Journal of **Concepts in Structural Biology & Bioinformatics**

BIOTECHNOLOGY ARTICLES

Research article: Master's research based.

This paper is related to a project Master's degree in Biological Sciences Startup Diploma 2022-2023, within the framework of the Ministerial Decree 1275.

هذا المقال حول مشروع ماستر 2022-2023 لنيل شهادة مؤسسة ناشئة في إطار القرار الوزاري 1275

Bioconversion of Potato Peels Waste into Starch and Bioplastic

REGUIG Sabah[1], TEMAR Abir [1] and RACHEDI Abdelkrim [*,1]

[1] Laboratory of Biotoxicology, Pharmacognosy and biological valorisation of plants, Faculty of Sciences, Department of Biology, University of Saida - Dr Moulay Tahar, 20100 Saida, Algeria.

[*]**Correspondence:** RACHEDI Abdelkrim – Email: abdelkrim.rachedi@univ-saida.dz, bioinformatics@univ-saida.dz

Published: 15 December 2023

Abstract

This research project investigates the conversion of potato peels waste into a valuable resource, primarily focusing on starch production as a market-competitive alternative to corn-starch. The study explores the feasibility of utilising potato peels, often discarded as agricultural waste, to extract starch in quantities and qualities that rival traditional corn-starch. The findings indicate that the derived potato-peel-starch not only meets industry standards but presents an eco-friendly solution to waste management.

In addition to starch production, the research extends its innovation to the creation of bioplastics from potato-peel waste, offering a sustainable alternative to petroleum-based plastics.

Additionally, this research showcases the versatile applications of the obtained starch. It has been successfully utilised in the creation of microbial culture media, expanding its utility beyond traditional industrial uses. Furthermore, through composting the residual potato-peels, a natural fertilizer has been produced, contributing to sustainable agricultural practices.

The multi-purpose utilisation of potato peels for starch, bioplastic, microbial culture media, and natural fertilizer production represents a holistic approach to waste valorisation. In particular, the potential impact of incorporating potato-peel derived starch and bioplastics into various industries is significant, with implications for fostering a circular economy and reducing reliance on conventional resources. This research aligns with global initiatives for sustainable living, offering not only environmentally friendly alternatives but also multiple avenues for repurposing agricultural waste. As we address the challenges of waste management and environmental conservation, the outcomes of this study advocate for a comprehensive and sustainable transformation of agricultural by products into valuable resources, paving the way for a more resilient and eco-conscious future.

However, this paper primarily reports only the results relevant to potato-peel-starch and bio-plastic. The full description of all results obtained in this project are reported in the master thesis by Reguig and Temar, 2023.

Key words: Waste valorisation, Agricultural waste, Potato peels starch, Corn-starch, Bioplastics, Market-competitive alternative, Eco-friendly solutions, Environmental conservation.

Introduction

Plastic is a synthetic material made up of macromolecules which are made from petroleum, the petroleum is refined, distilled, which makes it possible to obtain molecules called polymers, the word plastic is of Greek origin "plastikos" which means "malleable, which can be shaped" (Kara. 2012;Laurent. 2013). The first plastic is of biomass origin, celluloid was developed by the HYETT brothers in1870 during a competition asking to find a material to replace ivory in the manufacture of billiard balls (Dorbane, Benslimane. 2014). Currently the world production is 311 million tons in 2014, of which china ranked the first producer in the world by 26 % of the world production (Pnue, 2014).

Algeria and according to the national investment development agency, plastic consumption is one million tons per year, of which 2/3 of the primary materials are imported (ANDI, 2013). And according to the national statistics office, the plastics manufacturing sector experienced an increase of 1.5 % during the year 2012 compared to previous years (OMS, 2012).According to the direction of commerce of the city of Saida, the number of plastic recycling units is seven (7) units. The quantity of plastic to be recovered for the year 2015 is estimated at only 102 tonnes at the level of the technical landfill centre in level of the city of Saida, 10km capital of the city it considered as a minimal quantity (Epgcet, 2015). Despite the wide use of plastics in our daily lives, they are exposed to widespread criticism due to their harmful impact either on the environment or on human health (Dorbane*et al.* 2012; Laurant2013).

Plastic waste causes $13 billion in financial damage to marine ecosystems (PNUE, 2014), recent studies of Bisphenol A and pH Talates, chemicals in plastics, show they can cause diseases like cancer (Laurant 2013, Pnue 2014).

According to the direction of health of the city of Saida, the number of cancer patients for period from 2011 to 2015, is 1041 patients and according to the same source that very large percentage resulting from chemical products and especially by the use of badly recycled plastic products (DSP .2015).

Considering the environmental impacts, and the health impact; the large amount of residual material from packaging made from ordinary plastic; in face of this critical situation, certain. Measures are taken into consideration such as the ban the use of single –use plastic bags, for example France ban the use of single-use bags from January 1, 2016 (energy transition law article n°75 of August 18.2015). In addition the encouragement of manufacture and use of plastic from renewable resources or bio-plastics (Kara S. 2012).

Materials and Methods

The main product that has been produced by this project is a cheaper **potato peels**' based **starch** product that has been given the commercial-name "**PeelGold**" for a Biological Sciences Startup project within the framework of the Algeria's Ministerial Decree 1275. This is proposed as a food product alternative to the **corn-starch** product available in the market known as "**Maizena**" imported from the main corn-growing countries including the United States, China, Brazil and India.

The project undertakes this bioconversion production using the available household potatoes (*Solanum tuberosum* L.) waste, mainly potato peels, thrown in waste landfills (dumps or disposal areas). Thus, this project makes a significant contribution in bio-waste recycling and waste management and in environment protection.

Additionally, this project worked on the creation of important commercial and environment-friendly products such as bioplastic, organic fertiliser (compost), bacterial culture/growth media.

Collection of the potato peels:

This project reflects the interest in sustainability and highlights the valorising potential of food waste which shouldn't be seen as just useless waste but rather a resource of raw material that can be transformed into a variety of commercially important products, Figure 1.

Figure 1. Small part of the Doui-Thabet landfill, Saida, a variety mixture of different types of waste including food waste.

A quantify of 5 kg of potato peels was used in our the project. To collect potato peelings we needed to collect potato peels from homes, order them from restaurants and procuring from municipal waste landfills, Figure 2.

Figure 2. Sample of collected potato peels at the Doui-Thabet landfill, Saida

Extraction of the Starch material:

The method employed in the extraction is outlined below is modified version of a widely recognized starch extraction protocol (Mueez S. A. *et al.*, 2023).

Material:

To extract starch from potato peels, we need the following materials:

1. Potato peels and/or potatoes leftovers
2. Water
3. Blender
4. Large pot
5. Fine mesh strainer
6. Bowl
7. Spoon.

It's important to ensure that all equipment and materials used in the extraction process are clean and free from contaminants to obtain high-quality starch. The final product is sterilised using autoclave.

Method:

There are several methods for extracting starch from potato peels. The following simple method is used:

1. Collect and wash the potato peels to remove any dirt impurities, Figure 3.
2. Cut and shred the raw material into small pieces, roughly the same size, Figure 4.
3. Pieces of the peels are placed in a large pot and add enough water to cover theme completely.
4. The mixture is mashed thoroughly with the blender until they are completely smooth and free of lumps. Figure 5.
5. Line the fine mesh strainer over another bowl and pour the mixture into the strainer,Figure 6.
6. Use a spoon to press down the mixture to help extract the starch.
7. The potato starch liquid will filter through the strainer and collect in the bowl underneath.
8. Let the potato starch settle for few hours, or until it forms a thick layer at the bottom of bowl, Figure 7.
9. Carefully pour off the clear liquid on top of the starch layer, being careful not to disturb it.
10. Once the liquid has been poured off, use a spoon to scrape the starch from the bottom of the bowl and transfer it to a clean, dry container, Figure 8.
11. Wash the resulted active-ingredient in airtight container in a cool, dry place until ready to use.

Figure 3. Potato peels after collection and washing

.

Figure 4. Shredding the quantity of the potato peels

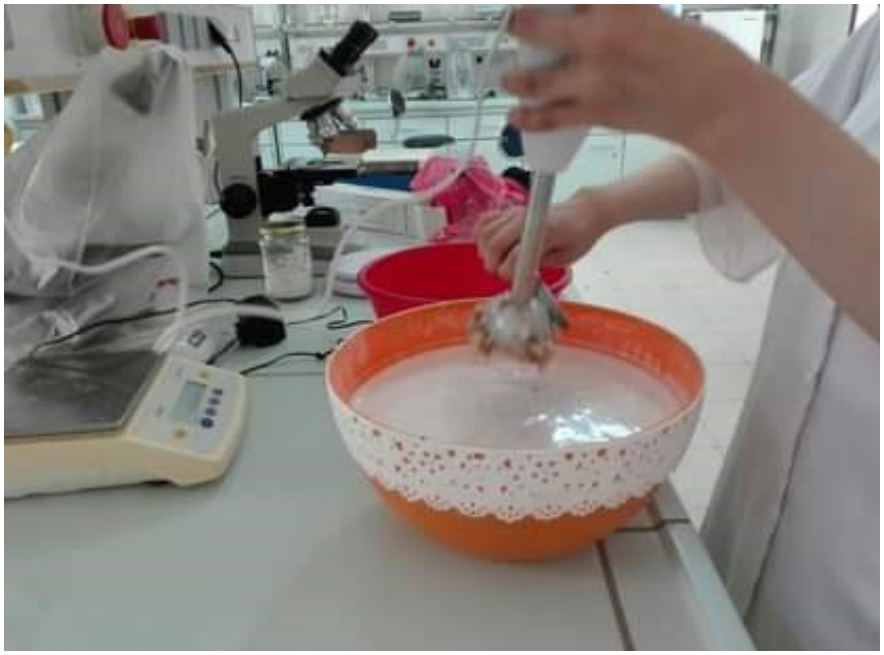

Figure 5. Potato peels mashing using a hand-held electric blender

Figure 6. Straining the mashed potato peels for starch extraction in bowl.

Figure 7. Sample of extracted and spoon collected starch after straining

Figure 8. Strained starch left to settle to the bottom of bowls.

Starch Drying and Weighing

Starch drying conditions:

The obtained starch, still wet at this stage, was dried using the laboratory drying tool ETUVE (Figure 9) set to the temperature of 30°C and fan, monitoring air circulation, set to 20% for 15 minutes, as shown below.

Figure 9. ETUVE drying machine

The process underwent two stages until drying state was achieved, Figure 10.

Stage 1:

Time 15 min →
Temp 30°C →
Fan 20% →

} semi-dried = 155 g starch

Stage 2:

Time ~~15 min~~ →
Temp 30°C →
Fan 20% →

} dried = 75 g starch

Figure 10. Dried and bottle collected starch

Bioplastic production:

In this project, a certain percentage of the starch produced in the process described above is converted to bioplastic. Below descriptions and details are provided for materials and methodology adopted from a widely recognized protocol for making bioplastic from starch (Navasingh R.J.H., *et al.* 2023).

Material:

1. Potato starch: one quantity of starch.
2. Water: four quantity of water.
3. 15 mils of acetic acid for each 50g of starch quantity.
4. 15 mils of glycerol for each 50g of starch quantity, as per need.
5. Few drop of colours (if desired).
6. Heating equipment: A stove or heating plate will be required to heat and mix the starch, acetic acid, and water.
7. Mixing utensils: Utensils such as spoon or spatulas will be needed to mix the ingredients thoroughly.

Method:

To produce bio-plastic from potato starch, the following steps have been followed:

1. Mix well the quantity of starch with the quantity of water and let it rest for few minutes around 5 min.
2. Add the acetic acid and the glycerol (when needed) and mix well.
3. Add some colour (optional) and mix, Figure 11.
4. Heat up the mixture with continuous mixing, Figure 12.
5. Cook it well until a malleable mass is obtained, Figure 13.
6. Leave to cool (to touch)for few minutes.
7. Store and/or mould the mass of bio-plastic to desired shape, Figure 14.

Figure 11: Mixing the ingredients including the colour, red colour is used in this case.

Figure 12. Heat application to the mixture

Figure 13. Malleable masses of bio-plastic coloured in red and green.

Figure 14. Example of moulding a mass of bio-plastic into a beaker shape, see also **Results & Discussion** section chapter.

The work in this project involved creating hard and flexible types of bio-plastic on the following procedural bases:

- Production of hard (not flexible) bioplastic: Use of 25 g of starch +10 mils of acetic acid 9% +100 mils of water +colour; red mass in Figure 13.
- Production of flexible bioplastic: Use 25 g of starch +10 mils of acetic acid +10 mils of glycerol +100 mils of water + colour; green mass in Figure 13. See **Results & Discussion** section for more about the types of bioplastic produced in the project.

Results & Discussion

Results of the starch production

The final obtained quantities, summarised in Table 01 below, are the results of potato-peels-starch extraction from three experiments carried out in this project, Chapter 2. Each process represents the grinding of 1 kg of potato peels and the average obtained amount of totally dried potato starch extracted from 1 kg of potato peel is 80g.These results fall within the average value reported in literature of 14 ± 2% (Alrefai R. *et. al.*, 2020) and of 13.5 – 15 % (Khanal S. *et al.*, 2023). However, the quantity of starch can be extracted from potato peels may vary depending on the type of potatoes the peels come from.

Table 01: Summary of the three experiments and obtained results

Experiments using 1kg of potato peels	Obtained Starch Semi-dried/ grams	Obtained Starch Dried/grams
1	155	73
2	182	88
3	164	79
Mean values	167	80

This average quantity of starch extracted from potato peels is obviously competitive to the imported corn-starch currently heavily consumed by our society which burdens the central bank large amounts of foreign currency. The potato-peels starch thus constitutes a primary product result of this project, Figure 15, and can potential be packaged and sold to the local market as a competitive product.

Figure 15. Example of starch extracted from potato-peels.

Potato peels sources and availability:

Large quantity and uninterrupted supply of potato peel raw material are abundantly available since potatoes are a staple crop with well-established supply chains, contributing to the reliability of sourcing potato peels. Potatoes constitute an important part of daily life consumption habit of most societies not only in Algeria but worldwide. The availability is present all year around independently of season movements and main sources can be listed below, next page:

Household bio-waste:

Households generate a significant amount of potato peels through everyday cooking practices.

Restaurant and Food Service Industry:

Large-Scale potatoes consumption restaurants and food service establishments, especially those specializing in potato-based dishes, generate substantial quantities of potato peels on a daily basis.

Potato Processing Industry:

Potato processing industry such chips producing companies generate vast quantities of potato peels.

Potatoes farms:

In addition to the potatoes themselves being the source of the potato peels waste as shown above, another source of large quantities potato waste that can be used in this project are the low quality and bad potatoes.

It is noted here that all these sources of the raw material mostly end up in the municipal landfills.

Although the exact total quantities of such types of waste in the landfill are not available, as estimation can be made based on statistics for the years 2018/2019 worked out by the Algerian National Waste Agency- Agent Nationale des Déchets (ANDوون) الوكالة الوطنية للنفايات- (AND, 2018/2019).

This government official documents states that the average quantity if waste of a verity of different types is 13.1 million tonnes for the year 2018. The amount of biological type of waste is ~ 53.6%, Figure 16, being the largest type of waste thrown in the landfills. This means that biological waste amounts to around ~ 7.02 million tonnes.

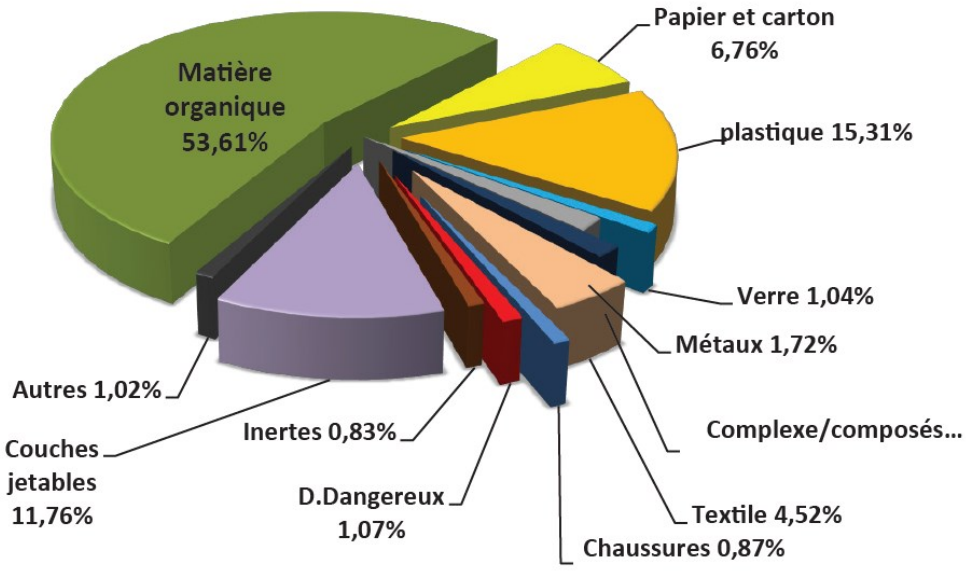

Figure 16. The average composition of household and similar waste in the 4 seasons, Algeria (AND, 2018/2019).

Though the statistics are limited, it is still possible to have a rough estimation based on the potato peels amounts and availability discussed above, it would be expected that potato peels would reach annual average quantities of the order of, at least, some few hundred thousand tonnes which still reflect a potential for large-scale starch production business.

To put this in perspective, perhaps its worth to notice that globally, it is estimated that around 8 million tonnes of potato peels waste alone could be generated in 2030 (Ebrahimian F. *et al.*, 2022).

It is, thus, safe to conclude that the obtained average quantity value of 80g/kg potato starch is very significant as it means that potato peels waste would generate an average of 80 kg/tonne of starch and for 1ktonne. This means that the potential amounts of generated starch would reach the order of thousands of tonnes yearly.

Such high potato based starch production expectations show significant market competition to the corn based starch thereby the project reflects a significant contribution to national economy in generating work opportunities, income and foreign currency savings.

Results of the production of bio-plastic

Small amounts of starch extracted from the potato peels as described in the methodology above have successfully been used to obtain bioplastic material types as described below:

Hard bio-plastic:

This type of bio-plastic has been produced without the use of glycerol and concentrations of 6% and 9% acetic acid. Two mould types of bio-plastic have been created; a thick block and sheets. As the sheets dried showed cracks, see Figure 17. The used acetic acid concentrations showed no important impact though more investigation using other grades of acetic acid may show effects on the final characteristics of the bio-plastic.

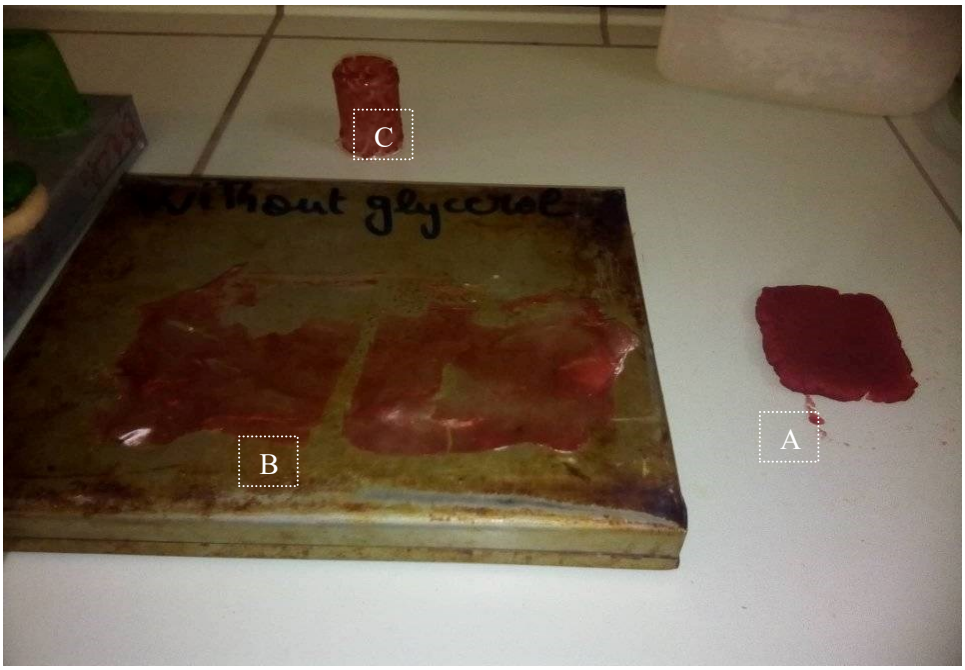

Figure 17. Hard bioplastic coloured red; A 1cm thick block, B crackable sheet and C beaker shaped mould.

Shredded hard bio-plastic:

For practical commercial reasons, the hard bio-plastic is shredded to small pieces or pallets, Figure 18. This pallets product form is commonly used for moulding into a variety of mould patterns by heat application to manufacture, for example, of hard type of kitchenware such as cups, plates and spoons.

Figure 18. Shreds or pallets of hard bioplastic that can be used in moulding process for the creation of hard type kitchenware like spoons and plates.

Flexible bio-plastic:

This type of bio-plastic has been produced with the use of glycerol and concentrations of 6% and 9% acetic acid. Two mould types of flexible bio-plastic have been obtained a shaped blob and sheet style and both of which remained flexible after drying:

A. Thick mouldable flexible, Figure 19, here also, the used acetic acid concentrations showed no important impact. More investigation using other grades of acetic acid may show effects on the final characteristics of the bio-plastic.

4

Figure 19. Flexible bioplastic coloured green; in thick and flower shaped blob using a press mould.

B. Films of flexible bioplastic, as quite a number of commercial applications such as food packaging and storing flexible bioplastic can be used, Figure 20, B and C.

Figure 20. Transparent flexible bioplastic film can target packaging, storing food industry and may be used as alternative to plastic bags.

Conclusion

The research project focused on recycling potato peels waste to produce starch has demonstrated significant potential for creating a sustainable and market-competitive alternative to corn-starch. The quantity and quality of the starch obtained from potato peels not only meet but exceed the standards set by traditional corn-starch. This breakthrough not only addresses the issue of waste management by utilizing potato peels but also offers an environmentally friendly alternative to a widely used agricultural product.

The positive impact of this project on environment and reduction of global warming can be seen if we consider the global 2030 projected generation of the quantity of 8 million tonnes of potato peels waste, as reported above, with greenhouse gas emissions of 5 million tons of CO_2 equivalent associated with its disposal (Ebrahimian F. et al., 2022).

Furthermore, the project's innovation extends beyond starch production, as the development of bioplastics from the same potato peel starch, produced in the project, presents a viable alternative to petroleum-based plastics. This dual-pronged approach not only tackles the challenges associated with waste reduction but also contributes to mitigating the environmental impact of plastic pollution.

Although more analysis and further studies are still need to refine the quality of the starch and define the degradability time of the bioplastic produced in the project, the successful integration of these findings into various industries could mark a crucial step towards a more sustainable and circular economy. The adoption of potato peel-derived starch and bio-plastics has the potential to reduce dependency on conventional resources, decrease environmental degradation, and foster a more eco-friendly approach to industrial processes.

In the broader context, this research not only adds value to a commonly discarded agricultural by product but also aligns with global efforts to develop innovative solutions for sustainable living. As we navigate the complexities of modern waste management and environmental conservation, the findings from this study offer a promising avenue for creating a more sustainable and competitive market, with the added benefit of reducing our reliance on non-renewable resources.

References

- Albertsson A. C. & HakkarainenM. (2017). Designed to degrade-Towards advanced sustainable polymers. Advanced Drug Delivery Reviews,107,223-240
- Alrefai R, Alrefai A, BenyounisK. Y., Stokes J.(2020). An evaluation of the Effects of the Potato Starch on the Biogas Produced from the Anaerobic Digestion of Potato Wastes
- Andi (2013). Agence Nationale de Developpement de l'investissement Données statistiques Alger
- AND (2019). Caractérisation des déchets ménagers et assimilés campagne nationale 2018/2019. https://and.dz/caracterisation-des-dechets-menagers-et-assimiles-campagne-nationale-2018-2019/.
- Andrady, A.L.(2015). Plastics and environmental sustainability. John Wiley and Sons
- Ahti.E.(1984). Fertilizer-induced leaching of phosphorus and potassium from peatlands drained for forestry. Proceedings of the 7th International Peat Congress, Dublin 3:153-163
- Auras R., Harte B. & Selke S.(2004). An overview of polylactides as packaging materials. Macromolecular bioscience,835-864
- Bayram B, Greiff K.(2023) Life cycle assessement on construction and demolition waste recycling: A systematic review analyzing three important quality aspects
- Chen G.Q.(2009). A microbial polyhydroxyalkanoates(PHA) based bio and materials industry. Chemical Society Reviews,2434-2446
- Chiellini E, (2003). Biodegradable polymers: Market trends and new perspectives. Emerging technologies in plastics recycling,28-45
- Dorbane N.(2004). Gestion des dèshets solides urbains dans le cadre du dèveloppement durable cas de la ville TisiOuzou (Doctoral dissertation, Universitè de Tizi Ouzou-Mouloud Mammeri)
- DSP, (2015). Direction de la santé et la population de la wilaya de Saida. Bilan des activitès du registre cancer de l'annèe 2015
- Ebrahimian F., Denayer J.F.M., Karimi K. (2022) Potato peel waste biorefinery for the sustainable production of biofuels, bioplastics, and biosorbents. Bioresour Tech 360:127609. https://doi.org/10.1016/j.biortech.2022.127609
- EPGCET, (2015). Entreprise publique de gestion et controle et l'enfouissement technique de la wilaya de Saida
- European Bio-plastics, (2020). Bioplastics in the circular economy

- European Bio-plastics, (2020). Environmental benefits of bio-based plastics
- European Commission.(2020). Plastics Strategy. https://ec.europa.eu/environment/circular-ecoomy/plastics-strategy-en
- Mueez S. A., Siddique Y., Mehnaz S., Bilal Sadiq M. (2023). Extraction and characterization of starch from low-grade potatoes and formulation of gluten-free cookies containing modified potato starch. Heliyon, 9 (9). e19581. https://doi.org/10.1016/j.heliyon.2023.e19581
- Garcia; B. and al.(2023). Advances in Biotechnology for Improved Biodegradability of Bioplastics. Biotechnology Advances, 41, 107804
- Hoornwey D, Bhada-Tata P. (2012). WHAT A WASTE: A Global Review of Solid Waste Management. Urban Development Series Produced by the World Bank's Urban Development and Local Government Unit of the Sustainable Development Network, No. 15.
- Hopewell J., Dvorak R & Kosior E.(2009). Plastics recycling: Challenges and opportunities. Philosophical Transactions of the Royal Society B: Biological Sciences,364(1526),2115-2126
- Johnson E. and al. (2020). Dietary Fiber Intake and Cardiovascular Disease Risk: A Systematic Review and Meta-Analysis of Prospective Cohort Studies. Critical Reviews in Food Science and Nutrition,,pp.1680-1690
- Kara S. (2012). Prèparation des copolymers hydrosolubles à base d'amidon, Modification et controle des proprieties. Thèse magister en chimie, universitè Abou Baker BELKAID, Telemcen
- Khanal S., Karimi K., Majumdar S., Kumar V., Verma R., Bhatia S.K., Kuca K., Esteban J. & Kumar D. (2023). Sustainable utilization and valorization of potato waste: state of the art, challenges, and perspectives. BiomassConv. Bioref. https://doi.org/10.1007/s13399-023-04521-1
- Lal A. and Cheeptham N.(2012). Starch Agar Protocol. American Society for Microbiology; https://asm.org/ASM/media/Protocol-Images/Starch-Agar-Protocol.pdf?ext=.pdf
- Laurent(2013). Etude sur la performance Environnementale comparativement aux plastique pètrochimiques, Universitè de Sherbrooke Canada
- Kijchavengkul T. A. R., Rubino M. & Selke S. (2008). Improving the performance of polylactic acid for use in blends and composites. In Handbook of Bioplastics and Biocomposites Engineering Applications (65-98). John Wiley and Sons.
- Mohanty, A. K.,Misra, M. & Drzal L.T. (2002). Green plastics: An introduction to the new science of biodegradable plastics. Princeton University Press.
- Narayan R. (2018). Biopolymers: New materials for sustainable films and coatings. Wiley
- Navarrate-Bolanos JL, Lizardi-Mondosa J. (2020). Bioactive compounds from potato peel ad

their health benefits: A review. Food Funct.

- Niaounakis M. (2019). Biopolymers: Biobased Materials and Their Applications. CRC Press
- PNUE (2014). Programme des Notions Unies pour l'environnement
- Navasingh R. J. H., Gurunathan M. K., Nikolova M. P. and Królczyk J. B. (2023). Sustainable Bioplastics for Food Packaging Produced from Renewable Natural Sources, Polymers, 15(18), 3760; https://doi.org/10.3390/polym15183760
- Reguig D. and Temar A. (2023). Bioconversion of Potato Peels Waste into Starch, Bioplastic, Microbial Culture Media and Organic Fertilizer, Master Thesis, University of Saida – Dr. Moulay Tahar.
- Roy A. (2019). Handbook ofBio-plastics and Bio-compositesEgineering Applications. Wiley
- Selke S.(2012). Packaging and the environment. CRC Press
- Shen L., Worell E. (2014). Plastic recycling. Handbook of Recycling. Boston: Elsevier, pp. 179-190
- Shogren R.L., Willett J.L.,Deschamps A.M.(2007). Starch-based biodegradable plastics: synthesis, characterization, and industry outlook. Macromolecules,404-415
- Shrestha S., Khatiwada JR, Sharma HK, Qin W. (2021). Bioconversion of fruits and vegetables wastes into value-added products, in advances in science, technology and innovation.(Switzerland: springer nature),145-163
- Smith; A. and al. (2022). Enhancing Biodegradability and Mechanical Performance of Bio-based Polymers. Journal of Applied Polymer Science, 139(45), e53315
- Smith; J. and al. (2017). Nutritional Value and Health Benefits of Potato Peel: A Review. Food Chemistry, pp. 494-501
- Stevenes E.S. (2002). Green plastics: An introduction to the new science of biodegrdable plastics. Princeton University Press
- Tassinari G; Bassani A; Spigno G; SoregaroliC. (2023). Do biodegradable food packaging films from agro-food waste pay off. A cost-benefit analysis in the continent of Europe, science of the total environment, 856 (September 2022). Doi:10.1016/j.scitotenv.2022.159101
- Van wyk JPH.(2005). Aprofessional and developmental approach.Juta: cape town.second edition.pp.466-488
- Zhang R., Su J., Liu H. (2020). Application of Biowaste to Energy Conversion Technologies: Current Status and Future Trends. Journal of Cleaner Production, 262, 121198