Opportunities for New Biorefinery Products from Ethiopian Ginning Industry By-products: Current Status and Prospects

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Abstract
The global demand for textile products is rapidly increasing due to population growth, rising living standards, economic development, and fast fashion trends. Ethiopian growth and transformation plan (GTP) gives high priorities for the textile and apparel sectors to transform its agriculturally led economy to an industrial-based economy. To achieve this, the number of textile and apparel industries is rapidly expanding. However, the rapid growth in textile industry is generating mountains and mountains of by-products. In this review, possible applications of cotton stalk and cotton ginning waste in a variety of technologies and products are discussed in Ethiopian context. The finding of this study shows that Ethiopian current cotton cultivating area is about 80 000 hm², even though the country has a potential of about 3 000 810 hm² land for cotton cultivation. From the current cultivated area, more than 240 000 t of cotton stalk and 9240 t of cotton ginning trash have been generated as a by-product. But only a very little portion of the cotton stalk is being used as a raw fuel for household purposes and a small portion of cotton ginning trash is used for animal feed. Therefore, these underutilized lignocellulosic biomasses can be used as raw materials for producing different high-value biomaterials and thus country can perceive an economic and environmental benefit. A closer look at the structure and composition of the by-products shows that the whole part of cotton stalk and ginning waste can be used as a source of cellulose which can be exploited for conversion into a number of high-value biomaterials. Thus, conversion of the waste into valuable products can make cotton stalk and ginning by-products an attractive raw material for the production of high value bio-products.

Keywords
cotton stalk; cotton ginning waste; biobased materials; biorefinery; waste utilization

1. Introduction
Rapid urbanization, industrialization and population growth and economic development are leading to the generation of enormous amounts of solid waste, hazardous to living things as well as to the environment (Sharholy et al., 2008; Karthikeyan et al., 2016; Vaish et al., 2016). Human activities generate much amount of waste materials that are often discarded because they are considered as useless and unwanted. However, many of these waste materials especially wastes in solid form can be converted into useful materials, and thus they can used as a raw materials for different industries (Tchobanoglous and Kreith, 2002).

Because of increased population growth, material consumption is highly increased all over the world. Clothing is one of the most consumable products which needs higher production and this leads to generation of solid as well as liquid wastes. Due to population growth, rising living standards, economic development and fast
fashion trends the global demand for textile products is rapidly increasing (Yalcin-Enis et al., 2019). To satisfy high global demand of textile products, the production capacity of world textile industries also increased and this resulted in a higher consumption of textile fibers. Over the last 20 years, the world fibre consumption experienced dramatic changes (Fig. 1) (ICAC, 2015). World fibre production was about 110 million tons in 2018, out of these 32 million tons of natural fibres and 79 million tons of manmade fibres, both regenerated and synthetic fibre. Cotton accounted for 80% of natural fibre production by weight, which means the total estimated cotton production in 2018 was 25.6 million tons (Townsend, 2020).

More than 100 countries (Fig. 2) are producing cotton in the world, and total planted area is 33.4 million hectares in 2017/2018 and 32 million hectares in 2018/2019 (Johnson et al., 2018; Khan et al., 2020). The cultivation of cotton generates plant residue three to five times the weight of the fibre produced (Reddy and Yang, 2009). This biomass left in the field after picking seed cotton is called cotton stalks (Sidhu, 2015). Globally more than 100 million tons of cotton stalk is produced annually (Reddy and Yang, 2009; Li et al., 2010). It is cheap and abundant lignocellulosic agricultural by-products that turn it into different cellulose-based high value bio-materials (Li et al., 2010) like film (Goksu et al., 2007), activated carbon (Girgis et al., 2009; Li et al., 2010; Chen et al., 2013), biomorphous porous carbon (Wang et al., 2012), nanocrystalline cellulose aerogels (Rahbar Shamskar et al., 2016), carboxymethyl cellulose (Zhang et al., 2011) and it can also be a source of bioenergy production (Adl et al., 2012; Al Afif et al., 2020).
The other cotton by-product is cotton seed and cotton ginning trash. Cotton gin trash is generated during the separation of cotton lint from cotton seed in the gin. The trash composition varies depending on the different types of gins and harvesting practices, but it is generally in the form of boll cover (burr), stems, leaves and lint (Klasson et al., 2009). Cotton ginning trash is also a lignocellulose by-product, and can be used to recover different cellulose based bio-materials, for example nanocellulose crystals (Jordan et al., 2019) and moreover, adsorbents activated carbons (Klasson et al., 2009) can also be produced. However, none has been focused on comprehensive investigation of ginning industry by-products to help to ascertain their possible valorisation. The aim of this study is to review the possibilities of use and conversion of ginning industry by-products into high-value biomaterials. Since ginning industry by-products are lignocellulosic, it is believed that they are a valuable biomass and their beneficiation could result in their sustainable conversion into high-value biomaterials.

2. Method
An extensive literature search dealing with process description of cotton cultivation and ginning industry, availability of cotton and ginning by-products, physicochemical characteristics of cotton stalk and ginning trash, disposal techniques, current use and future valorisation route was carried out to compose this review article. A vast number of the world’s renowned databases were used to search for publications. These included, but were not limited to, Google Scholar (https://scholar.google.co.za/), ScienceDirect (http://www.sciencedirect.com/), Academia (https://www.academia.edu/) and SCOPUS (https://www.scopus.com/). Publications were searched
3. Overview of Cotton Stalk and Cotton Ginning Waste in Ethiopia

3.1. Process description of cotton cultivation

In Ethiopia, cotton is a major agro-industrial crop grown by small scale and big commercial farmers to earn income. Cotton is the only crop fiber in Ethiopia which is used as a single raw material for the modern textile industries, traditional textile sectors, local handcraft and ginning factories. Cotton seed which is the ginning by-product is also an input for edible oil manufacturing factories and animal feed processing industries. Studies show that cotton fiber contributes about 70% of the total raw materials required for Ethiopian textile industries (EIAR, 2017. Cotton Research Directory). To acquire the highest quality of cotton fibre, it is picked up after the bolls are mature and freshly opened (Fig. 3). Cotton can either be picked by hand or by machines. Manual picking is slow but better preserves fibre characteristics of cotton (Chaudhry, 1997).

![Fig. 3 Cycle of growth of a cotton plant (Nadia, 2020. Cycle of growth of a plant of a cotton isolated on a white background. Dreamstime (online))](image)

Quality of the cotton fiber varies with many factors including variety, weather conditions, harvesting and storage practices, moisture and trash content, and ginning processes (Gordon and Hsieh, 2007). About 30%–35% of world production is machine picked and the rest is picked by hands manually (Chaudhry, 1997; Gordon and Hsieh, 2007). Cotton production in Sub-Saharan Africa including Ethiopia, typically no machinery is available for the harvest. The harvesting of cotton is done by hand picking, with the help of seasonal workers (Bedane and Egziabher, 2019). The cotton stalk is left in the field after cotton bolls picked and this cotton residue can be an input for production of biobased materials.

3.2. Process description of cotton ginning

After harvesting cotton fibre from the field, cotton lint is separated from the cotton seed in ginning machines. As shown in Fig. 4, the minimum machinery required to process clean, hand-harvested cotton consists of a dryer and/moisture restoration device followed by a feeder to uniformly meter seed cotton into a gin stand. The ginner must be able to adjust the moisture of the cotton up or down, individualize the locules of cotton, meter the locules uniformly into the gin stand to separate the fibre from the seed, and then package the fibre and seed for market (ITC, 2015).
Foreign matter levels in seed cotton before gin processing usually range from 1% to 5% for hand harvested, from 5% to 10% for spindle-harvested, and from 10% to 30% for stripper-harvested cottons. The level of foreign matter dictates the amount of cleaning need and this cotton ginning trash can be used as a raw material for industries if managed properly.

### 3.3. Availability of cotton stalk in Ethiopia

Ethiopia has a long practice of cotton cultivation in its low land and river basin areas, like Awash Valley, Gambela, Humera, and Metema (Bedane and Egziabher, 2019). Cotton is grown under rain-fed (peasant smallholdings) and irrigated (large-scale commercial farms) in Ethiopia; production methods and problems vary considerably between the two types. There is a vast potential to grow cotton both under rain-fed and irrigated conditions, as Ethiopia has about 3 million ha of land potentially available for cotton production (Ethiopian Investment Copmision (EIC), 2017. Cotton, Textile and Apparel Sector Investment Profile Summary-Ethiopia). However, out of the country’s total potential areas for cotton production, currently only about less than three percent is being utilized. As a result, the amount of cotton produced in the country is small. The cotton cultivation and production trends are shown in Table 1.

| Crop year | Area harvested (ha) | Production (t) | Year-to-year variations |
|-----------|---------------------|----------------|------------------------|
|           |                     |                | Absolute (t) | %     |
| 2010/11   | 99 000              | 55 000         | –           | –     |
| 2011/12   | 93 000              | 62 000         | 7 000       | 13%   |
| 2012/13   | 85 000              | 45 000         | (17 000)    | –27%  |
| 2013/14   | 57 000              | 28 000         | (17 000)    | –38%  |
| 2014/15   | 98 000              | 40 000         | 12 000      | 43%   |
| 2015/16   | 65 000              | 38 000         | (2 000)     | –5%   |
| 2016/17   | 82 000              | 45 000         | 7 000       | 18%   |
| 2017/18   | 60 000              | 38 000         | (7 000)     | –16%  |
| 2018/19   | 77 000              | 53 000         | 15 000      | 39%   |
| 2019/20   | 80 000              | 57 000         | 4 000       | 8%    |

Source: Ethiopian Textile Industry Development Institute (ETHIDI) and Foreign Agricultural Service (FAS) Addis Ababa Forecast, 2019

Cotton production for 2019/20 is forecast at 57 000 t and consumption is forecasted to be 64 000 t with thriving investments in the textile industry (FAS, 2019). Because of high potential for cotton cultivation, the Ethiopian government has plans to increase production of cotton to satisfy the local demand and in addition to
fulfil the need of local textile industry there is a plan to export cotton for different countries. As shown in Table 2, Ethiopia has planned to produce 1 116 280 t of lint cotton from one million hectares cultivated areas in 2032.

| Parameter                      | 2017   | 2020   | 2025   | 2032   |
|-------------------------------|--------|--------|--------|--------|
| Cultivated area (hm²)         | 368 000 | 520 000 | 1 155 000 | 2 596 000 |
| Productivity (kg seed cotton per hm²): |        |        |        |        |
| Smallholder rainfed           | 1500   | 1600   | 2000   | 2200   |
| Smallholder irrigated         | 2400   | 2600   | 3000   | 3300   |
| Large farms rainfed           | 1500   | 1600   | 2000   | 2200   |
| Large farms irrigated         | 2400   | 2600   | 3000   | 3300   |
| Average                       | 1736   | 2008   | 2303   | 2596   |
| Production (t) seed cotton    | 39 000 | 76 800 | 520 000 | 638 000 |
| Ginning outturn (%)           | 37%    | 39%    | 42%    | 43%    |
| Lint Cotton Production (ton)  | 51 393 | 195 780 | 644 700 | 1 116 280 |
| Yield (kg lint/ hm²)          | 644    | 783    | 969    | 1116   |
| Lint classed by instrument (%)| 5%     | 20%    | 50%    | 100%   |
| Share higher grades (%)       | 10%    | 25%    | 50%    | 75%    |
| Identity/sustainable cottons (%)| 5%   | 25%    | 50%    | 100%   |
| Domestic mill uses (t, lint cotton) | 40 000 | 100 000 | 350 000 | 600 000 |
| Exports (t, lint cotton)      | 11 393 | 95 780 | 294 700 | 516 280 |
| Cotton seed ratio (%)         | 57%    | 56%    | 54%    | 54%    |
| Cotton seed production (t)    | 79 173 | 281 120 | 828 900 | 1 401 840 |
| Oil content (%)                | 15%    | 16%    | 18%    | 20%    |
| Cottonseed oil production (t) | 11 876 | 44 979 | 149 202 | 280 368 |

There is a high potential of cotton stalk in Ethiopia and its collection is also simple because most of cotton is cultivated in large farms and the harvesting is hand picking. It is difficult to determine the actual yield of cotton stalk in Ethiopia, because there is no previous study related to the cotton stalk. Based on the research done on other countries, the yield of cotton stalk is more than 3 t/hm², therefore Ethiopia produces 240 000 t of cotton stalks per year which is a huge amount and forecasted to 750 000 t and 3 million tons in 2020 and 2032, respectively (Zhang et al., 2011).

3.4. Availability of cotton ginning waste

Currently about 80 000 hm² are cultivated by cotton plants and the lint cotton is about 51 400 t per year. According to the Ethiopian Textile Industry Development Institute (ETIDI) and Foreign Agricultural Service (FAS) report the current Ethiopian ginning out turn (GOT) is 37% and the cotton yield is 642 kg/hm². The rest 63% is ginning by products like ginning trash and cotton seed. As shown in Fig. 5, in cotton ginning the ginning trash covers about 6% which is composed of stems, leaves, burrs, immature seeds or seed fragments, and sand removed from cotton at the gin.
As shown in Table 3 the average ginning outturn for nine consecutive production years is 36.9%, which is similar to ETIDI report. But the ginning trash and cotton seed percentage is deviated from ETIDI study. As observed in the field study the waste collection method is poor, ginning trash is mixed with seed parts and they are considered as the number of seeds. This reduces the percentage of ginning trash and it increases seed percentage. Sometimes cotton supplier adds unnecessary materials like stone, soils and sands to increase the weight of seed cotton and their incomes. So, due to such reasons the percentage of ginning by-product varies from time to time depending on amount of foreign matters added to raw cotton and the method of waste collection during ginning process.

Table 3  Ginning outturn and ginning by products (Availability study)

| Year   | Bought raw cotton (kg) | Processed input raw cotton (kg) | Output lint cotton (kg) | GOT (%) | Cotton seed (kg) | Seed (%) | Ginning trash (%) |
|--------|------------------------|-------------------------------|-------------------------|----------|------------------|----------|-------------------|
| 2010/11| 556 281                | 2 04 207                      | 36.71                   | 319 013  | 57.34            | 9.45     |
| 2011/12| 2 762 346              | 2 1 21 814.8                 | 37.10                   | 1 360 800| 61.41            | 4.8      |
| 2012/13| 3 990 243              | 1 427 437                    | 35.77                   | 2 247 937| 56.33            | 7.89     |
| 2013/14| 1 710 530              | 635 379.9                    | 37.14                   | 1 038 850| 60.73            | 2.12     |
| 2014/15| 1 225 763              | 465 976.5                    | 38.01                   | 733 862 | 59.86            | 2.11     |
| 2015/16| 1 89 142               | 702 257                      | 37.7                    | 1 109 647| 59.68            | 2.54     |
| 2016/17| 2 945 483              | 1 106 727                    | 37.57                   | 1 77 215 | 60.16            | 2.26     |
| 2017/18| 2 475 975              | 2 121 816                    | 36.90                   | 1 245 470| 58.93            | 4.15     |

Note: GOT, ginning out turn.

According to FAS, ETIDI and Ethiopia’s National Cotton Development Strategy, the total amount of land cultivated in 2018/19 is 80 000 ha². From this about 154 000 t of raw cotton is produced. Therefore, after ginning of this raw cotton about 57 000 t of lint cotton, 87 000 t of cotton seed and 9240 t of cotton ginning trash is produced from all Ethiopian ginning factories. Currently cotton seed was sold for oil producing companies and ginning trash is disposed in landfill. The price of cotton seed varies with seasons, especially in...
summer and if food oil is available, the price of the cotton seed becomes low. Some ginning factories pay for disposal of their wastes like ginning trash.

4. Utilization of Cotton Stalk and Cotton Ginning Trash: Present Scenario

4.1. Physicochemical properties of cotton stalk and cotton ginning trash

Physical and chemical properties of cotton by-product vary with different conditions, including growing location, season, harvesting, processing methods, varieties, method of cultivation, rainfall, soil type as well as analysis procedures (Silverstein et al., 2007; Binod et al., 2012). Today in Ethiopia there are 34 different cotton varieties, out of these 29 varieties are for irrigated areas and the rest 5 varieties are for rain fed areas (Bedane and Egziabher, 2019). Researchers studied chemical, morphological and anatomical properties of cotton stalk in Turkey (Tutus et al., 2010). Based on their result, the traversing section of cotton stalk from bark to core has four distinct tissue systems (Fig. 6): vessels, fibres, parenchyma cells and collenchyma when observed with light microscope.

![Transversal sections of cotton stalks stem](image)

**Fig. 6** Transversal sections of cotton stalks stem (Tutus et al., 2010)

The cotton stalks contained short fibers with 0.81 mm mean length and 24.98 μm width, lumen (16.75 μm width) and cell wall (4.12 μm thickness) (Fig. 7). Physicochemical properties of cotton stalk collected from large-scale farms at Upper Awash Agro-Industry was studied by Tadesse (2018) and their findings were shown in Table 4.

![Macerated sample of cotton stalks stem](image)

**Fig. 7** Macerated sample of cotton stalks stem (F: fibers; P: parenchyma cells; and V: vessels) (Tutus et al., 2010)
Table 4 Composition and heating value of cotton stalk (Tadesse, 2018)

| Parameter          | Cotton stalk |
|--------------------|--------------|
| Proximate analysis |              |
| Moisture content (%) | 8.33         |
| Ash content (%)    | 5.63         |
| Volatile matter (%) | 78.437       |
| Fixed carbon (%)   | 15.933       |
| Elemental analysis |              |
| Carbon (%)         | 44.418       |
| Hydrogen (%)       | 5.787        |
| Oxygen (%)         | 49.795       |
| H/C                | 0.1303       |
| O/C                | 1.121        |
| Elemental composition of ash |      |
| CaO                | 27.51        |
| MgO                | 10.47        |
| Fe₂O₃              | 6.74         |
| Al₂O₃              | 7.89         |
| SiO₂               | 22.47        |

Ma et al. (2015) have studied the properties of cotton stalk to extract cellulose fibre. Based on their experimental result the chemical composition of cotton stalk is varying from section to section within a single stem as presented with Fig. 8 and Table 5, respectively.

![Cotton stalk break section](image)

**Fig. 8** Cotton stalk break section

Table 5 Properties of different cotton stalk bark section

| Parameter       | First section | Second section | Third section |
|-----------------|---------------|----------------|--------------|
| Wax (%)         | 3.16          | 1.02           | 0.96         |
| Water soluble (%)| 17.66        | 16.10          | 14.70        |
| Pectin (%)      | 4.67          | 3.84           | 2.86         |
| Hemicellulose (%)| 26.99        | 24.22          | 23.34        |
| Lignin (%)      | 23.35         | 22.54          | 21.58        |
| Cellulose (%)   | 23.72         | 32.28          | 36.56        |

Source: Li and Zhao, 2015.

The composition analysis of cotton stalk (Indian) was determined by (Binod et al., 2012) as per the National Renewable Energy Laboratory (NREL) protocols and the result shows that 30% cellulose, 13% hemicelluloses and 31% lignin. Soni et al. (2015) studied the chemical composition of cotton according to the high performance liquid chromatography (HPLC) analysis and their results showed that the dry biomass of cotton stalk contains 65.8% carbohydrate, 30.9% lignin and 1.8% ash. The carbohydrate part consists of 40.1% glucose, 19.3% xylose, 2.4% galactose, 1.9% arabinose and 2.1% mannose (Binod et al., 2012; Soni et al.,
2015). Valorisation of these wastes needs in-depth analysis on chemical composition of cotton stalks (Huang et al., 2015; Soni et al., 2015; Keshav et al., 2016; Akperov and Akperov, 2019).

Cotton gin waste is a heterogeneous material composed of clean lint, seeds, hulls, leaves, sticks, and dirt (Huang et al., 2015). Cotton gin trash is a by-product of cotton ginning which is considered as waste in most Ethiopian ginneries. But this waste material can be utilized and converted into valuable materials. The conversion of cotton ginning trash depends on the level of impurities and its physicochemical properties.

Huang et al. (2015) studied the physicochemical properties of cotton ginning waste that collected from four different ginning industries in USA. The cotton seed shows the highest variation, which ranges from 0% to 24% and the fractions of stem and grass were very small. According to this study cotton ginning waste contains small leaf fraction (14%–35%), clean lint (5.3%–15%), hulls (17%–48%), stick/stems (3.6%–7.1%), grass (0.1%–1.1%), seed (0%–24%), motes (15.6%–24%), small leaf (14%–35%), pin trash (0.6%–6.7%) and others (0.5%–5.3%). This shows that the fractional composition of cotton ginning waste varied among gins as well as the ginning seasons. Chemical composition of this cotton ginning waste consists of ash (10%–22%), ethanol extractives (7.5%–11.5%), acid-insoluble material (19.2%–25%), arabinose (1.1%–3.9%), xylose (3.4%–10.5%), mannose (0.6%–2.0%), galactose (1.2%–2.9%) and glucose (25%–33%). The total fraction of carbohydrate ranges 32%–44% of dry mass of cotton ginning wastes. Out of this glucan and xylan constituted 80%–90% of the total carbohydrates. The ash content of cotton ginning waste was higher as compared with other lignocellulosic agricultural residues such as cotton stalk, wheat straw and corn stover. Agblevor et al. (2006) studied the chemical composition of the cotton gin motes and cotton gin trash obtained from United States Department of Agriculture (USDA) Research Facility in Stone-Ville, exhibits the cellulose content of 67.4% and 30.9%, respectively (Table 6).

| Component                        | Content (wt%) |
|----------------------------------|---------------|
|                                  | Gin motes     | Gin trash    |
| Extractable                      | 9.55 ± 0.09   | 19.04 ± 0.04 |
| Celluloses (glucans)             | 67.40 ± 2.40  | 30.90 ± 1.31 |
| Hemicellulose (xylans)           | 4.34 ± 0.37   | 9.74 ± 0.42  |
| Arabinan                         | 1.30 ± 0.14   | 1.45 ± 0.32  |
| Galactan                         | 1.82 ± 0.05   | 2.44 ± 0.03  |
| Acetate                          | 0 ± 0.00      | 2.77 ± 0.29  |
| Acid-soluble lignin              | 0.68 ± 0.01   | 0.76 ± 0.02  |
| Acid-insoluble lignin            | 12.77 ± 0.31  | 19.30 ± 0.43 |
| Ash                              | 0.43 ± 0.22   | 0.53 ± 0.18  |
| Other                            | 1.71 ± 1.62   | 13.07 ± 0.41 |

Therefore, cotton ginning waste a lignocellulosic material which contains cellulose, hemicellulose and lignin, is an important raw material for the recovery of biobased high value materials such as cellulose nanocrystals (CNC), activated carbon and other cellulosic-based biomaterials.

4.2. Disposal technique

4.2.1. Incineration

Currently, cotton stalks (Fig. 9) have limited use and are mostly burned on the ground (Fig. 10) especially in majority of African and Asian countries reduce the costs of land preparation for the next agricultural cycle and also prevent the spread of pests and diseases in future crops (Reddy and Yang, 2009; M. Coronado et al., 2015; Hughes, 2019; Jordan et al., 2019). According to Ethiopia cotton board, in every crop year the production of cotton stalks is more than 260 million tons. Out of this only a little quantity is being used for the purpose of home needs and the remaining quantities are being burnt in the fields.
4.2.2. Controlled land filling
Currently more than 9000 t of cotton ginning trash are generated in Ethiopian cotton ginning industries. Out of this much amount of this waste is unutilized and disposed in the land fill. This disposal of ginning waste has additional costs for transportation and the land besides the water and land pollution. As observed in the field visit, some ginning factories pay for disposal of their ginning trash.

4.3. Current uses
Currently in Ethiopia only very little portion of cotton stalk is being used as raw fuel for household purposes and small portion of cotton ginning trash is used for animal feed.

5. Utilization of Cotton Stalk and Ginning Trash: Prospects
As discussed in the previous sections, currently Ethiopian cotton stalk and cotton ginning trash are unutilized to produce agricultural lignocellulosic by-products, which can be converted into different biomaterials and biofuels. However, currently there is no academic literature which shows how Ethiopian cotton stalk and ginning trash can be utilized into various biomaterials and biofuels. Because of this scenario, the current by-products generating from cotton cultivation and cotton ginning industries resulted in environmental pollution. The aim of this review paper is to indicate the possible utilization opportunities of cotton stalk and cotton ginning wastes available in Ethiopia. Proper utilization of these inexpensive, renewable, and widely available cotton by-products become a source of income generation and it prevents environmental pollution by avoiding disposal of wastes in the land fill and burning cotton stalk in open air. Therefore, different high value materials can be synthesized and produced from these unutilized cotton by-products.
Cotton stalk and ginning trash are lignocellulose, a combination of cellulose, hemicellulose, lignin, ash, and others (Hughes, 2019). Currently supramolecular structure of lignocellulose biomass can be converted into smaller molecules with different methods including acid, alkali, high temperature or pressure, radiation, microwave, ionic liquids, enzyme and other physical, chemical, or biological methods (Chen, 2015). Cotton stalk can be used as a renewable material for production of value-added products, such as ethanol, glucose, xylose, xylitol, xylooligosaccharides (XOs), CMC, CNC, etc. (Chen, 2015). Similarly cotton ginning trash can be used to produce cellulose based high value materials.

5.1. Recovery of xylan and its derivatives from cotton stalk and their applications

Lignocellulosic biomass is composed primarily of cellulose, lignin, and the hemicellulose. In addition to these, it also constitutes a small amount of pectin, protein, wax and extractives (Akpinar et al., 2011; Naidu et al., 2018). Cotton stalk is one of highly available lignocellulosic agricultural residues, which contains cellulose (35.00%–37.00%), xylan (21.42±1.96%) and lignin (19.87%–28.88%) (Akpinar et al., 2007; Deng et al., 2009; Rennie and Scheller, 2014). But the composition of these constituent elements of cotton stalk varies depending on the types of species, environmental condition and other related factors.

Cellulose is the most abundant biomass in earth which mainly is found in plants and agricultural products and residues. It consists of D-glucose units which are joined via β–1,4–glycosidic linkage and a long cellulose chain is formed by combining each repeating glucose unit with hydrogen bond and van der Waal forces and microfibrils are formed by cross-linking of the cellulose chains through hydrogen bond as shown in Fig. 11. Lignin is hydrophobic, extremely resistant to chemical and enzymatic degradation, which is made up of phenylpropane units, and is closely bound to hemicellulose and cellulose. It acts as the glue and provides structural integrity and rigidity of lignocellulosic biomass. Hemicelluloses are made up of 1,4 linked β-D–pyranol residues such as glucose, mannose and xylose (Deng et al., 2009).

Fig. 11 Illustration of lignocelluloses biomass (Naidu et al., 2018)

Xylan mainly consists of xylose units with various additional substitutions such as acetyl, glucuronic acid (GlcA), 4–O–methylglucuronic acid (Me-GlcA), and arabinoseresidues. But their composition varies with the type of plant and also type of varieties even in one plant species (Naidu et al., 2018). Chemical composition of cotton stalk xylans consists (83.60 ± 0.66)%, (7.12 ± 0.73)%, and (9.28±1.29)% of xylose, glucose and uronic acid respectively and it can be used as a renewable raw material for a variety of chemical productions such as ethanol, glucose, xylose, xylitol, and XOs.

As shown in Fig. 12, cotton stalk xylans contain about 83% of xylose and are possible to extract xylose components from cotton stalk. From this extracted xylose different biochemicals and biobased products can be produced. Ethanol, LA, xylitol, and furefural are the most common biobased chemicals which are recovered
from xylose. The most common solvent, ethanol can be extracted from xylose and it can also be used as fuels. The other very important biochemical produced from the cotton stalk xylan is lactic acid which has wide application areas like textile industries, biomedical and for synthesis of bioplastics. Xyilot is used in food, deontological and pharmaceutical industries. Biobased hydrogel, bio-composite and XOs are biobased materials extracted from the cotton stalk xylan and each of these products has wide applications and their applications are discussed as in the following sections.

Fig. 12 Biobased materials extracted from cotton stalk and their applications (Naidu et al., 2018)

5.1.1. Applications of XOs
The XOs (sugar oligomers made up of xylose units) is high value-added ingredients for functional foods which are used to reduce cholesterol, maintain gastrointestinal health, and improve the biological availability of calcium, and can be produced from cotton stalk by different production methods including enzymatic production methods, chemical fractionation and hydrolytic degradation (Vázquez et al., 2000; Akpinar et al., 2007; Rennie and Scheller, 2014). As presented in Fig. 13, it is used for food and non-food applications.
The XOs are stable for a wide range of pH (2.5–8.0) and temperature (up to 100 °C) and used as a food ingredient because of wide varieties of biological, nutritive and technological properties such as an acceptable odour, and non-cariogenic and low-calorie, allowing their utilization in anti-obesity diets, and ability to stimulate the growth of intestinal bifidobacteria (Vázquez et al., 2000). They can inhibit starch retrogradation, improve the nutritional and sensory properties of food. They have many health benefits. For example they are used as prebiotics for selective stimulating the growth of beneficial gut microbiota, reduction in blood glucose and cholesterol, reduction of pro-carcinogenic enzymes in the gastrointestinal tract, enhanced mineral absorption from large intestine and immune-stimulation (Vázquez et al., 2000; Akpinar et al., 2007).

5.1.2. Application of xylitol
Xylitol (C$_5$H$_{12}$O$_5$) is also known as polyol or polyhydroxy alcohol which is a pentitol type (Fig. 14) natural compound. It is stable in a wide range value (1–11) (Mussatto, 2012). Xylitol is a biomaterial produced from cotton stalk by acid hydrolysis method (Akpinar et al., 2007). It has various applications such as food, dietary supplements, pharmaceuticals, cosmetics, oral hygiene products, medical applications for the prevention and treatment of human health treatment of acute otitis media and respiratory infections.

Since xylitol has high chemical and biological stability, it is used as food preservatives. It has many advantages as compared to sucrose and other polyols like sorbitol, arabinol, and mannitol. Xylitol is found in
chewing gum, confectioneries (including candies, jellies, pastilles, toffees, lozenges, tablets, and mini-mints), chocolates, frozen desserts etc. as a sweetening agents and preservatives. As shown in Fig. 15, it has many application areas due to its nutritious and is beneficial to health. It is used for treatment of diseases (like diabetes, hemolytic anemia and renal and parenteral lesions) and prevention of diseases such as dental caries, acute otitis media, osteoporosis, respiratory infections, inflammatory processes and colon diseases (Mussatto, 2012; Naidu et al., 2018).

Fig. 15 Industrial applications of xylitol (Naidu et al., 2018)

5.1.3. Application of xylan based hydrogels
Hydrogels are three-dimensional cross-linked polymeric networks that can imbibe large amounts of water or biological fluids. Cellulose based hydrogels can be producing from cotton stalk xylan and their in-vivo swelling property, mechanical strength, and the compatibility with the biological tissues have attracted different applications such as pharmaceutical, drug delivery and biomedical engineering (Lugani and Sooch, 2018).

Xylan based hydrogels has been used for a wide range of applications (Fig. 16), for example it is used as a water remediation tool for the absorption of heavy metals, drug carrier systems for a number of reasons such as immunological defence, inhibition of cell mutation, anti-cancer and antioxidant properties, and it also is possible to produce photo-responsive hydrogels for selective drug release with azobenzene a copolymer (Das, 2018).
Multi applicable (Fig. 18) cellulose-based superabsorbent hydrogels can be synthesised from cellulosic biomass like cotton stalk and cotton ginning trash, by two techniques/methods, chemical methods like aqueous solution polymerization, inverse-phase suspension polymerization, and microwave radiate and physical cross-link techniques like freeze/thaw cycle technology and hydrogen bond crosslink. Introducing of this cellulosic based superabsorbent hydrogel helps to overcome the disadvantages of synthetic-based superabsorbent and it has additional advantages like high absorbency, high strength, good salt-resistance, excellent biodegradable ability and biocompatibility, and other special functions that promise a wide range of applications in many field. So, the production of this super absorbent material helps to produce biocompatible, environmentally friendly, biodegradable and affordable sanitary and hygiene products.

Currently more than 90% of personal care products are made of synthetic based superabsorbent hydrogels. Personal hygiene products including disposable diapers, training pants and adult incontinence products (Fig. 17) use superabsorbent hydrogels to absorb fluids and moistures from skin in order to improve health and comfort of consumer (Bashari et al., 2018). But cellulose based superabsorbent hydrogels are preferable for personal care products due to their biodegradability, environmentally friendly, environmentally sustainable production process and biocompatibility features (Sannino et al., 2009; Kabir et al., 2018).
Besides comfort, the use of superabsorbent hydrogels in personal hygiene products controls the spread of germs, reduces the risk of fecal contamination and generally it helps to reducing the risk of spread of gastrointestinal illnesses (Sannino et al., 2009; Kabir et al., 2018; Mao et al., 2019). Due to compatible and nontoxic to the biological cells and tissues (Das, 2018) (Fig. 18), cellulose based hydrogels are used for biomedical applications mainly as drug delivery, wound healing and tissue engineering.

5.2. Lactic acid and its applications
Lactic acid could also be produced from cotton xylan and it is used for packaging, prosthetics, and drugs (Kabir et al., 2018). As it is clearly seen in Fig. 19, different chemicals could also be produced from lactic acid through oxidation, dehydration, esterification, self-esterification and hydrogenation processes.

![Scheme showing chemicals that can be produced from lactic acid](image)

**Fig. 19** Scheme showing chemicals that can be produced from lactic acid (Kabir et al., 2018)

A wide range of catalytic transformations of lactic acid are feasible leading to the selective production of green solvents, fine chemicals, commodity chemicals and fuel precursors (Fig. 20).

![Role of catalysis in novel synthesis routes to lactic acid and in its use as a platform](image)

**Fig. 20** Role of catalysis in novel synthesis routes to lactic acid and in its use as a platform (Naidu et al., 2018)

The polylactic acid (PLA) has raised interesting in biotechnological, biomedical, drug delivery systems, cosmeceutical products, and therapeutic applications. So far, many of such PLA-based bio-constructs have been exploited (Fig. 21).
5.3. Recovery of carboxymethyl cellulose (CMC) from cotton stalk and its application

Since cotton stalk and cotton linters from the ginning wastes rich lignocellulose, can be converted into bioproducts like CMC, which are widely used in detergent, food, paper, paint, textile, pharmaceutical and cosmetic industries as thickening, binding, emulsifying, film-forming, lubricating, dispersing, stabilizing and gelling agent (Zhang et al., 2011; Ruiz-Ruiz et al., 2017; Huang et al., 2017). Multiapplication of this biobased material is due to its properties shown as in Fig. 22. Currently Ethiopian industries imported CMC for different applications. So, recovery of this multi-functional biomaterial from unutilized cotton residue helps to save foreign currency besides environmental protection. If this product is produced locally, textile industries use as a sizing material which improves weave-ability in loom shed, facilitates the desizing process and also reduces power consumption of sizing and desizing processes.

Due to its hydrophilic character, good film forming properties, high viscosity, and adhesive performance, among other features, CMC has a wide variety of applications as describing in Fig. 23. The use of CMC in construction industries improves the dispersion of sand in the cement and intensifies its adhesive action due to hydrophilic and stabilizer nature. The addition of CMC in detergents helps to inhabit redeposition of grease. In paper industry, coating papers with CMC improve smoothness and lustrous of paper, reduce the consumption of

Fig. 21 The PLA application as drug delivery (Dusselier et al., 2013)

Fig. 22 Functions and properties of carboxymethyl cellulose (CMC) (Huang et al., 2017)
wax and printing ink, improve grease resistance and prevent flocculation. Generally, the CMC is used as a thickener, suspending agent and film forming in paints and cosmetics like shampoos, lotions, creams, and other hair care products, similarly in food industries it acts as auxiliary agent, thickener, and fillers. It is also used as suspending agent and adhesives in agricultures.

Fig. 23 Application of CMC (Ruiz-Ruiz et al., 2017)

5.4. Recovery of crystalline nanocellulose (CNC), CMC, cellulose nanofibers (CNF) from cotton stalk and its application

Nowadays most of inorganic materials are substitutes with biomaterials, because biomaterials are produced from renewable biomass and they are environmentally friendly, biocompatible and biodegradable. Cellulose is an abundance biomass on earth, which is mainly found in plants and agricultural products and by-products. Agricultural by products like cotton stalk and cotton ginning trash are lignocellulosic biomass are one of the major renewable sources for production of nanocellulose such as CNC, bacterial nanocellulose (BNC) and microcrystalline cellulose (MCC) and CNF (Haleem et al., 2014) (Fig. 24).
The CNF can be used in wide applications such as biomaging and biomedical materials, nanofillers for polymer nanocomposites, protective coatings, barrier membranes and filtration media, transparent films, antimicrobial films, pharmaceuticals, drug delivery, and components of electronic devices (Fig. 25).

5.5. Bacterial cellulose in biomedical applications

Because of the ideal structure, biocompatibility, and sustainability of bacterial cellulose (BC), it is used in a variety of applications, such as medical (Fig. 26), food, paper, textiles, and electronics (Shankaran, 2018). Since the number of industries are rapidly increasing, high amount of liquid waste is released to water bodies without treatments. This affects aquatic living things as well as others including human beings. So, production of environmental adsorbents activated carbons from cotton gin waste and cotton stalk helps to prevent environmental pollution (Klasson et al., 2009; Wang et al., 2012; Moniri et al., 2017). Activated carbon can also be used for electronic component such as supercapacitor (Deng et al., 2011).
6. Conclusions
Deriven by huge population growth and rural poverty, biomass is expected to source significant share for ethiopian economy. With the assistance of sustainable waste management approaches biomass resource such as cotton stalks and cotton ginning trash can provide different economic benefits. This article has identified the potential availabilities of cotton stalk and cotton ginning trash for further high value added biobased materials in ethiopia that may assist the country’s sustainable development. According to the availability study result, 80 000 hm² are cultivated by cotton plants and produced 154 000 t of raw cotton annuly. Therefore, after ginning of the raw cotton about 57 000 t of lint cotton, 87 000 t of seedcotton and 9540 t of cotton ginning trash is produced from all ethiopian ginning factories. However, these huge amounts of by-products are currently unutilized just thrown to controlled land fill and incineration. This uneconomical disposal technique also resulted in environmental pollution. As different studies approved, cotton stalk and ginning trash are cellulose based by-products in the value chain of textile industries. There are several options to convert these cellulosic resources to various alternative materials. Policies should incorporate holistic social, cultural, economic and technological renovation for better utilization of these biomass resources. Hence, assuring the sustainability of biomass resource utilization and synchronously increasing the supply of materials through measures like import substitution are animated intervention fields. Enhancing research and development capacities and dissemination biorefinery technologies are important policy measures to be taken for modern textile waste utilization alternatives.

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Conflict of Interest
There is no conflict to declare.

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