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Assessment and Current Management Practices of Selective Post-Consumption Fruit waste in Eritrea

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Abstract - *There is a threefold increase in global fruit production during 1973-2022, whereas in Eritrea the ministry of agriculture recently expanded the fruit cultivation from 734 ha to over 5000 ha in 2023. As a result, production of banana, papaya and mango together accounted for 28,369 tons, in which banana alone adds more than 90% of the production. Post consumed fruit waste, when it is disposed into the landfills causes significantly in releasing greenhouse gases. In context, a survey conducted to assess the post consumption fruit waste from selected business centers in Asmara and to understand their current waste management practices. Survey revealed that the major fruit waste accounted for papaya and banana fruits, causative more than 80% (by weight). In addition, total post consumption wastes of selected fruits; banana, papaya and mango estimated as 8274 tons in 2023 based on their specific waste generations, which is notably huge amount to manage. Despite practicing to feed the post consumed fruit waste to animals, as the fruit production rises in 2023, special attention must be paid by the researchers for improved valorization of the waste through its prudential utilization.*

Key Words: Fruit waste assessment, waste management, post consumption fruit waste, environmental pollution, solid waste management, bio-waste valorization

1.INTRODUCTION

The major fruits by their production globally include banana, apples, grapes, mangoes, papayas, oranges and watermelons [1]. However, their production quantities vary across different countries and regions based on their agro-climatic conditions [2]. Bananas are one of the most widely produced fruits with a global export industry generating around USD 9.1 billion per year. In 2020, South American suppliers exported an estimated 530,000 tons of bananas, with Brazil and Peru being the leading exporters. India is also a significant producer of bananas, with more than 30 million tons produced annually [3]. Papayas are predominantly grown in tropical regions, with India, Mexico, and Brazil being among the top producers. Further, papayas account for approximately 15.36% of the total tropical fruit production, behind mangoes and pineapples [4]. Nevertheless, global production of papayas projected to reach 18 million tons by 2032 [5]. Mexico is the largest global exporter of mangoes with a 3% growth in exports in 2020. Mangoes are the second most produced tropical fruit, accounting for approximately 10.66% of total fruit production [5]. India, China, Thailand, and Indonesia are also among the top producers of mangoes, with global production projected to reach 84 million tons by 2030 [2,3].

The current production and productivity of most fruit crops in Eritrea is low when compared to regional and world averages. The fruits that are cultivated in Eritrea include banana, papaya, mango, orange, guava, lemon, mandarin and others. Based on the year 2022 statistics the fruit harvested area in Eritrea was estimated at 734 ha and the production of fruits was at a level of 4,871.53 tonnes. As shown in chart 1., the annual fruit production in Eritrea varied in between 4791 tonnes per year in 2011 to 5000 tonnes in 2012. Over the period considered (2011-2022) for the production of fruits in Eritrea, however, continued to indicate a relatively flat trend pattern due to variety of problems like technical, environmental and economic issues [6]. In value terms, fruit production expanded remarkably to $15M in 2022 estimated in export price [7]. Furthermore, the ministry of agriculture (MoA) in Eritrea has focused on improving their fruit production in 2023 and expanded the fruit cultivation to over 5000 hectares and as a result more 76000 tons of fruits were produced in 2023 as shown in chart 1[8].

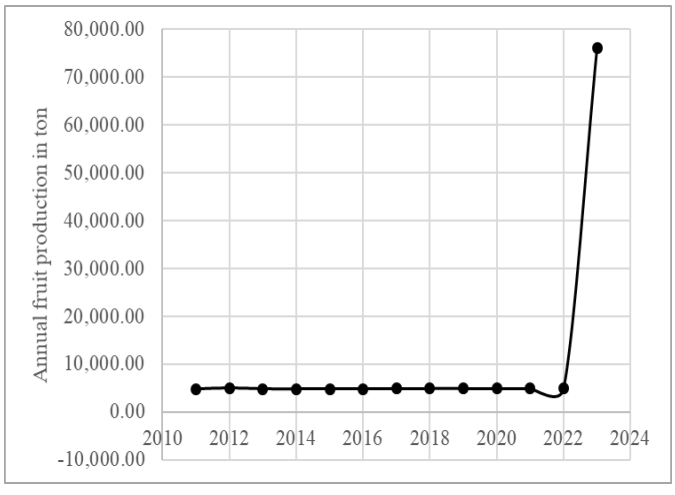

Chart -1: Annual fruit production trends in Eritrea

With the global production of fruits between 1973 and 2022 increased substantially from 290 million to 933 million tons, the generation of large amounts of by-products and waste has become a significant concern [7]. In general fruit

waste include fruit injuries, bruising, over-ripening during food transport and storage, and by-products from fruit processing. Otherwise, the term "post-consumption fruit waste" refers to the waste generated after the consumption of fruits, which encompasses the waste generated by the end consumer of a material stream. This type of waste includes parts that are not needed, such as fruit skins, seeds and they are typically discarded in waste receptacles, landfills, or through other disposal methods. Post-consumed fruit waste contributes to greenhouse gas emissions through various processes. When food waste, including fruits, ends up in landfills, it decomposes and produces methane, a potent greenhouse gas that contributes to climate change. Thus globally, wasted food accounts for about 8% of all greenhouse gas emissions [9]. Furthermore, the carbon footprint of yearly food waste is approximately 3.3 gigatons of carbon dioxide, emphasizing the need to develop strategies to curtail food wastage and manage food waste effectively [10]. Therefore, the proper management of post-consumed fruit waste is essential for mitigating its contribution to greenhouse gas emissions and addressing climate change.

Fruit waste not only impacts the environment but also represents a loss of valuable resources. Several studies have highlighted the potential benefits of converting fruit waste into energy, such as biofuel production, emphasizing the need to understand the impact of post-disposal waste and the potential for energetic purposes [11], which not only minimizes waste but also reduces the overall cost of running businesses. Therefore, the proper assessment and management of post-consumed fruit waste are essential for mitigating environmental impacts and promoting sustainable practices.

In developing countries, the management of post-consumed fruit waste poses several challenges, including lack of infrastructure for waste management, limited resources such as scarce financial and technical facilities [12], food safety concerns, variety of waste and environmental impacts for implementing effective waste management practices [13]. Addressing these challenges requires a multi-faceted approach, including investment in infrastructure, technology, and resource management, as well as the development of tailored waste management strategies to suit the specific characteristics of each region. In contrast, the assessment of post-consumption fruit waste offers several potential benefits such as recovery of bioactive compounds [14], sustainable resource utilization, creating economic opportunities, enhanced health benefits contribution to “Zero Waste” goals [15] and the promotion of circular-economy practices globally. Further, a circular economy model proposes the manufacturing of bioplastics based on fruit waste to minimize the carbon footprint and production cost, while also contributing to the generation of employment and recovering the value of fruit residues through packaging manufacturing [16]. Another study reveals that the integrated valorization of fruit by-products from food processing industries creates a potential opportunity for the extraction of value-added compounds through the application of sustainable and green methodologies, contributing to the circular economy approach [17].

Based on existing knowledge, it is known that Eritrea's agricultural sector produces a variety of fruits, and the waste generated may include fruit injuries, over-ripening, and by-products from fruit processing. However, detailed information on the specific types of fruit waste and their management in Eritrea is not readily available in any official reports so far and hence in the present work, focused on assessment of post-consumption fruit waste that generates from several fruit consuming business centers in Asmara, the capital of Eritrea as the data generated may serve as source for further management actions to be implemented.

2. METHODOLOGY

2.1 Study Area and Ecology

Asmara, as the capital, is one of the most populous city of Eritrea with 13 administrative regions, located in the highlands of the Central Region. It is situated on a rocky highland plateau, which separates the western lowlands from the eastern coastal plains and is located at 2,352-meter (7,628 ft.), altitude. In spite of its small size, Eritrea divides into six main agro-climatic zones as displayed in fig 1. Generally, Eritrea has two types of prevailing climates, subtropical highland climate and cold semi-arid climate [18]. The altitude ranges from less than 100 meters in the coastal plains up to 2400 meters in the central highlands with small area above that. In the Highlands, Western-Escarpment and South Western Lowlands rainfall usually occurs during summer (June-September). Average annual rainfall in these area ranges from 400 to 700 mm. in the coastal plains rainfall occurs during the winter months with an average of less than 200 mm per year. The Green Belt Zone is an exceptional area that enjoys high rainfall occurs during the period November-March. Average annual rainfall in this zone exceeds 1000 mm.

The diverse agro-climatic regions of Eritrea is an advantage for producing diversified fruit crops. Extending the season is also possible for many crops creating an opportunity for many crops to be available throughout the year. Generally, fruits crops like banana, papaya, mango, orange, guava, lemon, mandarin and others are produced.

Papaya (Carica papaya L.) is a short-lived tree grown throughout the tropics and in mild sub-tropical climates in Africa, Australia and North America. In Eritrea, it was introduced early in the 1900s and is commonly cultivated along river banks in the midlands and lowlands, e.g. around Mereb valley, Filfil, Ghinda, Keren, Mai-Habar and Mai-Aini, 500-1,600 m and cultivated whole year. Mango (Mangifera

indica L.) is also a tropical fruit trees cultivated in warmer areas of Eritrea. It production is biennial and cultivated well from 500 to 1,800 m along the river banks of Anseba, Barka, Mereb-gash and in irrigated horticultural sites. Banana (Musa sp. family) is grown in all tropical and some sub-tropical countries. In Eritrea, banana can grow in all parts of Eritrea's lowlands, majority produced along the river basins of Anseba, Barka and Mereb-Gash (Ministry of Information, Eritrea). The majority of the banana cultivation is carried out in the subzones of Agordet, Dighe, Tesseney, and Haikota areas in the Gash-Barka region and its production extends the whole year (but differ in management system) [19].

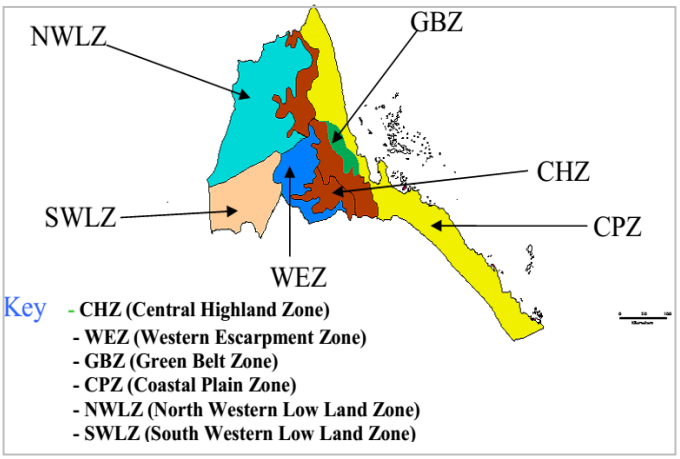

Fig -1: Agro-climatic Zones of Eritrea (*Source:* Brhan KS, 2006)

2.2 Fruit Waste Assessment Methodology

The assessment of post-consumed fruit waste involves various methodologies, including data analysis, experimental assessments, and practical measurement methods. This study was conducted during the months of June, July and August in 2023 once in a week for eight consecutive weeks for banana and papaya, six consecutive weeks for the case of mango at three different fruit based business centers located in Asmara such as Milkias, Shallom and Capri as these places consume considerable amounts of fruits daily for juices and other kind of fruit processed products.

Practical methodologies for assessing fruit waste include self-reported questionnaires and preplanned waste collection methods, which have been compared empirically to measure post consumed fruit waste accurately. In each study center, waste fruit generated is collected in plastic containers of 100 or 200-liter capacity. The survey is conducted at the end of each study day and the amount of fruit waste produced is separately quantified directly through a weighting machine and recorded.

2.3 Identification of waste management practices

The management of post-consumption fruit waste involved identifying waste disposal and collection methods, and potential recycling techniques, emphasizing the need for a comprehensive approach to waste assessment and management. Post-consumed fruit waste that include skin and seeds was collected manually in the plastic containers at the studied centers as shown in fig 3. Total wastage of fruits selected for this study composed of different non-edible (unavoidable waste) wastage parts. In case of papayas peel and seed, from mangoes, peels and kernel are found as waste, while in the case of banana peel and rotten fruits. Overall, the assessment of post-consumed fruit waste encompasses a range of analytical and practical methods, aiming to understand waste generation through the interpretation of survey reports, feasibility of utilization, and effective management strategies.

Fig -2: Post-consumed fruit waste collected at different centers, (a) Milkias, (b) Shallom and (c) Capri

3. RESULTS AND DISCUSSION

3.1 Fruit waste and their divergence

As the study identifies papaya, banana and mango fruits are the major sources of post-consumed fruit waste generated from the centers studied in Asmara, capital of Eritrea. The wastes generated were quantified end of every business day for eight consecutive weeks. As the table 1. shows, the daily average fruit waste generated on each day were measured as 44.56 kg, 41.76kg and 19.48 kg for papaya, banana and mango fruits respectively. The result from the study evidently showed that papaya and banana generate highest wastes due to their high consumption at fruit juice business centers studied. However, waste from mango was noted low due to its limited seasonal availability. Overall, as non-consumable weight of papaya fruit including seed and peel is quite more, the study discloses that post-consumed fruit waste generated from papaya is the highest than banana.

Table -1: Weekly assessment of selected fruit total post-consumer waste.

Fruit	Week-1 (kg)	Week-2 (kg)	Week-3 (kg)	Week-4 (kg)	Week-5 (kg)	Week-6 (kg)	Week-7 (kg)	Week-8 (kg)	Average (kg)
Banana	39.33	48.86	42.43	45.93	43.16	32.83	48.73	32.8	41.76
Papaya	47.83	46.4	38.3	43.18	40.07	41.26	51.07	48.39	44.56
Mango	22.7	21.1	23.2	15.9	17.97	16	-	-	19.47

3.2 Specific wastes of Selected fruits

The specific fruit waste is defined as the waste generated per kilogram of fruits. Specific wastes of papaya, banana, mango and orange fruits were determined after their consumption for at least 10 samples for every variety of the fruits and the average values are reported as 0.295kg, 0.475kg, 0.28kg and 0.25kg for papaya, mango, banana and orange fruits respectively. Although mango fruits generate approximately 50 % of its weight as waste, due to its uncertain availability as the supply depend on suitable seasons, it doesn't contribute significantly in the post-consumption fruit waste generated from the centers studied. Further, as portrayed in Chart 2, the waste generated from papaya contributes for 42.11%, the highest one than 39.48 % and 18.4 % shared by banana and mango fruits respectively.

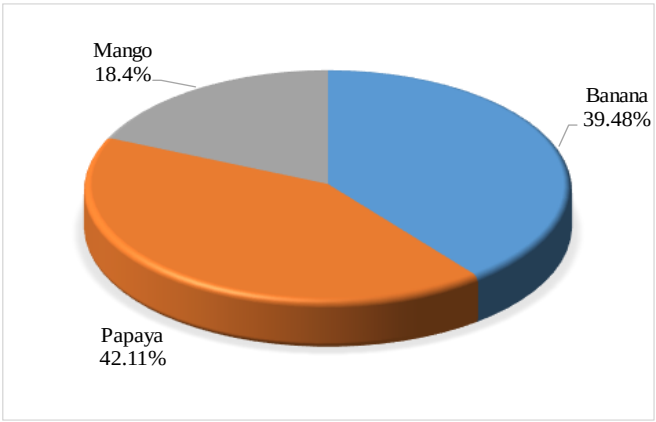

Chart -2: Fruit waste distribution of selective fruits in Asmara

The post-consumed fruit waste of selective varieties at different business centers studied have varied randomly based on their supply management issues, seasonal availability of fruits, and their locations which inherently determine the accessibility to customers. As depicted in Chart 3, the study revealed that Capri fruit juice center generate more waste than others. Consequently, the segregated wastes of all selected fruit; banana, papaya and mango are also measured higher at Capri center. Further, papaya and banana consumptions at Milkias center found competitive with Capri business center while Shalom center left with lowest fruit waste than others although which is one of the significant local business center.

3.3 Fruit Waste Management Practices in Eritrea

The best practices for managing post-consumption fruit waste include various methods such as composting, feeding to livestock, and donation to food banks. Composting fruit and vegetable waste is an effective method to reduce the environmental impact of waste disposal. It allows for the organic matter to decompose and be reused as a natural fertilizer, promoting a circular economy approach and reducing the volume of waste sent to landfills [20]. Further, giving fruit and vegetable culls to local food banks is a beneficial practice that helps to reduce food waste while providing nutritious food to those in need. This approach supports the community and contributes to the reduction of post-consumption fruit waste [21]. In addition, storing culled fruit and vegetable waste on-site for a limited time and returning it to the field on which it was grown can be an effective method to manage waste while allowing for natural decomposition and nutrient recycling [22]. Otherwise fruit and vegetable waste can be utilized as animal feed, providing

a sustainable and low-cost alternative to traditional feed sources. This practice not only reduces waste but also contributes to the circular use of resources within the food system [21].

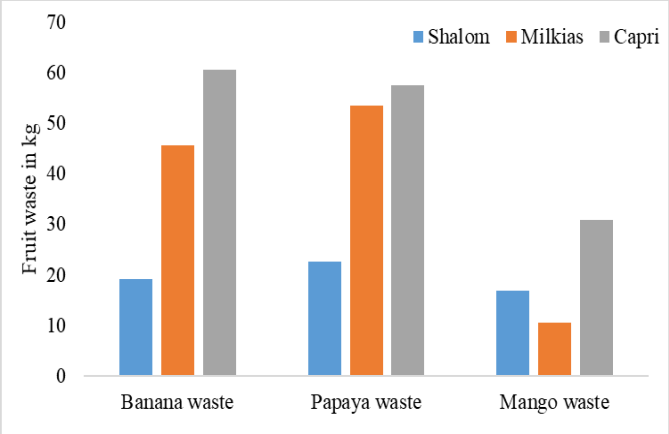

Chart -3: Fruit waste deviations among selected fruit juice centers in Asmara

Poor management practices of post-consumption fruit waste can lead to environmental and economic challenges. In case of specific post-consumption fruit waste generated from the business centers studied from Asmara, majorly from banana and papaya fruits are managed by utilizing it as a livestock feed. Otherwise, the mango kernels are practiced for composting and using it as a fertilizer. In addition, the fruit waste generated from the house holds eventually ended into municipal solid waste, which has been practicing to carry and dumping at near bet giorgis (Scarico) location.

Further, the management of industrial fruit wastes is important not only to decrease the volume of food waste accumulated in the landfills but also to promote a circular economy approach [1]. Circular economy approach emphasizes the need for novel and new processes and products to allow the utilization of virgin in a second step, to maximize the use of the waste throughout the supply chain, by promoting circularity, thus closing the loop and decreasing the amount of noxious materials deposited in the environment. The people in Eritrea need to be practiced to segregate their waste before dumping it to the municipality, which may help the authorities to recover value added products at predefined scales. In context, the authorities need to provide such awareness campaigns to the public to circulate their household waste in an optimized direction. However, the lack of integrated recovery strategies for fruit waste leads to the under-utilization of its potential value, including the recovery of bioactive compounds and the production of commercial products [2]. Additionally, the excessive landfill disposal of fruit waste contributes to the generation of methane, a potent greenhouse gas, and represents a lost opportunity for resource recovery and recycling [1].

3.4 Potential scope of utilizing selective fruit waste for distinguished applications

Papaya (*Carica papaya L.*) is one of the most economically important fruit cultivated throughout the year and it is rich in various bioactive compounds such as carotenoids, phenolic compounds, vitamins like A, C and E. Further, papaya also enriched with minerals like potassium and magnesium. In addition, papaya fruit is folate and fiber, which have many beneficial health effects on our body that are attributed to antioxidant properties [23]. Current study discloses that papaya peel (PP) and papaya seed (PS) are the major byproducts of papaya processing and together representing 29.5% of fruit weight. Further reviews focused on analyzing physicochemical composition and valorization of PP revealed that, it can be used for obtaining many valuable products such as biofuels, adsorbents, dietary fibers, biomedicines and biomaterials by fermentation [23]. Another review describes that PS exploited as an alternative protein feed ingredient for poultry with crude protein of 24-30%, in vitro protein digestibility of 80% and proportion of essential amino acids of 47% [24].

Banana (*Musa sp. family*) is the highly consumed fruit in Eritrea and the generated peel waste is managed by utilizing it as cattle feed. As many consumers avoid consumption of meat and meat products due to high cholesterol level but by feeding banana peels, serum cholesterol in the blood, meat and liver reported to be reduced [25]. In fact, banana peel reported with considerable amount of mineral ash when it is converted into biochar which can improve the quality of the soil. Banana peel also reviewed as a potential source of carbon with eminent denitrification ability to enrich nitrogen content of the soil. Further the potassium content of banana peel reported as 40% of the peel content, which improves the germination of the crops when applied as fertilizer. In addition, several studies revealed that feeding poultry with starchy banana peel rapidly rises the rate of production, particularly weight gain in chicken [26].

Today, the materials science gained much attention in the world, banana peel suggested as a porogenous agent by blending 20 weight % of it with clay as it contains 73.4 % (weight) of starch, for developing highly porous ceramics. An attempt also made to utilize the ripened banana skin powder to produce edible coatings and active packaging films based on various functions exhibited by their carbohydrates. Further, the presence of high quality lipids of about 34% in banana peel made them a cheap and efficient feedstock for the cultivation of microorganisms resulting in improved biodiesel. In addition, as banana peels have a distinguished level of nutrients, employing cow dung as inoculum, they eventually hike the production biogas [26].

The mango (*Mangifera indica L.*) is considered to one of the world's preferable fruit because of its color, taste and

excellent nutrients. As the mango peel constituents 10-20% of the fruit which contains 51.2 % of dietary

fiber it can be consumed in food products like biscuits that are incorporated with improved antioxidant properties. It was also reported that mango peel is a good source of high quality jelly grade pectin. Mango peels can also be used for biogas production by anaerobic digestion, which can produce a gas that contains 40-52% of methane. Further, the mango kernel contains 10-15% edible fat, it can be used in bakery, confectionery and pharmaceutical products. Seed kernel extracts determined with high quantity of phenolic components, which are suitable for use in food, cosmetics, nutraceutical and pharmaceutical applications. The seed kernel also found in applications of animal feed, composting and vermicomposting [27]. Further, feeding of mango seed kernel waste in poultry diets reviewed on solving the problem of competition between poultries and humans for cereal grains as well as contributing to reduce the disposal issues [28].

3.5 Valorization of Eritrean Fruit Waste for its Potential Applications

Eritrea is a small country with 3,687,728 of population measured in the month of May, 2023 [29]. Further, the major fruit varieties produced in the country include banana, papaya and mango besides the other common fruits like cacti fruits (belles), oranges, lemon, date palm, water melon, peach, tangerine, apples and grapes [6]. Among the three selected major fruit varieties as shown in fig 4, banana production is on top with 25659.6 ton in 2023 followed by mango and papaya productions of 1610.6 and 1098.9 tons respectively.

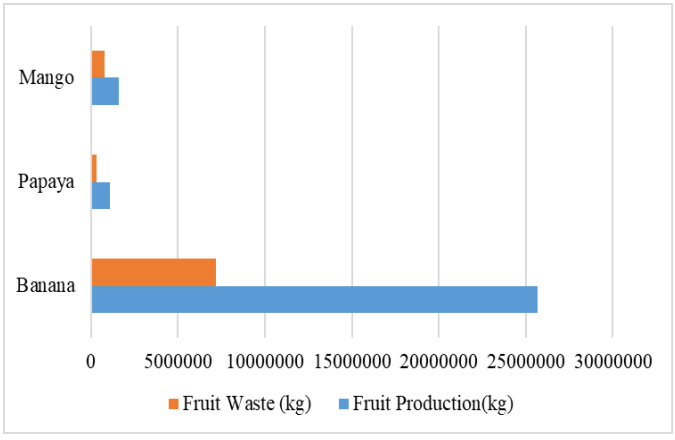

Chart -4: Fruit waste verses fruit produced for the selective fruits in Eritrea

Further, it was estimated that, banana alone generate the post consumed waste of 7184.688 tons per year which has been practicing traditionally as a cattle feed. In contrary, since the ministry of agriculture (MoA) in Eritrea has been trying to find a best natural fertilizer, banana peel could be a better choice to serve as a feedstock for biochar fertilizer production which can stabilize the soil with enrichment of nutrients such as nitrogen and potassium. In addition, mango and papaya fruit wastes of 765 tons and 325 tons respectively, could also be significant feedstock for value added products. For instance, papaya peel and seed waste could be a better feedstock for biofuel or biomedicine. Besides, mango fruit waste also has potential to use as a feedstock for biogas production by fermentation. Although these waste have several benefits of using it as animal feed, yet local researchers can divert their works for further potential benefits of the country.

4. CONCLUSIONS

Post-consumed fruit wastes contribute significantly in municipal solid waste everywhere in the world. A survey carried out at three fruit business centers in Eritrean capital city, Asmara has disclosed that the peel and seed waste of papaya is about 42.11% (by weight), followed by banana peel waste with 39.48 % and the rest by mango kernel and skin wastes. Although the specific waste of mango is quite higher than banana and papaya, its contribution in the total waste is quite low due to its seasonal availability. Currently, the fruit waste generated managed by feeding animals partially from the business centers, but the waste comes from the households directed into municipal solid waste and thereby contributing to greenhouse gases releases from the landfills. Since ministry of agriculture (MoA) of Eritrea expanded the cultivation of fruits from 734 ha in 2022 to over 5000 ha in 2023 and as a result approximately 76000 tons of fruit production recorded. Banana fruit waste alone estimated as 7185 tons, which is notably higher than the waste generated in 2022 and thus it is salient to assess the total fruit waste generation for more appropriate management in the future. In addition, banana, papaya and mango fruit wastes found in several applications with value added products. Hence, the local researchers need to pay attention to divert their ideas for better valorization of these wastes.

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