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Electrochemical Energy Storage Electrodes from Potato Biochar: A Minireview

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ABSTRACT

The production and storage of energy from sustainable and renewable resources such as biomass have become one of the most significant issues worldwide. Biomass has become very popular in recent decades due to reducing environmental pollution and production costs. Potato is one of the best biomass resources due to its abundant availability, high yield, and potential for conversion into various forms of energy and valuable chemicals. This review aims to prepare an overview of the progress in the potato-based electrochemical energy storage (EES) electrode as the most essential part of the electrochemical energy storage (EES) devices, which includes batteries, supercapacitors, and hybrid devices. The carbonized potato waste (potato biochar) can be used as electrodes of batteries, supercapacitors and hybrid devices. The potato biochar's electrochemical results in the EES devices have been reported and compared. The results indicate that potato biochar has acceptable electrochemical activity besides its low cost and environmentally safe performance.

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1. Introduction

In recent years, the energy demand has increased surprisingly due to the increase in the earth's population. This factor has caused extensive environmental damage, global warming, ozone depletion, and plant and animal species extinction can be mentioned. Renewable energies are a promising solution, offering a cleaner and more sustainable way to power our lives. Biomass is one of the best and most effective energy production and storage sources.

Biomass is a renewable energy source that is generated from organic materials, such as plants, wood, and agricultural waste. It has gained popularity as a sustainable and environmentally-friendly alternative to non-renewable energy sources, such as oil and coal. Biomass can be used for various applications, including electricity generation, heating and cooling, transportation fuels, and chemical production.

The process of generating energy from biomass typically involves either combustion or gasification. Combustion involves burning biomass to produce steam that powers turbines, generating electricity. Gasification consists of converting biomass into a gas, which can be used as fuel for many applications.

Biomass is an attractive energy option because it reduces greenhouse gas emissions and helps tackle climate change. Unlike fossil fuels, biomass is a carbon-neutral resource, which releases the same amount of carbon dioxide during burning or gasification as the plant absorbed during its growth.in addition to the environmental benefits, biomass reduces production costs.

Energy storage is a topic that has attracted a lot of attention in recent years. Here, electrochemistry has come to the aid of humans and helps us reduce costs and environmental problems.

One of the most efficient energy storage methods is electrochemical energy storage (EES), which uses electrochemical processes to store and discharge electrical energy. EES devices are important components in many applications, including portable electronics, electric vehicles, and distributed renewable energy systems.

Batteries, supercapacitors, and hybrid devices are some of today's most prominent energy storage devices. They serve different purposes and offer unique benefits and drawbacks, but both are essential in our modern world, powered by electronics and renewable energy.

Battery technology has a long history dating back to ancient times. The "Baghdad Batteries" were one of the earliest known battery-like devices, which consisted of an earthenware jar holding copper cylinders and iron rods immersed in an electrolyte solution. These batteries were not as powerful as modern ones, but they were an early expression of people's curiosity and experimentation with electricity and electrochemistry. Similarly, primitive galvanic cells were discovered in the ruins of the ancient Greek city of Ephesus, dating back to around 600 BCE. These devices were used to perform electroplating and may have used vinegar or lemon juice as an electrolyte.

One of the most critical inventions in electronics is capacitors. This device, which stores and releases electrical charge when needed, is integral to numerous electronic applications, from radio and television to computer and power grids. The capacitor, invented in the late 18th century, has undergone significant advancements and improvements over the years, leading to the development of a modern version known as the supercapacitor.

Since batteries have the highest energy density and supercapacitors have the highest power density among EES devices, hybrid devices were produced to simultaneously have the highest energy density and power density. The EES devices have several advanced applications to store electrochemical energy and deliver it in an optimized procedure [1].

The main parts of the EES device include electrodes, binders, electrolytes, and membranes. Several studies have been done to improve all four elements.

Many efforts have been made to perform electrochemical devices through inorganic, organic, organic-inorganic hybrid materials, and biomass.

All parts of EES can be made from biomass, and many studies have been done in this field. The use of biomass has two benefits for us, firstly, reducing production costs, and secondly, it is more compatible with the environment.

Plants are one of the best sources of biomass on earth, and potato biomass is one of the most promising sources of biomass due to its abundant availability, high yield, and potential for conversion into various forms of energy. Potato biomass can be converted into many forms of energy, such as biogas, biofuel, and electricity, making it a versatile and practical energy source that can be utilized in various applications. In this article, we will explore potato biomass's potential as a source of renewable energy, its advantages, limitations, and current applications in the energy sector.

According to the FAO data, updated in December 2022, 376.12 million metric tonnes of potatoes were produced worldwide. The largest potato-producing countries are listed in **Figure 1**.

Also, **Figure 2** illustrates the changes in potato production in the last two decades.

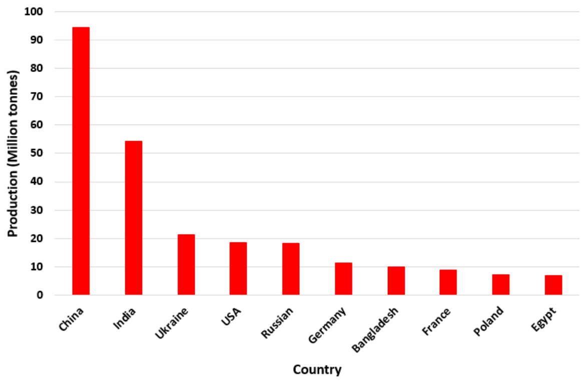

Figure 1. The top ten potato producers in the world in 2022

As for consumption, Belarus has the highest per capita consumption of potatoes, with an average of over 360 kg consumed per person per year. Other countries with high per capita potato consumption include Latvia, Ukraine, and Lithuania. Regarding total potato consumption, China, India, and the United States are the top three, followed by Russia and Germany.

According to the United Nations Environment Programme, approximately one-third of all food produced is lost or wasted yearly, with root and tuber crops (including potatoes) having one of the highest waste rates. In Europe alone, it is estimated that 48 million tonnes - or 16% - of all potatoes produced are lost or wasted each year. In the United States, the potato industry is estimated to generate approximately 3.8 billion pounds (or 1.7 million tonnes) of potato waste annually.

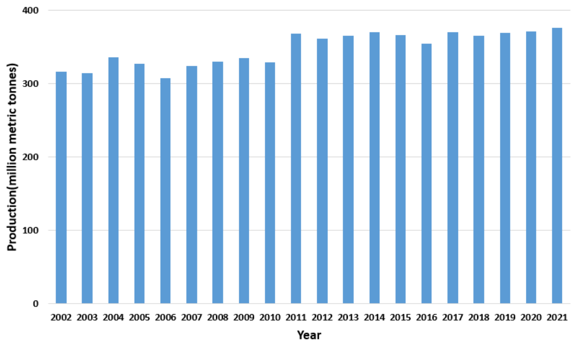

Figure 2. The global potato production in (2002-2021).

Some common causes of potato waste include spoilage during storage and transportation, overproduction or surplus on farms, and misshapen or visually unappealing potatoes being discarded.

Efforts are being made to reduce potato waste, such as using unwanted or surplus potatoes to produce animal feed or biofuels. The biochar-based electrode for batteries and supercapacitors have been extensively studied in recent years [2–4]. Different physicochemical modifications have been developed to improve the electrochemical properties of the biochar-based electrodes through increasing porosity [5,6] and generating functional groups in the carbon structure [7].

2. Results and Discussion

2.1. Potato-based electrodes for batteries

The electrodes of the batteries including the anode and cathode can be fabricated from biochar materials [8]. The studies that reported potato biochar-based electrodes for batteries are reported in **Table 1**. Also, potato-based starch can be used as an anode binder for Li-ion batteries [9], potato-based biochar as an electrocatalyst for zinc-air batteries [10], and electrolytes like potato starch-magnesium acetate electrolyte [11] and potato starch-based gel polymer electrolyte [12]. Therefore, different parts of the batteries can be prepared from potato wastes as a low-cost and benign resource to overcome the global crisis in battery production, especially for electric vehicles (EVs). In the following tables, pyrolysis atmosphere (PA), modification method (MM), specific surface area (SSA), initial discharge capacitance (IDC), cycle stability (CS), cycle stability percent (CSP), and hydrothermal pyrolysis (H_2O) have been reported. The CSP can be calculated by the following equation:

$$\mathrm{CSP}\ (\%) = \left(\frac{\text{Final discharge capacity}}{\text{Initial discharge capacity}}\right) \times 100$$

There are only six studies on potato biochar-based electrodes for batteries (**Table 1**). It means this subject should be more developed in the future. Also, the best results of Table 1 are reported in **Table 2**. Most publications have used KOH for the chemical modification of biochar materials. Potato starch has considerable potential to be used as a precursor for battery electrolytes. Therefore, future studies on electrolytes should more focus on low-cost starch-based electrolytes.

Table 1. The potato biochar-based electrodes for batteries.

Potato waste	Battery	Electrode	PA	MM	SSA ($m^2\ g^{-1}$)	IDC ($mAh\ g^{-1}$)	CS (Cycles)	CSP (%)	Year	Ref
Potato	K-ion	Anode	Ar	None	620.77	~ 220	400	87.5	2019	[13]
Potato starch			N_2	KOH	954	~ 50	1000	~ 50	2022	[14]
Sweet potato	Li-ion		Ar	H_2O	79.1	~ 440	50	~ 40	2015	[15]
Potato starch			N_2	None		~ 750	70	~ 50	2021	[16]
Potato Peel	Li-S	Cathode							2021	[17]
Sweet potato			N_2	KOH	991	1035.8	100	60.24	2022	[18]

Table 2. The best results of the potato biochar-based electrodes for batteries.

	SSA ($m^2\ g^{-1}$)	IDC ($mAh\ g^{-1}$)	CS (Cycles)	CSP (%)
Content	991	1035.8	400	87.5
Potato waste	Sweet potato		Potato	
Battery	Li-S		K-ion	
Electrode	Cathode		Anode	
PA	N_2		Ar	
MM	KOH		None	
Ref	[18]		[13]	

2.2. Potato-based electrodes for supercapacitors

The potato-based biochar as a low-cost porous carbon substance can be used as supercapacitor electrodes. The studies that reported potato biochar-based electrodes for supercapacitors are reported in **Table 3**. Also, the best results of Table 1 are reported in **Table 4**. The gravimetric energy density (ED) and gravimetric power density (PD) as two significant supercapacitor parameters are reported in **Table 3**. The PD is reported at the highest ED to facilitate the comparison of the supercapacitors. The higher ED and PD indicate the better performance of the supercapacitor. Potato starch can be used as a supercapacitor electrolyte [19]. As mentioned in the previous section, potato starch can prepare electrolytes. Recent studies have determined the potential of potato starch as a supercapacitor electrolyte [20,21]. The Ragon plot (**Figure 3**) has determined the energy density and power density of the supercapacitors (**Table 3**).

Table 3. The potato biochar-based electrodes for supercapacitors.

Potato waste	PA	MM	SSA ($m^2\ g^{-1}$)	SC ($F\ g^{-1}$)	ED ($Wh\ Kg^{-1}$)	PD ($W\ Kg^{-1}$)	CS (Cycles)	CSP (%)	Year	Ref
Potato	N_2	$ZnCl_2$	1052	255			5000	93.7	2015	[22]
		H_2O	330	134					2020	[23]
	N_2	None		223			5000	92.6	2021	[24]
Potato peel		KOH	1911.5	323	45.5	800	10000	94.3		[25]
		KOH, H_2SO_4		237			1000	80	2021	[26]
Potato starch	N_2	KOH	2342	314			900	86	2009	[27]
		$Fe(NO_3)_3$	1930	268					2012	[28]
		H_2O	456	245	21.5	759	4000	98	2015	[29]
		H_2O, KOH	3300	160			10000	90		[30]
	CO_2	None	2437.1	161.9					2018	[31]
	N_2	KOH	1367.87	272	25.9	249.6	10000	97		[32]
		BiOCl, H_2O, K_2CO_3		1243	17.2	250.9	3000	90.3		[33]
Rotten potato		KOH	960	269	4.27	405.6	7000	95	2016	[34]
		None	2201	54	20.8	524	5000	~ 100	2021	[35]
Sweet potato leaves	N_2	H_3BO_3	844	296	14	1200	10000	96		[36]
Sweet potato starch		KOH	3072	372					2019	[37]

Table 4. The best results of the potato biochar-based electrodes for supercapacitors.

	SSA ($m^2\ g^{-1}$)	SC ($F\ g^{-1}$)	ED ($Wh\ Kg^{-1}$)	PD ($W\ Kg^{-1}$)	CS (Cycles)	CSP (%)
Content	3072	372	45.5	800	10000	97
Potato waste	Sweet potato starch		Potato peel		Potato starch	
PA	N_2					
MM	KOH					
Ref	[37]		[25]		[32]	

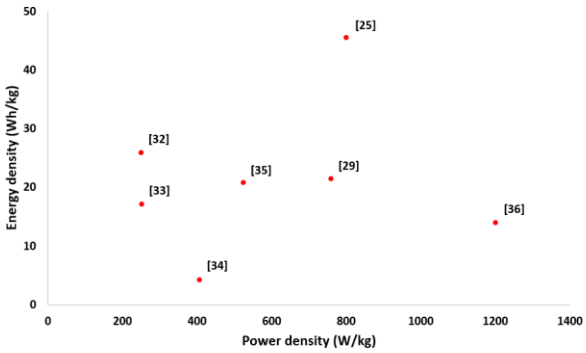

Figure 3. The Ragon plot of potato biochar-based electrodes for supercapacitors.

2.3. Potato-based electrodes for hybrid EES devices

The hybrid EES devices have a battery-like anode and a capacitor-like cathode and are considered the next generation of EES devices to have higher ED and PDs. Batteries have higher energy densities and supercapacitors have higher power densities but the hybrid EES devices (like Li-ion capacitors and Na-ion capacitors). The number of studies on biochar-based electrodes for EES devices is lesser than the batteries and supercapacitors. Hence, the biochar-based electrode for the metal-ion capacitors should be more developed in the future projects. The hybrid EES electrodes from potato-based biochar are listed in **Table 5**.

Table 5. The potato biochar-based electrodes for hybrid EES devices.

Potato waste	PA	MM	SSA ($m^2\ g^{-1}$)	SC ($F\ g^{-1}$)	ED ($Wh\ Kg^{-1}$)	PD ($W\ Kg^{-1}$)	CS (Cycles)	CSP (%)	Year	Ref
Sweet potato		$ZnCl_2$, KOH	3424	336	112	385	10000	93	2021	[38]
Potato starch	N_2	KOH	2760	106.6	51	91	10000	97.9	2022	[39]

According to the data in Table 2, 4 and 5, the modification of the potato biochar especially with potassium hydroxide has a considerable influence on their electrochemical properties as electrodes for supercapacitors and batteries. Also, the thermal parameters like heating time, heating temperature, and heating rate can improve the SSA value and electrochemical properties.

3. Conclusion

The potato wastes as low-cost, available, and benign resource can be used to prepare biochar materials. The potato-based biochar can be used to fabricate electrodes for the EES devices like batteries and supercapacitors. The electrochemical properties of the potato biochar determined its acceptable potential as the EES electrodes. The chemical modification and pyrolysis conditions can improve the electrochemical properties of potato biochar.

Conflict of interest

The authors declare no competing interests.

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