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JACKFRUIT WASTE: A PROMISING SOURCE OF FOOD AND FEED

F. Akter[1] and M. A. Haque[1*]

Abstract

All the food sources comprise edible and non-edible waste portions. With increasing demand for food and feed the current agriculture is focusing on agro-processing to utilize the maximum portion of the plant or animal resources. This review paper aims at summarizing the present status of utilization of jackfruit (*Artocarpus heterophyllus* Lam, Moraceae) wastes in food, feed, and other industry. Apart from the non-edible portion like peel and axis, the edible by-products like seeds of jackfruit mostly remain underutilized worldwide including Bangladesh. This article has reviewed the works devoted to utilize different waste portions of jackfruit other than the juicy edible bulbs. There are many works which suggested that the thick peel of jackfruit can be utilized in nutrient enriched cattle feeds, extraction of bio-fuel, nano-porous adsorbent for removing dye etc. The peel and central axis of this fruit also had investigated for extraction of pectin. The seeds of jackfruit were attempted by many researches to be used in various bakery products. The starch and protein fractions were isolated from jackfruit seeds flour to make them use at a purified state in the food formulations.

Keywords: Jackfruit peel, jackfruit seeds, jackfruit central axis, nutritional composition.

Introduction

The varied agro-climatic zones of Bangladesh are amenable to grow a wide variety of fruits like mango, jackfruit and pineapple. Among them, jackfruit *(Artocarpus heterophyllus* Lam.) belonging to the family Moraceae is one of the most popular and evergreen trees in tropical areas like Bangladesh. It originated from the Western Ghats of India (Goswami *et al.,* 2010). For the abundant production and popularity, this fruit is termed as the national fruit of Bangladesh, locally called kathal. The climatic condition of this country is very suitable for jackfruit cultivation (Rahman *et al.,* 1999). The annual production of jackfruit is about 1031316 MT from about 27316 acres of land in Bangladesh (BBS, 2016). It is a leading source of bioactive compounds like vitamin C and beta-carotene that act as antioxidants to protect the body against free radicals and strengthens the immune system. It is also rich in various phytonutrients such as lignans, isoflavones, and saponins (Swami *et al.,* 2012).

There are abundant production of food wastes during processing the raw agricultural products to finished products. Some of this wastes end up as animal feed and some are returned to the land as a nutrient. Different industries related to the agricultural sector generate a lot of waste in the form of peels, seeds, whey, waste liquid, molasses, bagasse, and so on (Balasundram *et al.,* 2006). The generated waste is not only biodegradable

[1]Department of Agro-Processing, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur 1706, Bangladesh. *Corresponding author: mahaque@bsmrau.edu.bd

but also rich in nutrient components such as carbohydrate, protein, and vitamins depending upon the sources. Recycling is one of the most important means of utilization of the agricultural waste components to a number of new products such as organic fertilizer and as a raw material in the paper industry. Recovery of the beneficial bioactive compounds from fruits and vegetable wastes is a newer research trend. The isolated or extracted valuables from these wastes are evidently contributing to meet the nutritional requirements for human, animal, and plant as well as in the pharmaceutical industry (Sogi *et al*., 2002).

The increased food demand by the rapidly growing population of the world has posed a great challenge to the incumbent sectors such as food researchers and manufacturers to maximize the utilization of the existing food or plant resources. About, 70 to 80% of a jackfruit consists of waste and by-products. The outer rind or peel, central core, and perianth make up about 55 to 60% of this fruit (Subburamu *et al*., 1992). Seed is an important by-product that consists around 12-14% of a whole jackfruit (Prathima, 2008). Numerous food and feed research groups have been working on the possibility of using the waste or underutilized portion of jackfruit (Tiwari and Vidyarthi, 2015; Singh *et al*., 1991; Moorthy *et al*., 2017; Mukprasirt and Sajjaanantakul, 2004). This review paper has outlined the relevant literatures to summarize the information on processing and utilization of jackfruit wastes that would be useful for the possible extension of food and feed industries.

Jackfruit

Jackfruit (*Artocarpus heterophyllus* Lam.) is one of the largest edible fruits grown worldwide. A distinguishing feature of jackfruit tree is its ability to produce a higher yield of fruits than any other tree in the Moraceae family producing 70- 200 kg of fruit per tree depending on variety, cultural practices, and environmental factors. Average weight of a fruit is about 3.5 to 10 kg and sometimes a fruit may reach up to 25 kg (Kumar *et al*., 1988). Various types of jackfruits such as Khaja, Gala, and Durasha are found in the south-east Asian region (Haque, 1993). Khaja is characterized by the hard and crispy bulb, gala poses soft, juicy, and melted bulb, and Durasha is an intermediate between Khaja and Gala. The tender jack fruit is a popular vegetable and used in making soup and pickles. Chips and papads are also prepared from ripe and unripe pulp. The juicy pulp of the ripe fruit is eaten fresh or preserved in syrup. This fruit is potential for preparing jam, jelly and value added products due to the presence of pectin (Singh *et al*., 1991). During season, the poor people generally used to eat this fruit instead of rice at least once a day in jackfruit growing area. That’s why it is commonly referred to as “The Poor man’s food” (Rahman *et al*., 1995).

Common wastes and by-products of jackfruit and its utilization

The consumption of fresh jackfruit as well as the processing of this fruit result in a high amount of non-edible wastes such as peel and central axis and edible by-products such as seeds and perianth.

Non-edible wastes

Jackfruit peel

Jackfruit peel, also known as rind or skin, is the outer protective layer of the fruit which consists around 57.17, 46.45, and 40.05% in Khaja, Gala, and Durasha variety respectively (Anonymous, 1996). The unsystematic disposal of peel imposes a serious burden on the environment. However, proper utilization of the by-products not only increases the economic value but also reduces the cost of disposal. Jackfruit peel is reportedly rich in cellulose, pectin, protein, and starch comprising about 27.75%, 7.52%, 6.27%, and 4%, respectively (Sundarraj and Ranganathan, 2017).

Central core or axis of jackfruit

Subburamu *et al*. (1992) prepared a meal from the jackfruit central core and found carbohydrate (20.5%), crude protein (10.6%), and crude fibre (15.9%) are the principal proximate compositions.

Utilization of non-edible wastes

Animal feed

Subburamu *et al*. (1992) recommended the jackfruit peel as a valuable raw material for the cattle feed as this is a rich source of carbohydrate, protein, and fiber containing 24%, 8.7%, and 17.3%, respectively. Ajey (2013) studied on jackfruit waste for the nutrient-enriched animal feed by supplementing nitrogen and fermenting with yeast (*S. boulardii*) and LAB (*L. acidophilus*). The results revealed that the jackfruit waste feed supplemented with 2% ammonium sulphate and fermented by combined yeast and LAB recorded the highest crude protein (22.34%) and crude fibre (23.37%). The developed feed from jackfruit waste in the form of dried powder contained moisture 5.42%, carbohydrate 71.40%, protein 23.81%, crude fibre 22.63%, crude fat 6.37%, and ash 6.5%.

Kusmartono (2007) suggested that the jackfruit waste consisting of peel and axis, has a high potential as a ruminant feed, especially for sheep and steers. The sheep feeds were prepared by several formulations of jackfruit waste mixed with rice straw, urea etc. Addition of urea resulted into depressed intake of jackfruit waste by sheep, with as compensatory increase in the intake of rice straw. Higher digestibility of the feed materials in sheep receiving N supplementation were directly related to their rumen ammonia concentrations. The authors advised for molasses-urea cake supplementation rather than mixing urea with jackfruit waste for the optimized digestibility of the cattle feed.

Bio-fuel

Soetardji *et al*. (2014) extracted bio-oil from the jackfruit peel waste by pyrolysis process in a fixed bed reactor and investigated the extracted oil. After pyrolysis in a range of high temperatures (400-700^{o}C) they found that the peel contains high amount of volatile compounds which indicates this biomass as a suitable precursor for bio-oil production. Low sulphur (0.03%) and nitrogen (0.61%) contents were the strong indication to be environmental friendly bio-oil. The study found the best quality bio-fuel at the temperature of 550^{o}C with the highest organic content (85.2%) and the lowest water content (14.8%). On the other hand, Yuvarani and dhas (2017) extracted bio-ethanol (oxygenated fuel) from jackfruit peel by fermentation using *Saccharomyces*

Cerevisiae yeast as a microorganism. The main types of raw materials for ethanol production using biological method were cellulose, carbohydrate and sugar. The effect of various parameters such as composition of jackfruit peel, temperature, shaking rate, fermentation time, and nutrients were studied and the optimum conditions were obtained. The result showed that the ethanol extraction was increased by increasing the jackfruit peel composition and decreased by increasing the temperature.

Extraction of pectin

Xu *et al*. (2018) explored jackfruit peel for pectin content using different organic acids and mineral acids. They introduced a new method, ultrasonic- microwave- assisted extraction (UMAE), for extracting pectin and compared its performance with a conventional heating method. The UMAE method showed superior performance in extracting pectin in the optimum conditions such as extraction temperature 86 °C, extraction time 29 min, and solid-liquid ratio 1:48 (w/v). Begum *et al*. (2014) studied for yield and characterization of pectin from the core of jackfruit. The waste treated with ammonium oxalate, dilute sulphuric acid, and sodium hexametaphosphate yielded a good amount of calcium pectate (1.74-1.92%). However, the extracted pectin was poor in terms of solubility and high ash content compared to the commercial pectin.

Extraction of bioactive compounds

Zhang *et al*. (2017) carried out a comparative study to quantify the antioxidant and hypoglycemic contents in jackfruit peel, pulp, and seeds. The extracts were analyzed by HPLC and the results revealed that the peel extract contained the highest total phenolic and total flavonoid compounds than that of pulp and seeds. The predominant bioactive compounds like as prenylflavonoids, hydroxycinnamic acids and glycosides were also found in peel extract. The authors implied the jackfruit peel as a new source of natural antioxidants and hypoglycemic agents.

Nano-porous adsorbent for removal of industrial dye

In the race of finding organic compounds to remove the industrial dyes, Jayarajan *et al.* (2011) found the jackfruit peel as a nano-porous adsorbent for removing *Rhodamine* (Rd) dye from the wastewater. They explained the Freundlich isotherm model to show the extent of dye reduction by the jackfruit peels at different dosages, temperatures, and pH. The study recommended the jackfruit peel as a low-cost alternative for removing Rd dye from the commercial wastewater.

Edible wastes

Jackfruit seeds

The seeds make up around 10 to 15% of a jackfruit (Ocloo *et al*., 2010). These seeds are indeed very rich in digestible starch, protein, and minerals (Singh *et al*., 1991). Kumar *et al*. (1988) reported that jackfruit seeds contain 76.1% carbohydrate, 17.8% protein, and 2.1% lipid, on dry basis. Sumathy *et al*. (2007) quantified the significant amount of lignin, isoflavones, saponins, and many phytonutrients in jackfruit seeds. The health benefits of these nutrient components are wide-ranging from anticancer to antihypertensive, antioxidative, and antiulcer effects. Fernandes *et al*. (2011) found the seeds are good sources of vitamin B_1 and B_2. Bhat and Pattabiraman (1986) reported that the seeds extract inhibits the proteolytic activities of pancreatic hormones in different animal. Additionally, Odemelam (2005) found the satisfactory functional properties such as bulk density, oil absorption capacity, and gelation concentration of the seeds flour. Theivasanthi and Alagar (2011) proved the antibacterial effect of nano-sized particles of jackfruit seeds against *E. coli* and *B. megaterium.*

Jackfruit perianth

The edible bulbs in jackfruit are separated into compartments by latex-like filaments called 'rags' or perianth. This waste portion consists about 25% of a total fruit weight (Dam and Nguyen, 2013).

Utilization of edible wastes

Extraction of oil from jackfruit seeds

Babu (2017) carried out research on the extraction of oil from jackfruit seeds by a traditional milling process. About 6kg of the seeds was obtained to extract 2L of oil. He reported that jackfruit seeds oil was rich in Essential Fatty Acids like linoleic acid and alpha-linolenic acid. They estimated 1.35g/100g free fatty acid in the jackfruit seeds oil.

Processing of jackfruit seeds into flour

The jackfruit seeds can be processed into flour by using different processing methods such as autoclaved, dried, roasted, boiled and germinated (Eke-Ejiofor *et al*., 2014). Akter (2018) prepared jackfruit seeds flour by using the simple drying method. The seeds were washed properly after separating from the jackfruit bulb. Then they were sun dried so that the white outer layers of the seeds were easily separated. After cutting approximately 3 x 4 mm sized pieces they were dried into cabinet dryer to bring the moisture content within 10 - 12%. Finally, the seeds were ground to make flour and passed through a 75 micro size mesh sieves. The obtained flour was packed into airtight containers.

The flour from seeds is a fruit residue established as an alternative source of protein, starch, and fiber. Akter (2018) determined the proximate compositions of jackfruit seeds flour. The results are presented in Table 1. where she found the highest amount of carbohydrate (78.65%) in jackfruit seeds flour followed by protein content of 10.26%. This flour is a good source of minerals. Rengsutthi and Charoenrein (2011) studied the seeds flour for micronutrients and some functional components which are presented as in Table 2. Many works have been carried out to use the seeds flour as an ingredient in food formulation. Some works dedicated to separate the seed flour into starch and protein and to characterize them for their efficient uses. This part collated the research works on making seeds flour, isolation or extraction the flour components, and their use in food preparation.

Table 1. Proximate composition of jackfruit seeds flour

Properties	Values (% dry matter)
Moisture	7.63
Crude fat	1.11
Ash	2.35
Protein	10.26
Carbohydrate	78.65

Source: Akter (2018)

Table 2. Micronutrients and some functional properties of jackfruit seeds flour

Micronutrients/other components	Jackfruit seed Flour (per 100 g)
Calcium (mg)	77.3
Iron (mg)	0.59
Phosphorous (mg)	43.7
Potassium (mg)	14.7
Copper (mg)	1.04
Manganese (mg)	0.12
Neutral detergent fiber (g)	5.19
Amylose (%)	20
Amylopectin (%)	80
Titratable acidity (%)	5.78
Lactic acid (%)	1.12

Source: Rengsutthi and Charoenrein (2011)

Extraction of starch from jackfruit seeds flour

Starch is the most abundant and important food ingredient that attributes in innumerable industrial applications. Jackfruit seeds flour has been proved to be a good source of starch applicable to the various food industry (Mahumod *et al*., 2014; Rengsutthi and Charoenrein, 2011; Kittipongpatana and Kittipongpatana, 2011). Noor *et al*. (2014) studied the physicochemical and functional properties of flour and starch from three varieties of jackfruit seeds. They found the flours contain 81.05%-82.52% starch with 26.49%-30.21% amylose. They extracted starch using distilled water, alkaline, and α-amylase enzyme. The extracted starch contained a varied amount of components such as 8.39 to 12.20% moisture, 1.09 to 3.67% protein, and 0.03 to 0.59% ashes. Tulyathan *et al*. (2002) reported that the jackfruit seeds starch had 25% water absorption capacity, 17% oil absorption capacity, and 6% amylogram concentration. Rengsutthi and Charoenrein (2011) extracted starch from jackfruit seed and corn and compared their effectiveness to use as a thickener and stabilizer in chilli sauce.

Extraction of protein from jackfruit seeds flour

Protein from animal origin is continuously being replaced by that of the plant origin for its appreciated nutritional properties and expected health benefits (Nunes *et al*., 2003). Unlike starch, there are very limited reports on jackfruit seeds protein in the literature. Reis *et al*. (2016) studied the extraction of protein from the flour of jackfruit seeds by reverse micelle system. This system was composed of sodium dodecyl sulfate (SDS) as a surfactant, butanol as a solvent, and water. The study isolated the seeds protein with 79.00% crude protein content. Recently Akter (2018) has isolated the protein from jackfruit seeds by pH treatment and centrifugation process. This study isolated the crude protein with 76.9% purity. The isolated protein showed acceptable functional characteristics such as foaming, emulsion, and gelling properties (Table 3). The observed properties implied that the isolated protein is suitable for use as an ingredient in the food formulation.

Preparation of bakery products using jackfruit seeds flour

Value addition not only enhances proper utilization during the glut but also increases the shelf life of food materials in processed form. There are numerous works on the utilization of jackfruit seeds flour is documented in the literature (Chowdhury *et al*., 2012; Airani, 2007; Tulyathan *et al*., 2002). Some of them are discussed in the ensuing sections.

Table 3. Functional properties of the jackfruit seeds protein isolate

Properties	Values
Protein solubility	58.44%
Water holding capacity	2.89 mL/g
Oil holding capacity	1.57 mL/g
Bulk density	0.67 g/mL
Least gelation concentration	12%
Foaming capacity	74 % at pH 11.5
Foaming stability	47% at pH 11.5
Emulsion capacity	63% at pH 11.5
Emulsion stability	52% at pH 11.5

Source: Akter (2018)

Pasta

Abraham and Jayamuthunagai (2014) used the blends of jackfruit seeds flour and wheat flour at different proportions (100:0; 95:5; 90:10; 85:15; 80:20) for the preparation of pasta. Based on the study, the composite flour increased the nutrient content and improved the textural properties of the pasta. Substitution of 10% jackfruit seeds flour in the composite got the maximum consumer acceptability. The cooking quality of pasta was assessed based on the cooking time, cooked weight, and cooked firmness. The authors remarked that the control pasta exhibited a wavy like structure because of a good network by gluten matrix; however, the addition of jackfruit seeds flour resulted in the pasta with slightly swollen and irregular in size and shape. Incorporation of 10% jackfruit seeds flour provided a good starch and gluten network yielding a well-embedded starch molecule in the matrix.

Bread and biscuits

The availability and rich nutritional and functional properties of jackfruit seeds flour have drawn the attention of the researchers and bakery manufacturers. Butool and Butool (2015) successfully added jackfruit seeds flour in bread and biscuit preparation. Incorporation of 10% and 20% jackfruit seeds flour into bread and biscuit formulations gave an outstanding eating quality in terms of colour and texture. Addition of jackfruit seeds flour increased the crude fiber content of the products. The jackfruit seeds flour incorporated biscuits showed slightly increased ash and crude fibre contents but decreased carbohydrate content (Fig. 1). Aziz (2006) supplemented the jackfruit seeds flour with wheat flour in bread preparation and found increased fiber but slightly decreased protein content in the bread. In a similar work, Hasidah and Noor (2003) incorporated jackfruit seeds flour into bread upto 25% level and was accepted by sensory panel. They concluded that jackfruit seeds flour can be substituted at a certain level with wheat flour satisfying the consumer demands. Hossain *et al*. (2014) used jackfruit seeds flour in different proportion with wheat flour to find out the best composition for preparing bread. The percentages of jackfruit seeds flour used in the breads were 25%, 35%, 45% and 55%. They reported the bread with a substitution of 25% jackfruit seeds flour was most acceptable in terms of nutritional value and overall acceptability.

Cake

Khan *et al*. (2016) prepared cake by substituting wheat flour with 10%, 20%, and 30% jackfruit seeds flour. The specific volume of cake for 20% substitution was higher than that of all other cakes.

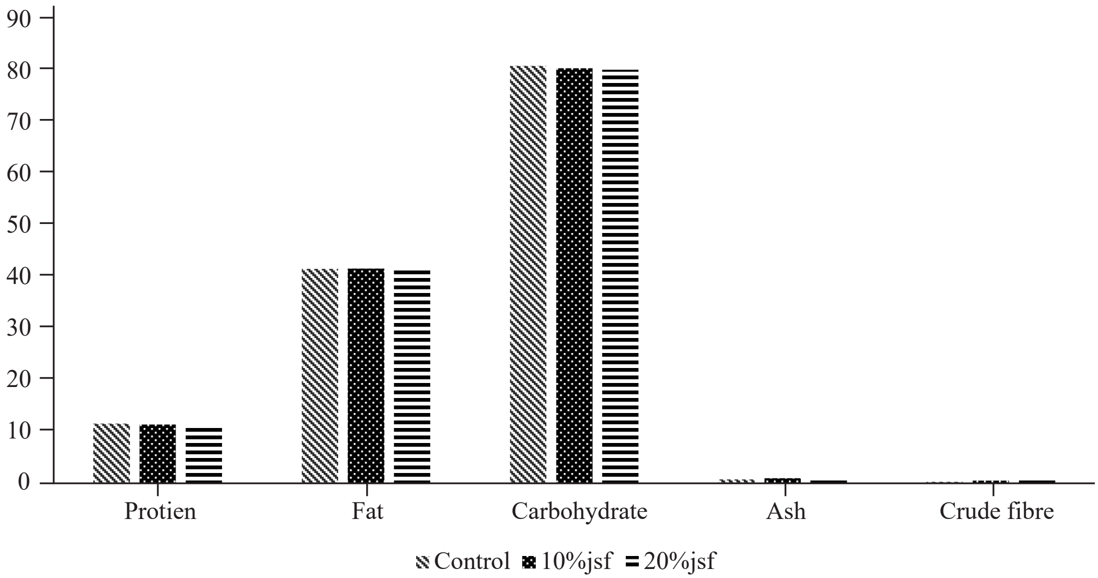

Fig. 1. Nutritional comparison of biscuits using jackfruit seeds flour (jsf).

Source: Butool and Butool (2015).

However, the cake with 10% jackfruit seeds flour supplementation received the highest acceptability by the panelists. There were varied crust and crumb characteristics because of incorporating jackfruit seeds flour. Unlike fat and protein, other proximate compositions like carbohydrate, ash, and fiber increased in the cakes. Some other researchers are found in the literature to develop nutritionally enriched cake by supplementing jackfruit seeds flour with wheat flour (Faridah and Aziah, 2012; Arpit and John, 2015).

Instant powder

Hema (2015) studied the development of nutritious instant dried powder by mixing bulb and seeds of the jackfruit. The study suggested that the increment of the jackfruit seeds powder in the formulation resulted into higher protein content and lower moisture content in the instant powder.

Use of jackfruit perianth

Dam and Nguyen (2013) prepared fermented beverage from the fruit rags and investigated the effects of using pectinase at different rates and temperatures. The study found the optimum conditions for juice extraction were use of 0.3% pectinase at 90°C. The beverage achieved the best fermentation condition after 84 hours while kept at 25°C. Subburamu *et al.* (1992) reported that the perianth meal contains valuable nutrients like 28.9% carbohydrate, 10.3% protein, and 12.7% crude fibre.

Discussion

After reviewing the relevant literatures, the current article suggests that the edible bi-products such as seeds and perianth of jackfruit have great potential to be used in food industry. Presence of high content of starch, protein and minerals in the seeds has attacked the interest of many food processing researches and manufactures of bakery and confectionary products worldwide. Incorporation of seeds flour in the bakery products not only contributes in nutrient quality but also protects the physical properties like crumb and crust characteristics of cake. High crude fiber content of jackfruit seeds is a plus point for it's usage in food formulation. The literature also advises that the edible perianth of jackfruit has good scope to be used in preparation of fermented beverage. The dried perianth could be used in mixed feed meal for its significant content of carbohydrate, protein and crude fiber. The non-edible portion such as peel and central core of jackfruit also has prospective to be used specially in animal feed manufacturing. Apart from direct use of peel, researchers suggested for fermented and dried peel for enhanced nutrient quality of feed meal. The peel and central core of jackfruit were also proved as the source of pectin, although more scientific study are required to establish their utility in food processing.

However, utilization of the above edible and non-edible waste portion of jackfruit is not very popular and has not been commercialized in Bangladesh. More researches collaborated with possible investors are required to scale up the utilization of these bi-products in food and feed industry.

Conclusion

With increasing pressure on the existing resources, there has been a substantial effort for the use of more and more agricultural waste and by-products to value-added products. Using jackfruit wastes and by-products for further exploitation have gained augmented interest because of their high value contents. The current review summarizes the important research efforts and findings on the utilization of jackfruit waste and by-products to make the information handy. The compiled information in this article would help the cattle feed producers, alternate food manufacturers and future researchers. Commercial production of animal feed using jackfruit peel, perianth and central core can be recommended in Bangladesh, as this country produces huge amount of these wastes every year. The seeds powder can be supplemented with other ingredients in the bakery food formulation.

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Table 1. Range, mean, standard error and co-efficient of variation of different characters of 31 inbred lines of sunflower

Characters	Range	Mean	SE(±)	Coefficient of Variation (%)
DM (day)	88-101	96	2.39	3.04
PH (cm)	48.29-137.67	97.25	8.50	10.71
HD (cm)	6.68-17.87	13.23	2.81	25.98
SD (cm)	1.12-2.27	1.60	0.19	14.96
SH (no.)	37-250	118.81	44.11	45.43
SW (g)	2.23-21.42	10.58	5.22	60.48
SY (g)	30.23-541.20	266.65	65.89	30.26

DM= days to maturity, PH= plant height (cm), HD= head diameter (cm), SD= stem diameter (cm), SH= number of seeds per head, SW= seed weight per head (g), SY= Seed yield (g)

Source : Rashid *et al.* (2018)

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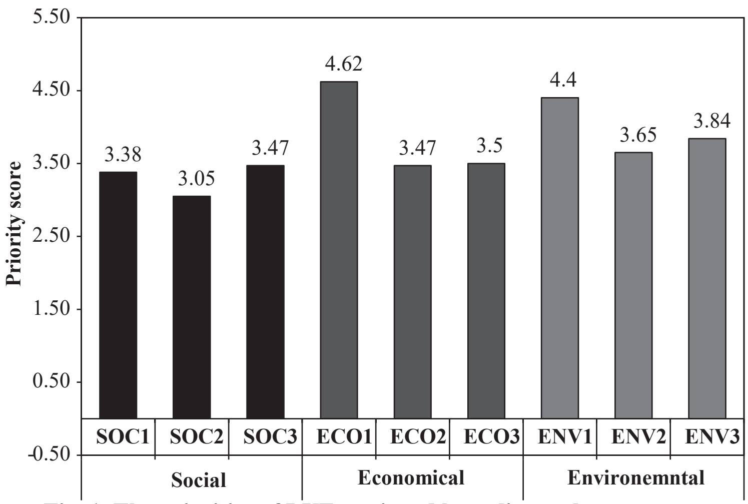
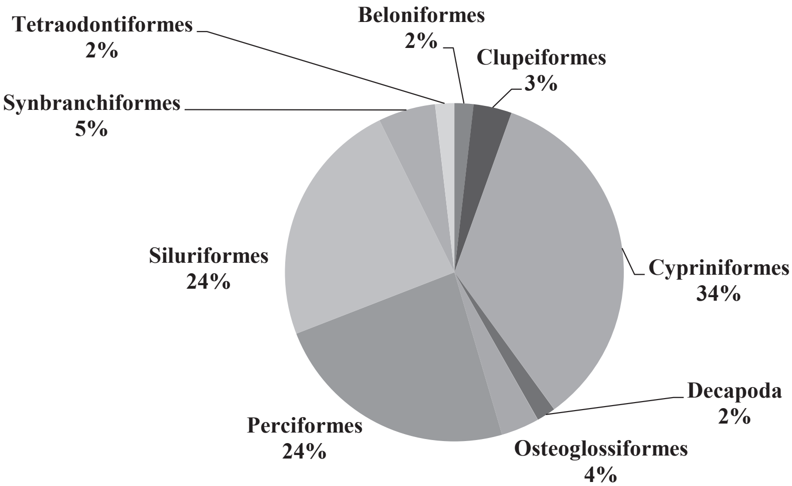


Fig. 1. The priorities of LUFs assigned by policy makers at present.

Source : Miah *et al.* (2018)



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Source : Islam *et al.* (2018)

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