Saccharatum*	189.0	9.0	27.58	18.4	–	–
Cannery wastes							
Pea pods[4]	*Pisum sativum*	237.0[a]	7.6[a]	27.2[a]	23.2[b]	3.3[b]	6.4[b]
Carrot pulp[4]	*Daucus carota*	1816.0[d]	228.2[c]	710.0[c]	292.8[c]	2.4[b]	3.4[a]
Citrus pulp[*4]	*Citrus limetta*	893.0[c]	138.6[b]	430.0[b]	0.02[a]	0.5[a]	27.3[c]
Sarson saag waste[4]	*Brassica campestris*	389.0[b]	11.4[a]	35.97[a]	26.0[b]	2.4[b]	6.2[b]
Pooled SE		9.94	5.63	9.03	2.51	0.31	0.22
Apple pomace[5]	*Malus domestica*	185.0	11.0	14.0	17	0.7	–
Grape pomace[2]	*Namily vitaceae*	41.0	–	24.0	–	–	–
Pineapple bran[2]	*Ananas comosus*	561.0	–	–	–	–	–
Sugar beet pulp[5]	*Beta vulgaris*	642.0	11.0	22.0	62.0	1.5	–
Tomato pomace[5]	*Solanum lycopersicum*	541.0	11.0	54.0	11.0	1.8	–
Fruit wastes							
Banana peels[4]	*Musa acuminata*	2947.0[c]	386.0[c]	1138.0[b]	522.0[c]	3.3[b]	6.0[b]
Muskmelon peels[4]	*Cucumis melo*	226.0[b]	54.4[b]	40.0[a]	20.40[b]	2.5[b]	6.0[b]
Watermelon peels[4]	*Citrullus lanatus*	185.0[a]	4.8[a]	39.3[a]	14.36[a]	0.8[a]	3.8[a]
Pooled SE		6.06	1.27	1.83	1.31	0.31	0.20
Requirement		12–18	10–18	21–73	13–24	NA	0.11
MTL		1000	40	540	1000	10	10

*Without peels; MTL- Maximum tolerance limit; [1]Wadhwa and Bakshi (2005); [2]NRC (1989); [3]Bakshi and Wadhwa (2012b); [4]Bakshi and Wadhwa (2013); [5]NRC (2001); Figures with different superscripts in a column (separately for vegetable, cannery and fruit wastes) differ significantly at $P<0.05$.

without any adverse effect on health, milk yield and DM intake (Belibasakis, 1990). The sun dried, ground TP could replace the concentrate mixture completely in the diet of male buffaloes without affecting DM intake, digestibility of nutrients, urinary purine derivatives, microbial protein synthesis and total volatile fatty acids (VFAs) production in the rumen (Bakshi, Kaur and Wadhwa, 2012). In Brahman-Thai steers dried TP could be included at 50 percent in TMR without any problem. Dairy cows fed TP (fresh) maize silage had DM intake (3.74 percent BW), milk yield (35 kg/day) and milk composition comparable with the cows fed with maize silage alone (Weiss, Frobose and Koch, 1997). Caluya *et al.* (2003) recommended that tomato pomace (fresh, dry or ensiled) can replace 50 percent of the roughage.

Non-ruminants: Fresh TP can be used at 6 percent and 35 percent as a supplement feed in grower and finisher pigs respectively without any adverse effect on their performance and by decreasing feed cost/kg gain. Dried TP can be introduced up to 20 percent in the diet of growing rabbits without significantly affecting performance (Sayed and Abdel-Azeem, 2009).

The sun dried, ground TP incorporated beyond 5 percent in the iso-nitrogenous and iso-caloric diets of day-old commercial broiler chicks revealed that during the starter phase the gain in weight was depressed significantly, while during the finisher phase the chicks could tolerate TP up to 10 percent level. Overall, the TP up to 5 percent in the diet did not show any adverse effect on the feed intake, gain in weight or feed conversion efficiency of broiler chicks (Sethi, 2012). Dried tomato pomace can be included up to 10–20 percent without any adverse effect on egg production, body weight (Calislar and Uygur, 2010) and overall egg quality (Salajegheh *et al.,* 2012), while higher levels may depress hen-day production (Jafari, Pirmohammadi and Bampidis, 2006).

Other vegetable wastes as livestock feed

A comparison of the nutritional evaluation of cauliflower (*Brassica oleracea* Botrytis) leaves with stem (CauL) (obtained after removing curd for human consumption) and cabbage (*Brassica oleracea* Capitata) leaves (CabL) with sugar beet (*Beta vulgaris L.*) leaves (SBL), black chick pea (*Cicer arietinum*) plant with empty pods (BCPP), pea (*Pisum sativum* var. *arvense)* vines (PV), radish (*Raphanus sativus L.*) leaves (RadL) and summer squash (*Citrullus vulgaris*) vines (SSV) revealed that the CP content varied ($P<0.05$) from 11.8 (PV) to 21.9 percent (SBL), while in CabL, RadL and CauL it was from 17 to 19.9 percent (Wadhwa and Bakshi, 2005). The NDF and ADF contents were lowest ($P<0.05$) in CauL and highest in PV (Table 3). The SBL had the highest ($P<0.05$) concentration of total sugars, which was followed by CabL and CauL (Table 4). The fractionation of proteins revealed that albumin constituted the major proportion followed by glutelins, globulins and prolamins (Table 5). Most of the vegetable wastes were a rich source of Ca, P, Na, K, S, Zn, Mn, Mo and Co (Tables 6 and 7). However, Mg in all the tested vegetable wastes, Na in SBL, S in CauL, CabL and RadL, Fe in PV were higher than the maximum tolerance levels (MTL) for ruminants and the concentrations of heavy metals like Ni, Pb and Cd were much below the MTL (Table 8). The *in sacco* DM degradability revealed that the insoluble but potentially degradable fraction was highest ($P<0.05$) in RadL followed by CabL and was lowest in PV. The degradation rate of DM was significantly higher ($P<0.05$) for RadL than for CabL and SSV; but the effective degradability was highest ($P<0.05$) for CauL followed by RadL and CabL. The low rumen fill values in RadL, CabL and CauL indicated that they have higher DM intake potential (Table 9). The *in vitro* gas production studies revealed that CabL had the highest (P<0.05) and PV the lowest NDF and true OM digestibilities (Table 10).

TABLE 8

Heavy metals content (ppm) of vegetable, cannery and fruit wastes

	Botanical name	Al	As	Cr	Ni	Cd	Pb
Vegetable wastes							
Sugar beet leaves[1]	*Beta vulgaris*	958.0^{f}	6.6^{e}	3.5^{e}	9.8^{c}	0.42^{b}	6.16^{b}
Cauliflower leaves[1]	*Brassica oleracea* B.	290.0^{a}	3.8^{b}	1.6^{a}	17.0^{d}	0.21^{a}	4.66^{a}
Black chick pea plant[1]	*Cicer arietinum*	800.0^{e}	4.9^{c}	2.4^{c}	5.8^{ab}	0.26^{a}	6.73^{c}
Cabbage leaves[1]	*Brassica oleracea* C.	722.0^{c}	5.6^{d}	2.6^{d}	5.8^{a}	0.40^{b}	6.31^{b}
Pea vines[1]	*Pisum sativum*	749.0^{d}	2.4^{a}	2.8^{d}	6.0^{b}	0.40^{b}	8.18^{d}
Radish leaves[1]	*Raphanus sativus*	486.0^{b}	5.6^{d}	1.9^{b}	9.7^{c}	0.46^{b}	6.26^{b}
Pooled SE		6.95	0.05	0.04	0.03	0.04	0.05
Cannery wastes							
Pea pods[2]	*Pisum sativum*	218.0^{b}	3.1^{b}	0.9^{a}	9.5^{b}	0.17^{a}	5.28^{a}
Carrot pulp[2]	*Daucus carota*	297.0^{c}	2.1^{a}	10.4^{c}	7.6^{a}	0.42^{c}	5.33^{a}
Citrus pulp[*2]	*Citrus limetta*	833.0^{d}	1.4^{a}	6.4^{b}	13.1^{c}	0.22^{ab}	7.66^{b}
Sarson saag waste[2]	*Brassica campestris*	139.0^{a}	1.7^{a}	1.7^{a}	8.5^{ab}	0.35^{bc}	5.95^{ab}
Pooled SE		8.03	0.20	0.40	0.45	0.04	0.44
Fruit wastes							
Banana peels[2]	*Musa acuminata*	180.0^{b}	3.8^{b}	17.4^{b}	12.7	0.57^{b}	7.24^{b}
Muskmelon peels[2]	*Cucumis melo*	143.0^{a}	2.4^{ab}	1.3^{a}	12.2	0.38^{ab}	4.50^{a}
Watermelon peels[2]	*Citrullus lanatus*	137.0^{a}	1.1^{a}	1.0^{a}	12.9	0.25^{a}	3.78^{a}
Pooled SE		3.42	0.34	0.41	0.50	0.06	0.43
MTL		1000	50	1000	50	0.50	30

*Without peels; MTL- Maximum tolerance limit; [1]Wadhwa and Bakshi (2005); [2]Bakshi and Wadhwa (2013); Figures with different superscripts in a column (separately for vegetable, cannery and fruit wastes) differ significantly at P<0.05.

The nutritional evaluation of cannery wastes [pea pods (PP), carrot pulp (CarP), citrus pulp without peels (CPWP) and sarson saag waste (SSW)] revealed that PP had the highest (P<0.05) CP content and SSW the highest cell wall constituents (Bakshi and Wadhwa, 2013). The CarP had the lowest (P<0.05) CP, NDF and ADF contents (Table 3). The total sugars, reducing and non-reducing sugars contents were highest (P<0.05) in CarP and total phenolics were highest (P<0.05) in CPWP (Table 4). In the true protein fraction SSW had the highest (P<0.05) proportion of albumin, PP had that of globulins, CPWP that of prolamin and glutelins (Table 5). Most of the tested cannery wastes are a rich source of macro and micro elements and could meet the daily requirements of ruminants (NRC, 2001). However, Ca in SSW, Fe in CarP, Cu in CarP, CPWP, Zn in CarP were higher than the MTL for ruminants (Table 6 and 7), suggesting that CarP should not form a sole diet. None of the cannery wastes were found to contain heavy metals above the MTL (Table 8). The *in sacco* DM degradability revealed that CPWP had the highest ($P<0.05$) rapidly soluble fraction, CarP had that of the insoluble but potentially degradable fraction, CPWP had the highest DM degradation rate and effective degradability. The low rumen fill values for CPWP and CarP suggest potential higher DM intake and nutritive index value as compared with other cannery wastes (Table 9). Most of the tested cannery wastes could serve as excellent alternate feed resources for ruminants.

Chaffed cauliflower leaves (CauL), fruit juice waste (FJW), mainly citrus pulp without peels, or a mixture of CauL and FJW in a 1:1 ratio, ensiled either alone or after mixing with either wheat straw, rice straw or berseem straw in 70:30 mixtures revealed that the ensiling alone resulted in a significant depression in the net gas production (NGP) and digestibility of nutrients because of the low DM content (7.8 to 9.0 percent). The NDF, ADF and cellulose contents were increased when CauL, FJW and CauL-FJW were ensiled with either of the straws irrespective of the source of added straw; highest ($P<0.05$) NGP and OM digestibility was observed in the ensiled FJW, while that of NDF was observed in ensiled CauL-FJW. Amongst the straws, the ensiled wheat straw, irrespective of the combination of fruit and vegetable waste, resulted in maximum net gas production and digestibility of nutrients (Bakshi *et al.,* 2007). It is concluded that excellent silage can be prepared by ensiling CauL or Caul-FJW (50:50) with wheat straw in a 70:30 ratio.

The *in vivo* evaluation of cauliflower leaves (CauL), cabbage leaves (CabL), pea pods (PP) and pea vines in comparison to conventional green oats fodder fed *ad libitum* to bucks (Wadhwa, Kaushal and Bakshi, 2006) showed that CabL had the highest (20.6 percent) and PP the lowest (4.8 percent) concentration of water soluble sugars. CauL had the highest concentration of total phenolics (5.9 percent) and the lowest was in PP (0.3 percent). The fractionation of proteins indicated that vegetable waste in general had a high concentration of albumin (54–62 percent) and a low concentration of prolamins (8–9 percent). The digestibility of nutrients except NDF was comparable for CabL and CauL, but was higher ($P<0.05$) than for other vegetable wastes and green oats. The total purine derivatives excreted in urine and microbial protein synthesis in the rumen were highest ($P<0.05$) for CauL, followed by PP and pea vines. The N-excretion as a percent of N-intake was lowest ($P<0.05$) in animals fed PP resulting in significantly higher N-retention and apparent biological value (BV), which were comparable to those for CauL and green oats. The ME value of both CabL and CauL was significantly higher than of pea vines. Another study on five month old crossbred (Alpine x Beetal) kids revealed that replacement of oat and berseem hay with ash gourd peel and pea pods in the control diet (berseem hay 40, oat hay 20, concentrate mixture 30 and green fodder 10 percent) did not influence voluntary dry matter intake and daily gain in weight; but nutrient utilization and feed conversion efficiency were improved. It was concluded that ash gourd peel and pea pods can be used to replace oat and berseem hay in the ration of growing kids without any adverse effect on their performance (Gupta, Rai and Atreja, 2004a, b).

It is concluded that baby corn husk, cabbage leaves, cauliflower leaves, sarson saag waste, tomato pomace, carrot pomace, cull potatoes, cull snow peas and pea pods could serve as excellent sources of nutrients for ruminants and can reduce the cost of feed production.

TABLE 9

Dry matter digestion kinetic parameters for vegetable, cannery and fruit wastes

	Botanical name	'a' (percent)	'b' (percent)	'c', (percent/h)	UDF (percent)	ED (percent)	TD (percent)	RF (kg)	PDMI, kg/day	NIV
Vegetable wastes										
Sugar beet leaves[1]	*Beta vulgaris*	43.0[b]	51.1[b]	0.08[a]	5.9[c]	81.9[d]	75.9[ab]	15.4[bc]	11.2[c]	79.6[e]
Cauliflower leaves[1]	*Brassica oleracea* B.	46.7[b]	50.4[b]	0.09[ab]	2.9[a]	86.1[f]	78.3[abc]	9.8[a]	11.8[cde]	84.9[f]
Black chick pea plant[1]	*Cicer arietinum*	29.5[a]	43.5[b]	0.09[ab]	27.0[e]	63.5[b]	78.1[abc]	17.4[cd]	9.9[b]	67.8[b]
Cabbage leaves[1]	*Brassica oleracea* C.	24.8[a]	70.4[cd]	0.11[b]	7.8b[c]	82.1[d]	81.3[cd]	9.2[a]	12.4[de]	74.8[d]
Pea vines[1]	*Pisum sativum*	26.6[a]	34.2[a]	0.08[a]	39.2[f]	52.3[a]	75.1[a]	21.9[d]	8.5[a]	55.4[a]
Radish leaves[1]	*Raphanus sativus*	22.7[a]	73.4[d]	0.14[c]	3.9[ab]	85.2[e]	84.9[d]	7.5[a]	13.8[f]	80.7[e]
Summer squash vines[1]	*Cucurbita pepo* L.	25.9[a]	62.8[c]	0.10[ab]	11.3[d]	75.9[c]	79.4[bc]	12.0[ab]	11.5[cd]	70.8[c]
Pooled SE		2.82	2.71	0.01	0.40	0.32	1.40	1.65	0.34	0.64
Cannery wastes										
Pea pods[2]	*Pisum sativum*	36.6[bc]	45.8[a]	0.06[a]	17.7[b]	68.1[b]	68.9[a]	17.6[b]	9.25[a]	66.1[b]
Carrot pulp[2]	*Daucus carota*	29.5[b]	68.2[b]	0.09[b]	2.3[a]	84.0[c]	79.6[b]	9.1[a]	12.2[b]	76.8[c]
Citrus pulp[*2]	*Citrus limetta*	46.1[c]	49.8[a]	0.12[c]	4.1[a]	87.6[d]	83.2[c]	8.2[b]	13.1[b]	90.9[d]
Sarson saag waste[2]	*Brassica campestris*	8.7[a]	66.6[b]	0.06[a]	24.7[c]	55.4[a]	69.9[a]	19.2[b]	8.9[a]	47.3[a]
Pooled SE		2.95	2.82	0.01	0.69	0.61	2.08	0.62	0.30	0.54
Fruit wastes										
Banana peels[2]	*Musa acuminata*	26.1	63.4[ab]	0.1	10.4[b]	77.0[b]	80.0	11.5[ab]	11.7	72.0[a]
Muskmelon peels[2]	*Cucumis melo*	33.0	47.8[a]	0.1	18.2[c]	72.0[a]	79.9	14.8[b]	11.0	72.4[ab]
Watermelon peels[2]	*Citrullus lanatus*	24.0	68.5[b]	0.1	7.4[a]	80.1[c]	81.1	10.2[a]	12.4	74.3[b]
Pooled SE		5.44	5.17	0.01	0.47	0.41	2.34	0.98	0.59	0.65

*without peels; `a'- Rapidly soluble fraction, `b'- Insoluble but potential degradable fraction, `c'- Degradation rate, ED- Effective degradability, TD- True degradability, UDF- Undegradable fraction, RF- Rumen fill, PDMI- Potential DM intake, NIV- Nutritive index value, Figures with different superscripts in a column (separately for vegetable, cannery and fruit wastes) differ significantly at $P<0.05$. [1]Wadhwa and Bakshi (2005); [2]Bakshi and Wadhwa (2013).

Nutritional worth of fruit and vegetable wastes from supermarket shelves

The potential of several vegetable and fruit wastes where the date of display had expired in supermarket shelves in the United Kingdom were assessed as ruminant feed by using the *in vitro* gas production technique (Marino *et al.,* 2010). The CP content was higher for vegetables with the exception of carrot and turnip, compared with fruits. The NGP was highest for orange, followed by onion, squash and clementine and lowest for tomato, grape and blackberry. Similarly, ME was highest for orange, followed by pea, squash, onion, cabbage, cauliflower and turnip. It was concluded that orange, squash, turnip, clementine, apple and pea can be explored as a ruminant feed. However, low dry matter content in these wastes can interfere in the transportation and utilization. Angulo *et al.* (2012a, b) evaluated fruit and vegetable waste (FV; composed of 43 percent fruit, 30 percent vegetables and 27 percent stems, leaves, leaf wrappers, corncobs, roots, refuse and others) from a market place in Colombia as bovine feed. On average, FV contained 10 percent CP, 36.6 percent NDF, 29.6 percent ADF, 87.8 percent ruminal degradability at 24 h, 0.59 percent Ca and 0.21 percent P. The FV included up to 18 percent in the concentrate mixture of high-yielding, lactating Holstein cows did not show any adverse effect on milk yield, but milk quality (cis-9, trans-11 CLA and α-linolenic acid content) was improved. These results suggest that FV represents a potential feedstuff for bovine feeding, and its recycling could avoid the discharge of a large amount of waste to landfills, which would minimize its environmental impact.

Conservation of fruit and vegetable wastes

The majority of fruit and vegetable wastes like tomato pomace, bottle gourd pomace, citrus pulp, carrot pulp, baby corn husk and forage, cabbage and cauliflower leaves, sarson saag waste and pea pods, pineapple waste and pineapple bran etc. are highly fermentable and perishable, mainly because of high moisture (80–90 percent), total soluble sugars (6–64 percent) and crude protein (10–24 percent) contents. During the peak production or processing season, huge quantities of these resources are available and cannot be consumed at the same pace as they become available and thus become surplus and can cause environmental pollution. Therefore, suitable methods should be adopted to conserve such resources so that these can be fed to the livestock throughout the year or specifically during the lean period of green fodder production. This will also help mitigate environment pollution. The most commonly used methods are drying (Box 1) or ensiling (Boxes 2, 3, 4 and 5).

TABLE 10

***In vitro* evaluation of vegetable, cannery and fruit wastes[1]**

Vegetable Wastes	Botanical name	NGP (ml/24 h/g DM)	NDFD (percent)	TOMD (percent)	ME (MJ/kg DM)
Sugar beet leaves	*Beta vulgaris*	130.6[b]	61.9[e]	83.0[d]	7.3[b]
Cauliflower leaves	*Brassica oleracea* B.	195.1[f]	52.2[b]	87.6[e]	9.0[e]
Black chick pea plant	*Cicer arietinum*	164.0[d]	56.8[d]	80.8[b]	7.8[c]
Cabbage leaves	*Brassica oleracea* C.	209.3[g]	76.3[f]	90.5[g]	9.2[e]
Pea vines	*Pisum sativum*	149.8[c]	41.7[a]	64.1[a]	7.1[b]
Radish leaves	*Raphanus sativus*	175.9[e]	61.7[e]	89.7[f]	8.7[d]
Summer squash vines	*Cucurbita pepo* L.	104.0[a]	54.5[c]	82.6[c]	6.1[a]
Pooled SE		1.94	0.21	0.08	0.07

Figures with different superscripts in a column differ significantly at $P<0.05$; NGP- Net gas production; NDFD- Neutral detergent fibre digestibility; TOMD- True organic matter digestibility; ME- Metabolizable energy; [1]Wadhwa and Bakshi (2005).

Vegetable wastes as a source of nutrients in urea molasses multinutrient blocks

The iso-nitrogenous and iso-caloric urea molasses multinutrient blocks (UMMBs), containing waste bread (WB), tomato pomace (TP) or WB and TP replacing wheat flour and mustard cake respectively in the conventional UMMB were formulated to assess the effect of such UMMBs on nutrient utilization in buffaloes in comparison with a conventional control diet without UMMB, supplementation (Choubey, Wadhwa and Bakshi, 2013). The male Murrah buffaloes in the control group were offered 2 kg concentrate mixture, while in experimental groups only 1 kg concentrate mixture was offered with *ad lib* of the respective UMMBs. The daily intake of UMMBs varied from 1.08 kg (conventional blocks) to 1.84 kg (block containing TP). The DM and water intake was higher ($P<0.05$) in block fed groups. The nutrient utilization, except that of CP, was comparable in all the groups, which improved ($P<0.05$) on UMMB supplementation. The digestibility of fibre fractions of the diet was numerically ($P>0.05$) higher in the UMMB supplemented group. Higher N-intake ($P<0.05$) with comparable N-excretion resulted in better ($P<0.05$) N-retention and apparent biological value (BV) in UMMB supplemented groups. The blood urea nitrogen (BUN) was higher ($P<0.05$) in UMMB supplemented groups. In another study in buffaloes the nutritional worth of conventional UMMB was compared with isonitrogenous and isocaloric UMMB containing spent sugar syrup [(SSS), sugar content 65–66°Brix, (Bx)] from Aamla (*Phyllanthus emblica*) preserve (murabba) industries (Unati Co-operative Marketing cum Processing Society Ltd., Talwara, Distt Hoshiarpur), sundried WB and/or TP (Wadhwa and Bakshi, 2013). Molasses in the conventional UMMB was replaced with SSS, wheat flour with WB and oiled mustard cake with TP. The DM and water intake, digestibility of nutrients, concentration of rumen metabolites, blood profile, urinary purine derivatives and N-retention were statistically comparable in all the groups. All the animals maintained their body weights.

It is concluded that agro-industrial wastes such as spent sugar syrup, waste bread and tomato pomace could be incorporated into UMMBs without any adverse effect on palatability, nutrient utilization or health of animals. The use of these unconventional feed resources in the preparation of UMMB could replace conventional ingredients which are generally expensive, resulting in decreased cost of feeding.

Novel value-added products from fruit and vegetable wastes

The huge quantity of fruit and vegetable wastes and by-products produced throughout the world, both in the organized and un-organized sectors, can be effectively utilized as livestock feed. These resources, i.e. peels, pomace and seeds etc. are rich sources of bioactive compounds, which can be extracted and utilized in food, cosmetic, pharmaceutical, and biofuel industries. Some of such novel value-added products and their utilities are discussed below.

Essential oils. The citrus peels are a potential source of essential oil (EO) and yield 0.5 to 3.0 kg oil/tonnes of fruit (Sattar and Mahmud, 1986). Citrus EO is widely used in alcoholic beverages, confectioneries, soft drinks, perfumes, soaps, cosmetics and household products owing to its aromatic flavor. It also serves as a masking agent in pharmaceutical products (Njoroge *et al.,* 2005). It improves the shelf-life and the safety of fresh fruits (Lanciotti *et al.,* 2004), skim milk and low-fat milk (Dabbah, Edwards and Moats, 1970) and exhibits broad spectrum antibacterial activity (Javed *et al.,* 2011). Oils from both sweet and bitter oranges are used in tea formulations and as an ingredient in stomachic, carminative and laxative preparations. Lemon EO contains D-limonene, which improves the immunity, counters occasional feelings of depression, promotes clarity of thought and purpose, energizes and stimulates the mind and body, opens and releases emotional blocks and supports skin health and reduces the appearance of wrinkles (Sharon Falsetto, 2008). Dried bitter orange oil is used in treating prolapse of the uterus and rectum, diarrhea and piles.

Polyphenolic compounds. The concentration of total phenolic compounds in the peels, pulp/pomace and seeds of citrus fruits, apples, peaches, pears, yellow and white flesh nectarines, banana, pomegranate, mulberry, blackberry, tomatoes and sugar beet etc. is more than twice the amount present in edible tissue. Apple and grape pomace are rich in proanthocyanidins and flavonoids, banana in catechin and gallocatechin, carrot pomace in hydroxycinnamic derivatives like chlorogenic acid and dicaffeoylquinic acids (Zhang and Hamauzu, 2004), mango seed kernels (Puravankara, Boghra and Sharma, 2000) and mango peels (Larrauri, Ruperez and Saura-Calixto, 1996) in gallic and ellagic acids. Babbar *et al.* (2011) reported that kinnow peel, litchi pericarp, litchi seeds and grape seeds can serve as potential sources of antioxidants for use in food and pharmaceutical industries. The beet root pomace is a rich source of flavonoids (Čanadanović *et al.,* 2011). The phenolic portion of the beet root peel depicts l-tryptophane, p-coumaric and ferulic acids, as well as cyclodopa glucoside derivatives (Kujala, Loponen and Pihlaja, 2001). The polyphenolic compounds exhibit anti-cancer, anti-microbial (pathogens), anti-oxidative and immune-modulatory effects in vertebrates. The peel and pulp of guava fruits could be used as a source of antioxidant dietary fibre (Jimenez-Escrig *et al.,* 2001). Polyphenols reduce incidence of cardiovascular diseases and are thought to inhibit oxidation of LDL (Rice-Evans, 2001). Polyphenols can reduce the systolic pressure and the level of plasma cholesterol in humans and animals, inhibit platelet aggregation and prevent thrombosis (Lurton, 2003). The terpenoid and flavonoids in banana foliage exhibit anthelmintic properties (Marie-Magdeleine *et al.,* 2010).

Edible oils. The fat in mango seed kernel is a promising source of edible oil and its fatty acid and triglyceride profiles are similar to those of cocoa butter. Guava (*Psidium guajava* L., Myrtaceae) seeds, usually discarded during processing of juice and pulp, contain 5–13 percent oil rich in essential fatty acids (Adsule and Kadam, 1995). The passion fruit seed oil is rich in unsaturated fatty acids (87.6 percent), mainly linoleic (73.1 percent) and oleic (13.8 percent) acids (Cassia Roberta Malacrida and Neuza Jorge, 2012). The oil has free radical scavenging activity.

Pigments. Tomato peel is a rich source of carotenoids such as lycopene (Knoblich, Anderson and Latshaw, 2005). It may be beneficial in curing cancer, coronary heart disease and other chronic conditions. The addition of tomato peel to meat products can result in a healthier product due to both the lycopene and fibre present in this by-product of tomato processing. Carrot pomace is also a good source of carotenoids (Zhang and Hamauzu, 2004). Anthocyanin pigments in banana bracts (leaves below calyx) and beet root pulp were evaluated for their potential application as natural food colorants. The beet root pomace contains 11–23 mg β-xanthins/g of dry extract (Čanadanović *et al.,* 2011). Beet root peel is a potential source of valuable water-soluble nitrogenous pigments, called betalains, which comprise two main groups, the red betacyanins and the yellow betaxanthins. They are free radical scavengers and prevent active oxygen-induced and free radical-mediated oxidation of biological molecules (Pedreno and Escribano, 2001). Betalains have been extensively used as natural colorants in the modern food industry (Azeredo, 2009).

Food additives. Carrot pomace can be used in bread (Osawa *et al.,* 1994), cake, dressing and pickles (Osawa *et al.,* 1995), and in functional drinks (Henn and Kunz, 1996); and onion pomace in snacks (Kee, Ryu and Park, 2000). In the food industry, synthetic antioxidants, such as butylated hydroxyanizole (BHA) and butylated hydroxytoluene (BHT), have long been widely used as antioxidant additives to preserve and stabilise the freshness, nutritive value, flavour and colour of foods. However, Schilderman *et al.* (1995) revealed that BHT could be toxic, especially at high doses. Therefore, interest in the substitution of synthetic food antioxidants by natural ones has increased over the recent years. The antioxidant compounds from waste products of the food industry could be used for protecting the oxidative damage in living systems by scavenging oxygen free radicals, and also for increasing the stability of foods by preventing lipid peroxidation (Makris, Boskou and Andrikopoulos, 2007).

Anti-carcinogenic compounds. Brassica extracts are reported to possess anticarcinogenic properties, which have mainly been ascribed to the hydrolytic products rather than to the intact glucosinolates (GLSs). The hydrolysis of GLSs by the myrosinase leads to the production of bioactive compounds such as isothiocyanates, nitriles, thiocyanates, epithionitriles, and oxazolidines. Glucosinolate hydrolysis products from glucoiberin, sinigrin and progoitrin have also been reported to possess anticancer effects (Cartea and Velasco, 2008).

Dietary fibre. Fruit and vegetable wastes/by-products such as apple, pear, orange, peach, blackcurrant, cherry, artichoke, asparagus, onion and carrot pomace, mango peels and cauliflower trimmings are used as sources of dietary fibre supplements (gelling and thickening agents) in refined food. These compounds increase the bulk of the food and help prevent constipation by reducing gastro-intestinal transit time (Schwartz *et al.,* 1988). They also bind to toxins in the food which helps to protect the mucus membrane of the gut and thus reduces colon cancer risk. Furthermore, dietary fibres bind to bile salts and decrease their re-absorption, thus helping to lower serum low density lipoproteins (LDL) cholesterol levels (Fernandez *et al.,* 1994). The typical inclusion levels of fruit and vegetable by-products varies between 2–15 percent. The vegetable materials were found to maintain antioxidant activity after extrusion, retarding product oxidation.

Enzymes. Plant food residues including trimmings and peels might contain a range of enzymes capable of having a wide range of applications. Proteolytic enzyme bromelain may be extracted from the mature pineapple and papain from latex of papaya fruit. Banana waste can be used for the biotechnological production of α-amylase (Krishna and Chandrasekaran, 1996), hemicellulase (Medeiros *et al.,* 2000) and cellulase (Krishna, 1999). Dried kinnow pulp supplemented with wheat bran in the ratio of 4:1 resulted in the highest filter paper cellulase (FPase) activity (Oberoi *et al.,* 2010). Agha *et al.* (2009) investigated the use of a crude peroxidase preparation from onion solid by-products. Gassara *et al.* (2011) used apple pomace for production of lignin and manganese peroxidase and laccase production by *Phanerocheate chrysosporium*. Sapota peels and citrus peels can be used as substrate for the production of pectinase (Sabika Akbar and Gyana Prasuna, 2012). Mango peels can be used for the production of cellulase (Saravanan, Muthuvelayudham and Viruthagiri, 2012).

Citric acid. It is used mainly in foods and pharmaceuticals. Most of the citric acid is manufactured mainly through solid-state fermentation (SSF) of starch/molasses exclusively by *Aspergillus niger* (Dhillon *et al.,* 2011). Recently molasses, fruit and vegetable pomace and cassava bagasse etc. have been used as a substrate for citric acid production (Kuforiji, Kuboye and Odunfa, 2010). Hang (1987) used apple pomace as substrate for citric acid production.

Bio-ethanol. These resources can either be used directly as an untreated material for microbial growth or be used by appropriate treatment with enzymes for bioenergy production. The products generated from perishable wastes can be in liquid or gaseous forms of biofuels. Amongst various wastes used for ethanol production, potato peels (Arapoglou *et al.,* 2010), apple pomace, waste apples (Tahir and Sarwar, 2012), banana peel, banana waste (Tewari, Marwaha and Rupal, 1986; Oberoi *et al.,* 2011a), beet waste, beet pomace (Dhabekar and Chandak, 2010), Kinnow mandarin *(Citrus reticulata)* waste (Oberoi *et al.,* 2011b) and peels (Sandhu *et al.,* 2012) and peach wastes have shown encouraging results. Pineapple pulp contains substantial amounts of sucrose, starch and hemicellulose, and may therefore be used for ethanol production (Nigam, 2000).

Methane mitigation potential. Mangosteen (*Garcinia mangostan*) peel containing 16 percent condensed tannins and 10 percent crude saponins on DM basis were supplemented at the rate of 100 g DM/day with 3 percent sunflower oil (SFO) and 3 percent coconut oil (CO) in a rice straw and ruzi grass (*Brachiaria ruziziensis*) based diet fed to dairy cattle. It improved rumen ecology, especially increased bacterial population and reduced protozoa without any significant effect on fungal zoospores population. Methane production in the rumen was reduced significantly when MSP, sunflower oil and coconut oil were supplemented. The milk yield and milk composition were not affected significantly ($P>0.05$) by supplementing the diet with MSP, SFO and CO (Suchitra and Wanapat, 2008). Methane production was reduced with mangosteen peel after 21 h incubation from 11.4 to 5.5 ml/g substrate while the reduction with calcium nitrate versus urea was from 15.2 to 7.4 ml/g of substrate, a drop of 51 percent in both the cases (Thanh, Preston and Leng, 2011). Lamba, Wadhwa and Bakshi (2012) also revealed that the methane production potential of cotton seed cake, corn gluten meal and tomato pomace was significantly lower than conventional (mustard cake, groundnut cake, soybean meal etc) and non-conventional (spent brewer's grains and maize oil cake) protein supplements.

Bio-gas. About 30 percent of the total production of Chinese cabbage is discarded as waste. According to Liu, Wang and Chen (2009) mesophilic fermentation condition was more suitable compared with thermophilic condition for biogas production from cabbage leaves. Gunaseelan (2004) obtained a methane yield of 309 and 291 mL/g volatile solids (VS) from cabbage leaves and stems respectively. It is well established that mixture of substrates containing both N and C rich substrates should be used in proper proportion for optimum bio-methane production. The higher specific methane yield of 686 Nm^3/tonnes VS (Ponsa, Gea and Sanchez, 2011) is achieved by co-digesting organic fraction of municipal solid waste (OFMSW) and vegetable oil (83:17 on DM basis). This is followed by co-digesting OFMSW and animal fat (83:17 on DM basis), and cow manure with fruit and vegetable waste (50:50 on DM basis) giving a methane yield of 508 (Ponsa, Gea and Sanchez, 2011) and 450 (Callaghan *et al.,* 2002) Nm3/ tonnes VS, respectively.

Single cell protein. Single cell proteins can be produced from dried and pectin extracted apple pomace by using *Trichoderma viride* and *Aspergillus niger*. The grape waste and pressed apple pulp have also been used as a substrate for *Aspergillus niger* to generate crude protein and cellulose. Pineapple waste for production of single cell protein production has also been utilized. Citrus peel juice has also been used to generate single cell protein using *Fusarium*. Potato peels supplemented with ammonium chloride have also been used for the production of protein by using a non-toxic fungi *pleurotus ostreatus*. Similarly, waste from orange, sugarcane and grape processing industry have also been utilized for the production of single cell protein (Gautam and Guleria, 2007).

Fermented edible products. A number of beverages such as cider, beer, wine and brandy, and vinegar can be obtained from the fermentation of fruit wastes. Apple pomace has been utilized for the production of cider. The possibility of making brandy from dried culled and surplus apples, grapes, oranges and other fruits has also been explored. Vinegar can also be prepared from fruit wastes. The fruit waste is initially subjected to alcoholic fermentation by acetic acid fermentation by *Acetobacter* bacteria, which produce acetic acid. Vinegar production by fermenting waste from pineapple juice and orange peel juice has been reported. Apple pomace extract can also be mixed with molasses in the ratio of 2:1 for producing vinegar (Gautam and Guleria, 2007).

Compost. Vegetable and fruit wastes can be composted and used to replace a significant part of the mineral nitrogen fertilisation with nitrogen recovery of 6–22 percent. The plots fertilised according to the nitrogen recommendations had comparable yields, whether this had been provided (partially) through VFG-compost or not. Long-term VFG applications resulted in a carbon accumulation in the top soil, mainly due to increase of the more resistant carbon fractions. The long-term compost applications improved the nitrogen status of the soil over the years (Tits *et al.,* 2012).

Bio-degradable plastic. Potato or cornstarch waste is hydrolyzed to glucose by high-temperature α amylase to solubilize the starch, and by glucoamylase to break it down into glucose. The glucose is fermented to lactic acid by *Lactobacillus*. Lactic acid with equal amounts of hydroxyl and carboxyl groups can self-condense to form linear thermoplastic polyester poly-lactic acid (PLA), a biodegradable plastic. It can be used as timed release coatings for fertilizers, pesticides, and agricultural mulch films, which degrade in the soil (Anon, 1990a, b; Studt, 1990; Keeler, 1991).

Miscellaneous products. Neohesperidin and naringin from bitter orange peel can serve as starting materials for the production of sweeteners. The orange peels can be used as low-cost and eco-friendly adsorbents for removing dyes from waste water (Fat'hi and Zolfi, 2012). Certain compounds in passion fruit peel has bronchodilator effect and can help relieve bronchospasm in asthma patients. Oral administration of the purple passion fruit peel extract is considered to reduce wheeze and cough and improves shortness of breath in adults with asthma.

Banana leaves can be used for the cultivation of *Volvariella volvacea*, an edible mushroom (Belewu and Belewu, 2005). The spent banana leaves containing low ADL, NDF and ADF content; and enriched with microbial protein can provide sustainable feed for ruminants, confirming the earlier report on the cultivation of *Volvariella volvacea* on rice straw and utilization of spent rice straw as livestock feed (Langar and Bakshi, 1986).

Conclusion

Fruit and vegetable wastes like baby corn husk, cauliflower and cabbage leaves, pea pods, sarson saag waste, culled snow peas and tomato pomace; citrus, carrot and bottle gourd pulp; banana and mango peels etc. are a rich source of nutrients and these can be fed either as such, after drying or ensiling with cereal straws, without effecting the palatability, nutrient utilization, health or performance of livestock. These can also be used for the production of value-added products like essential oils, polyphenols, anti-carcinogenic compounds, edible oil, pigments, enzymes, bio-ethanol, bio-methane, bio-degradable plastic, single cell proteins etc. The effective and efficient utilization of fruit and vegetable wastes will reduce the cost of animal feeding thereby increasing farmers' profits, generate an array of value-added products and help in waste management and reduction of environmental pollution.

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