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OVERSIZED ROAD TRANSPORT - PARTICULARITIES, REALIZATION CONDITIONS, PROBLEMS AND DEVELOPMENT PERSPECTIVES

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Abstract. Transport is in continuous evolution, regardless of the activity sector. Road transport faces various obstacles, and their management is a crucial part of planning and executing bulk transport operations. One of the main obstacles is the low height of bridges or power lines along the planned route. To avoid collisions with these obstacles, detailed studies of the route are carried out, identifying potential conflict points in advance. Preventive measures such as temporarily raising power lines or temporarily changing the height of bridges can be implemented to ensure the smooth passage of oversized cargo. Ground communication routes with a curved axis represent another limiting factor in oversized transport. Solutions include planning routes to minimize the number of bends or using special trailers with directional axles. These trailers allow for easier cornering and ensure that the transport can cross terrain with difficult geographical features. The necessary authorizations also represent a major obstacle. Oversized transport often involves dimensions and weights that exceed the usual limits, which is why it is mandatory to obtain authorizations issued by competent public authorities. But this stage, by way of consequence, determines the legality and admissibility of carrying out transport operations. To manage obstacles in oversized transport, a proactive approach is essential, with detailed route analyses, the implementation of appropriate preventive measures, and compliance with applicable regulations. These solutions contribute to the efficiency and safety of oversized road transport, ensuring harmonious integration in the context of the existing infrastructure.

Keywords: *oversized transport, special transport authorization, exceeded mass, authorized route, vehicle with overruns.*

Rezumat. Transporturile sunt într-o continuă evoluție, indiferent de sectorul de activitate. Transportul rutier se confruntă cu diverse obstacole, iar gestionarea acestora reprezintă o parte crucială a planificării și executării operațiunilor de transport agabaritic. Unul dintre principalele obstacole este înălțimea redusă a podurilor sau a liniilor de electricitate de-a lungul rutei planificate. Pentru a evita coliziunile cu aceste obstacole, se efectuează studii detaliate ale traseului, identificându-se în avans potențialele puncte de conflict. Măsurile preventive precum ridicarea temporară a liniilor de electricitate sau modificarea temporară a înălțimii podurilor, pot fi implementate pentru a asigura trecerea fără probleme a încărcăturii

agabaritice. Căile de comunicație terestră cu axa curbă, reprezintă un alt factor limitativ în transportul agabaritic. Soluțiile posibile în acest sens, includ planificarea rutelor astfel încât să se minimizeze numărul de curbe sau utilizarea de remorci speciale cu axe direcționale. Aceste remorci permit o manevrare mai ușoară în curbe și asigură că transportul poate traversa terenuri cu caracteristici geografice dificile. Un obstacol major este reprezentat și de autorizările necesare. Transportul agabaritic implică dimensiuni și greutăți care depășesc limitele obișnuite, motiv pentru care este obligatorie obținerea autorizațiilor emise de autoritățile publice competente. Însă această etapă, pe cale de consecință, determină legalitatea și admisibilitatea realizării operațiunilor de transport. Pentru a gestiona obstacolele în transportul agabaritic, este esențială o abordare pro activă, cu analize detaliate ale rutei, implementarea măsurilor de siguranță sporită și respectarea reglementărilor în vigoare. Aceste soluții contribuie la eficiența și siguranța transportului rutier agabaritic, asigurând o integrare armonioasă în contextul infrastructurii existente.

Cuvinte cheie: *Transport agabaritic, autorizație specială de transport, masă depăşită, traseu autorizat, vehicul cu depăşiri.*

1. Introduction

Trends and perspectives in the oversize transport sector are important for the evolution and development of transport enterprises. Among the most important sectors dependent on bulk transport include: construction, agriculture, energy (especially the green Sector: wind turbines, solar panels, heat pumps, etc.), metal structures, the oil industry, automotive, and others.

Each sector has its own particularities, with corresponding challenges and opportunities. It is difficult to predict how the European and world economies will evolve, and what effects it will have on the transport industry. Regarding the evolution of oversized transport, we can reveal some determining premises:

I. Increasing demand for oversized transport services.

Analyzing the statistical data for the years 2000-2022, we establish a significant increase in the volume of goods transported by road transport from 20,671.7 thousand tons (in 2000) to 45,082.1 thousand tons (in 2022) [1].

According to an analysis of Industry Market Research, Reports, & Statistics (IBIS) World [2], is reflected the dynamics of the increase in demand for oversized transport services. This demand is due to the increase in global trade and the dynamics of the construction industry in various European countries and beyond.

Every oversized transport operation involves the use of large machinery, especially at the beginning of the construction project. Construction companies request oversized transport services to have cranes, bulldozers, excavators, precast concrete materials, and many other types of equipment available on construction sites.

II. Digitization and automation of transport processes.

Digitization and automation are two processes that will dominate the development of bulk transport companies, direct and indirect. This trend will highlight new processes and technologies, capable of making the sector more efficient. Automation of ordering processes, tracking, and delivery of goods, represents only superficially the technological process. Digitization also includes the administrative side, which is indispensable for carrying out the activities of a transport company. From recording contracts to logistics notes, software

programs have the ability to significantly optimize the way a company works. For this reason, most of the top oversized transport companies try to find quality software.

III. Use of alternative fuels.

In Europe and beyond, concern for the state of the environment has grown significantly. Climate change and pollution are major problems that most countries on the European continent face. The use of alternative fuels is a good way to limit the negative impact on the environment.

IV. Road infrastructure development.

The road infrastructure in the Republic of Moldova is very poorly developed, which creates significant impediments to the development of oversized transport. The development of better highways and roads would better reflect the needs of national and foreign businesses. Also, the quality of the roads contributes to traffic safety.

V. Development of oversized transport technology

The level of the oversized transport industry is dependent on the development of new techniques, devices, and means of transport. From more efficient loading and handling equipment to specialized trailers and hybrid vehicles, the oversized transport sector is going through an incredible metamorphosis.

2. The particularities of oversized transport

One of the most complex types of road freight transport, both from the perspective of the organization and the actual transport, is oversized transport. Because it is a special

transport, the oversized transport must comply with certain specially regulated conditions, so that it can be carried out safely and in accordance with the legislation in force.

2.1. Conditions for the admission of motor vehicles

Oversized road transport is the road transport operation that is carried out exceeding the maximum mass and/or the maximum dimensions allowed and is regulated by the special rules of the Regulation regarding the performance of road transport on public roads exceeding the total mass of the masses on axles and/or of the maximum allowed dimensions approved by Government Decision No. 326 of May 18, 2022 (hereinafter - Regulation). The maximum allowed masses and dimensions are specified in annex no. 2 of the Roads Law No. 509/1995 as well as in Point 86 of the Road Traffic Regulation. However, the regulation contains special provisions regarding the permissible deviations in the mass and dimensions of vehicles.

Thus, in the case of weighing, according to point 6 of Regulation [3], deviations are allowed within the following limits:

1) at fixed weighing installations:

a) for the single axle in a group of axles + 200 kg

b) for the double axle + 300 kg

c) for the triple axle + 350 kg

d) for the total mass of the vehicle + 350 kg

2) When using portable weighing machines:

a) for the single axle in a group of axles + 200 kg

b) for the double axle + 300 kg

c) for the triple axle + 350 kg

In the case of the actual measurement of the vehicle dimensions, the following deviations above the maximum allowed limits are allowed:

1) height + 5 cm
2) width + 10 cm
3) length + 20 cm.

In the situation where the weighing facilities do not work, are missing, or cannot be used given the characteristics of the vehicle, the mentioned deviations are not applicable, but the total mass of the vehicle is determined from the following documents on board the vehicle: CMR, TIRE card, invoice, special transport authorization, international road vehicle weighing certificate, and registration certificate. So, in any case, these documents, which must be on board the means of transport, must contain data on the total mass of the means of transport.

According to point 8 of the Regulation [3], in the case of the actual measurement of the dimensions of the vehicles, the following deviations above the maximum allowed limits are allowed:

1) height + 5 cm
2) width + 10 cm
3) length + 20 cm.

With all these deviations, every road vehicle in motion must enter a circular area with an outer radius of 12.5 m and an inner radius of 5.3 m. The distance between the axis of articulation and the rear limit of an articulated vehicle, it, must not exceed 12 m.

The actual legislation regulates certain conditions for the circulation of vehicles exceeding the total mass and/or the maximum permitted dimensions as follows:

1. Vehicles must be admitted to traffic. In order to be maintained in road traffic, vehicles must undergo periodic technical inspection at authorized stations, under the conditions established by the legislation in force. The confirmation regarding the performance of the technical inspection is the badge printed on the periodic technical inspection report.

2. Correspond from the point of view of technical conditions and traffic safety requirements. The vehicles must comply with the standards and other normative acts related to road traffic safety, environmental protection, technical operating rules, and the instructions of the manufacturing companies.

3. Do not exceed the maximum authorized vehicle weights, established by the manufacturing plant. According to art. 49 of the Road Transport Code, the obligation to comply with the maximum authorized total masses and/or within the limit of the loading capacity established by the manufacturing plant of the road vehicle used and/or by the technical regulations in the road transport process rests with the road transport operator or company that performs road transport operations [4].

4. Have a valid special transport permit. The provisions of art. 62^1 para. (2) of the Road Transport Code, provides as an exception that the road transport of goods with road vehicles, registered in the Republic of Moldova or in other states, on public roads exceeding the maximum permissible total mass, the maximum permissible axle masses, and/or the maximum allowed dimensions is allowed only on the basis of the special authorization, issued by the National Transport Auto Agency (ANTA), under the conditions of Regulation [4].

5. Comply with the provisions written in the special transport authorization.

If we compare with Romanian legislation, on January 18, 2019, the new Norms regarding the authorization and movement of road vehicles with masses and/or dimensions that exceed the maximum permissible masses and/or dimensions provided for in Government

Ordinance no. 43/1997 regarding the road regime [5]. Among the important regulations of the issued act, we can highlight:

• training the driver who carries out oversized transports, on the territory of Romania and who must have a minimum knowledge of the Romanian language. Similar provisions regarding the mandatory training of drivers carrying out oversized transports are also contained in the Commission Directive 2000/56 CE "Safety factors relating to the vehicle, the load and transported persons" [6], which stipulates the need to hold driving licenses of all categories, at as well as Directive 2003/59 EC of 15 July 2003 on the training of "professional drivers" [7];

• issuance of the special transport authorization-AST by CNAIR – S.A. for roads other than those of national interest;

• extending the validity and deadlines for issuing AST;

• conditions for drawing up the transport project;

• conditions for drawing up the route study.

The admission conditions for vehicles involved in oversized transport also require their equipping with additional signaling devices. Thus, according to Chapter IV of the Regulation, the following distinctive and signaling signs for motor vehicles are provided for [3]:

a) If the width of the moving vehicle is between 2.60 and 3.50 m, it must have a warning plate with the inscription “CAUTION! SIZE EXCEEDED!”, which will have the size of

40×40 cm and the height of the letters of 15 cm, with red characters on a white background, and the tow truck will continuously use the orange rotating light.

b) If the width of the vehicle is between 3.50 and 5.00 m, it will be preceded in motion by a vehicle of the road transport operator or of the person concerned, equipped with an orange rotating light in continuous operation and with a warning plate with the inscription “CAUTION! EXCEEDED SIZE!”.

c) If the width of the vehicle exceeds 5 m, it will be preceded and followed by a vehicle of the road transport operator or of the person concerned, equipped with an orange rotating light in continuous operation and a warning plate with the inscription “CAUTION! EXCEEDED SIZE!”, mounted in front of the preceding vehicle and in the rear of the following vehicle.

In all situations, beacon-type lamps with flashing orange warning lights will be mounted on the highest parts of the vehicle, trailers, or cargo, so that during transport they are visible from all sides.

d) If the width dimension exceeds 3.50 m, the side edges that exceed the platform of the trailer or semi-trailer will be marked at the front and back (left and right) with plates 30 cm wide and 1.20–1.50 m high, with reflective strips, alternating white and red, with a width of 10 cm, having an inclination of 45°, descending towards the outside of the vehicle or load, or mounting in the same position some vertical plates with a height of 1.20–1.50 m, similarly painted.

In all the cases mentioned (letters a–d), until the special transport authorization is issued, the preliminary approval of the National Public Security Inspectorate is mandatory.

2.2 Conditions of carriage of oversized goods

The load that forms the object of the oversized transport must be marked on the sides and back by writing with paint, which will indicate the mass in tons and the dimensions of the outer contour in the transport position in centimeters (length, width, and height). The mass of motor vehicles, semi-trailers, and trailers will be marked with paint on a visible surface.

According to point 88 and point 89 of the Road Traffic Regulation, if the load exceeds the dimensions of the vehicle in the longitudinal plane, front or rear, by more than 1 m, in the transverse plane - by more than 0.4 m at the outer edge of the marker lights, it must be marked with a distinctive sign, as shown in Figure 1 [8], and at night - additionally signaled by white reflectors or lanterns in front and red in the back. Vehicles that, constructively or because of the transported load, exceed the maximum gauge limits can move on public roads only after being authorized by the road administrator (road administrators) and the National Inspectorate of Public Security, and if they have activated the orange roundabout lights.

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Oversized load

Figure 1. Means of vehicle identification. Distinctive sign no. 12 [8].

In order to carry out oversized cargo transports, the following conditions must be met:

1. Obtaining the Special Transport Authorization. This permissive act issued by the National Auto Transport Agency is mandatory and absolutely necessary for carrying out the oversized transport operation. Based on the reference document, the road administrator will establish the route and the fees charged for this route.

2. Payment of the tax for using the roads. All owners of motor vehicles whose total mass, mass load on the axle, or dimensions exceed the permitted limits are obliged to pay the tax for using the roads. The tax for the use of roads is calculated according to the total mass, the mass on the axles, the distance traveled, and the dimensions of the vehicles and is used for the administration, exploitation, consolidation, maintenance, repairs, and modernization of the roads they administer. The tax rates are established in annex no. 3 of Title IX of the Fiscal Code of the Republic of Moldova [9].

3. Route planning and safety measures. In the planning stage of oversized transport, a detailed study of the planned route is carried out. This study identifies potential obstacles such as bridges, power lines, or sharp curves and devises strategies to avoid them. An essential aspect is anticipating and solving any challenges that may arise during the course. At the same time, appropriate safety measures are planned and implemented. These may include possible temporary infrastructure changes to allow cargo to pass or close coordination with local authorities. By anticipating and applying these safety measures, it is ensured that oversized transport operations are carried out in a safe and efficient manner, respecting both the integrity of the load and the rules and regulations in force.

4. The availability on board of the means of transport of the documents related to the transported goods. There are numerous documents and special terms in the fields of logistics, forwarding, and national and international freight transport. International and national legislation regulates the specific documentation required for the transport of goods. However, there are transport documents required for any type of transport of goods, including oversized ones, which include: the tax invoice, the customs declaration (depending on the

customs regime under which the transported goods are to be placed), the international waybill (CMR), TIR Carnet [10] and other documents depending on the type of bulky goods and the geographical area served.

5. Professional training. Both the people who accompany the oversized transports, and the people who will draw up oversized transport projects, must have a specific professional training and be authorized by the competent authority. The drivers who will carry out the oversized transport must hold a certificate of professional competence issued by ANTA under the conditions of the Road Transport Code.

6. Police escort and discharge requirements. In the framework of oversized transport, it is required to accompany the transport by police bodies to ensure safety on the road and to facilitate the crossing of intersections and other critical points. The police force provides assistance in traffic management and ensures a safe route for vehicles with bulky and heavy loads. At the destination, specific procedures are implemented to safely unload the cargo. These procedures are aimed at minimizing the impact on the infrastructure and ensuring the protection of the cargo. Close coordination between the carrier, unloading personnel, and local authorities is essential to the efficient conduct of unloading operations, helping to prevent incidents and protect both cargo and infrastructure.

3. Types of oversized loads

Oversized transports are used in various fields, such as: construction, industry, energy, and agriculture. Carriers of bulky goods manage to attract the attention of the public by the distinct nature of the transported goods, as well as by their prudence and vigilance in the transport process. Each type of oversized cargo has unique characteristics that cannot be ignored by motor carriers and logistics teams.

In general, oversized loads are of the following types:

a. Oversized loads: goods or vehicles that exceed the maximum dimensions permitted on public roads, but not the maximum permitted weight. In other analyzed sources, is also specified the category of ***Long load*** – of which transportation on a truck, it will extend beyond the tailgate by at least 2 meters [11].

b. Overweight loads: goods or vehicles that exceed the maximum weight allowed on public roads but do not have the maximum dimensions allowed.

c. Oversized and overweight loads: goods or vehicles that exceed both the dimensions and the maximum weight allowed on public roads.

The most common oversized loads requested to be transported include:

1. Industrial components and equipment. In this category, we can include power generators, wind turbines, drilling equipment, industrial machines, and other types of heavy equipment.

2. Prefabricated construction elements and oversized machinery. Construction companies need large concrete beams, precast panels, cranes (of various sizes), excavators, bulldozers, ladders, and other large precast elements needed in the optimal execution of construction projects.

3. Metal structures. These include metal beams, pipes, and other types of steel elements, often used in large construction projects, for example: the construction of bridges, railways, or warehouses.

4. Agricultural equipment. In a predominantly agrarian country such as the Republic of Moldova, agricultural enterprises permanently require oversized transport services,

constantly needing agricultural machinery and equipment for their activity. Among the most common products transported in this segment are agricultural combines, tractors, seeders, complementary components of large and heavy agricultural machinery.

5. Transport and construction equipment. Conveying and handling equipment is needed in many industries. Among the most transported products are motor graders, road graders, bulldozers, excavators and other types of large machinery required for construction projects.

6. Equipment and machinery required for the green industry. The green energy industry is growing. Many countries start and run numerous green energy projects: wind turbine parks and solar parks.

The weight that is considered oversized also varies from place to place. In the United States, the weight that is considered oversized is 80,000 pounds. However, there are some places that have heavier weight limits [12].

4. Major problems of oversized transport in the European Community

The legal dimensions and weights vary between countries and regions within a country [13]. Any road transport is framed by the CMR Convention (Convention on the Contract for the International Carriage of Goods by Road) [14], which relates to various legal issues concerning transportation of cargo, predominantly by lorries, by road.

According to the Federal Motor Carrier Safety Administration, National Highway Traffic Safety Administration, Large Truck Crash Causation Study [15], 7% of U.S. trucking accidents are caused by improper cargo securement or cargo shifts. Shifting cargo can cause the truck to destabilize or the load can fall off completely leading to serious public safety issues. Load shifting is prohibited by law and it is the responsibility of the shipper, motor carrier, driver, receiver, and the securing device manufacturer to ensure the cargo is completely secured [16].

In a specific country, the roads are built in a way that allows a vehicle with dimensions within the standard legal limits to safely (though not necessarily easily) drive and turn. Roads that do not allow large vehicles may be marked with the traffic signs [17]. These may include per-axle load, height, width, or overall length limits.

The study of multiple informational sources highlighted several major problems in the field of the materialization of oversized transport in the European Community:

- Differences between the number of necessary escort crews;
- Differences between the format of the special transport authorizations and the filling language;
- The need for police escort crews, sometimes only from the zonal road service. This means that, in each county/city, a different police crew is needed;
- Differences in costs for obtaining special transport authorizations;
- The transit of a country is carried out only with accompanying crew certified according to the legislation of that country;
- Differences between possible dismantling of works of art;
- Different restrictions on the roads, at certain times of the year.

Conceptually, the transport of oversized goods is a special type of transport. In order to successfully complete the oversized transport process, it is necessary to complete the following steps:

- Choosing the right vehicle for transporting bulky goods;
- Analysis and estimation of the specifics of the regions to be transited;

- Choosing the convenient transport route from a financial point of view and transport time;
- Calculation of the duration of the transport;
- Analysis and estimation of possible difficulties that may arise in the transport process;
- Preparation of related documentation.

Compliance with the strict rules for loading, fixing and transporting oversized goods results from the need to immobilize it during transport, so that it remains intact and undamaged, until the destination and last but not least, oversized transport must not endanger the life and health of people, traffic road, infrastructure and environment. The rules for fixing oversized goods are strictly regulated by the European Commission [18]. Most of the regulations apply directly to drivers of vehicles who are directly exposed to the risks associated with oversized transport.

5. Conclusions

Today, there are certain norms and laws that regulate the transportation of oversized load in our country. These must be strictly adhered to ensure legal transportation.

First of all, moving a truck with oversized load along the roadway must take into account the Traffic Rules. If at least one violation is detected, it will be necessary to pay a fine in the prescribed amount.

Oversized transport has a significant development potential in the Republic of Moldova. This is due to the fact that the Republic of Moldova is a country with a growing economy, which needs imports of modern equipment and technologies.

A decisive role in favoring the development of oversized transport belongs to the public authorities, by making and/or developing contributions such as:

- Ensuring an adequate road infrastructure for oversized transport;
- Simplification of authorization procedures for oversized transport;
- Promoting collaboration with neighboring countries in the field of oversized transport.

The future outlook of oversized transport indicates a number of trends and changes that could shape the evolution of this field in the coming years. These can be leveraged by implementing and/or deepening the use of innovative levers, which include, but are not limited to:

Autonomous Vehicles (which can self-assess the surroundings in which they are, by means of several sensors, can also process the data received to later configure their operation accordingly). The integration of autonomous driving technologies into large-scale transportation could bring significant benefits in terms of efficiency and safety. Autonomous vehicles can better manage routes, reduce the risk of accidents, and enable more efficient transport.

Artificial Intelligence Technologies. Using of the artificial intelligence in the process of planning routes, simulating and strengthening traffic safety, as well as optimizing logistics processes will contribute to the efficiency of oversized transport.

Alternative Fuels. The use of fuels from renewable sources and with a low carbon content definitely reduces their impact on the climate. In this context, the use of alternative fuels is a topic actively analyzed and promoted by the European Union. Increasing environmental concerns will accelerate the transition to the use of alternative fuels in bulk

transport. Thus, the increased use of sustainable and innovative means of transport such as electric vehicles, hydrogen vehicles or other renewable energy sources will become more important and in demand.

Advanced Communication and Tracking Systems. Cooperative intelligent transport systems allow the exchange of information between vehicles, as well as between vehicles and the road infrastructure, and thus, increase road safety, making traffic more efficient and more comfortable. The development of advanced communication systems and tracking technologies will facilitate more efficient management of large vehicle fleets and increase the safety of operations.

Overall, the future of bulk transport will be shaped by advanced technologies, sustainability concerns, and adaptation to the specific requirements of ever-changing industries. These changes are expected to bring significant benefits to the efficiency, safety, and sustainability of this vital transport sector.

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MEAN-OF-2-4 QUICKSORT

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Abstract. By combining the Median-of-three and Regrouping-3 quicksort methods, the Joint quicksort is proposed, largely free from the shortcomings of the first two. For example, the time complexity of Joint quicksort, in case of lists of n equal elements, is $O(n)$. Analysis of the dependence of Quicksort time complexity on the ratio of the derived sublist sizes shows a relatively slow increase in sorting time as the ratio in question decreases from 0.5 to 0.1. The proposed category of Mean-of-K (MeK) sorting algorithms provides for the determination of pivot elements as the mean of K elements. It is shown that, in terms of sorting time, at $K \in [1, 4]$ and size r of the list/sublist of elements to be sorted, it is convenient to use (roughly): Insertion sort at $r \leqslant 9$, Me2 quicksort at $10 \leqslant r \leqslant 21$, Me3 quicksort at $22 \leqslant r \leqslant 46$, and Me4 quicksort at $r > 46$, yielding the Mean-of-2-4 quicksort method. It was found that the determination of pivot elements in the Median-of-three method requires more calculations than in the Mean-of-3 method; respectively, using Mean-of-3 method could also reduce sorting time. Of course, Mean-of-2-4 method could reduce this duration even further.

Keywords: *basic Quicksort, Median-of-three quicksort, Regrouping-3 quicksort, pivot element determination, time complexity, algorithm comparison.*

Rezumat. Combinând metodele de sortare rapidă Mediana-a-trei și Regrupare-3, este propusă sortarea rapidă Îmbinată, lipsită în mare măsură de neajunsurile primelor două. De exemplu, complexitatea temporală a sortării rapide îmbinate, în cazul unor liste din n elemente egale, este $O(n)$. Analiza dependenței duratei sortării Rapide de raportul dintre dimensiunile sublistelor derivate arată la o creștere relativ lentă a duratei sortării cu micșorarea raportului în cauză de la 0,5 șa 0,1. Categoria de algoritmi de sortare Media-a-K (MeK) propusă prevede determinarea elementelor pivot ca media a K elemente. Este demonstrat că, în ce privește durata sortării, la $K \in [1, 4]$ și dimensiunea r a listei/sublistei de elemente de sortat, este oportun de folosit (aproximativ): sortarea prin Inserție la $r \leqslant 9$, sortarea Me2 la $10 \leqslant r \leqslant 21$, sortarea Me3 la $22 \leqslant r \leqslant 46$ și sortarea Me4 la $r > 46$, obținând astfel metoda de sortare rapidă Media-a-2-4. S-a constatat că determinarea elementelor pivot la metoda Mediana-a-trei necesită mai multe calcule decât la metoda Media-a-3; respectiv, folosirea metodei Media-a-3 ar putea reduce și durata sortării. Bineînțeles, metoda Media-a-2-4 ar putea reduce această durată și mai mult.

Cuvinte cheie: *sortarea rapidă de bază, sortarea rapidă Mediana-a-trei, sortarea rapidă Regrupare-3, determinarea elementului pivot, complexitate temporală, comparare algoritmi.*

1. Introduction

Sorting - the ordering of entities according to a parameter (key) is widely used in computer science. As simple is the essence, so frequent sorting is encountered in practice, so wide is the multitude of approaches, and so easy it is to construct simple sorting algorithms. The first known sorting algorithm, *Radix*, based on the decimal numbering system, was proposed and implemented in electromechanical tabulators by Herman Hollerith in 1890 [1]. *Merge sort* was proposed by Jame W. Bryce and implemented in 1938 in the Collator machine, for merging cards from two different stations in a single sorting operation. In 1945 John Von Neumann implemented this method in the electronic computer "EDVAC" [1].

From the first publications in the field, appeared in the 1950s, dozens of sorting algorithms are proposed and research continues. Most of them were invented in the period 1954-1985 [2]. Approx. 30 such algorithms are described in [1] and a list of 74 chronologically systematized algorithms is published in 2014 [3].

New sorting algorithms are also proposed after 2014, including *pdqsort* published in 2021 [4] and *RevWay Sort* published in 2022 [5]. However, so far, there is no a generalized sorting algorithm that would best suit all situations in practice [6]. Thus, the search for a suitable sorting algorithm for specific situations is still current [2].

One of the most used is *Quicksort* [2]. For randomized data, especially for large lists, it is slightly faster than *Merge sort* and *Heapsort* [7].

At the same time, traditional Quicksort also has some shortcomings in certain situations, which led to the proposal of some of its developments. The best known of them is the *Median-of-3 quicksort* (Mo3), proposed in [9]. In this paper, some well-known and also newly proposed algorithms based on the traditional Quicksort algorithm are described and comparatively characterized.

2. Basic Quicksort

2.1. The essence of basic Quicksort

Quicksort was proposed by C.A.R. Hoare in 1961 [9], but also later independently in [10] and possibly by other authors. Later, some developments of it were also published. In the following, the version of basic Quicksort from [10] will be used.

Since there is a direct entity-key correspondence, in the following we will mainly operate with the keys of the respective entities called elements. Quicksort provides [9, 10] the choice, first, of the pivot element, say the last element in the list (it can be any) - s_{00}. Then the list of elements, as a result of $n - 1$ pairwise comparisons of element s_{00} with each of the other $n - 1$ elements, is regrouped (partitioned) into two sublists of elements and element s_{00}: one sublist, say G_{11}, will contain the smaller elements as s_{00}, and the second sublist, be G_{12} – elements equal to or greater than s_{00}. The comparison will be made consecutively with elements at the beginning of the list until an element greater than the pivot is identified, then with elements at the end of the list until an element smaller than the pivot is identified, and subsequently the two elements thus identified will swap with the place; the process continues in the same way until all $n - 1$ elements have been compared. Finally, the pivot element will swap with the first element in the second sublist. Thus, in the first step, the ordering of the elements is $G_{11} \rightarrow s_{00} \rightarrow G_{12}$, where for $\forall i \in G_{11}$ occurs $i \rightarrow s_{11}$, and for $\forall j \in G_{12}$ occurs $s_{00} \rightarrow j$. Element s_{00} is already in the final position.

In the second step, as a result of comparing the pivot element $s_{11} \in G_{11}$ (the last one in the sublist), $|G_{11}| > 1$, with the other elements of sublist G_{11}, sublist G_{11} is also regrouped into

two sublists and element s_{11}: $G_{21} \rightarrow s_{11} \rightarrow G_{22}$, where $i\big|_{i\in G_{21}} \rightarrow s_{11}$ and $s_{11} \rightarrow j\big|_{j\in G_{22}}$. If sublist G_{11} is empty or contains only one element, i.e. $|G_{11}| \leqslant 1$, then it is no longer taken into consideration in this and the following steps. Similar actions in this step are performed on the G_{12} sublist, obtaining $G_{23} \rightarrow s_{12} \rightarrow G_{24}$. Elements s_{11} and s_{12} are already in their final positions. The process continues until all derived sublists at some step k become unitary or empty, which signifies the termination of the ordering procedure.

The maximum number of pairwise element comparison operations ($U_{\max}$) occurs when, for each regrouping of a list/sublist into two sublists, one and only one non-empty element sublist will be formed. Such a situation occurs if the initial list of elements is ordered or in reverse order, or if all elements are equal. In this case [10]:

$$U_{\max} = \frac{n(n-1)}{2}. \tag{1}$$

On the contrary, the minimum number of pairwise element comparison operations ($U_{\min}$) occurs when, at each regrouping of a list/sublist into two sublists, two sublists of the same size will be formed. This condition can only be met for [11]

$$n = 1 + (1 + 2(1 + 2(1 + \ldots 2(1 + 2))\ldots) = \sum_{i=0}^{k} 2^i = 2^{k+1} - 1, k = 1,2,\ldots \tag{2}$$

and in this case it takes place [10]:

$$U_{\min} = (n + 1)\log_2(n + 1) - 2n. \tag{3}$$

At each current step, the elements in the list/sublist that are regrouped are written in the same table. Each element in the regrouping list/sublist gets a comparison operation with the pivot element and, if applicable, an additional 0.5 swap operations (the swap operation between the two sublists common to the two elements); finally, one more place swap operation is performed on the pivot element with the first element in the second sublist. Of course, the concrete implementation on a specific computer also involves other operations, but the basic ones are the nominated ones.

2.2. Dependence of Quicksort laboriousness on derived sublist sizes

The influence of the deviation of the value of n from that of Eq. (2) on the laboriousness of sorting is of interest. Let n have such a value that, at each regrouping of a list/sublist into two sublists, one of them will contain kd elements, and the other $(1 - d)k$ elements, where $d \in (0, 1)$. Obviously the minimum value of the sorting time T is obtained at $d = 1/2$ for all iterations. The sorting time of the algorithm is determined [12] by the following recurrent relation $T(k,d) = k + T(\lfloor d(k - 1) \rfloor) + T(\lceil (1 - d)(k - 1) \rceil, d)$. If, in approximate calculations, to operate with fractional numbers of entities, i.e. $T(k, d) = k + T(d(k - 1)) + T((1 - d)(k - 1), d)$, then the solution of this recurrent equation is [12]

$$\frac{T(n,d)}{T(n,\frac{1}{2})} = \frac{1}{-dd\ -(1-d)(1-d)}. \tag{4}$$

The essence of the quantity $g(d)$ – how many times the duration $T(n,d)$ is greater than the duration $T(n, 1/2)$ at $d \in [1/n, 1/2]$. The graph of the function $g(d)$ at $d \in [0.025; 0.5]$ is shown in Figure 1. From Figure 1 it can be seen that the laboriousness of Quicksort increases relatively slowly when d decreases from 0.5 (the ratio between the sizes of the two derived

sublists is 1:1) to approx. 0.1 (the ratio between the sizes of the two derived sublists is 1:9). Under uniform distribution of elements, the probability that the pivot element will be the one at position *s* of the final (sorted) list is 1/*n*. Obviously, *d* = *s*/*n*. Under such assumptions and taking into account that *g*(*d*) = *g*(1 – *d*), the mean value ($g_{med}(n)$) of *g*(*d*), at *d* ∈ [1/*n*, 1/2] and *n* even, is determined as

$$g_{med}(n)|_{d[\frac{1}{n},\frac{1}{2}]} = \frac{2}{n}\sum_{s=1}^{n/2} \frac{1}{-dd\ -(1-d)(1-d)}, \tag{5}$$

where *d* = *s*/*n*.

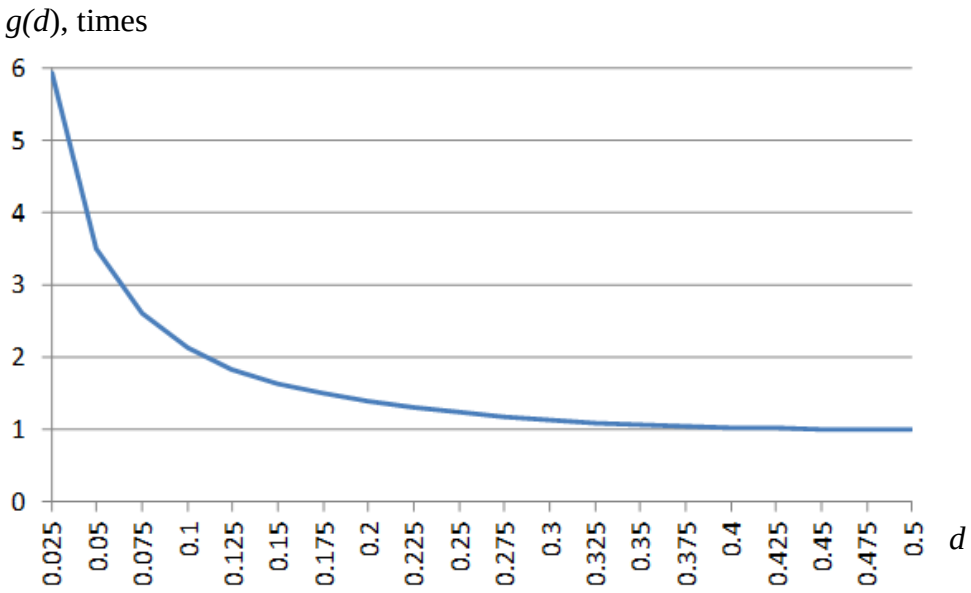

Figure 1. The increase of Quicksort laboriousness with the decrease of *d* < 1/2.

If the quantity *g*(*d*) can be used for the analysis of a Quicksort algorithm apart, then the quantity $g_{med}(n)$ can be used for the comparative analysis of some Quicksort algorithms. The graph of the function $g_{med}(n)$ at *d* ∈ [0.025; 0.5] is shown in Figure 2.

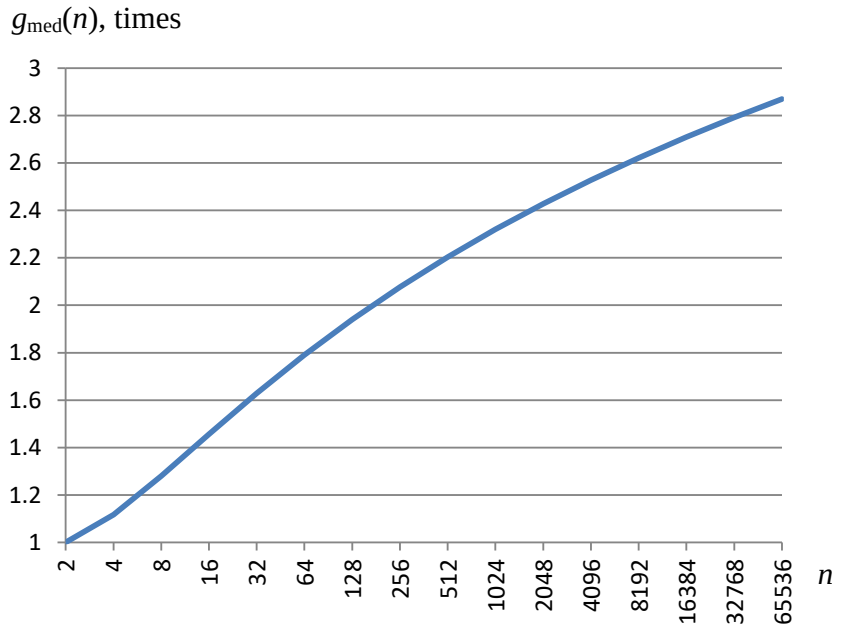

Figure 2. Dependence on *n* of the average value of *g*(*d*) at *d* ∈ [0.025; 0.5].

From Figure 2 it can be seen that the function $g_{med}(n)$ is increasing, that is, the efficiency of Quicksort decreases with the increase in the number n of elements of the initial list. At the same time, this growth is relatively slow, the abscissa scale being logarithmic. For example, $g_{med}(2048) = 2.43$, and $g_{med}(65536) = 2.87$.

Thus, approximately (taking into account the assumptions admitted in [12]), the average number of operations with Quicksort when sorting a list of 65536 elements is 2.87 times higher, compared to the situation when $d = 1/2$, both for the initial list as well as for all derived sublists.

3. Quicksort variants based on traditional Quicksort

As mentioned in Section 2.1, the maximum laboriousness of basic Quicksort occurs when the initial list of elements is ordered or in reverse order, or if all elements are equal. The Quicksort variants described in this section are partially or completely free of these shortcomings.

The **Median-of-three quicksort** (Mo3) [8] differs from the basic Quicksort by choosing the pivot element from three elements of the list/sublist to regroup: the first, the last, and the element in the middle position (obtained as the arithmetic mean truncated to integers of the positions of the first and last elements). These three elements are ordered and the middle element is used as the pivot element. Mo3 sorting allows reducing the volume of calculations for cases with lists of elements already ordered or in reverse order. However, this variant does not reduce the volume of calculations in the case of initial lists with entities that have equal keys.

The **Regrouping-3 quicksort** (R3), proposed in [10] and later in [13], operates efficiently in cases of equal elements, too. Its difference from basic Quicksort consists in regrouping each list/sublist not into two but into three sublists: the first sublist of elements smaller than the pivot element, the second – of elements equal to the pivot element, and the third – of elements larger than the pivot element. For example, the first step will obtain the sublists $G_{11} \rightarrow S_{11} \rightarrow G_{12}$, where the sublist S_{11} contains all elements equal to the pivot element s_{00}. Also, since equal elements usually occur less often, to reduce the amount of calculations, first check whether the element belongs to the subset G_{11} and only then to the S_{11} or the G_{12}. In this case, the number of operations to regroup the current subset will usually be less. The elements of sublist S_{11} are already in their final positions. In the same way, the regrouping of the new sublists is carried out.

Obviously, the number of pairwise element comparison operations (U), in the case when all n elements are equal and first the current element's membership in the first sublist is checked, is $U = 2(n - 1)$. At the same time, if there are no equal elements in the initial list, then the R3 sort requires twice the number of pairwise comparison operations than in the basic Quicksort. Moreover, R3 sorting does not reduce the amount of calculations in the case of already ordered or reverse-ordered initial lists.

Joint quicksort. Comparing the Mo3 and R3 sorts, it can be seen that they complement each other: the shortcoming of Mo3 (does not reduce the volume of calculations for initial lists of equal elements) is eliminated by the R3 sort, and the shortcoming of the R3 sort (does not reduce the volume of calculations in the case of initial lists already ordered or in reverse order) are mitigated by Mo3 sorting. So, combining these two algorithms results in a more efficient sort - Joined quicksort. This allows reducing the volume of calculations both for lists of equal elements and for lists of elements already ordered or in reverse order. The essence of Joint quicksort:

a) the pivot element is determined according to Median-of-three sorting;

b) each list/sublist is regrouped not into two but into three sublists according to Regrouping-3 sorting.

4. Determining the pivot element

Based on the idea of Mo3 sorting, the question arises: why Mo3 and not, for example, Mo2, Mo4 or, in general, Mo*K*? In what follows in this section, the variants: Me1 (Mean-of-1 - conventional average at basic Quicksort), Me2, Me3, and Me4 are investigated comparatively under certain conditions described in Section 4.1. The notation Me2, Me3, and Me4 is used rather than Mo2, Mo3, and Mo4 because the pivot keys are determined in a different way.

4.1. Description of the list of elements to be sorted and the sorting conditions

There are several variations of Quicksort. The following variant will be investigated in the section. Let be a list of r entities that have key values (elements) {1, 2, 3, ..., r – 1, r} and are placed within the list arbitrarily. So, the distribution of entity key values is deterministic uniform with the same distance of one unit between neighboring entities in the final ordered list.

At each step, for the sublist (hereafter the list) of size r that regroups into two sublists, the pivot element u is determined as the arithmetic mean (truncated to integer) of K elements, the neighboring ones being positioned in the list at approximately equal distances. For example, at K = 2, for the pair of elements {j, k} positioned on the first (1) and last (r) positions, respectively, is obtained $u = \lfloor (j + k)/2 \rfloor$. Likewise, at K = 3, for the triad of elements {j, k, l}, positioned on the first (1), the one in the middle ($\lfloor (1 + r)/2 \rfloor$) and, respectively, the last (r) positions is obtained $u = \lfloor (j + k + l)/3 \rfloor$.

By comparison with the pivot element, the list of r elements is regrouped into two sublists, such that each element in the first sublist is less than or equal to the smallest element in the second sublist. Regrouping into sublists continues until all sublists contain no more than one element each. Such a sort is called Mean-of-*K* (Me*K*) sort. Also:

r is even;

P_i - the probability that the list of r elements regroups into two sublists, one of which contains $i = \underline{1, r/2}$ elements, and the other contains (r – i) elements;

N_i - the number of different regroupings in two sublists, one of which contains $i = \underline{1, r/2}$ elements, and the other contains (r – i) elements, also taking into account the regroupings obtained from the end of the list;

N - the total number of different regroupings of the list of r elements into two sublists, also taking into account the regroupings obtained from the end of the list.

With such an approach, along with the sortings of the categories K = {2w +1}, w = 1, 2, 3, ..., which can be seen as a generalization of the Median-of-three (Mo3) sorting, they also make sense Mean-of-*K* (Me*K*) sorts of categories K = 2w, w = 1, 2, 3, ..., some of which will be examined in this section.

The comparison of Me*K* sortings, at different values of K = 1, 2, 3, ..., will be carried out within the assumptions of [12], in the case of which Eqs (4) and (5) hold.

4.2. Mean-of-1 quicksort

Me1 sort involves groupings with the mean value of an element (conventional mean - the value of the element itself) used as the pivot element.

Since at Me1 as pivot element u of regrouping the list of r elements into two sublists can be any of the r elements, in total there can be r different regroupings of the same

probability. At *r* even, the variants of regrouping the list of *r* elements into two sublists are: (1, *r* − 1), (2, *r* − 2), (3, *r* − 3), ..., (*r*/2 − 1, *r*/2 + 1), (*r*/2, *r*/2), (*r*/2, *r*/2), (*r*/2 + 1, *r*/2 − 1), ..., (r − 2, 2) , (*r* − 1, 1). Here, in regrouping (*x*, *y*), *x* and *y* specify the number of elements in the first and second sublists of the regrouping, respectively. It can also be seen that for *r* even and arbitrary selection of the pivot element *u* (for example, the first element in the list), the number of operations required:

- of the regrouping (1, *r* − 1) is equal to that of the regrouping (*r* − 1, 1);
- of the regrouping (2, *r* − 2) is equal to that of the regrouping (*r* − 2, 2);
- of the regrouping (*r*/2 − 1, *r*/2 + 1) is equal to that of the regrouping (*r*/2 + 1, *r*/2 − 1);
- of the regrouping (*r*/2, *r*/2), obtained starting from the beginning of the list, is equal to that of the regrouping (*r*/2, *r*/2), obtained starting from the end of the list.

At *r* even, there are *r*/2 cases where the first sublist has $i = \underline{1, r/2}$ elements and *r*/2 cases where the second sublist has $i = \underline{1, r/2}$ elements. Thus, in total there are *r* regroupings with *r* different pivot elements. So, at *r* even, one has:

$$P_i = 2/r,\ i = \underline{1, r/2}.$$

Under the assumptions in [12] and *r* = *n*, Eqs. (4) and (5) hold, and the dependencies *d*(*n*) and $g_{\text{med}}(n) = g_{\text{Me1}}(n)$ of *g*(*d*), at *d* ∈ [1/*n*, 1/2] and *n* even, in graphical form are shown in Figures 1 and 2.

4.3. Mean-of-2 quicksort

Me2 sorting assumes regroupings $M_{i,j}$ with the average value of two elements, either *j* and *k*, used as the (conventional) pivot element *u* = (*j* + *k*)/2, $(j,k) = \underline{1, r}, j \neq k$:

$$M_{j,k} = \left(\lfloor \frac{j+k}{2} \rfloor, r - \lfloor \frac{j+k}{2} \rfloor \right), (j,k) = \underline{1, r}, j \neq k. \quad (6)$$

The variants of regrouping the list of *r* elements into two sublists are the same as for Me1: (1, *r* − 1), (2, *r* − 2), (3, *r* − 3), ..., (*r*/2 − 1, *r*/2 + 1), (*r*/2, *r*/2), (*r*/2, *r*/2), (*r*/2 + 1, *r*/2 − 1), ..., (*r* − 2, 2), (*r* − 1, 1). Similarly, at *r* even, the number of regrouping operations required:

- of the regrouping (1, *r* − 1) is equal to that of the regrouping (*r* − 1, 1);
- of the regrouping (2, *r* − 2) is equal to that of the regrouping (*r* − 2, 2);

.....

- of the regrouping (*r*/2 − 1, *r*/2 + 1) is equal to that of the regrouping (*r*/2 + 1, *r*/2 − 1);
- of the regrouping (*r*/2, *r*/2), obtained starting from the beginning of the list, is equal to that of the regrouping (*r*/2, *r*/2), obtained starting from the end of the list.

So, only the cases of regroupings *i* ∈ [1, *r*/2] can be examined, but the obtained result will be multiplied by 2. At *i* ∈ [1, *r*/2], from the beginning of the list one has the regroupings:

(1, *r* − 1): 1|2, 2|1 - in total 2 cases (N_1= 2) , because ⌊(1 + 2)/2⌋ = 1 and ⌊(2 + 1)/2⌋ = 1 ;

(2, *r* − 2): 1|3, 1|4, 2|3 and vice versa - in total 3 + 3 = 6 cases (N_2 = 6), since ⌊(1 + 3)/2⌋ = 2, ⌊(1 + 4)/2⌋ = 2 and ⌊(2 + 3)/2⌋ = 2;

(3, *r* − 3): 1|5, 1|6, 2|4, 2|5, 3|4 and vice versa - in total 5 + 5 = 10 cases (N_3 = 10);

(4, *r* − 4): 1|7, 1|8, 2|6, 2|7, 3|5, 3|6 and vice versa - in total 7 + 7 = 14 cases (N_4 = 14);

.....

(*i, r* − *i*): in total N_i = (2*i* − 1) + (2*i* − 1) = 2(2*i* − 1) cases;

.....

(*r*/2, *r*/2): 1|*r* - 1, 1|*r*, 2|*r* - 2, 2|*r* - 1, 3|*r* - 3, 3|*r* - 2, 1|*r* - 1, ..., (*r*/2 − 1|*r*/2 + 1), *r*/2|*r* - *r*/2; in total 2(*r* − 1) cases.

Respectively, one gets:

$$N_i = 2 \cdot 2(2i - 1) = 4(2i - 1),\ i = \underline{1, r/2}.$$

$$N = \sum_{i=1}^{r/2} N_i = \sum_{i=1}^{r/2} 4(2i-1) = 4\sum_{i=1}^{r/2} (2i-1) = 8\sum_{i=1}^{r/2} i - \frac{4r}{2} == 8\left(\frac{r}{2}+1\right)\frac{r}{4} - \frac{r}{2} = r^2.$$

So,

$$P_i = \frac{N_i}{N} = \frac{4(2i-1)}{r^2}, i = \underline{1, r/2}. \quad (7)$$

Thus, under the assumptions of [12] and $r = n$, one obtains

$$g_{Me2}(n)|_{d[1/n,1/2]} == \sum_{d=1/n}^{1/2} P_{dn} g(d) = \frac{4}{n^2} \sum_{d=1/n}^{1/2} \frac{2dn - 1}{-dd\ -(1-d)(1-d)}. \quad (8)$$

In graphical form, the dependence of the mean value $g_{Me2}(n)$ on $g(d)$, at $d \in [1/n, 1/2]$ and n even, is shown in Figure 3.

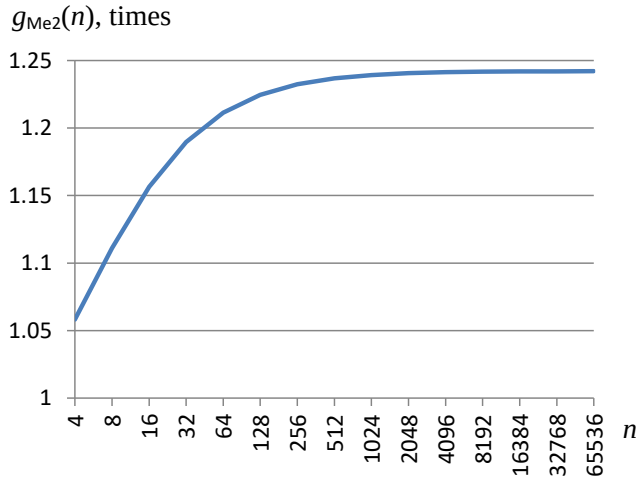

Figure 3. Dependence $g_{Me2}(n)$ at $d \in [1/n, 1/2]$.

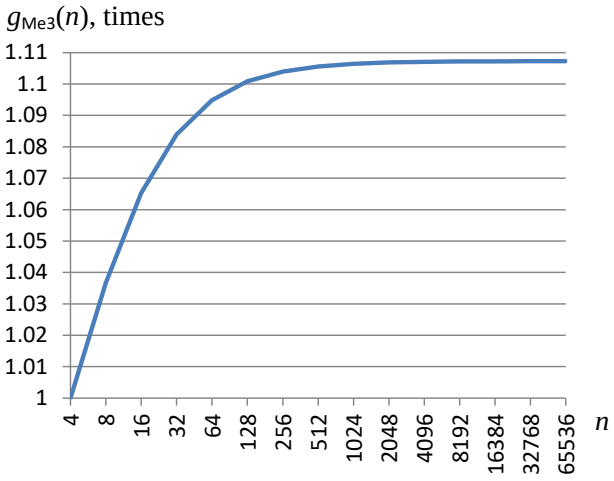

Figure 4. Dependence $g_{Me3}(n)$ at $d \in [1/n, 1/2]$.

The function $g_{Me2}(n)$ is increasing, and starting with, approximately, $n = 2048$ it changes a little: from $g_{Me2}(2048) = 1.240550 \approx 1.2406$ (times) and up to $g_{Me2}(65536) = 1.242014 \approx 1.2420$ (times).

4.4. Mean-of-3 quicksort

Me3 sorting assumes regroupings $M_{i,j,k}$ with the average value of three elements, either j, k and l, used as the pivot (conventional) element $u = (j + k + l)/3$, $(j, k, l) = \underline{1, r}, j \neq \{k, l\}, k \neq l$:

$$M_{j,k,l} = \left(\lfloor\frac{j+k+l}{3}\rfloor, r - \lfloor\frac{j+k+l}{3}\rfloor\right), (j, k, l) = \underline{1, r}, j \neq \{k, l\}, k \neq l. \quad (9)$$

In the Me3 sort, the variants of regrouping the list of r elements into two sublists are the same as in the Me2 sort. Likewise, only the cases of regroupings $i \in [1, r/2]$, can be examined, but the obtained result will be multiplied by 2. For simplicity, the case of using three elements j, k and l to determine the respective pivot element will be noted $j.k.l$. In total, with the same three elements, there are 3! different variants distinguished by their order: $j.k.l$, $j.l.k$, $k.j.l$, $k.l.j$, $l.j.k$, $l.k.j$ and $l.j.k$. In the following, only the variants in ascending order of the constituent elements will be explicitly specified (i.e. $j < k < l$), and the obtained result will be

multiplied by 3! From the beginning of the list, in ascending order of the constituent elements and $i = \underline{1, r/2}$ (the obtained result will be multiplied by 2·3!), we have the Me3 regroupings:

(1, *r* – 1): in total there are *N*1 = 0 cases, because $\lfloor(1 + 2 + 3)/3\rfloor = 2 > 1$;

(2, *r* – 2): 1.2.3, 1.2.4, 1.2.5 and 1.3.4, for each variant *x.y.z* of which $\lfloor(x + y + z)/3\rfloor = 2$ occurs, i.e. 4 cases. Thus, in total there are $N_2 = 4 \cdot 2 \cdot 3!$ cases;

(3, r– 3): 1.2.6, 1.2.7, 1.2.8, 1.3.5, 1.3.6, 1.3.7, 1.4.5, 1.4.6, 2.3.4, 2.3.5, 2.3. 6 and 2.4.5 for each variant x.y.z of which $\lfloor(x + y + z)/3\rfloor = 3$ occurs, i.e. 12 cases. Thus, in total there are $N_3 = 12 \cdot 2 \cdot 3!$ cases;

(4, *r* – 4): 1.2.9, 1.2.10, 1.2.11, 1.3.8, 1.3.9, 1.3.10, 1.4.7, 1.4.8, 1.4.9, 1.5.6, 1.5. 7, 1.5.8, 1.6.7, 2.3.7, 2.3.8, 2.3.9, 2.4.6, 2.4.7, 2.4.8, 2.5.6, 2.5.7, 3.4.5, 3.4.6, 3.4.7, 3.5.6, for each variant *x.y.z* of which loc $\lfloor(x + y + z)/3\rfloor = 4$ occurs, i.e. 25 cases. Thus, in total there are $N_4 = 25 \cdot 2 \cdot 3!$ cases;

and so on.

Respectively, one gets:

$$N_i = \{0, at\ i\ = 0 \quad 83!, at\ i$$
$$= 2 \quad N_{i-1} + 23!\{2(i+1)$$
$$+\frac{5}{2}(i-3), at\ i\ odd\ 2i + \frac{5}{2}(i-2), at\ i\ even \quad , i = \underline{3, r/2}.$$

$$N = \sum_{i=1}^{r/2} N_i.$$

$$P_i = \frac{N_i}{N}, i = \underline{1, r/2}.$$

Thus, under the assumptions of [12] and *r* = *n*, one obtains

$$g_{Me3}(n)|_{d[1/n,1/2]} == \sum_{d=1/n}^{1/2} P_{dn} g(d) = \sum_{d=1/n}^{1/2} \frac{P_{dn}}{-dd\ -(1-d)(1-d)}. \quad (10)$$

In graphical form, the dependence of the mean value $g_{Me3}(n)$ on $g(d)$, at $d \in [1/n, 1/2]$ and *n* even, is shown in Figure 4.

The function $g_{Me3}(n)$ is increasing, and starting with, approximately, *n* = 4096 it changes little: from $g_{Me3}(4096) = 1.107057$ (times) to $g_{Me3}(65536) = 1.107254$ (times).

4.5. Mean-of-4 quicksort

Me4 sorting assumes regroupings $M_{i,j,k,l}$ with the average value of four elements, let *j*, *k*, *l* and *m*, used as the pivot (conventional) element $u = (j + k + l + m)/4$, $(j, k, l, m) = \underline{1, r}, j \neq \{k, l, m\}, k \neq \{l, m\}, l \neq m$:

$$M_{i,j,k,l} = \left(\lfloor\frac{j+k+l+m}{4}\rfloor, r - \lfloor\frac{j+k+l+m}{4}\rfloor\right), (j, k, l, m) = \underline{1, n}, j \neq \{k, l, m\}, k \neq \{l, m\}, l \neq m. \quad (11)$$

In the Me4 sort, the variants of regrouping the list of *r* elements into two sublists are the same as in the Me2 sort. Likewise, only the cases of regroupings $i \in [1, r/2]$, can be examined, but the obtained result will be multiplied by 2. For simplicity, the case of using four elements (*j*, *k*, *l*, *m*) to determine the pivot element respectively, *j.k.l.m* will be noted. In total, with the same four elements, there are 4! different variants that differ by the order of the constituent elements. In the following, only the variants in ascending order of the constituent elements will be explicitly specified (i.e. $j < k < l < m$), and the obtained result will be multiplied by 4! From the beginning of the list, in ascending order of the constituent

elements and $i = \underline{1, r/2}$ (the obtained result will be multiplied by 2·4!), we have the Mo4 regroupings:

(1, r – 1): - in total there are N_1 = 0 cases, because $\lfloor(1 + 2 + 3 + 4)/4\rfloor = 2 > 1$;

(2, r – 2): 1.2.3.4, 1.2.3.5, for each variant $x.y.z.w$ of which $\lfloor(x + y + z + w)/4\rfloor = 2$ occurs, i.e. 4 cases. Thus, in total there are $N_2 = 2 \cdot 2 \cdot 4!$ cases;

(3, r – 3): 1.2.3.6, 1.2.3.7, 1.2.3.8, 1.2.3.9, 1.2.4.5, 1.2.4.6, 1.2.4.7, 1.2.4.8, 1.2.5.6, 1.2.5.7, 1.3.4.5, 1.3.4.6, 1.3.4.7, 1.3.5.6, 2.3.4.5 and 2.3.4.6, for each variant $x.y.z.w$ of which $\lfloor(x + y + z + w)/4\rfloor = 3$ occurs, i.e. 12 cases. Thus, in total there are $N_3 = 16 \cdot 2 \cdot 4!$ cases;

and so on.

Respectively, one gets:

$$N_i = \{0, at\ i = 1 \qquad N_2 = 224!, at\ i = 2\ N_{i-1} + N_i, i = \underline{3, n/2}.$$

$\Delta N_i = \Delta N_{i-1} + 2 \cdot 4!(j - 2)4 \cdot 2 + 2 \cdot 4!\ \{4, at\ i = 3 \qquad 7, at\ i = 4 \qquad 9, at\ i = 3j + 5, j = 0, 1, 2, \ldots 12, at\ i = 3j + 6, j = 0, 1, 2, \ldots 15, at\ i = 3j + 7, j = 0, 1, 2, \ldots$, at $i = \underline{3, r/2}$,

$$N = \sum_{i=1}^{r/2} N_i.$$

$$P_i = \frac{N_i}{N}, i = \underline{1, r/2}.$$

Thus, under the assumptions of [12] and $r = n$, one obtains

$$g_{Me4}(n)|_{d[1/n,1/2]} == \sum_{d=1/n}^{1/2} P_{dn} g(d) = \sum_{d=1/n}^{1/2} \frac{P_{dn}}{-dd - (1-d)(1-d)}. \qquad (12)$$

In graphical form, the dependence of the mean value $g_{Me4}(n)$ on $g(d)$ at $d \in [1/n, 1/2]$ and n even is shown in Figure 5.

The function $g_{Mo4}(n)$ is increasing up to, approximately, n = 2048, and then weakly decreasing. Thus, $g_{Me4}(2048)$ = 1.062616, $g_{Me4}(4096)$ = 1.062610 (times), $g_{Me4}(8192)$ = 1.062604 (times) and $g_{Me4}(65536)$ = 1.062598 (times).

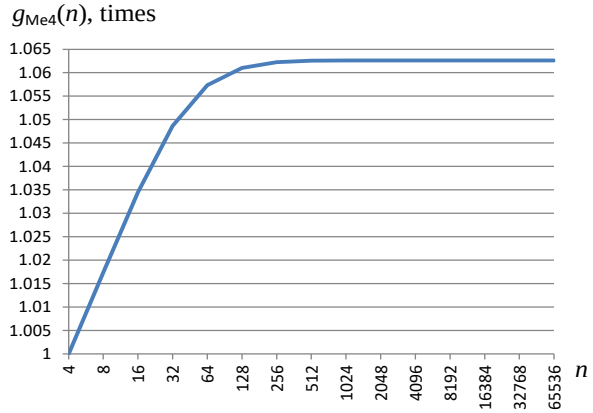

Figure 5. Dependence of mean value $g_{Me4}(n)$ at $d \in [1/n, 1/2]$.

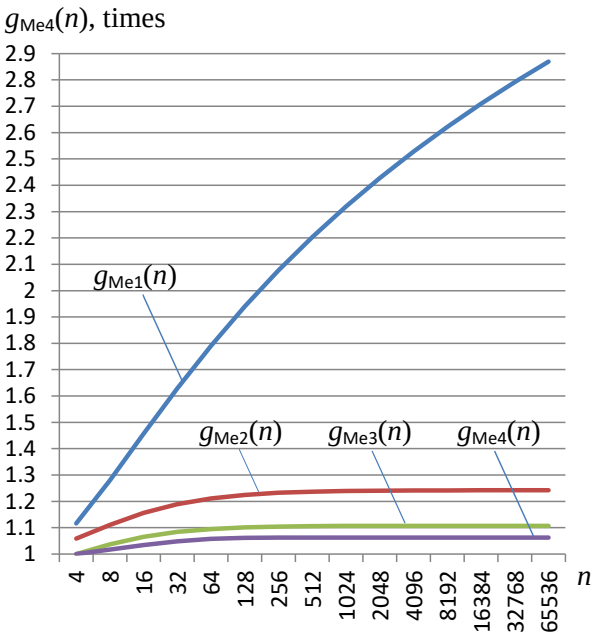

Figure 6. Dependences of mean values $g_{Me1}(n)$, $g_{Me2}(n)$, $g_{Me3}(n)$, and $g_{Me4}(n)$ at $d \in [1/n, 1/2]$.

4.6. Mean-of-2-4 quicksort

The Me2-4 quicksort is based on the results of comparing the Me1, Me2, Me3 and Me4 sorts. As already mentioned, the approximate comparison of these sorts can be performed based on the mean value $g_{MeK}(n)$ of $g(d)$ at $d \in [1/n, 1/2]$. For this purpose, Figure 6 shows the dependences $g_{Me1}(n)$, $g_{Me2}(n)$, $g_{Me3}(n)$, and $g_{Me4}(n)$ at $d \in [1/n, 1/2]$.

According to Figure 6, Me2, Me3, and Me4 sorts are considerably more efficient (in terms of the number of operations required) than Me1, with the former's advantages over Me1 sort increasing significantly as n increases. Of course, the computation of the pivot elements requires additional computations, but at values of n not too small, they, already knowing the value of the pivot element, are much smaller than the total number of sort operations.

In general, relationships take place

$$g_{Me1}(n) > g_{Me2}(n) > g_{Me3}(n) > g_{Me4}(n) \tag{13}$$

and

$$g_{Me1}(n) - g_{Me3}(n) > g_{Me2}(n) - g_{Me3}(n) > g_{Me3}(n) - g_{Me4}(n). \tag{14}$$

So, with the increase in the number K of elements, on the basis of which the pivot element is determined, the advantage of using a larger number of such elements decreases and may even be negative (due to the increase in the time needed to calculate the pivot elements). Thus, relationships can be expected to occur

$$g_{MeK}(n) - g_{Me(K+1)}(n) > g_{Me(K+1)}(n) - g_{Me(K+2)}(n),\ K = 1, 2, 3, \ldots \tag{15}$$

Therefore, it may not be appropriate to use too large values for K. However, the use of Me4 sorting might be appropriate in some cases, especially at relatively large values of n. For this purpose, only the dependences of the mean values $g_{Me2}(n)$, $g_{Me3}(n)$ and $g_{Me4}(n)$ of $g(d)$, at $d \in [1/n, 1/2]$ are shown in Figure 7.

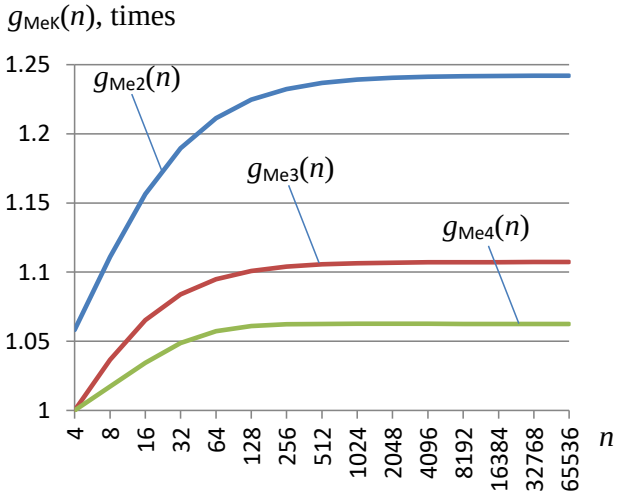

Figure 7. Dependences of mean values $g_{Me2}(n)$, $g_{Me3}(n)$, and $g_{Me4}(n)$ at $d \in [1/n, 1/2]$.

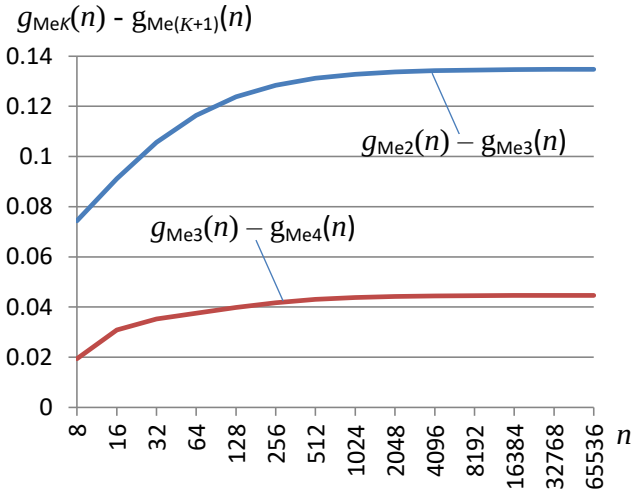

Figure 8. Dependences of differences $g_{MeK}(n) - g_{Me(K+1)}(n)$ at $K = \{2, 3\}$.

From Figure 7 it can be seen that the value of $g_{MeK}(n)$ with increasing K stabilizes (to some extent) at lower values of n.

A clearer quantitative difference in the efficiency of different sortings is presented by the value of the differences $g_{MeK}(n) - g_{Me(K+1)}(n)$, $K = 1, 2, 3, \ldots$ For $K = 1$, $K = 2$ and $K = 3$, some of these are shown in Figure 8 and Table 1.

Since for the sorts Me1, Me2, Me3 and Me4 the sorting times $T(n, 1/2)$ are approximately equal, the sizes $100(g_{MeK}(n) - g_{Me(K+1)}(n))$, $K = 1, 2, 3$ means, roughly, how much (in %) the Me(K+1) sort is more efficient than the MeK sort.

From Table 1 it can be seen that the differences $g_{Me1}(n) - g_{Me2}(n)$, $g_{Me1}(n) - g_{Me3}(n)$, $g_{Me1}(n) - g_{Me4}(n)$, $g_{Me2}(n) - g_{Me3}(n)$ and $g_{Me3}(n) - g_{Me4}(n)$ are increasing with respect to n, the first three of which, at $n = 65536$, reach considerable values, respectively (approximately): 1.628, 1.762 and 1.807. So only at very small values of n can it be reasonable to use the Me1 sorting over the Me2 one. At the same time, if the difference $g_{Me2}(n) - g_{Me3}(n)$ is relatively large, constituting (approximately) 0.133 at $n = 1024$ and 0.135 at $n = 65536$ (i.e. a reduction of the laboriousness of sorting by more than 13%), then the $g_{Me3}(n) - g_{Me4}(n)$ is not negligible in some cases, being (approximately) 0.044 at $n = 1024$ and 0.045 at $n = 65536$ (i.e. a reduction in sorting laboriousness of more than 4.4%).

Table 1

Absolute value of differences $g_{MeK}(n) - g_{MeL}(n)$

n	$g_{Me1}(n) - g_{Me2}(n)$	$g_{Me1}(n) - g_{Me3}(n)$	$g_{Me1}(n) - g_{Me4}(n)$	$g_{Me2}(n) - g_{Me3}(n)$	$g_{Me3}(n) - g_{Me4}(n)$
8	0.169002	0.243352	0.262709	0.074350	0.019357
16	0.299643	0.390807	0.421634	0.091164	0.030827
32	0.438706	0.544349	0.579620	0.105643	0.035271
64	0.578794	0.695242	0.732756	0.116448	0.037514
128	0.715023	0.838784	0.878588	0.123761	0.039804
256	0.844680	0.973064	1.014813	0.128384	0.041749
512	0.966614	1.097782	1.140836	0.131168	0.043054
1024	1.080642	1.213428	1.257245	0.132786	0.043818
2048	1.187120	1.320822	1.365054	0.133702	0.044232
4096	1.286613	1.420823	1.465270	0.134210	0.044448
8192	1.379800	1.514288	1.558846	0.134488	0.044558
16384	1.467298	1.601936	1.646549	0.134638	0.044614
32768	1.549702	1.684419	1.729061	0.134717	0.044642
65536	1.627536	1.762296	1.806952	0.134760	0.044656

Of course, the laboriousness of the sorting algorithms depends on the particularities of the implementation (programming language, computer, etc.). In approximate calculations, the laboriousness of operations will be considered (in conventional operations): of reading a number - c operations; of adding two numbers - a operations; of comparing two numbers - a operations; of exchange with the place of two elements - s operations; of dividing two numbers - h operations; of determining the position of the middle element of a list for the Me3 sorting - two operations of reading the positions of the first and last elements of the list, an operation of addition and an operation of division of two numbers (truncated to integers), so in total $a + 2c + h$ operations; of determining the positions of two non-marginal elements positioned at approximately equal distances from the neighboring elements (out of the four) in the list for the Me4 sorting – three addition operations, six read operations and one divide operation, so a total of $3a + 6c + h$ operations.

Under these assumptions, the consideration of operations with the determination of the pivot element can be carried out in the following way. Let the list/sublist, at the given sort step, consist of r elements and, in the case of sorting:

- Me1, the last element of the list is taken as the pivot element u. Only one read operation is then required, i.e. c conventional operations (conv. ops.);
- Me2, to determine the pivot (conventional) element u, the first and last elements of the list are taken. Then two read operations are required, one operation to add the two elements and one operation to divide; so in total $a + 2c + h$ conv. ops.;
- Me3, to determine the pivot (conventional) element u, the first, last and middle elements of the list are taken. Then there are required: one operation to determine the position of the middle element, three read operations, two operations to add the three elements and one divide operation; so in total $a + 2c + h + 3c + 2a + h = 3a + 5c + 2h$ conv. ops.;
- Me4, to determine the pivot (conventional) element u, the first, last and two non-marginal elements positioned at approximately equal distances from the neighboring elements (among the four) in the list are taken. Then it is necessary: an operation to determine the positions of the two non-marginal elements, four reading operations, three operations to add the four elements and a dividing operation; so in total $3a + 6c + h + 4c + 3a + h = 6a + 10c + 2h$ conv. ops.

Given the pivot element, it remains to determine the number of operations with regrouping the list/sublist of r elements into two sublists. Let the list of r elements be sorted in ascending order. The pivot element u (in the Me1 sort last in the list, and in the Me2, Me3 and Me4 sorts - a conventional element that is considered not to be contained in the list) is compared with the list elements as in the basic Quicksort. That is, the pivot element is consecutively compared with the elements at the beginning of the list until an element, say j, greater than the pivot is identified, then with the elements at the end of the list until an element, say k, smaller than the pivot is identified, and subsequently, the two elements thus identified change with the place; the process continues in the same way until all $r - 1$ (at Me1) or r (at 2, Me3, and Me4) elements have been compared. At each comparison of the pivot element u with another element there can be two options, each of probability 1/2: $j < u$ or $j > u$, respectively, $k < u$ or $k > u$. If $j < u$ or $k > u$, then each comparison has two read operations (of elements u and j or u and k, respectively) and a comparison operation of the two elements - a total of $2c + a$ conventional operations, since the elements j and k remain in place. But if $j > u$ and $k < u$, then each comparison has two read operations (of elements u and j or u and k, respectively), one comparison operation of the two elements and 0.5 exchange operations with the place of elements j and k - in total $2c + a + 0.5s$ conventional operations. In the case of sorting Me1 at the end, additionally, the pivot element will be swapped with the first element in the second sublist – a total of 2 read operations and a swap operation with the place of two elements.

So, if the pivot element is known, the number of conventional operations with regrouping the list/sublist of r entities into two sublists is roughly equal to $(r - 1)(a + 2c)/2 + (r - 1)(a + 2c) + 0.5s)/2 = (r - 1)(2a + 4c + 0.5s)/2$ on Me1 sort (since the pivot element is an element of the list) and with $r(a + 2c)/2 + r(a + 2c + 0.5s)/2 = r(2a + 4c + 0.5s)/2$ conv. ops. on sorts Me2, Me3, and Me4 (since the pivot element is a conventional one and is considered not to correspond to any element of the list).

Thus, the total number (R_{MeK}) of conventional operations with the regrouping of the list/sublist of r entities into two sublists is approximately:

- $R_{Me1}(r) = (r - 1)(2a + 4c + 0{,}5s)/2 + c$, when Me1 sorting;
- $R_{Me2}(r) = r(2a + 4c + 0{,}5s)/2 + a + 2c + h$, when Me2 sorting;
- $R_{Me3}(r) = r(2a + 4c + 0{,}5s)/2 + 3a + 5c + 2h$, when Me3 sorting;
- $R_{Me4}(r) = r(2a + 4c + 0{,}5s)/2 + 6a + 10c + 2h$, when Me4 sorting.

Let's determine at what values of r it is appropriate to use each of the sorts under discussion. Broadly speaking, using the MeK sort is as time complexity as using the Me(K+1) sort at

$$G_{Me(K+1),K}(r) = (R_{Me(K+1)}(r) - R_{MeK}(r))/R_{MeK}(r) = g_{MeK}(r) - g_{Me(K+1)}(r). \quad (16)$$

Example 1. Let: a = 1 conv. ops.; $c = 0.5a$; $h = s = 3a$.

Then $R_{Me1}(r) = 2.75r - 2.25$ conv. ops.; $R_{Me2}(r) = 2.75r + 5$ conv. ops.; $R_{Me3}(r) = 2.75r + 11.5$ conv. ops. and $R_{Me4}(r) = 2.75r + 17$ conv. ops.

Based on Eq. (16), we obtain: $(R_{Me2}(r) - R_{Me1}(r))/R_{Me1}(r) = 7.75/(2.75r - 2.25)$ conv. ops.; $(R_{Me3}(r) - R_{Me2}(r))/R_{Me2}(r) = 6.5/(2.75r + 5)$ conv. ops.; $(R_{Me4}(r) - R_{Me3}(r))/R_{Me3}(r) = 5.5/(2.75r + 11.5)$ conv. ops.. Then, taking into account the data of Table 1, it can be concluded that, approximately, it is appropriate to use the sorting: Me1 at $r \leqslant 12$, Me2 at $12 < r \leqslant 21$, Me3 at $21 < r \leqslant 46$ and Me4 at $r > 46$. At the same time, in [9] it is shown that for $r \leqslant 9$ instead of Mo3 sorting it is appropriate to use Insertionsort. This result can also be extended to Me3 sorting, mostly close to Mo3, and MeK sorting, respectively. So, for sorting Me1 only $10 \leqslant r \leqslant 12$ remains - very small area.

Thus, one can roughly conclude that for lists/sublists of size:

- $r \leqslant 9$ is appropriate to use Insertionsort;
- $10 \leqslant r \leqslant 21$ it is appropriate to use Me2 sorting;
- $22 \leqslant r \leqslant 46$ it is appropriate to use the Me3 sorting;
- r > 46 it is appropriate to use the Me4 sorting.

Based on the result of Example 1, it may be appropriate the Mean-of-2-4 sorting which for lists/sublists of size r uses: Insertionsort at $r \leqslant 9$, Me2 sort at $10 \leqslant r \leqslant 21$, Me3 sort at $22 \leqslant r \leqslant 46$, and Me4 sort at $r > 46$. Also, if the initial list of elements is known to contain multiple equal elements then the Mean-of-2-4 sort can be combined with the Regrouping-3 sort.

5. Comparing Median-of-three and Mean-of-3 quicksorts

The version of Mo3 sort proposed in [8], for sublists of size $r \leqslant 9$, uses Insertionsort. That is why when comparing Mo3 and Me3 sorts it is appropriate to consider the same conditions, i.e. whether Insertionsort is used or not. Either in both use Insertionsort at $r \leqslant 9$.

Also, for the list of elements to be sorted described in Section 4.1, the procedures used to determine the pivot elements lead to the same regroupings of lists into sublists. So, the time complexity difference between Mo3 and Me3 sorts for each list/sublist is only determined by the number of operations required to determine the pivot element. In turn, the two procedures for determining the pivot element differ only in that in the case of Mo3, after determining the three elements, they are sorted and the middle element is used as the pivot element; while in the case of Me3, after determining the three elements, their arithmetic mean is calculated, which serves as the pivot element.

Thus, the number of operations required to determine a pivot element in the Mo3 and Me3 sorts differs only at the last stage: in Mo3 – sorting the three elements, and in Me3 – calculating the arithmetic mean of the three elements. When Mo3 sorting, for the three-

element sorting procedure described in [14], on average, 10.5 operations to read one element and 3 operations to compare two elements are required – in total, at the complexities of the operations used in Example 1, 8.25 conventional operations. In Me3 sorting, for the procedure of calculating the arithmetic mean of three elements, 3 operations of reading an element, 2 operations of addition and one operation of division are required - in total, at the complexities of operations used in Example 1, 6.5 conventional operations.

So, when determining a pivot element, the Me3 sort requires 1.75 fewer conventional operations than the Mo3 sort. Given that the Me2-4 sort is preferable to the Me3 sort, the number of sort operations, when using the Me2-4 sort and the list of elements to sort described in Section 4.1, is even smaller compared to the Mo3 sort. It should also be noted that for some lists of elements to be sorted, different from the one described in Section 4.1, in some cases the pivot elements of the Me3 sort may be more successful, and for others - the pivot elements of the Mo3 sort may be more successful and, respectively, the solutions obtained. That is why, in specific cases, it may be appropriate to make the comparison in question through computer simulation.

6. Conclusions

By combining the Median-of-three and Regrouping-3 quicksort methods, the Joint quicksort is proposed, which allows reducing the volume of calculations both for lists of equal elements and for lists of already ordered elements or in reverse order. Also is introduced the category of Mean-of-*K* (Me*K*) quicksort algorithms that differs from the Median-of-three sort [9] by determining the pivot element as the mean of *K* elements, positioned, in the list to regroup, at approximately equal distances among them. For the basic Quicksort method (Me1) under some assumptions, $g(d)$ dependencies are analyzed – how many times the sorting time $T(n,d)$ is greater than the time $T(n,1/2)$ at $d \in [1/n, 1/2]$. The laboriousness of the Me1 sort increases relatively slowly as d decreases from 0.5 (the ratio between the sizes of the two derived sublists is 1:1) to approx. 0.1 (the ratio in question is 1:9).

For the comparative analysis of Me1, Me2, Me3, and Me4 methods, the average value ($g_{med}(n)$) of $g(d)$ at $d \in [1/n, 1/2]$ is determined. The calculation results show that the dependencies $g_{Me1}(n)$, $g_{Me2}(n)$, $g_{Me3}(n)$, and $g_{Me4}(n)$ at $d \in [1/r, 1/2]$, where $g_{MeK}(n)$ is $g_{med}(n)$ on Me*K* sorting, are increasing, that is, the efficiency of quick sort decreases as the number of elements of the initial list increases. At the same time, this growth is slower and slower, especially at higher values of *K*. Thus: $g_{Me1}(1024) \approx 2.320$, $g_{Me1}(2048) \approx 2.428$ and $g_{Me1}(65536) \approx 2.870$; $g_{Me2}(1024) \approx 1.239$, $g_{Me2}(2048) \approx 1.241$ and $g_{Me2}(65536) \approx 1.242$; $g_{Me3}(1024) \approx 1.106$, $g_{Me3}(2048) \approx 1.107$ and $g_{Me3}(65536) \approx 1.107$; $g_{Me4}(1024) \approx 1.063$, $g_{Me4}(2048) \approx 1.063$ and $g_{Me4}(65536) \approx 1.063$. Moreover, Eqs. (13) hold, i.e. the sorts with the higher *K* value, at $K \in \{1, 2, 3, 4\}$, are more efficient regarding the time of sorting.

Since for $K \in \{1, 2, 3, 4\}$, the sorting time $T(n,1/2)$ practically does not depend on *K*, the quantities $100(g_{MeK}(n) - g_{Me(K+1)}(n))$, $K = 1, 2, 3$ means, roughly, how much (in %) the time of the Me(*K*+1) sort is faster than that of the Me*K* sort. As a result of calculations, it is found that the differences $g_{Me1}(n) - g_{Me2}(n)$, $g_{Me2}(n) - g_{Me3}(n)$ and $g_{Me3}(n) - g_{Me4}(n)$ are increasing, reaching at $n = 65536$ values, respectively (approximately): 1.628, 0.135 and 0.045. So, at $n = 65536$, using Me4 sorting allows to reduce the sorting time by approx. 4.5% compared to Me3, which is sometimes not negligible.

The results of the comparison of Median-of-three and Mean-of-3 sorts show that the Mean-of-3 sort requires fewer calculations with the determination of pivot elements and,

respectively, could also reduce the time of the sort. Of course, Mean-of-2-4 sorting could reduce this time even further. At the same time, cases are not excluded when the Median-of-three quicksort could be more efficient than the Mean-of-3 quicksort or even the Mean-of-2-4 quicksort, if the pivot elements in the Median-of-three quicksort, for the respective lists of elements, would be significantly more successful. Such cases could be identified by computer simulation.

Conflicts of Interest: The author declares no conflict of interest.

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DEVELOPMENT OF FUNCTIONAL PROTOTYPE OF ELECTRICAL LOWER ESOPHAGEAL SPHINCTOR STIMULATOR

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Abstract. Scientific and technical innovations done since 1960s resulted in successful development and implementation in medical practice active implantable devices. Most of them are using traditional chemical batteries with limited longevity. Further research progress and development of semiconductors and passive elements base are allowing now to develop fully battery-free implants that could do same tasks, but with much lower sizes, less complication and more ease of use. In this article will be shared results of own development of an wireless-powered, remote controlled, fully implantable electrostimulator of lower esophageal sphincter (WIPLES) aimed to treat gastroesophageal reflux disease, that is very common in current days.

Keywords: *battery-free, electrostimulator, implantable, reflux disease, wireless-powered.*

Rezumat. Inovațiile științifice și tehnice realizate începând cu anii 1960 au condus la dezvoltarea și implementarea reușită în practica medicală a dispozitivelor implantabile active. Majoritatea acestora utilizează baterii chimice tradiționale cu o durată de viață limitată. Progresul ulterior al cercetărilor și dezvoltarea bazată pe semiconductori și elemente pasive permit acum dezvoltarea implanturilor complet fără baterii, care pot îndeplini aceleași sarcini, dar cu dimensiuni mult mai mici, mai puține complicații și mai ușurință în utilizare. În acest articol vor fi împărtășite rezultatele propriei dezvoltări a unui electrostimulator complet implantabil, alimentat fără fir și controlat la distanță al sfincterului esofagian inferior (WIPLES), destinat tratării bolii de reflux gastroesofagian, care este foarte răspândită în zilele noastre.

Cuvinte cheie: *alimentare fără fir, boală de reflux, electrostimulator, fără baterie, implantabil.*

1. Introduction

Implantable electrostimulators were initially introduced within medical practice in the early 1960s, marking the debut of the portable pacemaker, later renowned for its high reliability and enduring nature 1. Since then, these devices have seen a consistent surge in their application for both therapy and the diagnosis of various diseases. The most common stimulator depending on end application are cardiac pacemakers 1, deep brain stimulators (DBS) 2, sacral nerve Stimulators (SNS) 2, vagus nerve stimulators (VNS) **Error! Reference source not found.**, cochlear implants 5, gastric neurostimulator 7, lower esophageal sphincter (LES) stimulator **Error! Reference source not found.** and other types.

An inherent limitation of these active implants is their usage duration, primarily dictated by the capacity of the internal battery, typically lasting up to 6-8 years [9-10].

Simultaneously, advancements in wireless communications have coincided with the evolution of wireless power transfer technologies, offering prospects to elevate electronic device development to unprecedented heights. For example, recent studies showed basis for energy transfer of implanted stimulators even in several centimeters of tissue [11,12]. Transitioning from relying on non-rechargeable portable battery sources to harnessing energy from electric and/or magnetic fields or even mechanical body movements [13] holds the promise of substantially reducing device sizes while enhancing their quality, safety, and user-friendliness. Implantable stimulators represent a diverse range of devices used in various medical applications, offering therapeutic benefits by delivering controlled electrical impulses to specific areas of the body.

This study focuses on development of implantable LES stimulator for possible application in gastroesophageal reflux disease (GERD) treatments. According to the latest literature review, the prevalence of GERD is 18.1–27.8% in North America, 8.8–25.9% in Europe, 2.5–7.8% in East Asia, 8.7–33.1 % in the Middle East, 11.6% in Australia and 23.0% [14].

Recent studies showed high efficacy and safety of electrical LES stimulation, where the specially designed traditional battery-powered stimulators are used. Taking in account confirmed advantages of batter-free implants, having experience in developing of wireless implants, we hereby present result of developing process for lightweight, miniaturized, wireless-powered, and battery-free device that can be entirely implanted [15-17]. These advancements offer capabilities that meet or surpass those of connected and battery-operated options, overcoming their inherent constraints.

2. Materials and methods

As a result of previous research, literature review and scientific exploration, the key components of a fully functional prototype of the lower esophageal sphincter electrical stimulator have been identified as below:

1) central microcontroller;
2) wireless power receiver;
3) wireless communication module according to Bluetooth 4.0 BLE standards;
4) nanoAmper power controller with timer for energy saving;
5) low voltage step-up DC-DC converter from 0.7V to 3.3V;
6) digital thermometer module;
7) super-capacitor for energy storage;
8) hybrid constant current (CC) pulse module.

The general block diagram of developed device is presented on Figure 1.

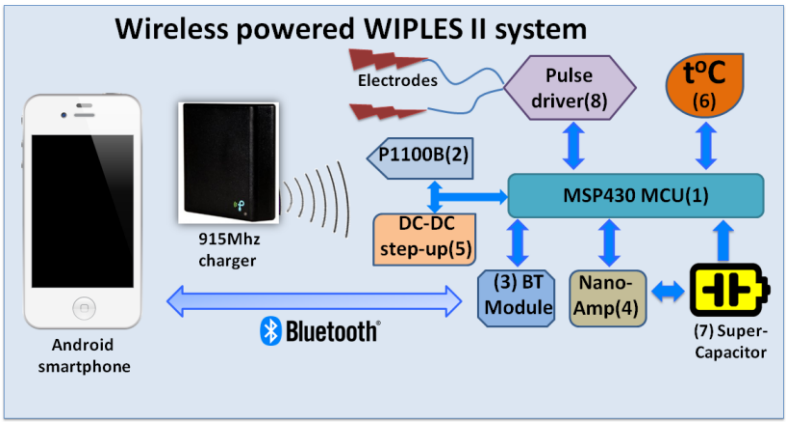


Figure 1. Functional block diagram of the prototype.

Below will be providing short description of each module included.

1) Central microprocessor is based on platform MSP430 from Texas Instruments™ (TI) MSP430 MCUs with non-volatile FRAM (ferroelectric random access memory) have 16-bit processing core, specially designed for ultra-low-power system management designs.

The unique features are the lowest standby power (up to 350 nA), 100 µA/MHz active power, and the ability to save and immediately restore system state after power failure. MSP FRAM MCUs are very reliable, having write endurance up to 10^{15} cycles, as well as 10-year data retention time, advanced code &data protection with integrated security features.

2) Wireless charging module is based on RF charging by cm waves, specially designed to work with 915 Mhz transceiver with power output 1W or 3W, with automatic disable function if is closer than 23cm to live organisms, to ensure necessary protection according to existing standards ERC 70-03 [18]. Technical parameters of the wireless module are listed in Table 1:

Table 1

Technical specification of a wireless power receiver module

Operating frequency	868…950 MHz
Output voltage	2.0…5.5 V
Output current	up to 50 mA
Input power	-12…10 dBm
Antenna type	50 Ohm
Type of energy store	super capacitor
Dimensions	15.9×10.9×2.3 mm

3) Wireless module used is type Bluetooth BLE 4.0 with GATT profile, which allows simple remote connection using any Serial port application. Module is based on low energy System-on-Chip from Dialog Semiconductor, model DA1458x, with chip dimensions of only 2.5×2.5×0.5 mm. Taking into account the high complexity of manufacturing a high-frequency wireless module of the Bluetooth standard, a ready-made module of the HJ-580B type based on the DA14580 chipset. This fully compliant with the Bluetooth BLE standard, the module has a standby consumption of only 2 µA, start time only 10ms and a maximum peak current of 500 µA.

4) NanoAmper power controller has a unique feature of radical reducing of system power consumption in idle state. Having inside nano-timer series TPL5xxx from TI with a watchdog feature, working in pair with load switch, this controller schematics is designed for battery-powered and battery-free applications. Usually these applications require use of a microcontroller, with keeping it in a low power mode to maximize current savings, waking up only during certain time intervals to collect data or doing service required.

Consuming only 35 nA in idle state, this type of controller offers power savings of almost two orders of magnitude, enabling the use of significantly power, especially in current application.

5) Low power DC-DC converter based on TPSxx platform from TI is designed to convert power energy, received by wireless charging module to standard system power of 3.3V. The distinctive feature is module starting only from 0.7V, providing necessary power even in worst conditions.

6) Digital thermometer series TMPxx from TI with ultra-low power consumption is used to provide precise temperature measurements of installed implantable prototype. It also is serving the function of remote monitoring of system state.

7) Super-capacitor was used to provide storage of necessary energy, received from wireless power receiving schematics. Taking in account, that super capacitors could be charged up to 100'000 times, the possible working period for implantable device could reach 20 years and even more, this is already more depends on biocompatibility properties of encapsulation cover.

8) Hybrid constant current (CC) pulse module is invention of author, having unique features of combining ultra-low supply current consumption with ease of digital current setting. This type of schematics ensures delivering same level of stimulation energy independent of stimulation electrode's impedance change during patient movements, contact aging or biological encapsulation [16].

Printed circuit board (PCB) design and prototype assembly

Complete design of the electrical circuit and printed circuit board was carried out in the Autodesk Eagle PCB and electronic schematics development environment.

The appearance of the PCB sized only 14×10 mm is shown on Figure 2.

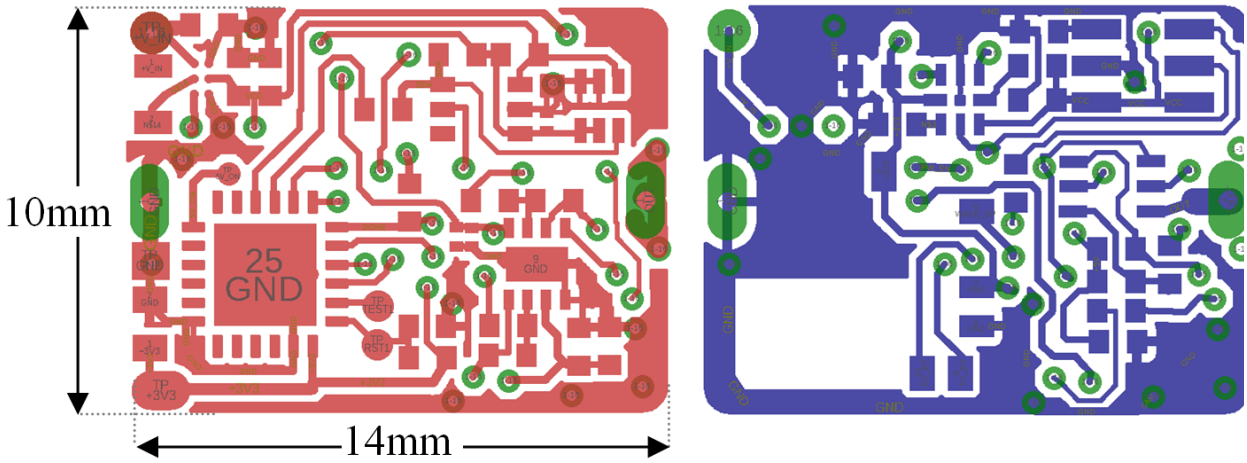


Figure 2. Developed PCB of the main board of prototype, top &bottom layers, scale 40:1.

Upon completion of the development of electrical circuits, a package of electronic drawings in Gerber format was prepared for the manufacture of printed circuit boards at a specialized factory with specification according to Table 2:

Table 2

Technical specification of developed PCB

Material	FR-4 TG130
Number of layers	2
PCB thickness	0.6 mm
Mask color	Green
Surface treatment	HASL (hot air solder leveling)
Minimum mask jumper	0.1 mm
Copper thickness	35 microns (300 g/m^2)
Minimum diameter of the via hole	0.2/0.25 mm
Minimum track width	0.12 mm

At the same time, the minimum size of discrete elements was only 0.60×0.30×0.23 mm (type SMD 0201). The minimum pin pitch of the microcircuits was only 0.3 mm.

The assembly of printed circuit boards was carried out using SMT technology with a laser stencil for applying solder paste.

Solder paste reflow was carried out in a controlled temperature environment using a digital programmable soldering oven type INFRARED IC HEATER T-962 with built-in industry standard temperature profiles for various soldering modes.

The appearance of the entire process is presented in Figure 3.

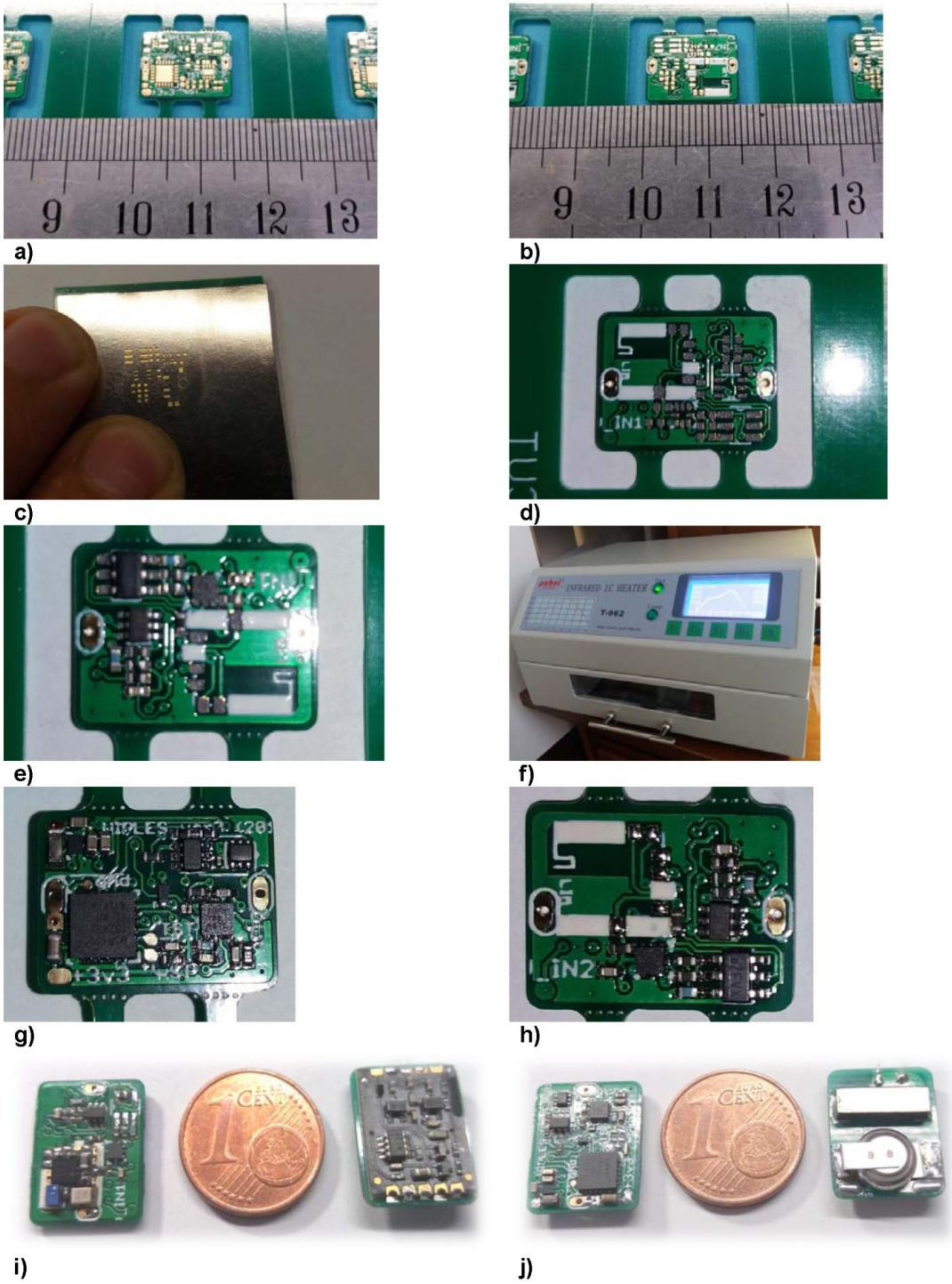


Figure 3. Step-by-step assembly of a printed circuit board: a) ready main PCB, top view; b) ready main PCB, bottom view; c) solder stencil matching; d) applied SMT solder paste; e) electronic components placed; f) SMT oven type IC HEATER T-962; g) soldered main PCB, top view; h) soldered main PCB, bottom view; i) assembled prototype (3 boards), top view; j) assembled prototype (3 boards), bottom view.

3. Results

After assembly and soldering of all PCB boards, further assembly of prototype was done. Final device is consisting of 3 boards:

- main PCB with MCU, power controller, 2.4 GHz Bluetooth BLE 4.0 module and constant current (CC) pulse driver [16];
- wireless charging module, working at 915 MHz [18];
- RF board with 915Mhz antenna and supercapacitor.

All 3 boards were linked together, as well was connected pair of stitch electrodes type Flexon™ (Covidien®, USA) and additional ¼ wave RF antennas.

After electric assembly, whole module was covered with two layer of biocompatible silicon compound, providing the necessary isolation from biological tissues and ensuring radio transparent transmitting and reception of RF signal [19, 20], see Figure 4.

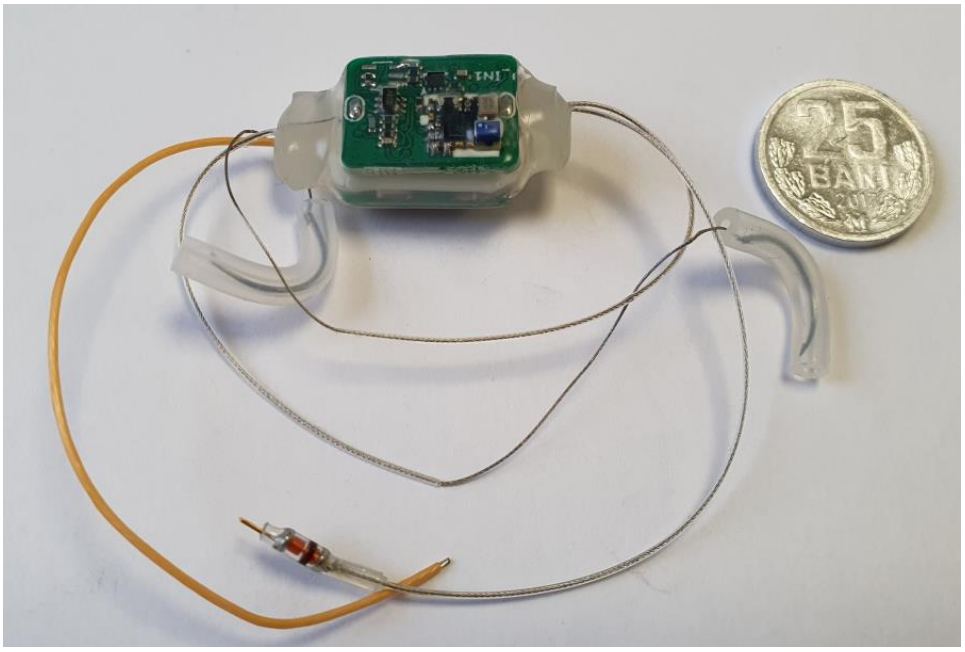


Figure 4. Assembled prototype.

Ready device is sized 25×12×8 mm only, including lateral isolation electrodes glands, made from silicone.

Several tests were carried out to evaluate the effectiveness of the device:

- measurement of the level of supplied current;
- measuring the range of stable communication;
- start-up test at different levels of accumulated charge.

The tests performed demonstrated stable energy transfer over a distance of up to 3 meters, while the relative spatial location of the transmitter and receiver of the device had virtually no effect on the received current, which ranged from 1 mA (at a distance of ~3 m) to 30 mA at (at distance of ~0.3 m).

At the same time, the quiescent current of the entire device was assessed, as well as the maximum operating time on a single charge. The measurement data demonstrated that the quiescent current varied with a frequency of several seconds, ranging from less than 1 μA to 48 μA, depending on the operating mode of the Bluetooth module and the sleep mode settings of the microcontroller.

According to processed tests, on a single charge the device remained functional for up to 12-15 hours, when using a supercapacitor with a capacity of 0.1 F.

Unique feature of developed device is using own elaborated constant current driver with ultra-low idle power consumption 16. Designed schematic is an invention of the author and will apply for a patent registration in Moldova.

During the performed tests, the CC module demonstrated the complete compliance of the real output characteristics to the calculated ones, namely:

- output current - within 0.1 - 10 mA, with a step of 0.078 mA;
- processed pulse width is within 100us – 500 ms;
- loading impedance range - from 10 to 1000 Ohms.

For further testing, the prototype was programmed for several operating modes, that could be selected after pairing of prototype with Android based smartphone with installed a simple BLE Serial port software, see Table 3.

Table 3

Prototype working modes

HEX command	ASCII symbol	Proposed action
0×31	1	Stimulation mode 1 (pulse 220 μs, frequency 20 Hz, 10s)
0×32	2	Stimulation mode 2 (pulse 100 μs, frequency 10 Hz, 10s)
0×32	3	Stimulation mode 3 (pulse 300 μs, frequency 40 Hz, 10s)
0×32	4	Stimulation mode 4 (pulse 220 μs, frequency 20 Hz, 60s)
0×32	5	Stimulation mode 5 (pulse 375 ms, 6 pulses/min, 60s)
0×6C	l	Set the stimulation current to 2 mA
0×6D	m	Set the stimulation current to 4 mA
0×68	h	Set the stimulation current to 6 mA
0×74	t	Measure ambient temperature
0×3F	?	Provide device version

Note: HEX means command in hexadecimal format, ASCII symbol - according to Windows-1252-character set.

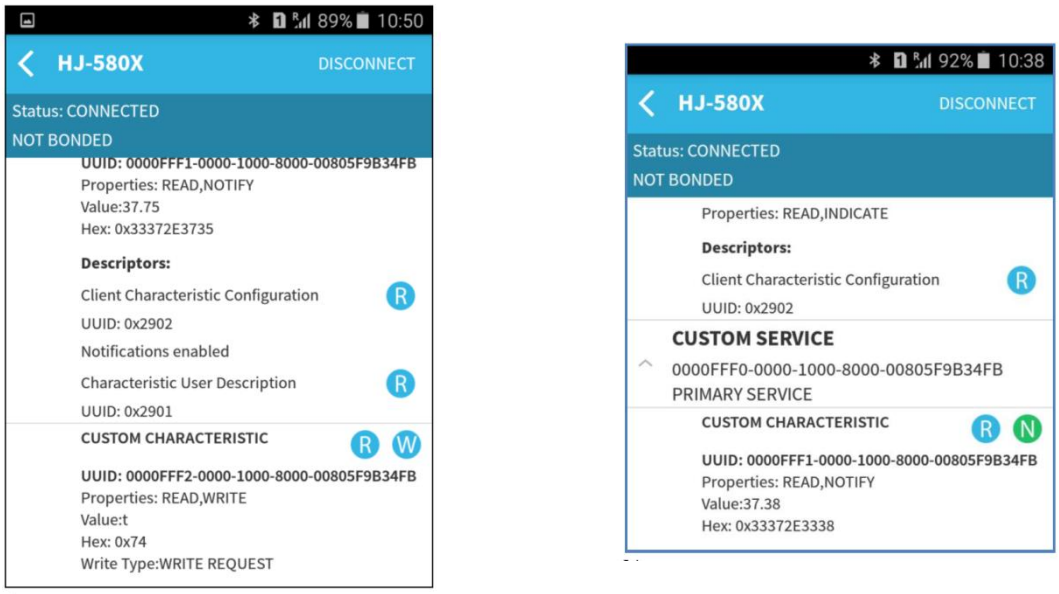
There are 5 different pulse stimulation modes and 3 output current levels. Additionally – device temperature measurement mode and displaying device version (WIPLES3_Vidiborschii).

Operating modes are set remotely using a mobile application “BLE Scanner v3.12” from BluePixel Technologies LLC, India.

This application is working with Bluetooth 4.0 enabled devices and uses next configuration:

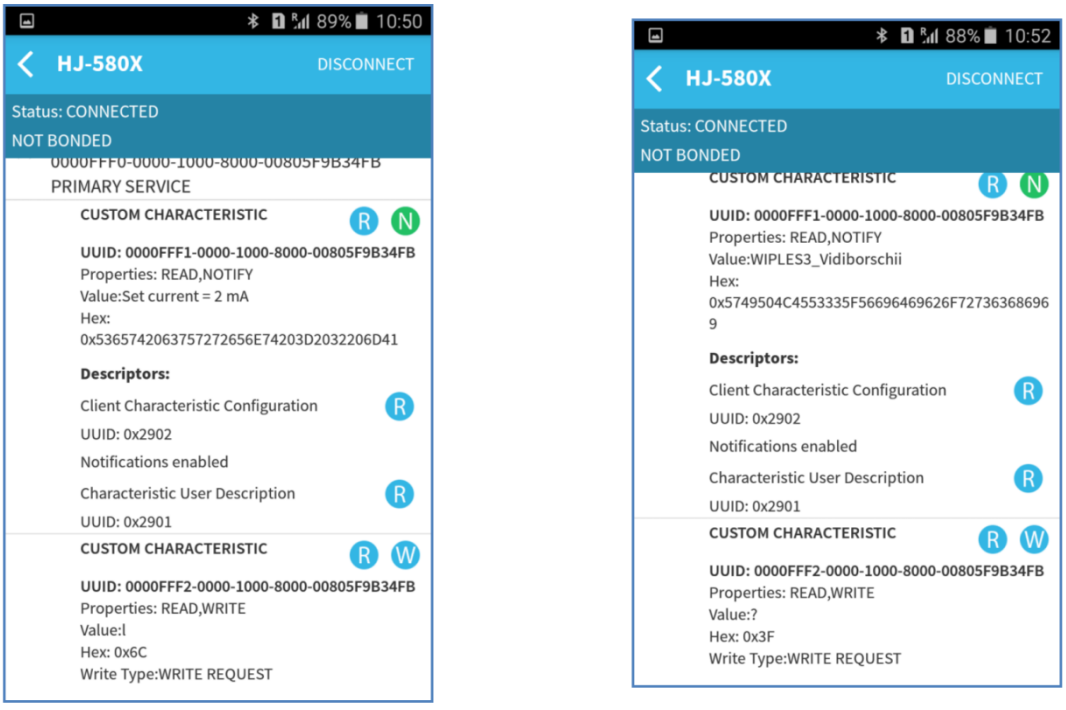
- Application level - for a mobile application on an Android smartphone;
- Host level (Bluetooth module in prototype, type HJ-580X), using GATT profile;
- Communication with controller is done the HCI interface (UART format).

The following screenshots demonstrate various software operations on a smartphone, see Figures 5 and 6.



a) b)

Figure 5. Screenshots of working remote control software: a) sending command “t” (0x74) – measure temperature; b) response to temperature measurement command.



a) b)

Figure 6. Screenshots of working remote control software: a) sending command 0×6C -> stimulation current 2 mA; b) received reply to “get version” command “?” (0×3F).

4. Discussion

The article discusses different application area of implantable stimulators. The development of an implantable electrical stimulator for the lower esophageal sphincter (LES) showcases significant technological advancements.

The transition from traditional battery-powered devices to a wireless, battery-free prototype presents a leap in implantable medical devices' design and functionality. The prototype successfully demonstrated stable energy transfer over distance, maintaining effective communication up to 3 meters.

The device's ability to deliver a range of current levels and pulse widths as per design specifications underscores its functionality.

Evaluation of the prototype's power consumption revealed encouraging results. With a supercapacitor of 0.1F, the device remained functional for 12-15 hours on a single charge. The utilization of an ultra-low idle power consumption constant current driver is a noteworthy feature that contributes to its energy efficiency.

The implementation of multiple stimulation modes and selectable output current levels, controlled remotely via a smartphone application, adds versatility to the device. This user-controlled customization enhances its adaptability for varying medical requirements.

The focus on developing an LES stimulator for gastroesophageal reflux disease (GERD) treatment aligns with the prevalence of this condition worldwide. The success of this prototype opens doors for potential clinical applications in addressing GERD and related esophageal disorders.

While the prototype demonstrated promising functionality, further rigorous testing and validation, especially in biological environments, will be crucial to ensure its safety and long-term feasibility for implantation within the human body.

5. Conclusions

Achievements and Innovation: The development of a functional prototype of an implantable LES stimulator represents a significant milestone in medical device innovation. The transition from traditional battery-operated devices to a wireless, battery-free implant demonstrates pioneering advancements in implantable medical technology.

Clinical Implications: The successful development of this prototype holds promising implications for the field of gastroenterology, particularly in addressing GERD. The device's customizable stimulation modes and energy-efficient design pave the way for potential therapeutic interventions for esophageal disorders.

Future Prospects: As this prototype undergoes further refinement and validation, its potential for clinical translation and broader applications in other medical domains becomes evident. Future research may focus on refining its design, enhancing its safety profile, and exploring its efficacy in diverse applications. After successful completions of additional safety tests, the research will move to the testing stage on laboratory animals.

Patent and Regulatory Considerations: The innovation of an ultra-low idle power consumption constant current driver within the prototype is a novel contribution eligible for patent registration, potentially fostering intellectual property development in medical technology. Ensuring compliance with regulatory standards will be imperative for its future deployment.

Closing Note: The successful development of this implantable LES stimulator prototype, with its wireless and battery-free design, marks a significant step toward enhancing the efficacy and usability of medical implants. Its potential impact on patient care underscores the importance of continued research and development in this area.

Conflicts of Interest: The author declares no conflict of interest.

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METHODOLOGY APPLIED IN THE CONSTRUCTION OF STRUCTURES USING NATURAL AND ALTERNATIVE MATERIALS FOR STABILIZATION WORKS IN ROAD CONSTRUCTION

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Abstract. The analysis of the current state of applications and the results of studies carried out at international level have led to the approach of an eco-efficient methodology for the recovery of waste generated from construction activities, demolition, and the addition of alternative stabilising materials to obtain optimized structures capable of providing a higher quality of the works carried out. Three types of stabilising slurry agents were selected for the experimental programme: the water-based polymer product AggreBind (AGB-BT), the Terra 3000 solution based on the Power binder, and the Earthzyme polysemantic product. Experimental studies on the use of these types of products in earthworks for stabilizing embankments, building and repairing road systems and industrial platforms have shown significant increases in strength and bearing capacity. The use of these environmentally beneficial alternative materials has led to significant reductions in construction time, decreasing total construction and maintenance costs in the short and long term.

Keywords: *stabilisation, waste, recovery, recycling, road systems, ecological material***.**

Rezumat. Analiza stadiului actual privind aplicațiile și rezultatele studiilor efectuate la nivel internațional au condus la abordarea unei metodologii eco-eficiente de valorificare a deșeurilor generate din activitățile de construcții, demolări și adaosuri de materialelor alternative de stabilizare pentru obținerea unor structuri optimizate capabile să confere o calitate superioară lucrărilor executate. Pentru programul experimental au fost selectate trei tipuri de agenți sub forma de suspensie cu rol stabilizator: produsul polimeric pe baza de apă AggreBind (AGB-BT), soluția Terra 3000 care are la baza liantul Power și produsul polienzimatic Earthzyme. Studiile experimentale referitoare la utilizarea acestor tipuri de produse în lucrările pentru stabilizarea terasamentelor, realizarea şi refacerea sistemelor rutiere, platformelor industriale au evidenţiat creşteri semnificative ale rezistenţei şi capacităţii portante. Utilizarea acestor materiale alternative cu efecte benefice asupra

mediului au condus la reduceri semnificative a duratei de execuție, costurilor totale de construcţie şi mentenanţa pe termen scurt şi lung.

Cuvinte cheie: *stabilizare, deșeuri, valorificare, reciclare, sisteme rutiere, material ecologic.*

1. Introduction

The paper is based on a review of the current state of research and a synthesis of the literature on the efficiency of solid waste recovery in construction works. The effect of the uncontrolled use of natural materials in road works and other types of infrastructure is manifested by the gradual depletion of resources, while the costs of purchasing and processing these materials are constantly increasing. Similarly, large amounts of industrial and domestic waste cause serious environmental impacts in terms of disposal and safe storage. Therefore, construction research concerns have focused on the implementation of techniques to use different types of waste as alternative materials with construction applications and natural resource conservation [1, 2].

Traditional building materials such as concrete, bricks, solid blocks, paving blocks and tiles are produced from existing natural resources. Minimising the negative impact of the technological chain attributed to raw materials used in construction (extraction, processing, manufacturing, transportation) and controlled and sustainable waste management contribute to environmental protection and human health [3].

In recent decades, environmental approaches have focused on the conservation of natural resources by recycling various types of solid construction and demolition waste for use in the production or refinement of construction materials. From an economic, sustainable point of view, the use of solid waste for the production of building materials is one of these innovative efforts [4].

The costs of building materials are increasing daily due to high demand, shortage of raw materials, and high energy prices. The use of alternative constituents in building materials is now a global concern, focusing on energy saving and natural resource conservation [5-9]. Extensive research and development studies dedicated to exploring new components are required to produce sustainable and environmentally friendly building materials. In Europe, municipal solid waste accounts for 10% of all waste generated [10]. In 2014, Germany, Austria, Belgium, Switzerland, the Netherlands, and Sweden achieved a recycling rate of 50% for municipal solid waste. The countries that showed the highest increases in recycling rates between 2004 and 2014 were Lithuania, Poland, Italy, the Czech Republic, and the UK [10].

Construction waste is a significant component of solid waste worldwide, comprising 50% of the total waste generated. This waste stream has substantial physical, economic, and environmental implications. According to EU27 data, member states of the European Union produced a combined amount of 530 million tonnes/year of construction and demolition waste. This waste primarily originated from renovation (60%), construction (15%), and demolition (25%). However, only 46% of this waste was reused or recycled [11].

Some countries in Europe achieved high rates of recycling or reuse for construction and demolition waste. The UK had a recycling rate of 75%, while Ireland reached 80%. Germany achieved an 86% recycling rate, Estonia achieved 92%, Denmark achieved 94%, and the Netherlands had the highest rate at 98% [12].

Studies conducted to date on waste stream valorisation have highlighted the use of different types of construction and demolition waste, quarries, wastewater treatment plants,

municipal solid waste sources in the process of land stabilization, applicable in the execution of road systems, parking areas, airport runways, and pedestrian walkways [13-18].

Existing experimental research has shown the effectiveness of construction and demolition waste in treating different categories of soils, from expansive clays to granular soils, as well as in improving physical and mechanical properties by increasing resistance to erosion or variations in moisture and temperature (freeze-thaw cycles).

Soil stabilisation using traditional materials such as lime and cement has been extensively studied in the literature [17, 19-21]. However, the substantial increase in the generation of solid waste has necessitated the development of a sustainable approach to efficient waste management and its use in soil stabilization. This approach has been particularly beneficial in developing countries, as it allows for waste reuse, addressing waste disposal issues, and reducing environmental costs associated with construction activities. Several studies have focused on the use of different solid wastes without the addition of primary binders, such as lime or cement, to stabilise land.

Numerous researchers, government organisations, and academic institutions have explored environmentally friendly technologies that minimise environmental impact and incorporate recycled materials in road infrastructure applications [1, 22, 23]. Technological programmes have been developed to obtain green materials that maintain or enhance current practises in construction engineering while offering innovative and environmentally friendly alternatives. These materials or methods resulting from these programmes are cost-effective and provide social, economic, and environmental benefits.

2. Configuration and Modelling of Optimised Structures

By systematising the work steps included in the experimental programme according to distinct sets of combinations of soils, stabilising agents with environmental benefits, and wastes generated from construction activities, it is proposed to simulate multicriteria requirements related to the technical and environmental performance associated with the modelled structures under laboratory conditions.

The configuration of a flexible methodology, correlated with the integration of eco-sustainable materials, solutions, and criteria, allows the efficient reuse and valorisation of construction and demolition waste in order to obtain optimised structures/elements dedicated to construction applications.

In the context of the current strategies adopted worldwide on the implementation of sustainable development practices, the approach to green design principles in the modelling process of alternative compositions consisted in the application of methods for the analysis and control of parametric links between relevant geotechnical characteristics according to the results of experimental simulations.

Depending on the applications in which the newly developed structures will be used, different types of soils, dosages of binder materials and test sets will be considered. The first category of structures modelled in the laboratory consisted of mixtures prepared from clay as the predominant material with different dosages of waste glass, sandstone, concrete, gypsum and materials with a stabilizing role (AggreBind, lime and cement) with potential applications in the manufacture or improvement of new construction elements (bricks, pavers, kerbs) by reusing the waste stream and materials with environmental benefits. The second category of modelled structures is dedicated to foundation stabilisation works, earthworks for roads and industrial platforms, railway infrastructure improvement works

(formation of mixtures used in base and form layers of roads and as controlled fills in civil and industrial constructions).

The first step in the design methodology of composite structures focused on the configuration of multiple series of experimental variants consisting of: soils with unstable structure such as expansive clays (soils with high swelling and shrinkage) and clay sands (soils sensitive to wetting), as well as filler soils; stabilizing materials in different dosages: enzymatic product (Earthzyme solution), polymeric product (AggreBind).

After the schematization of the work steps and the realisation of the structural models, the experimentation at the macro-structural level consisted of carrying out specific test sets to determine the strength and deformability characteristics, as well as the simulation of various exposure conditions, allowing the estimation of the technical and environmental performances associated with the obtained mixtures.

Through laboratory simulations, it is proposed to estimate the behaviour of the structures under mechanical stress and chemical interactions of the components as a function of the treatment period. Also, at the laboratory scale, unfavourable conditions that may occur in practise have been simulated, with specimens being exposed to normal temperature and humidity conditions, dry-dry cycles by accelerated induction of climatic conditions of excessive heat and dry duration, and alternative freeze-thaw cycles by accelerated induction of low temperature conditions of duration followed by periods of normal temperatures. Optimal recipes by component type were selected based on the maximum values of mechanical characteristics associated with the types of applications for the valorisation and performance criteria appropriate to the principles of sustainable development.

3. Experimental simulations on earth structures (clay) - stabilizing agent - waste concrete and sandstone

In the configuration of the clay-based structures, the water-based polymeric product AggreBind was selected as the stabilizing agent in suspension form. In the laboratory, composite structures modelled from clay, AggreBind suspension with water and construction and demolition waste (concrete, sandstone) were configured with the aim of obtaining two alternative variants with potential applications in the design of new pavement elements and the reuse of waste for stabilisation works in road construction. When configuring structures based on clay as the predominant material, it was established to make a simple set of samples with the addition of 5% stabilising agent of AggreBind type and a multi-composite set with 10% addition of concrete and sandstone waste, crushed and sorted with particle sizes ranging from 0.05-0.5 mm and 0.08-0.25 mm, respectively.

The clay soil was oven dried at 105 ˚C for 24 hours and increased to a particle size of less than 2 mm, adding water to bring the material to high humidity values of 27-36%, excessive moisture conditions were achieved. Determinations of strength characteristics corresponding to structures modeled from clay - AggreBind stabilizing agent and waste concrete and sandstone were carried out under different thermal conditions and treatment periods: (a) immediately after preparation; (b) after heat treatment by oven drying at 105 ˚C for simple compositions; (c) at 7 and 28 days with maintenance under normal temperature and humidity conditions (20-22 ˚C).

The values of the monoaxial compressive strength of the two sets of clay-based composite structures (Figure 1) indicate a marked increase of more than 400% of the strength characteristics after 7 days in the case of simple mixtures with AggreBind, respectively 1200%

in the case of mixtures with waste concrete and sandstone, compared to the values after preparation. Maximum compressive strength is observed to be reached at 28 days, and increases compared to the samples tested at 7 days are 30-60%, highlighting the influence of the treatment period on the increase in strength.

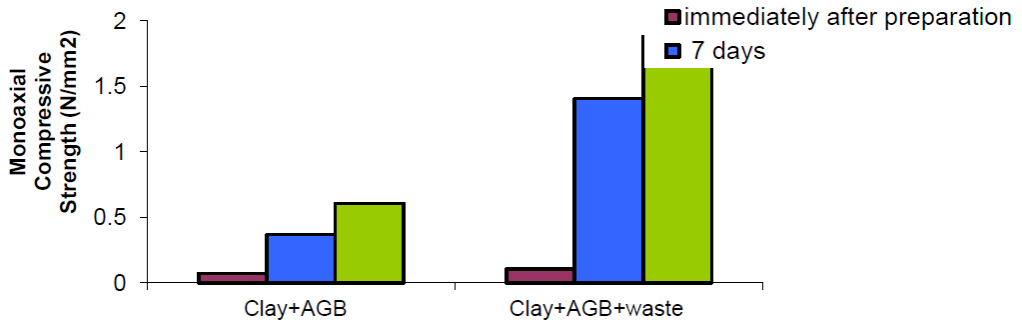

Figure 1. Compressive strength variation for clay-aggregate- waste concrete and sandstone structures.

To estimate the influence of binder additions on the deformability characteristics, tests were carried out under normal and saturated conditions to determine compressibility indices and swelling pressure. The physical characteristics and parameters determined by the compression-strain test obtained for the sets of structures based on clay, AggreBind polymer product, and waste concrete and sandstone are centralised in Tables 1 and 2, which show the data, and the compression-strain curves are shown in Figure 2.

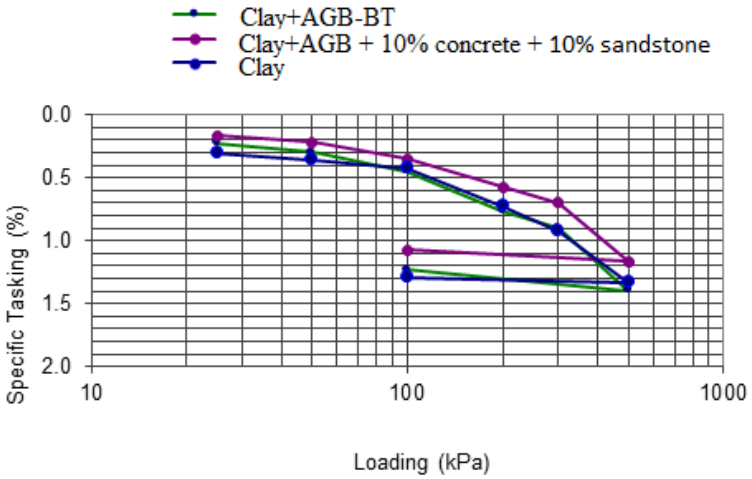

Figure 2. Illustrates the distribution of compression-strain curves obtained for clay-AggreBind-concrete and sandstone structures.

Table 1

Values recorded in compression tests - tamping for clay structures - AggreBind - waste concrete and sandstone

Structure type	Load steps (kPa)	Height difference Δh (mm)	Relative deformation $\varepsilon = \Delta h/h_0$ (%)
Clay + AggreBind	25	0.2218	1.109
	50	0.2968	1.484
	100	0.4487	2.244
	200	0.7618	3.809
	300	0.9025	4,513

Continuation Table 1

	500	1.3930	6.965
	100	1.2300	6.150
Clay +AggreBind+10% of sandstone +10% of concrete	25	0.1656	0.828
	50	0.2209	1.105
	100	0.3496	1.748
	200	0.5748	2.874
	300	0.6949	3.475
	500	1.1664	5.832
	100	1.0762	5.381

Table 2

The compression test on samples of clay-AggreBind-concrete and sandstone slabs provided the following parameters

Characteristic	UM	Natural sample		Clay+ AggreBind		Clay+AggreBind+ 10% concrete+ 10% sandstone	
		Initially	Final	Initially	Final	Initially	Final
Wet weight + tare weight	g	243.960	238.950	239.030	235.380	237.930	235.680
Wet weight + tare weight	g	205.19	205.19	197.29	197.29	198.92	198.52
Tare weight	g	84.52	84.52	81.50	81.50	84.51	84.51
Water contained	g	38.770	33.760	41.740	38.090	39.010	37.160
Wet sample	g	159.440	154.430	157.530	153.880	153.420	151.170
Dried sample	g	120.67	120.67	115.79	115.79	114.41	114.01
Humidity	%	32.13	27.98	36.05	32.90	34.10	32.59
Sample volume	cm^3	76.93	71.82	76.93	71.58	76.93	72.45
Natural density	g/cm^3	2.07	2.15	2.05	2.15	1.99	2.09
Density in dry state	g/cm^3	1.57	1.68	1.51	1.62	1.49	1.57
Porosity	%	41.25	37.07	43.63	39.42	44.30	41.06
Pore index	-	0.70	0.59	0.77	0.65	0.80	0.70
Degree of saturation	%	1.22	1.26	1.24	1.34	1.14	1.24
ε200	(%)	3.623		3.809		2.874	
Eoed200-300	kPa	10277.49		14214.64		16652.79	
mv	1/kPa	9.73E-05		7.04E-05		6.01E-05	
av	1/kPa	1.66E-04		1.25E-04		1.08E-04	

Note: Eoed - oedometric deformation modulus, ε - specific deformation, mv - coefficient of volume compressibility, av - coefficient of compressibility.

The values of the indices resulting from the compression tests show an increase in the edometric modulus of deformation of 38% and 62%, a decrease in the coefficient of volume compressibility of 27% and 38% and in the coefficient of compressibility of 25% and 35% for the composite structures with AggreBind and construction waste, compared to the values of the clay soil in its natural state. These aspects reflect a significant improvement in the deformability characteristics and the classification of the mixtures in the medium

compressibility category. The physical characteristics and parameters obtained from the determination of swelling pressure are centralised in Tables 3.

Table 3

Displays the recorded values obtained during the determination of inflation pressure for clay-AggreBind-concrete and sandstone structures.

Structure type	Loading steps (kPa)	Height difference Δh (mm)	Relative deformation $\varepsilon = \Delta h/h_0$ (%)
Clay + AggreBind	10	-0.2880	-1.440
	25	-0.1500	-0.750
	50	0.1390	0.695
	100	0.3546	1.773
	200	0.5435	2.718
	300	0.7374	3.687
	500	0.9466	4.733
	100	0.7568	3,784
Clay +AggreBind+10% sandstone +10% concrete	10	-0.1810	-0.905
	25	-0.0664	-0.332
	50	0.0185	0.093
	100	0.1592	0.796
	200	0.5982	2.991
	300	0.7649	3.825
	500	1.1100	5.550
	100	0.6233	3.117

Similarly to the results obtained for glass structures, an increase of 25% and 45% was observed in the modulus of oedometric deformation, along with a decrease of 19% and 31% in the volume compressibility coefficient and a decrease of 20% and 28% in the compressibility coefficient, respectively, compared to that of untreated natural earth. The effect of adding stabilising agents and construction waste is observed by a 66% and 70% decrease in swelling pressure, resulting in less active clay-based composites.

Experimental simulations on earth-fill structures - stabilizing agent - clay sand

The configurations of the laboratory-modelled structures with fill soil and clayey sand, together with the Earthzyme dosages, are shown in Figures 3 and 4.

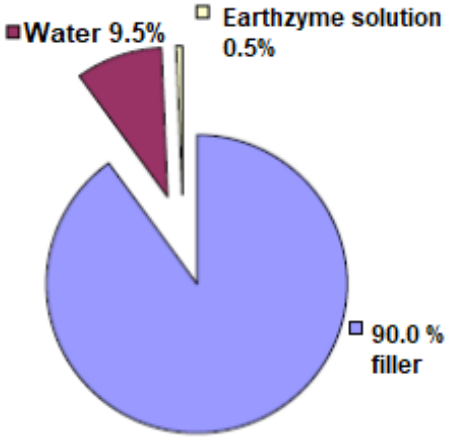

Figure 3. Illustrates structures that have been modeled using earth fill.

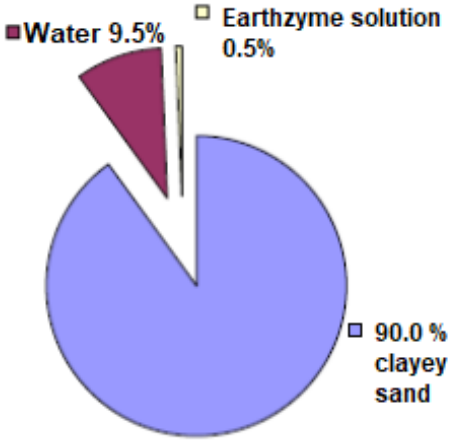

Figure 4. Structures formed with clay sand.

The results of the uniaxial compression tests obtained for the composite structures with earth, Earthzyme stabilizer and waste (Figure 5) indicate an increase in values of 27% at 7 days and 44% at 14 days associated with the earth fill composites compared to those corresponding to clay sand.

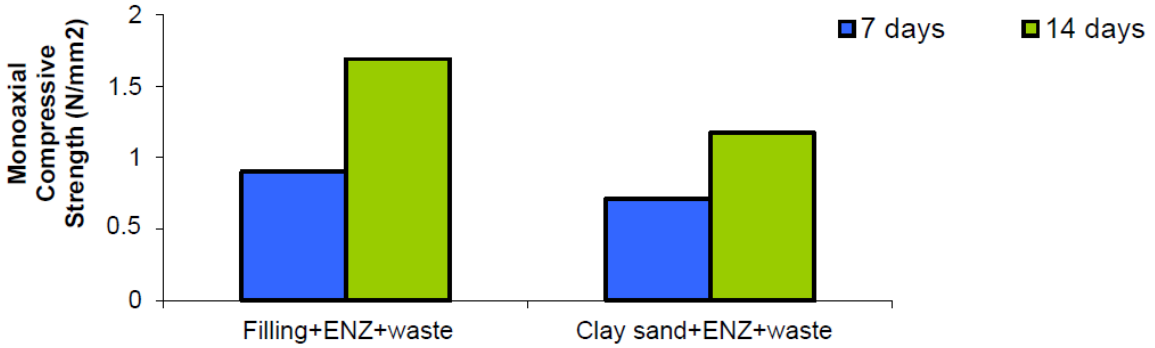

Figure 5. Compressive strength variation for optimal structures of earth-Earthzyme-waste compositions.

The increase in strength characteristics with the treatment period is evidenced by the significant increase of 65% in the case of the values obtained for the clay sand mixtures and 87% for those with filler earth.

4. Conclusions

The laboratory experimentation will consist of conducting macro-structural level experimental tests to determine the physical-mechanical characteristics of the simple and composite mixtures (including natural earth, construction waste, and stabilizing products). Furthermore, the behavior of these mixtures under the influence of mechanical, chemical, and environmental factors will be studied through various simulations under laboratory conditions. Methods of analysis and control will be used to establish parametric relationships between relevant geotechnical parameters, using both numerical and experimental simulations, with the aim of achieving the desired strength and stiffness characteristics. Optimal component recipes have been selected based on maximum values of mechanical characteristics suitable for the intended applications and performance criteria aligned with the principles of sustainable development.

The methodology applied through experimental laboratory modelling of the parametric links between strength, deformability and load-bearing characteristics allowed the configuration of optimized durable structures according to the types of potential applications.

In the case of clay-based composite structures, both those with AggreBind and waste concrete and sandstone, and those with lime, cement and gypsum waste, a similar trend of pronounced increase in compressive strength at 7 and 28 days is observed.

The evident increase in mechanical performance confirms the stability of structures modelled with clay as the predominant material and the possibility of using these types of waste and binders with a stabilising role in improving existing building elements or developing new durable products.

Concerning the second category of composite structures made of fill earth and clay sand, alternative stabilizing materials (Earthzyme) and waste, configured for potential applications in stabilization works of foundation and road layers, the bearing capacity values

showed significantly higher strengths corresponding to Earthzyme and waste compositions, with increases of more than 300% compared to untreated earth values.

The bearing capacity performance characteristics of laboratory-modelled configurations for earth stabilisation works for the construction of platforms and parking lots, pedestrian walkways, cycle paths, pavements and road structures will be simulated "in situ" in the next phase of the project. The verification of the bearing capacity "in situ" by means of analyses correlated with the results obtained in the laboratory could not be carried out in the current phase due to procedural difficulties in procurement.

Conflicts of Interest: The authors declare no conflict of interest.

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EVALUATION OF SEISMIC FORCES ACCORDING TO EUROCODE 8 AND SNiP II-7-81. COMPARATIVE ANALYSIS

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Abstract. The evaluation of seismic forces is very important for the design of all types of structures. In the present, Republic of Moldova is in a period of transition in the construction industry from the national design norms to the European design norms. The comparison provides an interesting and imperative approach in design of structures. During the design process it is very important to be aware of all the forces acting on a structure, especially the accidental forces. This paper presents a comprehensive analysis of a concrete frame structure, subjected to seismic action. A calculation is performed according to the current national design code SNiP II-7-81 and according to Eurocode 8. The purpose of the paper is the quantitative comparison of the values of the seismic forces and the qualitative evaluation of the factors that influence these forces.

Keywords: *Eurocode, Earthquake, Seismic forces.*

Rezumat. Evaluarea forțelor seismice este foarte importantă pentru proiectarea tuturor tipurilor de structuri. Având în vedere faptul că Republica Moldova se află într-o perioadă de tranziție în industria construcțiilor de la normele naționale de proiectare la normele europene de proiectare acest studiu comparativ este foarte important. În timpul procesului de proiectare este foarte importantă conștientizarea tuturor forțelor care acționează asupra unei structuri, în special forțele accidentale. Această lucrare prezintă o analiză a unei structuri de cadru din beton, supusă acțiunii seismice. Este prezentat un calcul efectuat conform codului național de proiectare actual SNiP II-7-81 și conform Eurocod 8. Scopul lucrării este compararea cantitativă a valorilor forțelor seismice și evaluarea calitativă a factorilor care influențează aceste forțe.

Cuvinte cheie: *Eurocod, cutremur, forțe seismice.*

1. Introduction

Design earthquake resistant structures has always been a challenge for engineers. In order to reduce the destructive effects on the constructions, certain constructive measures were applied. Initially, these measures were only intuitive principles, such as reducing the

height of structures or reducing their mass [1]. Later, certain constructive provisions received recommendation status, without being mandatory for implementation. It was not until the beginning of the 20th century that mandatory seismic design codes began to be developed in earthquake-prone regions [2]. These design codes differed depending on the region in which they were developed [3].

One widely recognized set of seismic provisions is the Eurocode, which is a series of European standards for the design of structures [4]. In the United States, seismic provisions are outlined in the International Building Code (IBC) [5] and the American Society of Civil Engineers (ASCE) standards [6,7]. The seismic regulations in Japan are outlined in the "Building Standard Law" and the "Building Standard Law Enforcement Order" [8]. China has implemented seismic provisions and building codes to address the seismic risks prevalent in certain regions of the country. Seismic design standards are primarily outlined in the "Code for Seismic Design of Buildings" (GB50011) [9].

These provisions are designed to mitigate the impact of seismic forces on buildings, bridges, and other infrastructure, with the ultimate goal of protecting human life and minimizing damage to property [10].

In the Republic of Moldova, 2 seismic design codes are relevant - SNiP II-7-81 [11] and SM EN 1998 [12], known as Eurocode 8. SNiP II-7-81 was adopted as a national design standard in 1982. SM EN 1998 is in the process of implementation.

2. Comparison of design codes

2.1. Seismic hazard

Eurocode 8 considers the seismic action in terms of PGA – peak value of ground acceleration, for a ground class A – a_{gr}. [3] The reference peak value of the ground acceleration, corresponds to the reference return period of the seismic action (T_{NCR}).

SNiP II-7-81 describes seismic action in terms of intensity, according to the MSK-64 intensity scale [13]. The MSK-64 intensity scale is based on an analysis of seismic action results and allows estimating the intensity of seismic action using statistical data. In the current version of SNiP, the parameter that describes the intensity of seismic action according to the MSK-64 scale – seismicity, measured in degrees. For each degree of seismicity (intensity) could be assigned maximum value of peak value of ground acceleration represented by the design intensity factor (I_p).

2.2. Classification of the terrain

Seismic action is directly influenced by ground conditions.

Eurocode 8 classifies the soil in 4 categories, depending on the value of the average speed of the shear waves ($v_{s,30}$), considered until a depth of 30 meters. If the value of the average shear wave velocity is not known, the standard penetration test shall be used to determine the ground characteristics [4].

SNiP II-7-81 classifies the soil into 3 categories, depending on the consistency index, porosity ratio and other physical-mechanical properties of the soil [11]. The terrain category directly influences the seismicity of the site, by amplifying or reducing the reference intensity of the site.

2.3. Elastic response spectrum

The main parameter that determines the impact of seismic action on structures is the elastic response spectrum [14].

According to **Eurocode 8**, the elastic spectrum is defined by the relationship:

$$\frac{S_e}{g} = S \cdot S_e(T), \tag{1}$$

where: $S_e(T)$ – elastic response spectrum defined by Eurocode with different calculation formulas depending on the fundamental period of the structure.
S – the terrain factor.

According to **SNiP II-7-81** the design spectrum is defined by the following relationship:

$$\frac{S_e}{g} = \beta \cdot k_{soil}, \tag{2}$$

where: β – dynamic coefficient, which is determined according to the terrain category.

2.4. Building behaviour factor

The main design concept for seismic actions of structures consists in energy dissipation, through the formation of plastic joints [15]. The amount of energy dissipated is directly influenced by the structural configuration [16]. According to **Eurocode 8** the behavior factor (q) represents the ratio between the design forces in the linear elastic domain for the critical damping fraction of 5% and the inelastic one, which takes into account the plastic joints.

Within **SNiP II-7-81**, the behavior factor (k_1) assumes the limitation of degradations, respectively the formation of plastic joints. Thus, in the situation when degradations are not allowed, the behavior factor will be equal to 1; when certain structural degradations are allowed, which do not affect the integrity of the people occupying this structure, the value of the safety factor will be lower than 1.

3. Comparative example

3.1. Initial data

A comparative numerical analysis of a three-level structure according to Figure 1 will be considered.

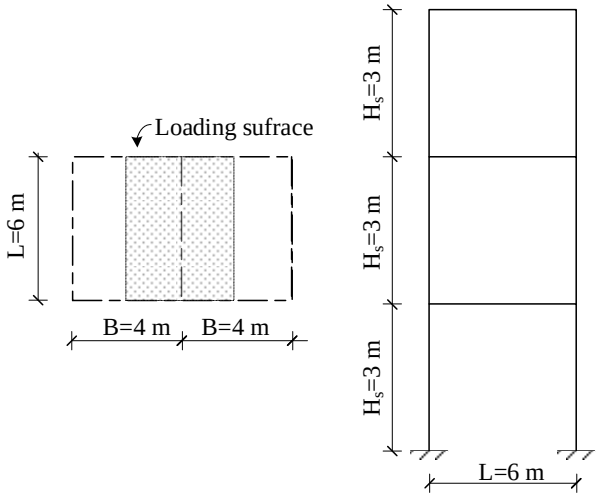

Figure 1. The 3-story frame structure.

The structure will be planned for both Sculeni in Iasi County and Sculeni in Ungheni district. These two localities are situated within a close proximity of less than 10 kilometers, as illustrated in Figure 2 sourced from Google Maps.

All pertinent data such as frame span, span length, story height, materials used, column sections, and other relevant information are centralized in Table 1 for ease of reference.

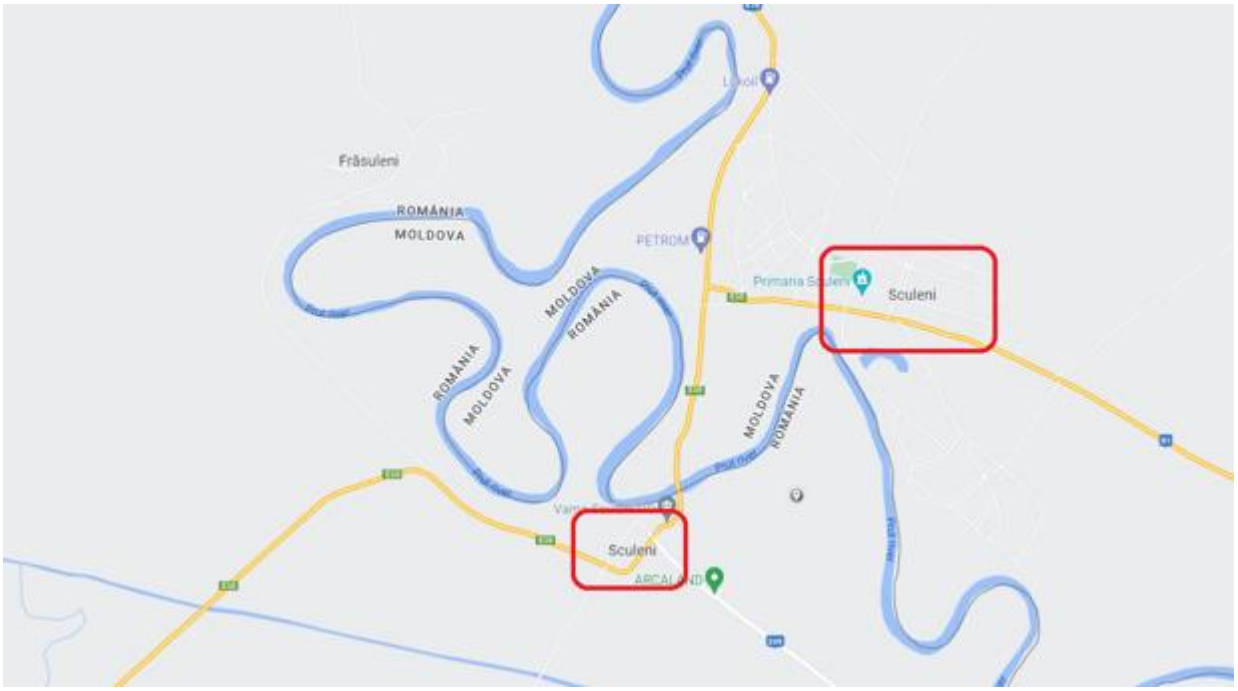

Figure 2. Position of the considered localities.

Table 1

Initial data

Description	Unit	Value
Frame span, L	m	6
Span length, B	m	4
Story height, H	m	3
Slab thickness, δ	cm	18
Material used	-	Concrete C20/25
Column section, b×h	cm	40×40
Beam section, b×h	cm	40×50
Live load	kPa	1.5
Site intensity according to MSK-64	-	8
Soil category according to SNiP II-7-81	-	III
PGA	m/s^2	0.16g
Soil type according to EC-8	-	Type C

Note: MSK - Medvedev–Sponheuer–Karnik scale

The same design loads will be considered for both cases, except for the snow load, which differs in design code of each country (Republic of Moldova and Romania). It is important to note that the snow loads are listed in Table 2, highlighting the variations between the two regions.

Table 2

Snow load classification

Snow load	Unit	Design value
Eurocode 1	kN/m^2	2.00
SNiP II.I-07.85		0.50

Building loads, are conveniently compiled in Table 3 for easy access and comparison.

Table 3

Building loads

Snow load	Unit	Design value
Total permanent load slab	$\mathrm{kN/m^2}$	4.96
Total permanent load roof	$\mathrm{kN/m^2}$	5.26
Permanent load on other elements		
Beam weight (*b*×*h*=40×50 cm)	$\mathrm{kN/m^2}$	5.28
Colum weight (*b*×*h*=40×40 cm)	$\mathrm{kN/m^2}$	4.22
Total live load	$\mathrm{kN/m^2}$	1.50

3.2. Calculation of concentrated masses

The structure will be reduced to a plane frame, to simplify the design. Later using the assumption of infinite stiffness of the slab in the horizontal plane, the plane frame will be reduced to an inverted pendulum with masses concentrated at the level of the story according to Figure 3.

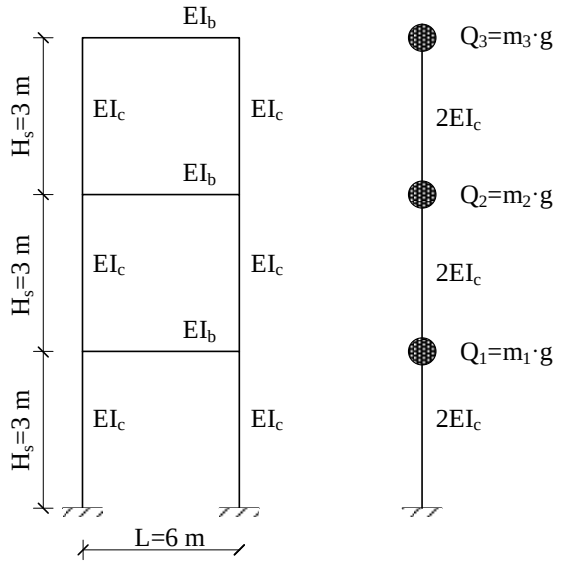

Figure 3. Inverted pendulum with masses concentrated at the level of the story.

$$Q_{perm,1} = Q_{perm,2} = q_{sl} \cdot B \cdot L + q_b \cdot L + q_b \cdot B \cdot 2 + 2 \cdot q_c \cdot H_s = 209.28\ kN \quad (3)$$

$$Q_{var,1} = Q_{var,2} = q_{var} \cdot B \cdot L = 36.00\ kN \quad (4)$$

$$Q_{perm,3} = q_{sl} \cdot B \cdot L + q_b \cdot L + q_b \cdot B \cdot 2 + 2 \cdot q_c \cdot H_s/2 = 204.96\ kN \quad (5)$$

$$Q_{var,3} = q_{var} \cdot B \cdot L = 36.00\ kN \quad (6)$$

Calculation of concentrated masses according **SNiP II-7-81:**

$$Q_1 = Q_2 = 0.9 \cdot Q_{perm,1} + 0.5 \cdot Q_{var,1} = 206.352\ kN \quad (7)$$

$$Q_3 = 0.9 \cdot Q_{perm,1} + 0.5 \cdot Q_{var,1} + 0.5 \cdot Q_{zăpadă} = 208.464\ kN \quad (8)$$

Calculation of concentrated masses according **Eurocode 8**

$$Q_1 = Q_2 = 1.35 \cdot Q_{perm,1} + 1.5 \cdot Q_{var,1} = 336.528\ kN \quad (9)$$

$$Q_3 = 1.35 \cdot Q_{perm,1} + 1.5 \cdot Q_{var,1} + 1.05 \cdot Q_{zăpadă} = 381.096\ kN \quad (10)$$

3.3. Calculation of the dynamic parameters of the structure

The similarity between the flexibility and stiffness matrices in both cases is due to the consistent use of the same materials and structural dimensions. Here, the terms $\boldsymbol{\delta_{ij}}$ represent the displacement along the degree of freedom $\boldsymbol{i}$ when a force equal to unity is applied solely along the dynamic degree of freedom $\boldsymbol{j}$, under conditions where the dynamic degrees of freedom remain unconstrained. The lateral stiffness matrix can also be determined by inversing the lateral flexibility matrix.

The flexibility matrix:

$$[U] = \begin{bmatrix} \delta_{11} & \delta_{12} & \delta_{13} \\ \delta_{21} & \delta_{22} & \delta_{23} \\ \delta_{31} & \delta_{32} & \delta_{33} \end{bmatrix} = \begin{bmatrix} 70.313 & 175.783 & 281.253 \\ 175.783 & 562.504 & 984.380 \\ 281.253 & 984.380 & 1898.446 \end{bmatrix} \cdot 10^{-9} \left[\frac{m}{N}\right] \quad (11)$$

The stiffness matrix:

$$[K] = [U]^{-1} = \begin{bmatrix} 8.752 \cdot 10^7 & -5.032 \cdot 10^7 & 1.313 \cdot 10^7 \\ -5.032 \cdot 10^7 & 4.814 \cdot 10^7 & -1.75 \cdot 10^7 \\ 1.313 \cdot 10^7 & -1.75 \cdot 10^7 & 7.659 \cdot 10^6 \end{bmatrix} \left[\frac{N}{m}\right] \quad (12)$$

The mass matrix:

- SNiP II-7-81

$$[M] = \begin{bmatrix} 2.104 \cdot 10^4 & 0 & 0 \\ 0 & 2.104 \cdot 10^4 & 0 \\ 0 & 0 & 2.126 \cdot 10^4 \end{bmatrix} [kg] \quad (13)$$

- Eurocode 8

$$[M] = \begin{bmatrix} 3.432 \cdot 10^4 & 0 & 0 \\ 0 & 3.432 \cdot 10^4 & 0 \\ 0 & 0 & 3.886 \cdot 10^4 \end{bmatrix} [kg] \quad (14)$$

The motion equation is:

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = -[M]\{1\}\ddot{u_g}(t) \quad (15)$$

The eigenvalue problem can be solved using the following relationships:

$$([K] - \omega^2[M])[\Phi] = 0 \quad (16)$$

$$|[K] - \omega^2[M]| = 0 \quad (17)$$

Spectral matrix and mode shape matrix:

- SNiP II-7-81

$$\Omega^2 = \begin{bmatrix} 5963.411 & 0 & 0 \\ 0 & 824.623 & 0 \\ 0 & 0 & 19.123 \end{bmatrix} \left[\left(\frac{rad}{s}\right)^2\right] \quad (18)$$

$$\Phi = \begin{bmatrix} 1 & 1 & 1 \\ 3.399 & 1.191 & -0.699 \\ 6.395 & -0.781 & 0.213 \end{bmatrix} \quad (19)$$

- Eurocode 8

$$\Omega^2 = \begin{bmatrix} 3644.906 & 0 & 0 \\ 0 & 494.535 & 0 \\ 0 & 0 & 10.730 \end{bmatrix} \left[\left(\frac{rad}{s}\right)^2\right] \quad (20)$$

$$\Phi = \begin{bmatrix} 1 & 1 & 1 \\ 3.408 & 1.217 & -0.697 \\ 6.425 & -0.708 & 0.189 \end{bmatrix} \quad (21)$$

Frequencies and natural periods of structures are:

- SNiP II-7-81

$$\omega = \begin{bmatrix} 4.373 & 0 & 0 \\ 0 & 28.716 & 0 \\ 0 & 0 & 77.223 \end{bmatrix} \left[\frac{rad}{s}\right] \quad (22)$$

$$T = \begin{bmatrix} 1.4368 & 0 & 0 \\ 0 & 0.2188 & 0 \\ 0 & 0 & 0.0814 \end{bmatrix} [s] \quad (23)$$

- Eurocode 8

$$\omega = \begin{bmatrix} 3.276 & 0 & 0 \\ 0 & 22.238 & 0 \\ 0 & 0 & 60.373 \end{bmatrix} \left[\frac{rad}{s}\right] \quad (24)$$

$$T = \begin{bmatrix} 1.9181 & 0 & 0 \\ 0 & 0.2825 & 0 \\ 0 & 0 & 0.1040 \end{bmatrix} [s] \quad (25)$$

3.4. Calculation of seismic forces

In this section, we will calculate the seismic forces according to SNiP II-7-81 and Eurocode 8. Initially, we will perform the calculation following the provisions of SNiP II-7-81.

- SNiP II-7-81

$$S_{ik} = K_1 \cdot K_2 \cdot Q_k \cdot A \cdot \beta_i \cdot K_\Psi \cdot \eta_{ik} = K \cdot Q_k \cdot \beta_i \cdot \eta_{ik}, \quad (26)$$

where:

$K_1 = 0{,}25$ – behavior factor;

$K_2 = 1$ – coefficient that takes into account the structure type;

$A = 0{,}2$ – coefficient that takes into account the seismicity of the site;

$K_\Psi = 1$ – shape coefficient.

Multiple coefficient K:

$$K = 0.25 \cdot 1 \cdot 0.2 \cdot 1 = 0.05 \quad (27)$$

In accordance with p.2.6 of SNiP II-7-81 for soil category III and vibration periods $T_i > 0.5$, the dynamic coefficient is computed by following expression:

$$\beta_1 = \frac{1.35}{T_1} \leq 0.8 \quad (28)$$

$$\beta_1 = \frac{1.35}{1.4368} = 0.94 \rightarrow \beta_1 = 0.8 \quad (29)$$

In accordance with p.2.6 of SNiP II-7-81 for soil category III and vibration periods $0.1 < T_i < 0.5$, the dynamic coefficient is computed by following expression:

$$T_2 = 0.2188\, s \rightarrow \beta_2 = 2.7 \quad (30)$$

In accordance with p.2.6 of SNiP II-7-81 for soil category III and vibration periods $T_i < 0.1$, the dynamic coefficient is computed by following expression:

$$T_3 = 0.0814\ s \ \rightarrow \ \beta_3 = 17 \cdot T_i + 1 = 2.384 \tag{31}$$

Relation for computing form coefficients can be found in SNiP II-7-81, p. 2.7.

$$\eta_{ik} = \frac{X_i(x_2)\sum_{j=1}^{2} Q_j X_i(x_j)}{\sum_{j=1}^{2} Q_j X_i^2(x_j)} \tag{32}$$

- For I mode of vibration:

$$\eta_{11} = 0.202, \ \ \eta_{12} = 0.685, \ \ \eta_{13} = 1.296 \tag{33}$$

- For II mode of vibration:

$$\eta_{21} = 0.462, \ \ \eta_{22} = 0.550, \ \ \eta_{23} = -0.361 \tag{34}$$

- For III mode of vibration:

$$\eta_{31} = 0.336, \ \ \eta_{32} = -0.235, \ \ \eta_{33} = 0.072 \tag{35}$$

Seismic force for each mode:

- For I mode of vibration:

$$S_{11} = 1.664\ [kN], \ \ S_{12} = 5.655\ [kN], \ \ S_{13} = 10.807\ [kN] \tag{36}$$

- For II mode of vibration:

$$S_{21} = 12.87\ [kN], \ \ S_{22} = 15.328\ [kN], \ \ S_{23} = -10.154\ [kN] \tag{37}$$

- For III mode of vibration:

$$S_{31} = 8.274\ [kN], \ \ S_{32} = -5.783\ [kN], \ \ S_{33} = 1.78\ [kN] \tag{38}$$

The resulted vector of forces on each story:

$$S_1 = S_{11} + S_{12} + \ S_{13} = 18.126\ [kN] \tag{39}$$

$$S_2 = S_{21} + S_{22} + \ S_{23} = 18.044\ [kN] \tag{40}$$

$$S_3 = S_{31} + S_{32} + \ S_{33} = 4.271\ [kN] \tag{41}$$

Following that, we will conduct the calculation in accordance with the guidelines outlined in Eurocode 8.

The seismic force, as the base shear force, in the k mode of oscillation is calculated with the relation:

$$F_{b,k} = \gamma_I \cdot S_d(T_k) \cdot m_k, \tag{42}$$

where:

γ_I – the factor of the building importance;

$S_d(T_i)$ – the design value of elastic response spectrum of the k mode of oscillation for the horizontal components of the ground motion, $[m/s^2]$;

m – the modal mass associated with the eigenmode of oscillation and is determined with the relation:

$$m_k = \frac{\left(\sum_{i=1}^{n} m_i s_{i,k}\right)^2}{\sum_{i=1}^{n} m_i {s_{i,k}}^2}, \tag{43}$$

$\gamma_I = 1$ importance class II.

The behavior factor $\boldsymbol{q}$ is defined as a function of the dissipation capacity of the structural system, through its base value $\boldsymbol{q_0}$ and the ratio $\boldsymbol{\alpha_u/\alpha_1}$ due to the redundancy or overresistance of the structure:

$$q = q_0 \frac{\alpha_u}{\alpha_1} \tag{44}$$

Multi-story frames or dual structures equivalent to frames: $\alpha_u/\alpha_1 = 1.3$.

For medium ductility class structures (DCM):

$$q = 3{,}0 \cdot \alpha_u/\alpha_1 = 3.9 \tag{45}$$

T_1, T_2, T_3 are natural period of vibration for fundamental modes of vibrations.

For $T_1 = 1.918\ s$

$$S_d(T_1) = a_g \cdot S \cdot \frac{2.5}{q} \cdot \left(\frac{T_c}{T}\right) = 0.24 \cdot 9.81 \cdot 1 \cdot \frac{2.5}{3.9} \cdot \frac{0.7}{1.918} = 0.551 \tag{46}$$

For $T_2 = 0.2825\ s$

$$S_d(T_1) = a_g \cdot S \cdot \frac{2.5}{q} = 0.24 \cdot 9.81 \cdot 1 \cdot \frac{2.5}{3.9} = 1.509 \tag{47}$$

For $T_3 = 0.1041\ s$

$$S_d(T_1) = a_g \cdot S \cdot \frac{2.5}{q} = 0.24 \cdot 9.81 \cdot 1 \cdot \frac{2.5}{3.9} = 1.509 \tag{48}$$

Calculation of the effective modal mass associated with the eigenmode of vibration:

$$m_k = \frac{\left(\sum_{i=1}^{n} m_i s_{i,k}\right)^2}{\sum_{i=1}^{n} m_i {s_{i,k}}^2} \tag{49}$$

$$m_1 = 78919.974\ [kg],\ \ m_2 = 35928.448\ [kg],\ \ m_3 = 6010.410\ [kg] \tag{50}$$

Seismic force, as the base shear force:

$$F_{b,1} = 43.484\ [kN],\ \ F_{b,2} = 54.216\ [kN],\ \ F_{b,3} = 9.114\ [kN] \tag{51}$$

The results of the comparative calculation of seismic forces according to SNiP and Eurocode are centralized in Table 4.

Table 4

Comparison of seismic forces

Mode	**Forces at story according to SNiP II-7-81, kN**	**Forces at story according to EC 8, kN**	**Ratio, $\frac{EC-8}{SNiP\ II-7-81}$**
1 mode	18.126	43.484	2.398
2 mode	18.044	54.216	3.004
3 mode	4.271	9.114	2.133

In this chapter, we embark on a comparative analysis of seismic calculations, aiming to elucidate the nuances of seismic design methodologies and their implications for structural outcomes. The study commenced with the utilization of two different regulatory standards: SNiP II-7-81 and Eurocode 8. The structural model, materials, and site characteristics remained consistent throughout the analysis, ensuring a fair and accurate comparison.

Seismic calculations were performed following the prescribed procedures outlined in each standard. It was observed that the Eurocode 8 approach tends to result in higher seismic forces in certain structural elements, reflecting a more conservative approach to seismic design. Conversely, the SNiP II-7-81 methodology, with its unique coefficients, demonstrates a nuanced consideration of the seismic environment.

4. Conclusion

The SNiP II-7-81 elaborated in 1981 do not have any significant modifications for over 40 years. On other side, Eurocode 8 that consists of 6 parts provides detailed information on every step of design.

Both normative have different approach of quantifying the seismic action i.e. ground motion. Nevertheless, the basis on which the hazard maps are made is the same – probabilistic seismic hazard analysis.

The soil classification is different in both codes. In Eurocode the soils are classified in categories by the shear wave velocities, SNiP II-7-81 that divides by mechanical proprieties of soil. The elastic response spectrum has similar shapes, which means that the structures with lower natural period of structure have higher acceleration values, and structures with high natural period that will have smaller acceleration values.

Behavior factor is as important coefficient in both codes. In Eurocode 8 the behavior factor is described more accurately, for each type of structure, and take into account energy absorption during a seismic event. In SNiP II-7-81 the behavior factor imposes the possibility or avoid the dissipation of the energy by plastic hinges or another plastic deformation in the structure. Even plastic hinges are allowed, the people safety have to be satisfied.

A comparative example had been performed for a simple 3 story structure. The result shown in table 9 denotes that final result using EN 1998 normative are higher than the results using SNiP II-7-81. The main cause is in coefficient that are used for load case combination. Other reason could be the impact of the response spectrum. The dynamic coefficient values are higher in SNiP II-7-81 then the seismic acceleration from spectrum response of Eurocode 8.

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PROPANOL DETECTION DEVICE FOR THE PURPOSE OF MONITORING THE QUALITY OF THE ENVIRONMENT

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Abstract. The aim of this study was to develop and characterize CuO/Cu_2O functionalized with AgPt nanostructures for gas sensing applications. Environmental pollution remains a pressing global concern, requiring effective detection methods. Metal oxide nanostructures, such as those based on copper oxides, offer promising solutions due to their sensitivity and selectivity for various gases. The research investigated the morphology and structure of the nanostructures using techniques such as scanning electron microscopy (SEM), X-ray diffraction (XRD), and Raman spectroscopy. In addition, the nanostructures were functionalized with noble metals such as silver and platinum to enhance their sensory properties. The deposition of polymer layers has been investigated as a method to improve sensor selectivity. The gas sensing properties of the CuO/Cu_2O/AgPt nanostructures were evaluated using the Keithley 2400 source meter and showed high sensitivity to gases such as propanol, acetone, hydrogen, and ammonia at elevated temperatures. The results showed that higher operating temperatures result in faster response and recovery times. In addition, the nanostructures exhibited saturation in response at higher concentrations of certain gases. These results highlighted the potential of CuO/Cu_2O/AgPt nanostructures in environmental monitoring applications, particularly in industries prone to gas emissions. Overall, this research contributes to the advancement of gas sensing technology for pollution prevention and control efforts.

Keywords: *sensors, propanol, nanostructutres, functionalized.*

Rezumat. Scopul acestui studiu a fost explorarea, dezvoltarea și caracterizarea nanostructurilor CuO/Cu_2O funcționalizate cu AgPt pentru aplicații de detectare a gazelor. Poluarea mediului rămâne o preocupare globală presantă, necesitând metode eficiente de detectare. Nanostructurile de oxizi metalici, cum ar fi cele pe bază de oxizi de cupru, oferă soluții promițătoare datorită sensibilității și selectivității lor pentru diferite gaze. Cercetarea a investigat morfologia și structura nanostructurilor folosind tehnici precum microscopia electronică de scanare (SEM), difracția de raze X (XRD) și spectroscopia Raman. În plus, nanostructurile au fost funcționalizate cu metale nobile, cum ar fi argintul și platina, pentru a le îmbunătăți proprietățile senzoriale. S-a investigat depunerea de straturi de polimeri ca

metodă de îmbunătățire a selectivității senzorilor. Proprietățile de detectare a gazelor ale nanostructurilor CuO/Cu_2O/AgPt au fost evaluate cu ajutorul aparatului de măsură cu sursă Keithley 2400 și s-a demonstrat o sensibilitate ridicată la gaze precum propanol, acetonă, hidrogen și amoniac la temperaturi ridicate. Rezultatele au arătat că temperaturile de funcționare mai ridicate duc la timpi de răspuns și de recuperare mai rapizi. În plus, nanostructurile au prezentat o saturație a răspunsului la concentrații mai mari de anumite gaze. Aceste rezultate au evidențiat potențialul nanostructurilor CuO/Cu_2O/AgPt în aplicațiile de monitorizare a mediului, în special în industriile predispuse la emisii de gaze. În general, această cercetare contribuie la progresul tehnologiei de detectare a gazelor pentru eforturile de prevenire și control al poluării.

Cuvinte cheie: *senzor, propanol, nanostructuri, funcționalizat.*

1. Introduction

The development of humanity today has led to one of the biggest global problems, environmental pollution. For this purpose, to prevent this phenomenon, the researchers started the active study on gas detectors based on different nanostructures of metal oxides such as SnO_2, In_2O_3, WO_3, ZnO, Fe_2O_3 and many others [1]. The performance of gas sensors is determined by the following factors such as sensitivity, selectivity, response and recovery times, stability, repeatability and others. The structure and morphology of CuO/Cu_2O nanostructures were characterized using techniques such as scanning electron microscopy (SEM), X-ray diffraction (XRD) and Raman spectroscopy. The sensitivity of the nanostructures to gas was tested, where the generation of the p-type response was observed for such gases as propanol, acetone, hydrogen and at relatively higher temperatures for ammonia as well. Similar researches were also carried out by other authors [2,3]. The detection of volatile organic compounds (VOC) by the researched nanostructures of CuO/Cu_2O/AgPt makes it possible to use them in such areas as monitoring the quality of the environment with the aim of preventing pollution, such as in factories, paint factories, pharmaceuticals and others. Doping and functionalizing nanostructures with noble metals such as Ag, Au, Pt and others, proved to be an effective method for improving sensor properties such as sensitivity, selectivity, response and recovery times, stability over time and others [4]. In this work, the nanostructures based on copper oxide functionalized with Ag and Pt were studied. Another technology quite often encountered lately is the deposition of polymer layers with the aim of improving the selectivity of the sensor, acting as a sieve for the gas molecule [5]. Similarly, to improve the properties of the sensor, a layer of PV3D3 polymer was deposited, where the difference was observed before and after the deposition of the polymer.

2. Materials and Methods

The CuO/Cu_2O structures were obtained by the chemical method, which is a simple and cost-effective method to implement [6,7]. To enhance the sensory properties of the obtained nanostructures, they were functionalized with noble metals like silver and platinum. The functionalization of noble metals can enhance the sensory properties of nanostructures [8], including sensitivity, selectivity, response and recovery time, repeatability, and others. Another effective method for improving the selectivity of nanostructures is the deposition of polymers that function as a flat net over the nanostructures, which enables the filtering of gas molecules by permitting their passage with smaller sizes [9].

For the determination of the sensory properties of CuO/Cu_2O/AgPt nanostructures, the Keithley 2400 source meter was used, which has high accuracy. The data obtained from the

source meter was processed and displayed using LabView software (from National Instruments). The following formula was used to transform the data obtained into percentages:

$$S = \frac{G_{gas} - G_{air}}{G_{air}} * 100\%, \quad (1)$$

where: S is the sensitivity of nanostructures, G_{gas} represents the electrical conductivity of nanostructures when exposed to gas, and G_{air} represents the electrical conductivity of nanostructures when exposed to air [10].

The average crystallite size (D_{hkl}) were determined using Debye-Scherer equation [11]:

$$D_{hkl} = \frac{0.9\lambda}{\beta cos\theta}, \quad (2)$$

where: λ – X-ray wavelength, β – full width at half maximum of the diffraction peak and θ – Bragg angle. Determined Dhkl was ~28.07 nm and ~42.84 for (111) Cu_2O plane and (-111) CuO plane, respectively.

Dislocation density (δ) was calculated using average crystallite size, as following relation:

$$\delta = \frac{1}{D_{hkl}^2} \quad (3)$$

For (111) Cu_2O plane and (-111) CuO plane was obtained 0.0013 and 0.0006 nm^{-2}.

3. Results and Discussion

3.1. Morphological and Strucutral Analysis of CuO/Cu_2O/AgPt

Morphology of the CuO/Cu_2O/AgPt sample was studied at different magnifications after gas tests, observing that nanostructures are deposited uniformly on the surface (Figure 1a, b). At higher magnification (Fgure 1c) nanodots of AgPt are visible, compared to the the SEM images before the deposition of nanodots. Average diameter of the AgPt nanodot was approximatively 20 nm, as observed in Figure 1d.

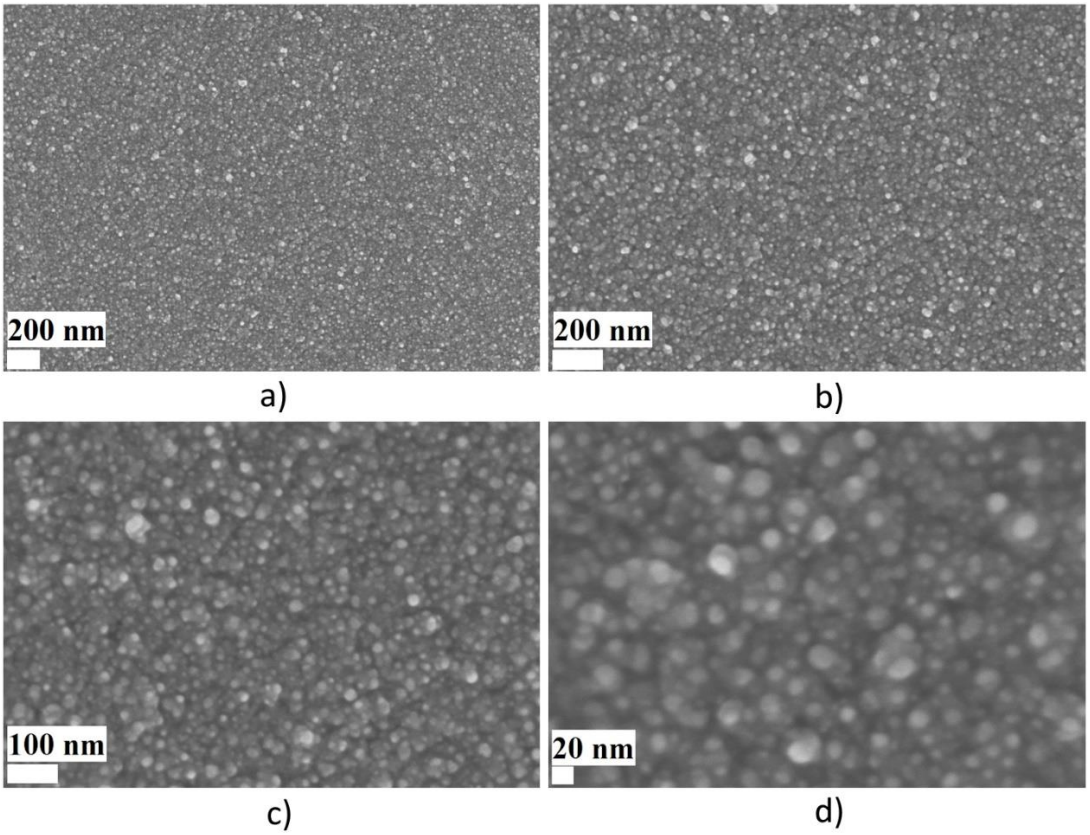

Figure 1. SEM images of the CuO/Cu_2O/AgPt after gas tests at different magnifications: a) 200 nm; b) 200 nm; c) 100 nm; d) 20 nm.

Figure 2 shows SEM images of the CuO/Cu_2O sample after coating with PV3D3. After comparing with Figure 1, it can be observed the same granular nanostructures, the only difference being the PV3D3 polymer layer deposited in Figure 2, so it is possible to observe a smoothening of the surface layer due to the uniform deposition of polymer on the sample, as previously observed in [9].

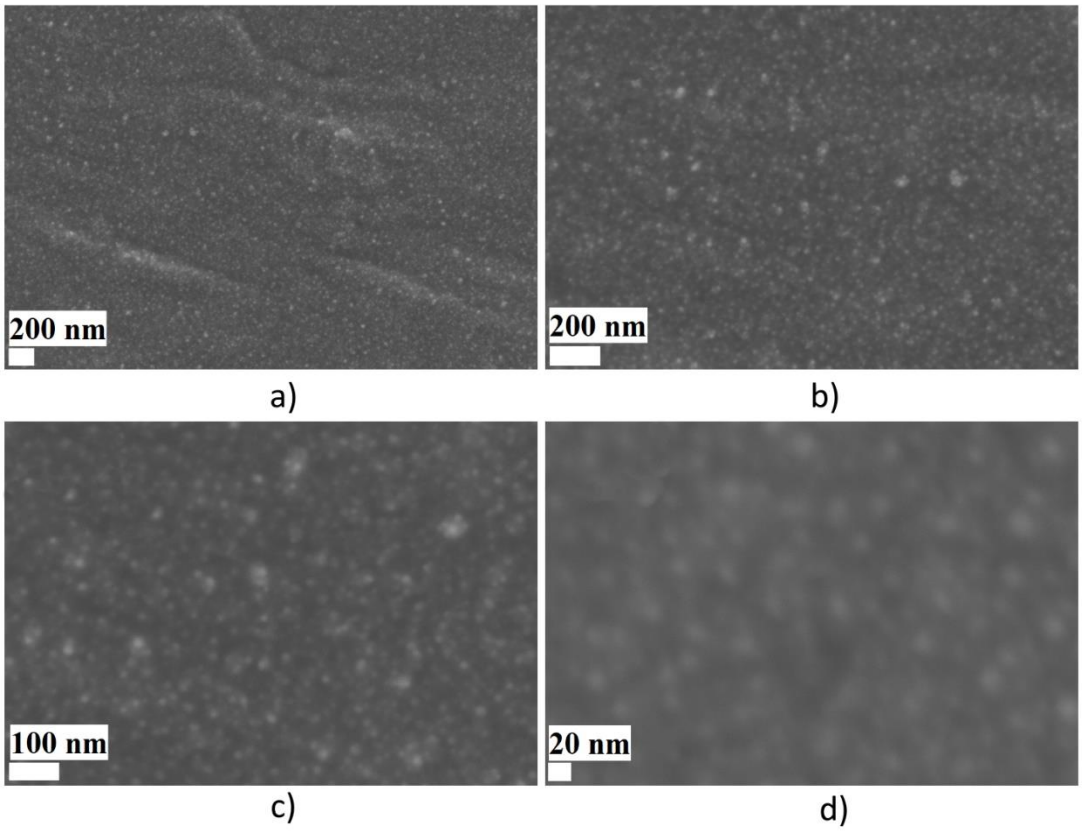

Figure 2. SEM images of the $CuO/Cu_2O/AgPt$ after gas tests and after being coated with PV3D3 layer at different magnifications: a) 200 nm; b) 200 nm; c) 100 nm; d) 20 nm.

XRD pattern of the sample was studied in the 10-90° 2θ values, with the results in the interval 30-80° 2θ presented in Figure 3.

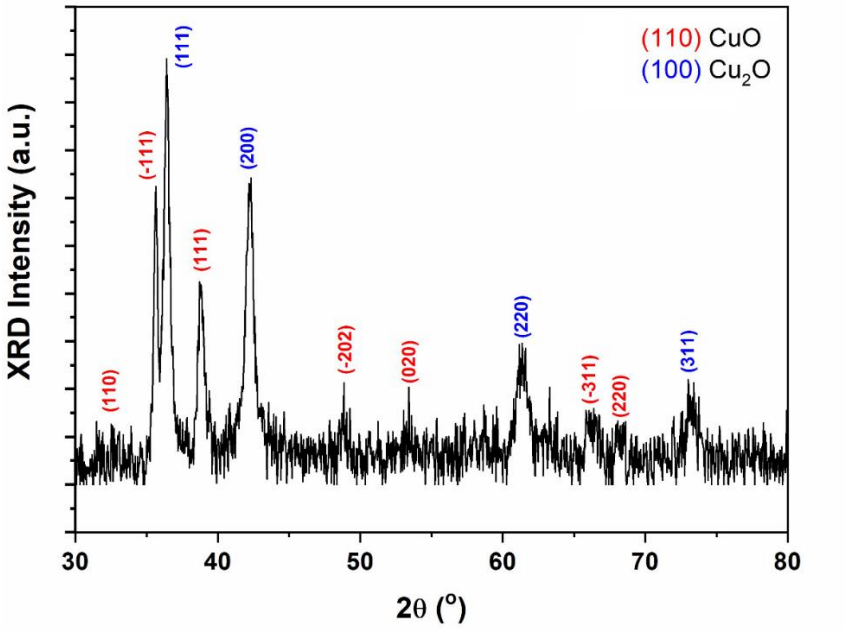

Figure 3. XRD pattern of the CuO/Cu_2O:AgPt sample.

There have been detected multiple CuO and Cu_2O peaks, according to CuO_00-005-0661 and Cu_2O_050667, respectively. Cu_2O cuprite peaks (111) and (200) have a higher intensity compared to tenorite peaks, which can be due to the slow formation of the CuO on top of Cu_2O layers [11]. Strong and sharp diffraction peaks indicate high cristallinity of the sample [12].

In Figure 4 is presented Raman spectra of the CuO/Cu_2O sample, observing multiple CuO peaks at 286 cm^{-1}, 335 cm^{-1} and 599 cm^{-1}, coresponding to the Ag and Bg, which are in accordance with the results of other authors [13,14]. A Cu_2O peak has been detected at 1040-1090 cm^{-1}, corresponding to multi-phonon transitions according to [15,16].

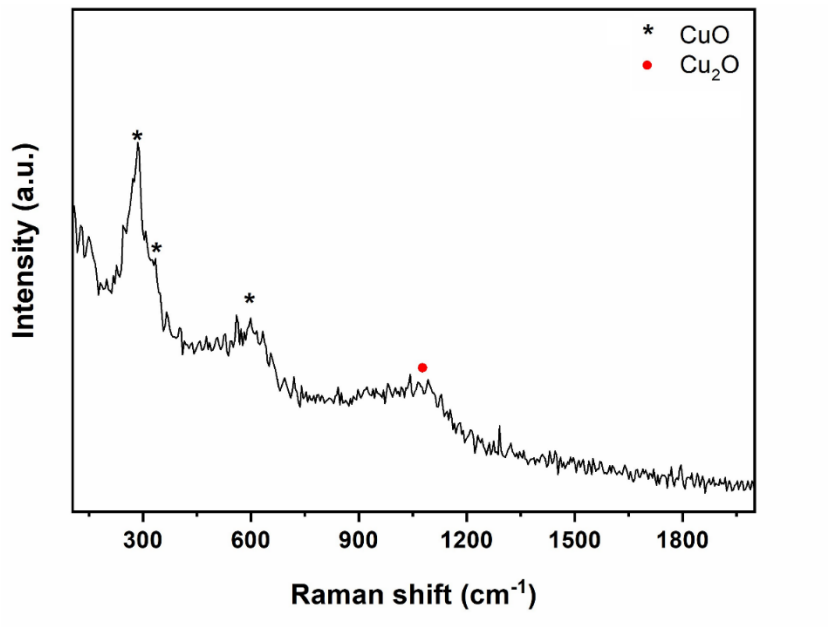

Figure 4. RAMAN spectra of the CuO/Cu_2O:AgPt sample.

3.2. Gas sensing properties of CuO/Cu_2O/AgPt

Figure 5 shows the operational response of the CuO/Cu_2O/AgPt nanostructures under the influence of the application of gases such as acetone, methane, hydrogen, ammonia, propanol and carbon dioxide with a concentration of 100 ppm.

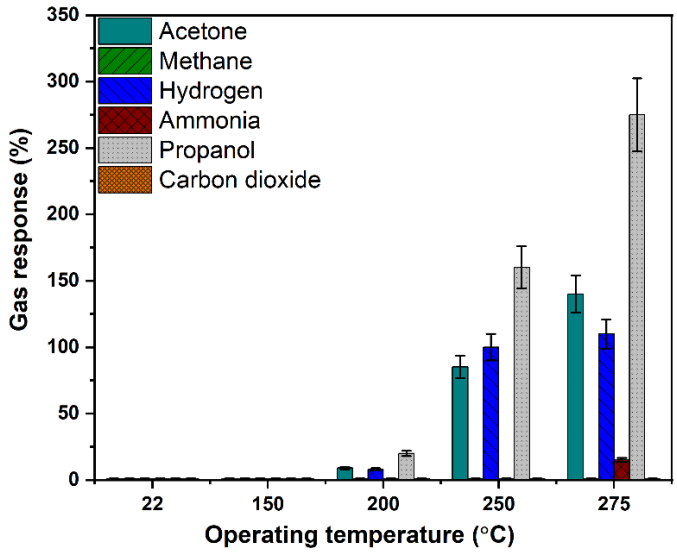

Figure 5. The dynamic response to all gases with 100 ppm concentration at RT, 150 °C, 200 °C, 250 °C, 275 °C.

It can be seen from the figure that the responses of these nanostructures appear at relatively high operating temperatures (200 – 275 °C). Starting with the temperature of 200 °C, a high sensitivity to propanol with a value of 20 % is observed. At a temperature of 250 °C, a more pronounced response to propanol appears, thus we have a sensitivity of 160 % to propanol. Hydrogen has a sensitivity of 100 %, and acetone 85 %. At the temperature of 275 °C we have a high sensitivity to propanol with the value of 275 %. Hydrogen has a response of 110 % while at this operating temperature the nanostructures already have a greater response to acetone with a value of 140 % and a response to ammonia of 15 % appears.

Figure 6 shows the dynamic response for propanol with a concentration of 100 ppm for different temperatures. According to these data, the response time of the AgPt:Bb nanostructures to propanol at the temperature of 200 °C is approximately 21.72 s, while the recovery time has a value greater than 41.4 s. At a temperature of 250 °C, the response time is approximately 22.6 s, and the recovery time is more than 76 s. At a temperature of 275 °C, the response time is 20.4 s, and the recovery time is approximately 75.2 s. From these results we can conclude that by applying a higher operating temperature we have a faster response and recovery time.

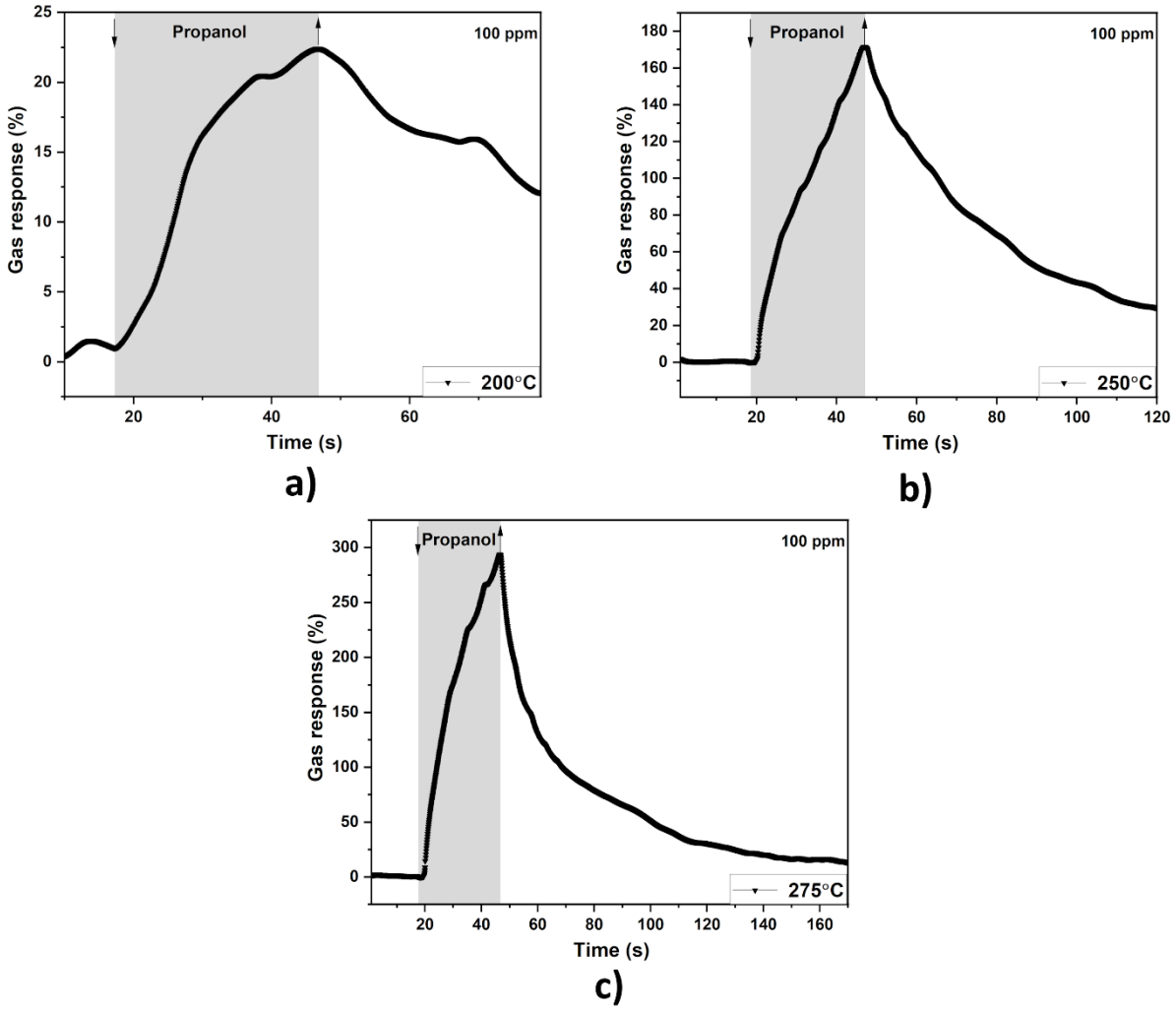

Figure 6. The dynamic response to propanol 100ppm at different operating temperatures: a) 200 °C, a) 250 °C, a) 275 °C.

Figure 7 shows the response of the nanostructures at the 300 °C operating temperature of different concentrations of propanol (1 ppm, 5 ppm, 10 ppm, 50 ppm, 100

ppm, 500 ppm, 1000 ppm). Thus, at a concentration of 1 ppm, the response time is approximately 18.71 s, and the recovery time approximately 38.86 s. At 5 ppm the response time is about 15.2 s and the recovery time is about 40 s. At 10 ppm the response time is approximately 21.55 s and the recovery time approximately 37.9 s. At the concentration of 50 ppm the response time is approximately 20.31 s and the recovery time approximately 42.78 s. At 100 ppm the response time is about 19.1 seconds and the recovery time about 57.2 s. At 500 ppm the response time is approximately 14.79 seconds and the recovery time approximately 64.45 s. At 1000 ppm the response time is approximately 19.99 s and the recovery time approximately 77.94 s. In Figure 7 can be seen that at concentrations higher than 500 and 1000 ppm the response value S of the sensor enters saturation. There is also a significant increase from 50 ppm to 500 ppm in the value of the S response.

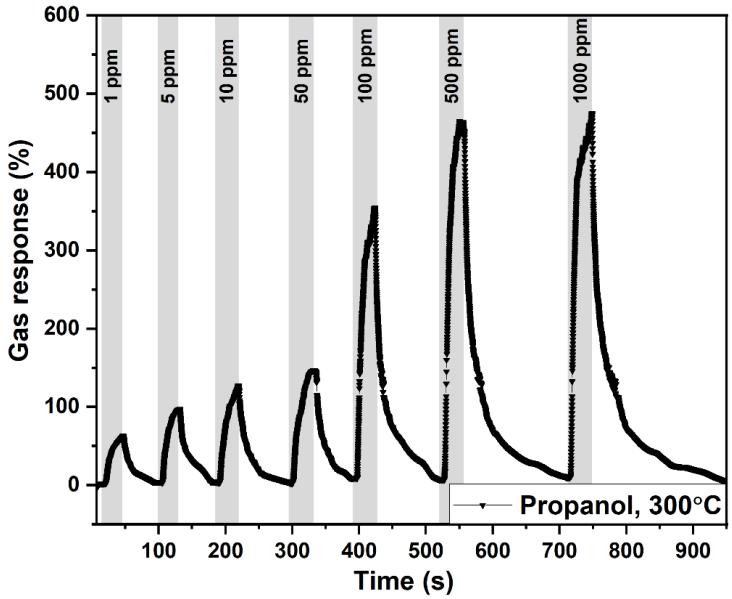

Figure 7. The dynamic response to propanol at 300 °C at different concentrations.

Like the previous figure, Figure 8 represents the response of nanostructures at a temperature of 300°C, but to acetone with concentrations of 1 ppm, 5 ppm, 10 ppm, 50 ppm, 100 ppm, 500 ppm, 1000 ppm.

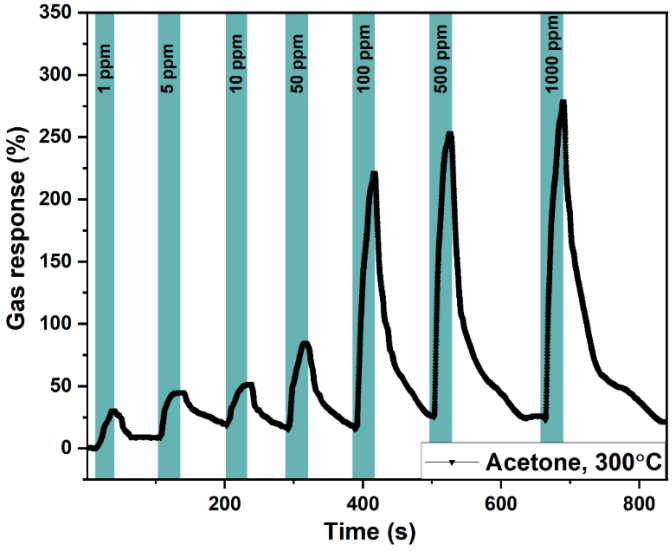

Figure 8. The dynamic response to acetone at 300 °C at different concentrations.

Likewise, in this case, the response and recovery times were determined, where it was observed that in the case of the response time, the best result at 50 ppm was 13.2 s, and in the case of the recovery time at 1 ppm, it was 24.47 s. It can also be observed that at higher concentrations of 500 ppm and 1000 ppm the nanostructures enter saturation, having an insignificant increase in the response.

4. Conclusions

The research conducted on CuO/Cu_2O functionalized with AgPt nanostructures for gas sensing applications provides significant insight into their potential utility in environmental monitoring and pollution prevention. Through careful characterization using SEM, XRD, and Raman spectroscopy, the morphology and structure of the nanostructures have been elucidated, providing a fundamental understanding of their functionality. The deposition of noble metals such as silver and platinum, as well as polymer layers, has been shown to improve sensor properties, including sensitivity and selectivity.

The gas sensing properties of the nanostructures show remarkable sensitivity to various gases such as propanol, acetone, hydrogen and ammonia, especially at elevated temperatures. In addition, the observed trends in response and recovery times underscore the importance of operating temperature in optimizing sensor performance. The saturation effects observed at higher concentrations of certain gases further highlight the need for nuanced calibration and sensitivity adjustments in practical applications.

Overall, this research contributes to the advancement of gas sensing technology and offers promising avenues for the development of efficient and reliable monitoring systems in industries susceptible to gas emissions. By harnessing the capabilities of CuO/Cu_2O/AgPt nanostructures, we can potentially reduce environmental pollution and protect human health. Future studies could delve deeper into optimization strategies and real-world deployment scenarios to further validate the efficacy of these nanostructures in practical environmental monitoring contexts.

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POSSIBILITIES OF OBTAINING AND VALORIZING DIETARY FIBERS IN THE CONTEXT OF THE CIRCULAR BIOECONOMY

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Abstract. This article aimed to review the recent literature on the characterization of dietary fibers and their role in the human body, focusing on the methods of extraction of dietary fibers from agro-food waste as well as their use in various areas of the food industry. Dietary fibers are biologically active substances with beneficial effects on human health. Soluble dietary fiber is involved in reducing cholesterol levels and blood sugar levels, while insoluble dietary fiber helps regulate intestinal transit and maintain colon health. It would be useful to identify the extraction procedures and characterization of dietary fibers from agro-food waste. Fruit waste contains relevant amounts of bioactive compounds, such as: phenolic acids, flavonoids, lignins, carotenoids, etc. In addition, fruit waste contains significant amounts of dietary fiber with nutraceutical important activities, such as modulating the intestinal microbiota, lowering cholesterol, triglycerides and glycemic load in the blood. Hence, obtaining dietary fiber from agro-industrial waste can solve a number of economic and environmental problems that aim reducing waste, increasing the sustainability and profitability of companies in the Republic of Moldova. Dietary fiber can be used in various types of food, such as products of bakery and confectionery, meat, dairy products, and pasta. They can be used as stabilizers with an impact on food texture or ingredients with low caloric value, partially replacing caloric constituents such as fats, starch or sugars. Another important property is the prebiotic effect of dietary fibers. This property is determined by the fact that dietary fibers are indigestible or poorly digestible and are fermented selectively by intestinal microbiota, conferring health benefits to the host.

Keywords: *agro-food waste, dietary fiber, extraction methods, physiological effects, functional products.*

Rezumat. Acest articol și-a propus să revizuiască literatura recentă despre caracterizarea fibrelor alimentare și rolul lor în organismul uman, cu accent pe metodele de extracție a

fibrelor alimentare din deșeuri agroindustriale precum și utilizarea lor în diverse domenii ale industriei alimentare. Fibrele alimentare sunt substanțe biologic active cu efecte benefice asupra sănătății umane. Fibrele alimentare solubile sunt implicate în reducerea nivelului de colesterol și a glicemiei, în timp ce fibre alimentare insolubile ajută la reglarea tranzitului intestinal și la menținerea sănătății colonului. Prezintă interes identificarea procedeelor de extracție și caracterizare a fibrelor alimentare din deșeuri agroalimentare. Deșeurile din fructe conțin cantități relevante de compuși bioactivi, cum ar fi: acizi fenolici, flavonoide, lignine, carotenoide etc. În plus, deșeurile de fructe conțin cantități semnificative de fibre alimentare cu activități nutraceutice importante, cum ar fi modularea microbiotei intestinale, scăderea colesterolului, trigliceridelor și încărcăturii glicemice în sânge. Prin urmare, obținerea fibrelor alimentare din deșeuri agroindustriale poate rezolva o serie de probleme economice și de mediu care au drept scop reducerea deșeurilor, sporirea sustenabilității și profitabilitabilității întreprinderilor din Republica Moldova. Fibrele alimentare pot fi utilizate în diverse formulări alimentare, cum ar fi produse de panificație și de cofetărie, carne, produse lactate, și paste făinoase. Acestea pot fi utilizate ca stabilizatori cu impact asupra texturii alimentelor sau ingrediente cu valoare calorică scăzută, înlocuind parțial constituenții calorici precum grăsimile, amidonul sau zaharurile. O altă proprietate importantă este caracterul prebiotic al fibrelor alimentare. Această proprietate este determinată de faptul că fibrele alimentare sunt nedigerabile sau slab digerabile și sunt fermentate selectiv de microbiota intestinală, conferind beneficii pentru sănătate gazdei.

Cuvinte cheie: *deșeuri agroalimentare, fibrelor alimentare, metode de extracție, efecte fiziologice, produse funcționale*.

1. Introduction

In recent years, there has been a particular interest in the development of functional foods mainly because they can provide physiological and nutritional benefits. These foods contain bioactive compounds including dietary fiber [1]. The health-promoting potential of dietary fiber includes lowering blood cholesterol and sugar levels, improving cardiovascular health, and more [2]. The recommended daily intake of dietary fiber is 38 g/day for men and 25 g/day for women, while the actual average intake is only 15 g/day [3]. In addition, dietary fiber is a promising food additive with technological properties necessary for the development of value-added products that promote health [4]. To meet dietary fiber requirements, the food industry is concerned with identifying low-cost dietary fiber sources with improved functional properties that allow obtaining food products with unique characteristics. In this context, fruit and vegetable by-products seem to be a promising alternative. In addition, the use of these by-products contributes to the reduction of residues and waste, which is a serious environmental problem worldwide [5].

The term "dietary fiber" was first mentioned in 1953 by the British scientist Eben Hipsley, who defined it as a component of the cell wall of plants that is not digested by the human body [6]. Subsequently, the concept of "dietary fiber" underwent a number of modifications and additions as additional analyses and observations concerning this group of components began to be carried out. Thus, according to the generally accepted explanation formulated in Codex Alimentarius Alinorm in 2009, digestible fiber is a group of substances, polysaccharides with three or a bit more monomers, which are unaffected by the action of digestive enzymes of endogenous nature, which implies that they cannot be broken down and assimilated by the small intestine [7]. However, it should be noted that the group of

dietary fiber also includes lignin, which is a non-carbohydrate substance, a polymer contained together with cellulose in the cell membrane. On the basis of the sources of derivation, dietary fiber can be classified as follows: i) polysaccharides that are part of the chemical composition of the edible parts of fresh fruits, vegetables and cereals; ii) dietary carbohydrate polymers that can be obtained from the crude products by physical, enzymatic and chemical methods and have proven biophysiological benefits to the human body (e.g. inulin); iii) artificially derived (synthetic) polysaccharides, also with proven benefits (e.g. methylcellulose) [8].

It should be noted that today there is an increasing interest in zero-waste production, that is, the use of all possible parts of food raw materials in maximum quantities, which will reduce the number of wastes. This is due to the fact that the amount of waste generated in food production has increased over the years, hence the economic and environmental problems have increased [9]. In order to minimize these problems, it is necessary to take food waste into consideration in order to explore its further use in the food industry as well as other industries. Such wastes are usually valuable raw materials in terms of dietary fiber or bioactive components. Dietary fiber, especially pectin, are usually obtained from apple pomace, pears or plums, raw materials that are typical for the Republic of Moldova.

Edible fiber extracted from vegetable and fruits by-products of processing can be used for food fortification. Extraction of these components is carried out in order to develop and produce functional foods.

The EU food industry produces more than 100 million tonnes of waste consisting of inedible plant tissues (seeds, peels, husks, etc.) every year. Most of this waste can be utilized to produce food supplements of high nutritional value. The dietary fiber as well as other compounds such as essential oils, proteins, pigments and flavor compounds can be isolated using various extraction methods [10]. Therefore, this article aimed to review the recent literature on the characterization of dietary fibers and their role in the human body, focusing on the methods of extraction of dietary fibers from agro-food waste as well as their use in various areas of the food industry.

2. Characteristics of dietary fibers

Dietary fibers are carbohydrate polymers such as cellulose, hemicellulose, lignin, and pectin that provide structural rigidity to the plant cell wall. Based on water solubility, dietary fiber is classified as soluble dietary fiber and insoluble dietary fiber. Insoluble dietary fiber is resistant to the digestive enzymes of the human gastrointestinal tract and accounts for approximately 2/3 of the fiber volume in most foods. They include cellulose, hemicellulose, lignin, and resistant starch [6].

Cellulose is a polymer of natural origin, which is often obtained from plants, as it is the basic element of their cell wall. It equally be further synthesized and modified in laboratory conditions to improve the chemical and physical properties of the substance. Chemically, cellulose is an unbranched carbohydrate composed of multiple D-glucose monomers (more than a thousand units) [11].

Hemicellulose also like cellulose is a biopolymer that is predominant in the cell wall of wood and annual plants. Unlike cellulose, it belongs to the class of heteropolysaccharides, that is, it consists of various residues of simple sugars (in addition to glucose, it includes xylose, mannose, galactose, etc.) [12].

Lignin is a part of the cell barrier which allows hemicellulose and cellulose to bind together, which gives the cell a stiffer and more impermeable structure. Compared to the previous two fibers, lignin is not a carbohydrate but is a phenolic polymer [12].

Resistant starch is starch and other starch breakdown products that enter the body with food but cannot be digested by enzymes of the human digestive tract. Thus, resistant starch passes through the small bowel directly into the large intestine, after which it is excreted from the body or undergoes fermentation and as a consequence serves as a necessary carbon substrate for the vital activity of intestinal microflora. A special feature of this group is its specificity for each individual, i.e. it is not necessarily the case that the same type of starch for two different people will be resistant [13].

Soluble dietary fibers are dissolved in an aqueous enzymatic medium. They are characterized by the absorption of water with the formation of a gel, which in turn affects the digestive processes, slowing them down. This group is represented by pectin, beta-glucans (β-glucans), galactomannan gum and inulin [6].

Pectin is a natural polymer and structural component of plant cell wall, which is well soluble in water. This polysaccharide is able to retain water and form gels, which takes an active participatory stance in the alimentary sector [6].

β-glucans are polysaccharides consisting of several glucose molecules, capable of being produced by many prokaryotic and eukaryotic organisms. In addition, this group of sugars is found in the cell walls of bacteria, fungi, yeasts, algae, and cereal plants, especially oats and barley [14].

Galactomannan gums are natural polysaccharides usually extracted from the endosperm of various leguminous crops. The peculiarity of chemical structure is mannose chain with galactose branches, hence is a heteropolysaccharide. It also has antioxidant and antibacterial properties [15].

Inulin is a carbohydrate polymer that is a natural, water-soluble dietary fiber and is also found in many plants as a backup energy source. Inulin is chemically structured as a carbohydrate consisting of several fructose residues. In addition to its fiber properties, inulin serves as an effective prebiotic, providing the necessary conditions for the development of a favorable intestinal microflora in our body [16].

For each type of dietary fiber, there are certain raw materials in which it predominates and from where it can be extracted to improve the characteristics of the finished product. Thus, insoluble fiber is predominantly found in cereals and bran, fruits and vegetables, and legumes. In turn, soluble types of dietary fiber are common in a more diverse range of foods. For example, apples and citrus fruits are high in pectin and pectin substances, while β-glucans are prevalent in bran and cereal grains such as oats and barley. Galactomannans, on the other hand, can be found in legumes other than cereal grains. For inulin, the best-known sources are Jerusalem artichoke (*Helianthus tuberosus*) and chicory, and in smaller concentrations onion and garlic [17].

As mentioned above, dietary fiber can be obtained directly from the intake of vegetables and fruits, berries and cereals, or through the extraction of these substances during their technological processing, which is of great interest to the food industry. This allows combining several production problems: increasing the biological value of products and minimizing food waste at the end of the technological process. Especially for the Republic of Moldova with its diversity of agricultural products.

3. Dietary fiber from agro-food wastes

In this paper we will consider dietary fiber, which can be obtained directly from fruit crops or from the products of their processing, typical for our republic. It is conditioned by the fact that at this stage of food industry development it is necessary to improve production technologies at the expense of more rational use of vegetable raw materials and reduction of food waste in the process of their processing.

Referring to the statistical data, it is possible to determine the sown areas and annual yield of fruit species for the year 2022, which will clearly demonstrate the most developed areas of fruit and berry cultivation on the territory of the Republic of Moldova, Figure 1 [18]. As a result of the study of statistical data, it was revealed that the yield of apples for 2022 was 447.7 thousand tonnes, which was harvested from 51.2 thousand hectares of land. For pears and quince these figures were 4.7 and 2.6 thousand tonnes from 2.8 and 1.2 thousand hectares respectively. Peaches and apricots were grown on 5.4 thousand hectares for the former and 4.5 thousand hectares for the latter, accounting for 20.5 and 11.8 thousand tonnes of yield. Plum as well as apples occupy relatively large areas equal to 21.0 thousand hectares, and their quantitative indicator is 100.2 thousand tonnes of fruit [18].

If we consider berries, the biggest specific weight falls on grapes and makes 528.2 thousand tonnes of harvest, and the sown areas occupy 116.5 thousand hectares. These indicators exceed the values of any fruit grown on the territory of the Republic of Moldova in 2022 [18].

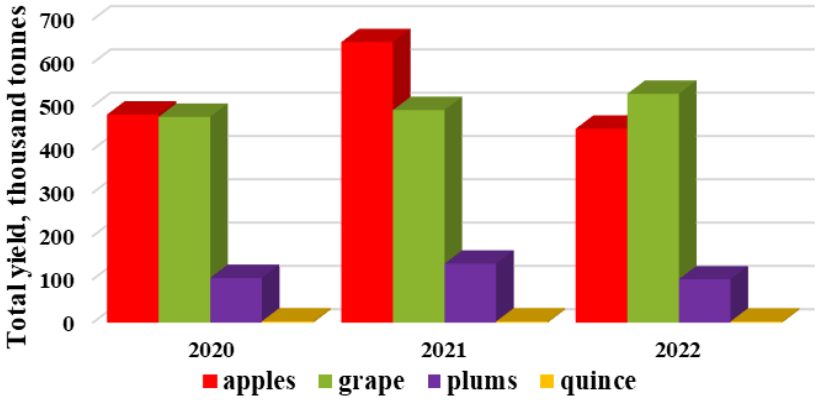

Figure 1. Yield volumes of some fruit and berry species in the Republic of Moldova (years 2020-2022) [18].

On this basis, it can be concluded that on the territory of Moldova the most common fruits are grapes, apples and plums and, therefore, it is appropriate to consider them as a nutritional fiber source for food fortification.

It can also be noted that quince is a specific fruit for this region, which makes it appropriate to study it as an additional source of fiber, despite the insignificant volumes of its cultivation.

3.1 Apple

Apple is a product of wide use, both fresh and in technological processes, due to its balanced and nutritious composition and variety of varieties. The biological value of the edible parts of apples can vary for each component based on the species, cultivation and degree of processing.

However, the main and characteristic components of each species are water, which occupies the largest percentage of the product (85.60 %), followed by sugars (13.8 %),

proteins and lipids in smaller quantities, and dietary fiber, which is of interest to us, which amounts to about 2.40 g/100 g of product [19].

Among the micronutrients, we can mention that apple is a good source of potassium (107 mg/100 g), β-carotene (27 mg/100 g) and other minerals and vitamins such as phosphorus, calcium, magnesium, vitamin C and B group and others [19].

As mentioned earlier, apples are universally used in food processing technology in large quantities, and this, in turn, is accompanied by a significant amount of wastes from their processing. Mainly apple by-products include peel and pulp (95 %), seeds (2-4 %), and stems (1 %) [20], which exhibit high biological properties and have the potential to be reused as a great source of bioactive substances. The chemical composition of apple crop by-products is mainly represented by dietary fiber, phenolic compounds, and fatty acids and also, they include carbohydrates, proteins and ash to a lesser extent [21].

Dietary fiber accounts for 55.48 g/100 g dry matter (DM), of which the largest percentage is insoluble dietary fiber (43.58 g/100 g DM), the remaining 11.06 g/100 g DM reflects the quantitative content of soluble dietary fiber [22]. The quantitative and qualitative composition of dietary fiber varies from variety to variety, but this does not reduce the importance of using apple by-products for enrichment of mass-produced food products.

For example, in their study, a doctoral student from the Wroclaw University of Environment and Life Sciences demonstrated the quantitative content of insoluble dietary fiber in pomace from two apple varieties Aidared and Champion. The outcome of this research indicated that cellulose and hemicellulose were predominant in the Champion variety compared to the Aidared variety, and the amounts varied between 16.10g/100 g DM and 9.37g/100 g DM for Champion, respectively. Aidared is slightly inferior in quantitative values for cellulose (13.64 g/100 g DM) and to a large extent for hemicellulose (4.26 g/100 g DM). However, when studying lignin, a variation of values was found, i.e. an advantage was noted in the performance of the Aidared variety, and it varied between 6.17 g/100 g SM (Aidared) and 5.80 g/100 g DM (Campion) [23].

The most common soluble dietary fiber of apple fruits are pectin and pectin substances, which are already quite extensively applied in the food processing industry as a jelly component (mainly in the manufacture of confectionery products).

3.2 Grape

In addition to apples, the fruit of grapes is also rich in chemical composition and of high economic importance. This is due to the quantitative indicators of the harvested crop, as well as the products processed from it. For example, according to [18], the wine production in the Republic of Moldova in 2022 was 14.4 million decalitres. The result of the whole production is not only the finished product, but also the food waste that is not used further, such as pips, skins, pulp residues, etc., which has a significant impact on the economy of the enterprise and the ecology of the country.

However, it should be noted that the products of processing in wine production have high biological value, due to which they can be used as functional additives in the production of other types of products. These components contain high amounts of dietary fiber, both soluble and insoluble, as well as polyphenolic compounds, which can also be used to improve the performance of the final product.

Based on a study by the Complutense University of Madrid, white grape pomace contains 76.37 g/100 g DM of dietary fiber, of which 23.01g/100 g DM-soluble and 53.36

g/100 g DM-insoluble dietary fiber. Also, the amount of extractable phenolic compounds varies from 7.82 to 7.88 g/100 g DM. In supplementing the above components, grape pomace contains proteins, fats, carbohydrates, organic acids, and other substances [24].

3.3 Plum

The third object under study is plum fruits, which are also quite widespread within our country. Their quantitative indicators are comparatively lower than the two previous samples, but still make up a decent specific volume of the total amount of cultivated fruits and berries. On the chemical side, these fruits also have a high value and diversity of composition, which is similar to apples in terms of large amounts of water (86-89 %) and carbohydrates (6.7-15.0 %), proteins and fats make up a relatively small proportion (up to 1 %), and dietary fiber varies from 1.3 to 2.4 %. In addition to fiber, plum fruits contain phenolic compounds (111 mg/100 g), as well as trace elements represented by various minerals (potassium, calcium, magnesium, and others) and vitamins (mainly B vitamins) [25]. If we consider the dietary fiber included in plums, the main mass is represented by pectin as soluble dietary fiber, as well as lignin and cellulose as insoluble fiber. Their specific gravity is 0.76 g/100 g, 0.30 g/100 g and 0.23 g/100 g, appropriately [26].

3.4 Quince

The composition of quince fruits is quite diverse and balanced, which is interesting from a biological point of view due to the positive effects on the human body. Their consumption can help in the fight against asthma, liver disease, digestive disorders, heart disease, and also helps to improve immunity in general. Like all fruits contains a large amount of free moisture and soluble carbohydrates, a small amount of fats and proteins. The vitamin composition in quince is different and is represented by both water-soluble (group B and vitamin C) and life-giving vitamins (A, E, K) [27]. To mineral substances can be attributed potassium, phosphorus, calcium, magnesium, a little sodium, iron and zinc. In addition to the listed components of quince fruit, they also include organic acids, polyphenolic compounds, and also certain types of amino acids (aspartic acid, asparagine and glycine) [27]. The active ingredients in the fruit are the tannin in the seeds, but it should be noted that consuming the seeds in large quantities can be toxic. Other active ingredients include pectin, mucilage, sugars and organic acids found directly in the fruit. Dietary fibers also have their specific weight in this fruit and are present in both forms: soluble mainly in the form of pectin and insoluble - cellulose and lignin [27].

Thus, in the work of Romanian researchers, the quantitative content of cellulose, lignin, and the total amount of non-cellulosic polysaccharides (hemicelluloses) in quince pomace was determined based on the processing method. Three samples were submitted: untreated pomace and pomace treated with water or ethanol. The results ranged from 6.24 to 11.07 % for cellulose, 27.78 to 34.97 % for lignin, and 22.07 to 33.62 % for hemicelluloses. Describing each sample in more detail, the untreated pomace was characterized by a higher cellulose content (10.16 g/100 g), an average lignin content (30.10 g/100 g) and a relatively low amount of non-cellulosic polysaccharides (23.43 mg/100 g). The ethanol treated sample had the highest values for lignin (33.30 g/100 g) and hemicellulose (32.93 mg/100 g) and the lowest value for cellulose (6.80 g/100 g) among the presented pomace. In turn, water treated pomace had intermediate values for cellulose (9.55 g/100 g) and hemicellulose (25.56 mg/100 g) and the lowest value for lignin (28.70 g/100 g) [28].

In summary, it can be concluded that the selected raw material is a good source of dietary fiber not only in its natural appearance but likewise as processed products (fruit pomace). This observation allows us to set the direction for further studies in order to solve both economic and environmental problems of the country and physiological disorders in the population (reducing the risks of various diseases by enriching food products).

4. Extraction methods for dietary fiber

Currently, chemical, mechanical, thermal and/or enzymatic processing methods are used to extract dietary fiber or to enhance their extraction from plant materials. The yield and functional properties of the dietary fiber gained are predominantly dependent on the extraction conditions, which include temperature, processing duration, solvents, and pH [29]. Thus, the reviewed studies aim to optimize these conditions by applying classical methods together with modern methods to minimize the consumption of solvents and/or duration and temperature to achieve food products with at the target rate of output and quality parameters [30].

Such developments are contributing to a significant change in the industrial paradigm, calling for more sustainable methods as well as a more responsible approach to the environment. In parallel with the technological advantages, there is an emphasis on material and technical research that will reduce the environmental impact of obtaining raw materials, which in turn reduces the number of resources used and waste generated.

There has been a significant increase in interdisciplinary co-operation between engineering and science, addressing complex problems of efficiency, sustainability and ecosystem impacts. This demonstrates a holistic approach to thinking about the processes of derivation, stimulating innovation to find greener solutions [29].

Dietary fiber and other polymeric compounds are cross-linked with other components of the plant cell wall to form a stricture network. On this basis, water or other more sophisticated means of extraction and methods (like alkaline solutions or enzyme hydrolysis) are required to remove many polysaccharides from the structural composition composed of covalent and non-covalent bonds. The extraction procedure can be difficult due to the structural complexity of dietary fiber and their components. Mechanical and enzymatic techniques have been employed as pretreatments to improve fiber extractability and yields. And one of the most prevalent extractive practices is thermal extraction along with chemical extraction, Figure 2 [30].

Thermal impact on dietary fiber fragments is influenced by the conditions of the process and also by the bonding of polysaccharides to dietary fiber and other cell wall compounds. Heat treatment can release dietary fibers from the cell membrane and dissolve labile substances which are related with dietary fiber structure, such as arabinoxylans, beta-glucans, oligosaccharides, and pectin.

Also, heat treatment can promote the cleavage of glycosidic bonds as a result of elimination of pectin substances, leading to solubilization of insoluble dietary fiber. Processing at high temperatures can change structural pectin or protopectin into soluble forms by hydrolysis, thereby increasing the soluble dietary fiber content. It is worth noting that more intensive processing may lead to degradation of soluble pectin. On the other hand, the reduction of insoluble fiber levels by heat is due to the partial degradation of cellulose and hemicellulose into simpler sugars (primarily glucose and, respectively, xylose and galactose) [31].

Unfortunately, at this period of time there is not enough information about modern and non-thermal methods of obtaining dietary fibers from plant raw materials. Thus, ultrasonic and microwave irradiation was mainly used to increase the yield as a result of extraction.

Extraction caused by microwave radiation - electromagnetic waves of different frequencies are used, which do not cause ionization of atoms and molecules of substance but provoke structural changes in plant cells. This method of extraction results in one-sided processes of heat and mass transfer. Microwave energy acts directly on the material, due to the interaction of molecules with the magnetic field, converting electromagnetic power into heat energy. Then the thermal energy needs to be scattered in the sample volume. These changes increase the permeability of the cells, and the diffusion of compounds internally and externally is what ultimately drives up the efficiency of extraction [32].

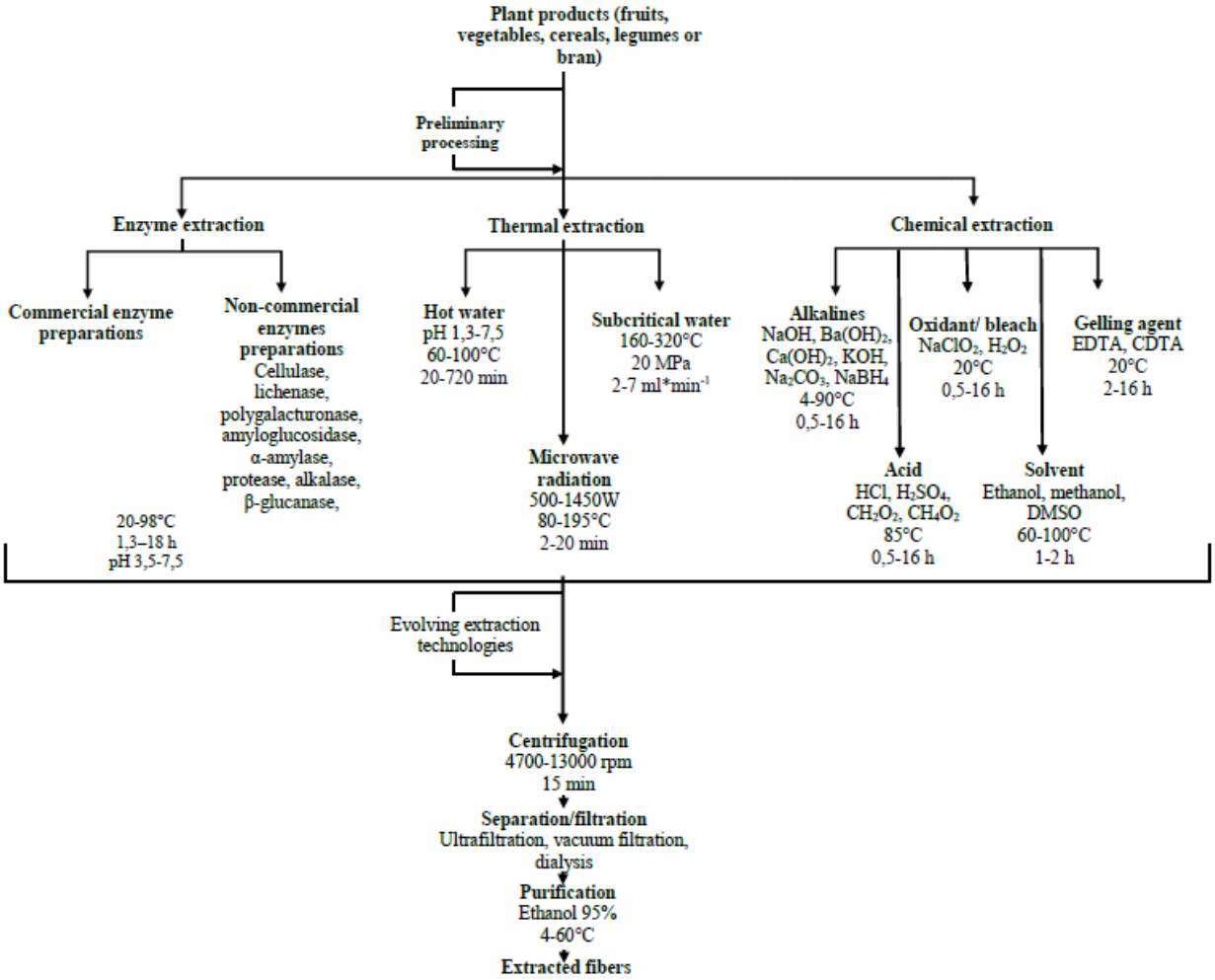

Figure 2. Scheme for extraction of dietary fiber from plant products [30].

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Three-phase separation is a new nonchromatographic method of biological separation, the principle of which is the separation and extraction of simple organic compounds from lipids, by isoelectric precipitation, and precipitation of co-solvents in solutions of tert-butanol and ammonium sulfate. This method is characterized by high efficiency due to the increase in the extract level and low energy consumption, and also allows to preserve the physiological activity of raw materials [29].

Ultrasound extraction involves the use of special devices capable of generating ultrasound to extract bioactive substances. In this process, acoustic cavitation is used, which leads to cell wall damage of vegetation raw materials. This causes an increased release of biologically active components. The principle of action of ultrasound is based on the effect of mechanical waves, which are characterized by amplitude, frequency, intensity, length, power and speed. The frequency of ultrasound waves is in the diapason from 20 kHz to 10 MHz [30]. The advantages of this method are less consumption of solvents and energy, reduced time and heat requirement as opposed to traditional techniques of extraction. Ultrasonic extraction methods have been successfully utilized as a promising method which is gaining an increasingly strong foothold in the food industry. This is determined by a number of factors: the methods are quite cost-effective, environmentally friendly and easy to apply, which contributes to the improvement of food quality as well as the development of functional products. Ultrasound due to cavitation disrupts the cell wall structures of plants, maximizing the access of solvent to all tissues, while microwaves release polysaccharides from cell walls, increasing extract yield [30]. Aqueous extraction methods using ultrasound improved the physical, chemical, microstructural and physiological characteristics of edible fiber recovered from orange, grapefruit and lemon seeds. In addition, ultrasound treatment raised the proportion of soluble dietary fiber extracted from papaya peels [33].

Extraction under the action of a pulsating electric field. This method suggests electroporation, which induces cell wall damage. Pore building causes mechanical degradation of cell walls and the substance is reported to be disintegrated. Factors affecting extraction when subjected to a pulsed electric field include its strength, treatment time, pulse waveform, conductivity, material porosity, solvent ionic strength and pH. The results of using the described method include high extraction efficiency by increasing the diffusion of intracellular materials and the rate of mass transfer [32].

Supercritical fluid extraction involves solvents used at pressures and temperatures above critical limits. Under such conditions, the properties of both liquid and gaseous solvent can be observed. Carbon dioxide is commonly used for supercritical fluid extraction because it has low levels of critical pressure and temperature and is classified as being non-toxic, nonflammable and cheap. Supercritical fluid extraction is predominantly used for separation of lipid fractions from vegetal raw sources [32].

As follows from the above, the potential use of emerging techniques such as ultrasonic and microwave processing for extraction and modification of dietary fiber is evident and should be taken into consideration for more detailed study in future research [30].

5. Role of dietary fiber in human body

Dietary fiber has attracted much attention over the years, due to its potential as a pharmaceutical product because of its ability to lower cholesterol [34], prevent coronary heart diseases and diabetes, prevent the obesity development, and improve intestinal peristalsis, which is particularly relevant to the elderly [35,36]. Dietary fiber is a material that binds potential nutrients, leading to the formation of new metabolites, and may also increase

the growth of intestinal villi, increasing the assimilation of substances. A large number of studies have shown that soluble dietary fiber is beneficial to health due to its immunomodulatory and anti-inflammatory effects, and insoluble fiber due to stimulation of intestinal function [37,38].

5.1 Gastrointestinal function

Current research shows that consuming optimal amounts of dietary fiber has beneficial influence on the digestive tract, for example, regulating bowel function, improving glucose tolerance in diabetics, and having a preventive effect for chronic diseases that can cause colorectal cancer [39]. Fiber-rich foods contain a wide range of compounds that may prevent various types of cancer. In addition, some fibers have demonstrated their ability to adsorb carcinogenic agents [40].

The World Health Organization (WHO) has suggested a total fiber consumption of 25 g/day [41]. Nevertheless, actual dietary fiber intake ranges from 14 to 29 g/day. Very few countries report fiber intakes above or at the same level as WHO recommendations. Most values are below national recommendations [42].

Dietary fiber has been shown to influence the intestinal microflora by changing bacterial fermentation activity, composition of colonies and their sizes [43]. Indigestible carbohydrates are the main source of energy for many gut microorganisms and can directly affect species that rely heavily on this substrate [44].

5.2 Cardiovascular system

Dietary fiber may have important effects on the cardiovascular system, influencing the glycemic response and various other aspects of metabolism [45]. These days, a large number of studies report a decreased risk of circulatory system diseases due to regular consumption of high-fiber foods. Some experiments have suggested that dietary fiber may change major cardiovascular disease risk factors, which include metabolism of lipids and lipoproteins, inflammatory signs, insulin homeostasis and coagulation, and improve insulin sensitivity, whereby lowering the risk of cardiovascular mortality [46]. Define in spite of studies have shown positive influence on cardio-metabolic danger factors by soluble gel-forming fiber, dietary sources consisting mostly of non-soluble fiber are still more closely associated with reduced cardiovascular disease risks [46]. The results of the several studies also give the idea that the role of fiber is dependent on its source and type and not on the amount of its consumption [47,48]. Various types of dietary fiber can cause dissimilar effects on physiology; soluble fiber is in control of lowering the level of cholesterol, while non-soluble fiber has contact with the intestinal walls and stimulates its function [49,50].

Many scientific sources support the importance of dietary fiber in developing metabolic health. They lower insulin resistance by slowing down gastric emptying, reducing carbohydrate digestion and absorption, and increasing glucose intake by peripheral tissues [51]. Dietary fiber prevents the onset of cardiovascular disease due to different processes including regulation of weight, better glucose metabolism, control of blood pressure, reduction of oxidative stress and subclinical symptoms of inflammation [52].

5.3 Postoperative recovery

Studies have shown that malnutrition for patients with malignancy is 31-97% [53,54], mostly with gastric cancer, so it is necessary to choose the right dietary therapy for these patients. Preliminary enteral nutritional base is recommended after gastrointestinal surgery. Exist a lot of types of nutrients such as omega-3, probiotics and dietary fiber that can

modulate immune function [55]. Short-chain fatty acids are the principal source of energy for intestinal epithelial cells and play an important role in supporting colon activity and inhibiting growth of cells. The amount of these acids is influenced by dietary fiber fermentation in the gut [56]. The use of enteral nutrition can restore intestinal mucosal integrity following surgical procedures [57], and early support of enteral nutrition reduces the risk of infection [58,59]. Leukocytes engage and relocate from the blood to inflamed tissue via multiphase process that requires the activation and expression of some proteins such as chemokines and cell adhesion molecules, and short chain fatty acids modify this process [60,61] by modulating the amount or type of molecule coupling. Such fatty acids may modify leukocyte recruitment, reducing the chronic inflammatory response of the gastrointestinal tract. A couple of researches claimed that early administration of enteral nutrition with soluble dietary fiber may improve nutritional status, delay weight loss in patients and reduce the incidence of digestive complications [62,62]. Thus, dietary fiber intake may reduce the inflammatory response and improve postoperative immune function.

5.4 Problems associated with malnutrition

Satiety is a part of the appetite control system of the body engaged in restricting food intake. Satiety shows in the amount and length of time of food intake. Moreover, it is represented in the quantity of meals and the intervals between meals [64]. Regulating food consumption by eating food products with high nutritional value can be one of the solutions to help decrease obesity. The effectiveness of various types of dietary fiber contribute to satiety differs [65,66]. A growing body of evidence shows that physical and chemical properties of dietary fiber that include water-binding capacity, viscosity, and ferment ability, can lead to reducing food consumption [66,67]. Viscous fiber increase production of saliva and chewing process [56], which may lead to early satiety and reduced food uptake [68,69]. Moreover, fibrous residues improve the metabolism of lipoproteins and lipids by decreasing the rate of absorption of fats, increasing cholesterol fecal excretion and decreasing the synthesis of cholesterol in the liver. Increased fiber intake entails a prolonged feeling of satiety, hence may be important in the fight against obesity [70,71].

Concluding the above, it can be concluded that from a functional perspective, dietary fiber is an essential component for the health improvement of the population. However, due to the lack of population awareness or unwillingness of people to pay proper attention to them, it is necessary to find a way to introduce them into the ordinary life of the inhabitants of both our country and the whole world. Thus, one of the directions may be the enrichment of mass consumption food products with fiber in order to provide the daily requirement for each consumer.

6. Use dietary fiber in food products

Numerous process residues and secondary products generated in the manufacture of treated goods are not properly utilized. Certain of them can be useful as a high source of fiber, thus reducing environmental contamination and at the same time increasing the nutritional value of the foods [72]. Food enrichment with edible fiber, influencing the finished material's rheological properties, is an effective method to improve nutritional and organoleptic parameters, as well as to increase their functionality [73]. Dietary fiber has all the necessary characteristics to be an additional component in the production of special purpose products since its biological activity and physiological value is proven due to its beneficial effects for human health [74].

To date, scientific research that is based on the study and implementation of dietary fiber in food products is more focused on products of animal origin (dairy and meat foods), on flour and confectionery products, as well as on some types of beverages [75]. A few examples from the above industries will be discussed below, with reference to the impact on the quality parameters of finished food products.

6.1 Dairy products

The elevated level of fat in ice cream and frozen yoghurt fulfils certain functions. Examples include the following types of high-fiber substances that replace fat when added to dairy products: guar gum, alginates and cellulose gels. This in turn improves emulsion and foaming, imparts viscosity and stability during freezing and/or thawing, controls melting properties and ice crystal size (mostly small), and simplifies the process of extrusion [76].

Multiple analyses have shown the fact that supplementing dietary fiber in variable amount to yoghurt boosts the nutritive quality including consistency, texture, and general consumer satisfaction [77]. Experimental data showed that yoghurt fortified with inulin from wheat (concentration 1.3%) and apple fiber was a possible alternative increase fiber supplementation and its popularity among consumers also increased [78]. However, the yoghurt to which 3% fiber was added as well had similar measures of sourness and sweetness, firmness and smoothness, and also overall acceptability. This resulted in yoghurt with high organoleptic performance and positive health benefits [79].

An experiment was conducted using pith from apple as a naturally occurring stabilizer and texture former in the production of thermostatic yoghurt. Different apple pomace concentrations (0.1, 0.5 and 1 % by weight) were added to skimmed milk and fermented with a combination of *Streptococcus thermophilus* and *Lactobacillus delbrueckii subsp*. *Bulgaricus* at 42 °C. The obtained results suggested that the addition of 1% of the squeeze resulted in a significant increase in pH and a reduction in gelation time. What's more, all of enriched yoghurts showed better consistence and connectivity during storage for up to 28 days [80].

The impact of different sources of dietary fiber likewise oats, wheat, apple and inulin on the rheological and thermic properties of ice cream mixes was also investigated. The insoluble fiber content remarkably enhances viscosity and liquefaction of the ice cream by increasing the general solids level and the creation of meshes of hydrated hemicellulose and cellulose. Increasing the soluble content did not essentially modify the samples' rheology, but limited the freezing point decrease, which suggests a possible cryoprotective effect [81]. The supplementation of apple fiber improved the viscosity and increased the values of transition temperature, most notably in the protein's presence. The implications of the findings indicated that it is possible to potentially use dietary fiber as regulators of recrystallization and crystallization processes in dairy products which have been frozen, i.e., it is possible to influence the malformations such as ice and snowiness of ice cream.

The effect of soluble edible fiber inclusions on the kinetics of milk coagulation was determined experimentally. Before adding rennet, three types of fiber were added to the milk: acacia gum, inulin or pectin. Milk curdling controlled by a voltage-controlled rheometer, near infrared transmissive sensor and hot wire sensor. The gelation time and coagulum solidification rate were identified from the response characteristics of the sensor. Pectin (0.2-0.4 %) significantly reduced gelation time. The addition of pectin at contents above 0.2 % increased the gelation time of the coagulum and lead to limitations in the casein network

development [82]. This study may have a positive impact on the manufacture of cheese and other dairy products, subsequently increasing production efficiency.

Inulin, guar gum and pectin are additionally used in the production of cheese to reduce fat percentage and, consequently, to reduce the caloric content of the finished product. At the same time, the addition of these substances does not affect the sensory characteristics of cheese such as texture, flavor, and aroma [74].

6.2 Bakery and confectionery products

Many bakery and pasta products made from flour with added dietary fiber are currently on the market. The introduction of insoluble and soluble dietary fiber has been found to affect the biological and chemical composition, textural characteristics, and cooking qualities as raw so boiled pasta [83].

Usually flour or functional flour products such as biscuits, whole meal bread, muffins contain edible fiber [74]. Fiber supplements have been demonstrated for increasing the values of flour hydration when is in use in bakery products. For instance, apple squeezes, similar to any other source of fiber, enhance the flour water absorption ability. In overall, pomace of apple has the same effect on the rheological characteristics of wheat flour dough as gluten. As the concentration of apple extract increased from 0% to 30%, the density of the cake grew from 0.48 to 0.67 g/cm^3 owing to the water-binding ability of the fiber, which also affected the texture. The volume of the product decreased from 850 to 620 cm^3 and the texture increased from 1.03 to 1.46 kg-force, indicating a decrease in porosity and airiness of the product. The addition of such a squeeze in the preparation of products eliminates the addition of other flavoring elements, as the pomace imparts an enjoyable fruity smell [84]. Apple pomace can also be used in bakery products as a well-source of polyphenols with antioxidant qualities.

Biscuits have a great forbearance for the inclusion of apple pomace, with several research reports revealing a replacement rate as high as 30 %. A not long past investigation utilized hydrated apple pith powder to part substitute flour in the preparation of biscuits [85]. The results of this research demonstrated that with an increase in the substitution level from 0 to 15 %, the physical features of biscuits such as porosity, volume, and diameter decreased dramatically by 25 %, 23 % and 11%, accordingly. Meantime, after substitution, the fruit flavor of the biscuits intensified, and the taste of cereals reduced. It was found that the overall satisfaction of the enriched biscuits decreased, according to an organoleptic assessment, however the acceptability of all processes was higher than 90 % [85].

The contrary impact of the addition of apple pomace on the hardness of bread has been reported in another study. The quality of a traditional Iranian bread (Sangak bread) that contained apple squeeze powder, the specific proportion of which was 1-7 % by weight of flour, was evaluated. The results revealed that adding apple squeeze powder could decrease the firmness of the bread structure and slow down the staling of bread. They came to the conclusion that the most effective percentage of addition of apple pith was 3 %. Additionally, organoleptic testing demonstrated that adding less than 3 % of apple pomace could improve odor [20].

Grape pomace, being a by-product of winemaking, can be a great source of fiber, as mentioned above. For example, in one study dried pomace from red Cabernet Sauvignon grapes was used to produce chocolate spread (a chocolate-flavored paste product). The primary purpose of the analysis was to identify an opportunity of their use as a sugar and

milk powder substitute. The by-products of wine production were dried and milled to obtain a powder, which was further integrated into the product. The consequence revealed that as the content of dried grape pomace expanded, and therefore the fiber input increased, the textural parameters of the product deteriorated: the structure of the spread became harder, which reduced the plasticity and elasticity of the finished product. However, when using pomace at concentrations of 3.61%, 5.64% and not exceeding 10%, the consistency characteristics are observed, which are the closest to the control sample according to the standard formulation [86]. Also, such powders are rich in polyphenolic compounds, which, along with dietary fiber, can increase the biological value of chocolate spread, but it should be noted that high concentrations of applied powder (10 g/100 g) have a negative effect on sensory parameters due to the appearance of bitter taste. In conclusion, the author states that dried grape pomace can be used in the production of chocolate spreads as a partial substitute for sucrose, milk powder and whey powder. Among the positive aspects of such an introduction, it can be highlighted the increase in functional properties of the product and the reduced cost. However, the most important technological parameters should be modified (such as, plasticity, particle size and distribution, and others) to comprehensively improve the quality of functional spreads [86].

6.3 Meat products

There is a lack of dietary fiber in meat, thus the main goal of most nutritionists and food scientists is to enrich various meat products with fiber of different origins in order to increase the quantity of biologically active substances. Every day, enriching meat with fiber is becoming more and more popular due to their property of extending the shelf life of the product, its qualities, and various technological characteristics [87].

Natural fiber extracted from soy and beetroot and other polysaccharides like cellulose and pectin are used to improve organoleptic properties of products made of meat and are also suitable for low-fat products [88].

Thus, the addition of fiber to meat products can be a good alternative, as it has a number of technological effects: increasing the moisture retention capacity; it can be a fat substitute, which reduces the overall caloric content of the product; improving the texture and stability of the emulsion; increasing the yield of finished products, which in today's reality is one of the main objectives of producers [89].

An example of additional natural raw materials in the production of meat products can be vegetable dietary fiber. Fiber found directly in fruits can be used as a fat substitute and to improve the texture of meat products by making them juicy and tender. At the same time, the use of raw fruits for saturating meat products with dietary fiber is inefficient. This is due to their high moisture content, which can adversely affect the technological characteristics and microbiological safety indicators in the production process. Thus, it is recommended to use them in small quantities or replace them with dried fruits, which will significantly reduce the moisture content [89].

For example, patties made of buffalo meat were enriched with apple pomace in concentrations 2-8% [90]. The content of dietary fiber, fat and moisture had a significant beneficial influence in dependence of the quantity of natural additives. The same results were obtained in viscosity and cooking yield. Furthermore, textural properties as hardness and thickness were increased. In meat examples with the level of fiber more than 6%, firmness was not enough to form the right shape of patty [90].

The introduction of grape seed extracts (GSE) at concentrations up to 1000 μg/g did not make any remarkable changes in the organoleptic performance of prepared pork cutlets in any of the quality parameters tested but was effective in limiting the intensity of excessive flavor, which is usually associated with the oxidative process of fat rancidity in cooked meat [91]. GSE also reduced off-flavor in cooked beef and pork. Restructured chicken slices with added red grape fine dry particles were accepted as a reference sample. They were given a rate: good up to very good in their organoleptic properties such as texture, taste and appearance. The addition of grape pomace did not affect the acceptability of beef sausages and had relatively high scores from an organoleptic point of view [91].

The following study was aimed at investigating the addition of natural grape fiber with antioxidant properties in the production of hamburger chicken patties. The main parameter of the study was the susceptibility of both raw and cooked samples to oxidation during storage (in the refrigerator at 4 °C). For this purpose, dietary fiber was used at different concentrations (0.5 to 2 %) and analysis was performed on the same day, on day 3, on day 5 and the final analysis was performed on day 13 of storage [92]. The organoleptic characteristics of the product were also evaluated: color, taste and acceptability for consumption. Thus, it was determined that the addition of grape dietary fiber improved the oxidative stability and antioxidant activity of the lipids, thus increasing shelf life, and did not affect the overall palatability of the cutlets. Hence, can be applied as an effective fat oxidation inhibitor for the production of chicken meat products [92].

In another study, fiber microparticles (FMPs) were separately extracted from the plum pulp and peel. There are α- and γ-tocopherols, co-extracted β-carotenes, polyphenols and lutein in the plum chemical composition. FMPs of pulp and peel were appreciated as organic antioxidant additive (at a concentration of 2.0% by weight) in raw chicken breast patties subjected to oxygen influence [93]. FMPs decreased the accumulation of toxic substances of thiobarbituric acid in uncooked cutlets in the time of 10-day storage at 4.0 °C. The iron reduction capacity was 78-158% higher in patties enriched with fiber, mostly extracted from the peel, which has been credited to the antioxidants provided by FMPs [93]. This could also be related with the growing levels of γ- and α-tocopherols observed in the patties with added fiber. In addition, the higher content of pectin and lower lignin content of pulp FMPs are responsible for the greater hydration, stabilization of cyanidin and thus the dark-red color imparted to uncooked cutlets and the higher firmness of prepared cutlets. FMPs from plums pulp and peel are effective supplements for meat products made of chicken [93].

Synthetically derived dietary fiber or preparations of dietary fiber, which also find their application in meat products due to their economic and technological features, can serve as another solution for enrichment of meat products. They provide good water absorption capacity, improve flavor and are cheaper than meat [89].

6.4 Beverage and sauce production

In beverages, natural fiber, mostly soluble, is usually added in order to get higher stability and thickness. These can form gelatinous mass when it contacts with liquids, that increases viscosity of beverages and keeps them from dissociation of their components. Natural fibers that are used for improvement of organoleptic properties are β-glucan, cellulose, and pectin [74].

A small study was also conducted to assess the acceptability of fiber-enriched drinking water and conclusions were drawn based on the organoleptic perceptions of patients at a

hospital in Lucknow. In appearance, the fiber-enriched sample did not differ from normal drinking water, but had a faint aroma that increased after drinking, and a pungent taste that left an aftertaste. When analyzing the texture of the samples presented, the fiber-enriched water appeared slightly granular, which could also be felt during tasting, visually the sample did not contain any solvents. In general, fortified water can be a good additional source of dietary fiber, but the unpleasant aftertaste should be neutralized, and the optimal dosage should be determined, and further laboratory analyses should be carried out [94].

Apple pomace is commonly used for light alcoholic drinks preparation in order to make richer and better flavor. The experimenter prepared alcoholic beverages from dried apple extrusion and yeast colonies such as *Saccharomyces cerevisiae*, dry wine yeast accompanied by β-glucosidase ferment and *Hanseniaspora uvarum* [95]. Fermentation lasted 4 weeks and the temperature regime was 16 ± 2 °C. Distillation of the liquids was done twice and the alcohol strength was 20-21% (*v/v*) in the first step and 60 % (*v/v*) in the second one. Each one of the beverages had high level of the alcohol, starting with 261 g/10 m^3 absolute alcohol for *Hanseniaspora uvarum*, to 509 g/10 m^3 absolute alcohol for *Saccharomyces cerevisiae*. Nevertheless, the usage of enzymes was claimed inappropriate due to the excessive methanol concentration [95].

Experiments were carried out on the enrichment of sauces such as Béchamel. Among the different white sauces enriched with apple fiber (AF401), potato fiber (KF200) and microcrystalline cellulose (MCC) were selected [96]. All were formulated by removing milk and corn starch and their replacement with 3% of various natural fiber. The freeze/thaw stabilization of three white sauces with addition of natural fiber was studied by examination of their physicochemical, sensory properties and rheological one in dependence of freezing and defrosting. The sauce enriched with MCC was mostly similar to the control sample (0 % fiber), demonstrating more thermal stability and viscosity. After undergoing freezing and thawing, the viscosities of the samples were as follows (Pa·s): control - 1.45; AF401 - 1.17; KF200 - 1.38 and MCC - 2.03 [96]. Moreover, the MCC-enriched treated samples showed a lower percentage of syneresis compared to the control. For example, the fresh control sample showed a syneresis of 6.88%, whereas the AF401 sample showed 24.9%, the KF200 sample showed 5.72%, and the MCC sample showed 6.68%. The fiber-enriched samples had the strongest matches with the organoleptic properties both before and after processing, with higher creaminess and less heterogeneity. Thus, MCC can be used in sauce preparation for high nutritional value product creation, acceptable for frozen meals, as shown by normal freeze/thaw qualities that are similar to those of a corn starch-based control sample [96].

7. Conclusions

This review paper highlights that dietary fiber are biologically active substances that can serve as an additive to enrich food products in order to make them functionally aimed at preventing many diseases associated with digestive disorders, cardiovascular problems and obesity. It becomes possible to regulate the intestinal absorption of carbohydrates and lipids, accelerate the appearance of the feeling of satiety, improve the quality of the microbiota of the large intestine and therefore immunomodulation. There are a large number of fiber extraction methods that are already widely used practically - chemical, mechanical, thermal and enzymatic.

Studies have indicated an increased use of dietary fiber in products from different food industries. Thus, for the bakery, confectionery and pasta industry, the actual functional

products are whole meal bread, biscuits and pasta made of flour enriched with fiber and resistant starch. The addition of dietary fiber provides increased flour hydration values when used in baking, improves the culinary properties of pasta products, and also improves the stability of the emulsion of halva mass and structural parameters of halva.

In the dairy industry, dietary fiber is actively used to replace fat due to their gel-forming ability, to provide viscosity, improve emulsion, foam, freezing stability and biological value, and as catalysts for protein coagulation in milk.

For meat products, the addition of fiber may be due to its ability to increase viscosity, which may have beneficial influence on the structure and juiciness of meat. Dietary fiber can also be used as a fat replacer in dietary sausages to reduce their calorie content and as inhibitors of lipid oxidation in chicken meat to increase the storage life of products made from it.

It is possible to enrich drinks, which will improve their biological value and prevent the precipitation or separation of ingredients, and various sauces, which entails an increase in their stability during freezing and thawing, therefore, it is possible to store them for a long time without losing their organoleptic properties.

Thus, thanks to dietary fiber, it is possible to increase the range of functional food products and to solve a number of problems related to the irrational use of food industry waste in the Republic of Moldova. However, it is necessary to continue the study of dietary fiber, which can be obtained not only from fruit raw materials, but also from other sources (vegetables, legumes and cereals) in order to identify more positive aspects or possible risks of their introduction into foodstuffs. In addition, there is a need to review the functional foods already consumed with dietary fiber in order to determine their acceptability for the population and future generations, as well as the rationality of their use for producers, for the country's economy and for the preservation of the ecosystem through the possibility of ensuring zero-waste production.

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EXPLORING THE MICRO AND MACRO TERROIR OF FETEASCĂ NEAGRĂ WINE FROM MOLDOVA

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Abstract. This study delves into the intricate realm of Moldovan winemaking, focusing on the iconic Fetească Neagră grape variety. The research highlights the importance of indigenous grape varieties in shaping a unique wine identity for the region. Drawing on the concept of terroir, the study investigates the microbial terroir specific to three designated geographical regions in Moldova during the 2022 vintage. The research employs a multifaceted approach, combining climate data analysis, mini vinification experiments, microbial DNA extraction, and sensory evaluation techniques. Results reveal significant variations in climatic conditions and microbial diversity across the three regions, influencing the sensory characteristics of the resulting wines. On vintage 2022 the Codru is temperature, and the Stefan-Voda and Vadul lui Traian are warm climates. All the 3 regions are moderately dry. The Stefan Voda is 14.0% , and manifests the highest ethanol content among the regions, alongside the lowest pH level. The sensory evaluations show Stefan Voda evincing heightened creaminess, Codru showcasing prominent herbal nuances, and Vadul lui Traian displaying elevated scores in berry, cherry, violet, and black pepper descriptors. Through meticulous analysis, the study underscores the dynamic interplay between environmental factors, microbial communities, and wine attributes, shedding light on the complex tapestry of Moldovan winemaking. Ultimately, this research contributes to a deeper understanding of terroir-driven wine production and emphasizes the importance of preserving indigenous grape varieties to uphold the distinctiveness of Moldovan wines on the global stage.

Keywords: *Fetească Neagră, terroir, Geographical Indications, indigenous varieties, microbial analysis, climate data, sensory evaluation.*

Rezumat. Acest studiu aprofundează tărâmul complex al vinificației moldovenești, concentrându-se pe soiul emblematic de struguri Fetească Neagră. Cercetarea subliniază importanța soiurilor de struguri indigene în formarea unei identități unice de vin pentru regiune. Pornind de la conceptul de terroir, studiul investighează specificul microbian a trei regiuni cu indicații geografice din Republica Moldova în perioada recoltei 2022. Cercetarea

folosește o abordare cu mai multe fațete, combinând analiza datelor climatice, experimente de mini vinificare, extracția ADN-ului microbian și tehnici de evaluare senzorială. Rezultatele relevă variații semnificative în condițiile climatice și diversitatea microbiană în cele trei regiuni, influențând caracteristicile senzoriale ale vinurilor rezultate. In vintage 2022, zona Codru a avut un climat temperat, iar zonele Stefan-Vodă si Valul lui Traian - un climat cald. Toate cele 3 regiuni au avut climă moderat uscată. Vinurile din zona Stefan Voda au prezentat cel mai mare conținut de etanol -14,0%,vol., cu cel mai scăzut nivel de pH. Evaluările senzoriale arată că vinurile din zona Ștefan Vodă se evidențiază printr-o suavitate sporită, cele din zona Codru prezentând nuanțe proeminente de plante, iar vinurile din zona Valul lui Traian prezintă scoruri ridicate la descriptori de fructe de pădure, cireșe, violete și piper negru. Printr-o analiză meticuloasă a fost evidențiată interacțiunea dinamică dintre factorii de mediu, comunitățile microbiene și atributele vinului, aruncând lumină asupra tapiseriei complexe a vinificației moldovenești. În cele din urmă, această cercetare contribuie la o înțelegere mai profundă a producției de vin bazată pe teren și subliniază importanța promovării soiurilor de struguri indigene pentru a susține caracterul distinctiv al vinurilor moldovenești pe scena globală.

Cuvinte cheie: *Fetească Neagră, terroir, indicatii geografice, soiuri autohtone, analiză microbială, date climatice, evaluare senzorială*

1. Introduction

Fetească Neagră, alternatively referred to by synonyms such as Poama fetei neagra de Moldova, Poama fetei neagră, Păsărească neagră, and Coada rândunicii etc., stands as an ancient Romanian cultivar with historical origins linked to the Dacian heritage. It is posited as a discernible selection from Vitis silvestris, originating in the Iași region along the Prut River [1]. This grape variety holds a significant historical prominence within the aged vineyards of Moldova, specifically recognized for its role in enhancing the distinguished Uricani wine, alongside indigenous black grape varieties [2]. Currently, Fetească Neagră is cultivated throughout the wine-producing regions of both Romania and the Republic of Moldova, producing wines with both protected geographical indication (PGI) and conventional classifications. Until 2023, the planting area registered in the Moldova National Vine and Wine Registration System (RVV) was 423.0 hectares. According to data from the Romanian National Office for Vine and Wine Products (ONVPV), in Romania in 2023, the planting area of Fetească Neagră was 3,300 hectares.

The term "terroir," derived from France, is extensively utilized in the wine industry. Traditionally, terroir is conceptualized to encompass natural elements, including climate, soil, and topography, alongside human factors such as variety selection, cultivation methods, and winemaking technology [3,4].

In recent years, the concept of "microbial terroir" has surfaced in oenology, driven by advancements in high throughput sequencing (HTS) techniques. HTS enables the identification of microbial ecology in vitivinicultural regions [5]. Research has demonstrated that both grape variety and geographical origin exert substantial influence on the microbial diversity of grapes, thereby contributing to the distinct styles found in wines [6].

Moldova possesses a rich heritage in grape cultivation and winemaking, placing a primary emphasis on the exportation of its wines [7-9]. In recent times, Moldovan wines have achieved noteworthy success on the international stage [10]. Functioning as a cultural ambassador, Moldovan wine is gaining acclaim among a growing audience, comprising both

consumers and experts in the field of winemaking. Despite its promising potential in viticulture and wine production, Moldova continues to be relatively underrepresented in the global market.

The success of the global wine market hinges on its originality and typicality, both of which are attributed to the concept of terroir. In the Republic of Moldova, our predominant cultivation involves grape varieties of European origin, with fewer instances of indigenous varieties, thus compromising the inherent typicality of the wine [11]. The cultivation of autochthonous varieties plays a pivotal role in enhancing product diversification and shaping a novel, specific wine identity that is characteristic and unique to our country.

Against the backdrop of a burgeoning and diverse Moldovan wine export market, the utilization of indigenous grape varieties, distinguished by their unique terroir, offers an opportunity for Moldovan wines to carve out and maintain a presence in the highly competitive European and global wine markets. Wines crafted from Moldova's native grape varieties not only showcase the distinctive terroir of the region but also enhance the competitiveness of Moldovan wine and the overall image of the nation.

In recent years, wines produced from native Moldovan-Romanian autochthonous grape varieties have gained increasing acclaim in both domestic and foreign wine markets. Fetească Neagră, celebrated as the most representative local variety for high-quality red wine, has become a focal point in global discussions about Moldovan wine. However, there is a paucity of research articles on the terroir specific to Moldovan Fetească Neagră.

This research aims to investigate Fetească Neagră wine produced in three PGI regions of Moldova in the 2022 vintage. Utilizing a combination of microbial analysis and sensory evaluation, the goal is to identify the microbial terroir unique to each production area in Moldova. The objective is to spotlight and establish the distinctive characteristics that contribute to the uniqueness of Moldovan Fetească Neagră wine.

2. Materials and Methods

Grape Sample. Fetească Neagră grapes were sourced from three vineyards representing Moldova's 3 PGI regions: Codru (C), Stefan Voda (S), Vadul lui Traian (T). In each region, 20 kg of healthy and mature grapes were chosen, resulting in a total harvest of 60 kg.

Table 1

Classes of viticultural climate for the dryness index, heliothermal index and cool night index of the grape-growing regions [12]

Index	Class of viticultural climate	Acronym	Class interval
Heliothermal index, HI	Very warm	HI +3	>3000
	warm	HI +2	>2400 ⩽ 3000
	Temperate warm	HI +1	>2100 ⩽2400
	Temperate	HI -1	>1800 ⩽2100
	Cool	HI -2	>1500 ⩽1800
	Very cool	HI -3	⩽1500
Night cold index, CI (°C)	Very Cool nights	CI+2	⩽12
	Cool nights	CI+1	>12 ⩽ 14
	Temperate nights	CI-1	>14 ⩽ 18
	Warm nights	CI-2	>18

Continuation Table 1

Dryness index, DI (mm)	Very dry	DI+2	⩽−100
	Moderately dry	DI+1	⩽50 > −100
	Sub-humid	DI-1	⩽150 > 50
	Humid	DI-2	>150

Climate data analysis. This study encompasses the computation of average monthly temperature and rainfall for the vintage of 2022. Additionally, the study includes the calculation of average monthly temperature and rainfall for multiple years. In conjunction with these conventional measures, three synthetic and complementary viticultural climatic indices are employed: heliothermal index (HI), cool night index (CI), dryness index (DI) were selected, calculation method reference Jorge et al.'s articles [12].

Table 2

The comparison of 2022 vintage with other famous production areas around the world

HI (Degrees x Days)/ DI (mm)	Very dry = ⩽−100	Moderately dry = ⩽50 > −100	Sub-humid = ⩽150 > 50
Cold (>1500 ⩽1800)	Champagne, Alpine vineyards	Oregon USA, southern New Zealand	Washington, Columbia britanica
Temperature (>1800⩽2400)	Bordeaux, Charentes	**CODRU-2022** Languedoc, Valee du Rhone	Rioja, Chile (central part), Napa
Warm (>2400⩽3000)	Uruguay, India, Tailanda	**SV-2022, VT-2022** Corsica, Madeira, Canary Islands, Southern Brazil	Mendoza, California, Australia

Mini-vinification. For each wine, 5 kg of Feteasca Neagra grapes were crushed by hand, 0.2 g/L *Saccharomyces. cerevisiae* inoculated, and 100 mg/L potassium metabisulphite (PMS) added. Alcoholic fermentation takes place under 26 °C, and the must density be monitored daily. PMS adds. Malolactic fermentation is conducted by lactic bacteria when the sugar is <3g/L.

DNA extraction. Fermentation samples (100 mL volume each) were centrifuged, and deoxyribonucleic acid (DNA) was isolated from the sediment. Isolation was performed according to the Biamp PowerFecal DNA extraction kit (QIAGEN) procedure.

Physical Chemical and Sensory Analysis. Fourier transform infrared spectroscopy (FT-IR) was utilized for physical-chemical analysis. The samples were served together at a temperature of 20 degrees in individual booths and in the International Organization for Standardization /the Institut National de l'Origine et de la Qualité (ISO-INAO) glasses into which about 75 mL of wine was poured. Each of the analyzed samples was coded with a three-digit code. The samples were evaluated by six panelists from the professional sommelier. The panelists have 3 women and 3 men, aged between 25 to 60 years, average age of 34 years. The Model of tasting sheet for sensory analysis of Fetească Neagră wine from the previous experiment [13].

Table 3

The tasting sheet for sensory analysis of FN wine [13]

Olfactory description	Abbreviation	Gustatory description	Abbreviation	Persistence	Abbreviation
Forest fruit	O.F_fruit	Structure	G.Structure	Olfactory	Per.Gus
Cherry	O.Cherry	Body	G.Body	Gustatory	Per.Olf
Prune	O.Prune	Tannin	G.Tannin		
Violet	O.Violet	Bitter	G.Bitter		
Sweet spice	O.S_spice	Alcohol	G.Alcohol		
Black pepper	O.B_pepper	Oak	G.Oak		
Plant	O.Plant				
Dairy	O.Dairy				
Smoke	O.Smoke				
Oak	O.Oak				

Date analyze. Microsoft Excel was used to collate the data, and **Origin Pro 2021** was used to generate graphical representations of the data.

3. Results

3.1 The Climate analysis

The HI serves as an informative metric regarding the heliothermal potential, calculated over a biologically acceptable average period. This index offers valuable insights into the sugar potential of grape varieties, surpassing traditional temperature sums, and thereby providing qualitative information.

The CI is defined as the mean minimum night temperature during the later stages of the ripening period. This index provides a measure of the ripening potential of a wine-growing region. Specifically, it indicates the suitability of the region concerning the development of secondary metabolites, such as polyphenols and aromas, in grapes and wines. By focusing on the minimum night temperatures during the critical phase of ripening, CI offers valuable information about the climatic conditions that can influence the synthesis of important compounds in grapes. Lower night temperatures during this period are often associated with the preservation of acidity, color compounds, and aromatic compounds in grapes, contributing to the overall quality of the resulting wines. Therefore, CI becomes a significant factor in assessing the potential of a wine-growing region in terms of producing grapes with desirable characteristics for wine-making [14]. While daytime warmth is essential for berry ripening, cooler nighttime temperatures produce secondary metabolites associated with high-quality flavor and aroma. High nighttime temperatures can elevate respiration and contribute to the degradation of malic acid in grapes [15]. Therefore, cooler nights play a critical role in preserving the acidity of berries. Malic acid, which often transforms into lactic acid through malolactic fermentation by winemakers, typically constitutes around half of the total acidity in both grapes and wines. In contrast, tartaric acid, the other primary acid, exhibits greater stability during the ripening process. Wines deficient in malic acid, either due to conversion to lactic acid or degradation, may exhibit a bland taste and heightened susceptibility to microbial spoilage.

Conversely, excessive malic acid degradation can result in wines lacking complexity, emphasizing the significance of maintaining a delicate balance in acidity to enhance overall quality and aging potential [16].

When the HI is coupled with the Cool Night Index (CI, discussed later), it enables effective discrimination of regional climates. This dual consideration accounts for both the overall heliothermal conditions during the vegetative cycle of the grape and the cool night conditions crucial during the ripening period. The combination of HI and CI contributes to a comprehensive understanding of the grapevine's environmental conditions, particularly about sugar development and the maturation process.

The DI is assessed through a modified adaptation of Riou's potential water balance of the soil index, specifically tailored for vineyard applications. This index serves as a tool for characterizing the water-related aspects of the climate within a grape-growing region. It provides insights into the potential availability of water in the soil, offering valuable information about the dryness level prevalent in a given region. This climatic factor holds significant importance concerning the ripening of grapes and the overall quality of the resulting wine. The Dryness Index thus plays a crucial role in understanding and managing the water dynamics within a vineyard, influencing key factors in grape development and, consequently, the ultimate characteristics of the wine produced [12].

Table 4

The HI, CI and DI of 3 site in vintage 2022

Region	HI	CI	DI
Codru	2017	6.31	-25.21
Stefan-Voda	2408	6.59	16.10
Vadul lui Traian	2433	1.94	-50.22

Note: HI - heliothermal index; CI - cool night index; DI - dryness index.

Table 4 shows the HI, CI, and DI indicators for the three production regions in Moldova in 2022, combined with previous research by Yao Meiling et al. [17] on the relevant indicators for the three regions from 2018 to 2020. In Jorge et al.'s Géoviticulture Multicriteria Climatic Classification System, the three production regions in Moldova are classified as follows: according to the HI classification, the Codru region is in the HI+1 (temperate warm) zone, while S and T are in the HI+2 (warm) zones. The CI zones of the three regions all belong to CI+2 (very cool nights). The DI indicator shows significant variation between years, with the C and T regions mainly in the DI--1 (sub-humid) zone, and S mainly in the DI+2 (very dry) zone. World-famous production regions in the HI+1 and HI+2 zones include Rioja (Spain), Lujan de Cuyo (Argentina), and Mildura (Australia), while those in the DI--1 and DI+2 zones include Bordeaux (France), Sacramento (USA), and Modena (Italy). Compared to other world-famous production regions, Moldova's three regions have the potential to produce high-quality red wines.

3.1.1 Temperature

The annual average temperature and monthly averages at the three sites (Purcari, Mircesti, and Bugeac) in 2022 surpass the multi-year average temperature. At the Purcari site, the 2022/multi-year average temperature is 12.1/9.58 °C. For the Mircesti site, it is 10.8/9.0 °C. At the Bugeac site, the values are 11.8/9.9 °C. Notably, the average temperature in February exceeds that in March, potentially impacting early grapevine budding. During the critical months of June, July, and August, when grapes undergo growth and ripening, there is a significant increase in the average monthly temperature compared to other months.

The temperature during these berry growth and ripening months significantly influences grape flavor.

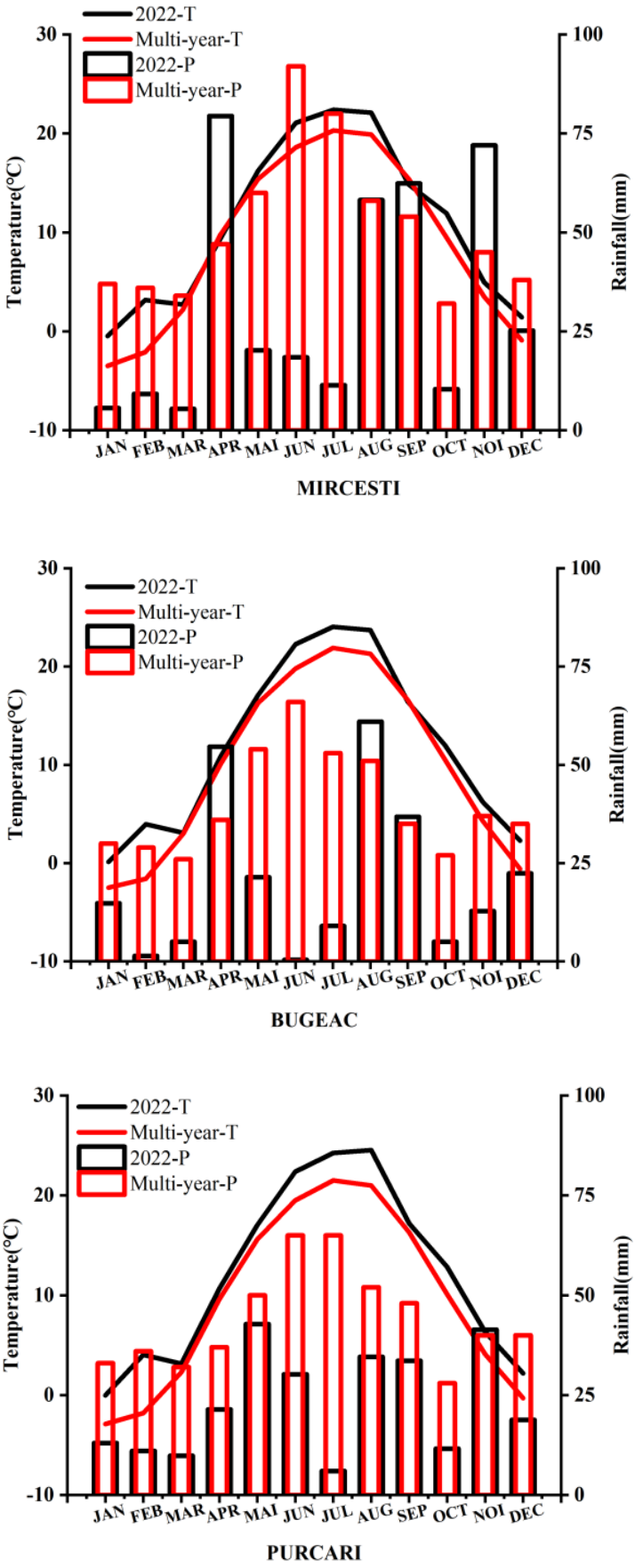

Figure 1. The climate data of 3 site in vintage 2022 compare with the multi-year.

The temperature during the months of grape growth and ripening is crucial for flavor development. Reference to Alex et al.'s study on Chablis wine indicates that a gradual warming trend between 1963 and 2018, especially during the growing season, led to an increase in favorable years for Chablis wine [14]. According to Alex et al.'s study, the average temperature during the growing season (April to September) is a pivotal factor in the scoring model for Chablis wine [18].

The study conducted by Wu et al. [19] on Cabernet Sauvignon and Sauvignon Blanc in Bordeaux vineyards revealed interesting findings regarding the impact of temperature on grape metabolites. With a moderate increase in temperature, the study observed that the content of primary metabolites in grape berries did not exhibit significant changes.

However, the study underscores the necessity of paying attention to the influence of high temperatures, particularly on the polyphenols of grape berries. High temperatures may have potentially negative effects on the aroma quality of the grapes.

These results suggest that while moderate temperature increases might not markedly alter primary metabolites, the impact on secondary metabolites like polyphenols can be more pronounced. Polyphenols play a crucial role in wine characteristics, and their alteration due to high temperatures could influence the overall aroma quality of wines made from these grape varieties. This underscores the importance of understanding the nuanced effects of temperature changes on different grape components for informed viticultural and wine-making practices.

This temperature analysis suggests that the 2022 conditions, with elevated temperatures during critical growth and ripening months, may have a substantial impact on grape flavor, akin to findings in studies on other wine regions.

3.1.2 Rainfall Analysis

The monthly average rainfall at the three stations in 2022 differs significantly from the multi-year monthly average.

The total rainfall in 2022 is notably lower than the multi-year average rainfall. Mircesti Site Rainfall in 2022 was 377.8 mm. The multi-year average was 613 mm. Bugeac Site Rainfall in 2022 was 244.6 mm. The multi-year average was 479 mm. Purcari Site Rainfall in 2022 was 274.2 mm. The multi-year average was 526 mm.

In April, a critical month for grape budding, both Mircesti and Bugeac experienced higher rainfall than the multi-year average. In August, the Bugeac site witnessed higher rainfall compared to the multi-year monthly average. Similarly, the Mircesti site experienced higher rainfall in September compared to the multi-year monthly average.

These variations in rainfall, especially during critical months like April for budding and August to September for grape ripening, can significantly influence the grapevine growth and maturation process. The differences between the rainfall in 2022 and the multi-year averages highlight the need for careful consideration of these factors in viticulture and winemaking practices.

3.2 The fungi diversity of 3 regions

The microbial diversity within grapevines is subject to a range of influences, encompassing both anthropogenic and natural factors. Climatic elements, such as temperature, ultraviolet light, and rainfall, can substantially affect the abundance and diversity of microorganisms. However, unraveling the specific impacts of these factors on the microbial community is intricate due to the intricate nature of their interactions. Previous

research has presented conflicting outcomes, with some studies proposing that increased rainfall correlates with heightened microorganism populations, while others suggest the contrary.

The advent of high-throughput sequencing techniques has markedly improved our comprehension of the grapevine microbiota. Nevertheless, the influence of climate on microorganisms remains intricate and not fully elucidated. Numerous studies underscore that the microbial community is shaped by a myriad of factors, including grape variety, vintage, and geographical location. In contrast to human-related factors, the impact of natural factors on the microbial community has garnered comparatively less attention. Researchers typically conduct statistical analyses on microbial communities categorized by distinct natural factors deemed statistically significant, highlighting the complexity and multifaceted nature of these interactions [20].

The origins of microorganisms in wine are intricate, stemming from various sources such as those inherent in grape berries, introduced through the winery environment and equipment, and intentionally added through the inoculation of commercial *Saccharomyces cerevisiae* during the fermentation stage. The structure of the yeast community changes at different growth stages of grape berries. The yeast species identified in grape berries at harvest are predominantly the same taxa initially present at the onset of alcoholic fermentation. Subsequently, these yeasts are succeeded by other non-*Saccharomyces* yeasts, which persist and contribute to the fermentation process until its completion.

Throughout the alcoholic fermentation, *Saccharomyces cerevisiae* remains consistently present in the grape juice, owing to its higher ethanol tolerance compared to other yeasts found in the winemaking environment.

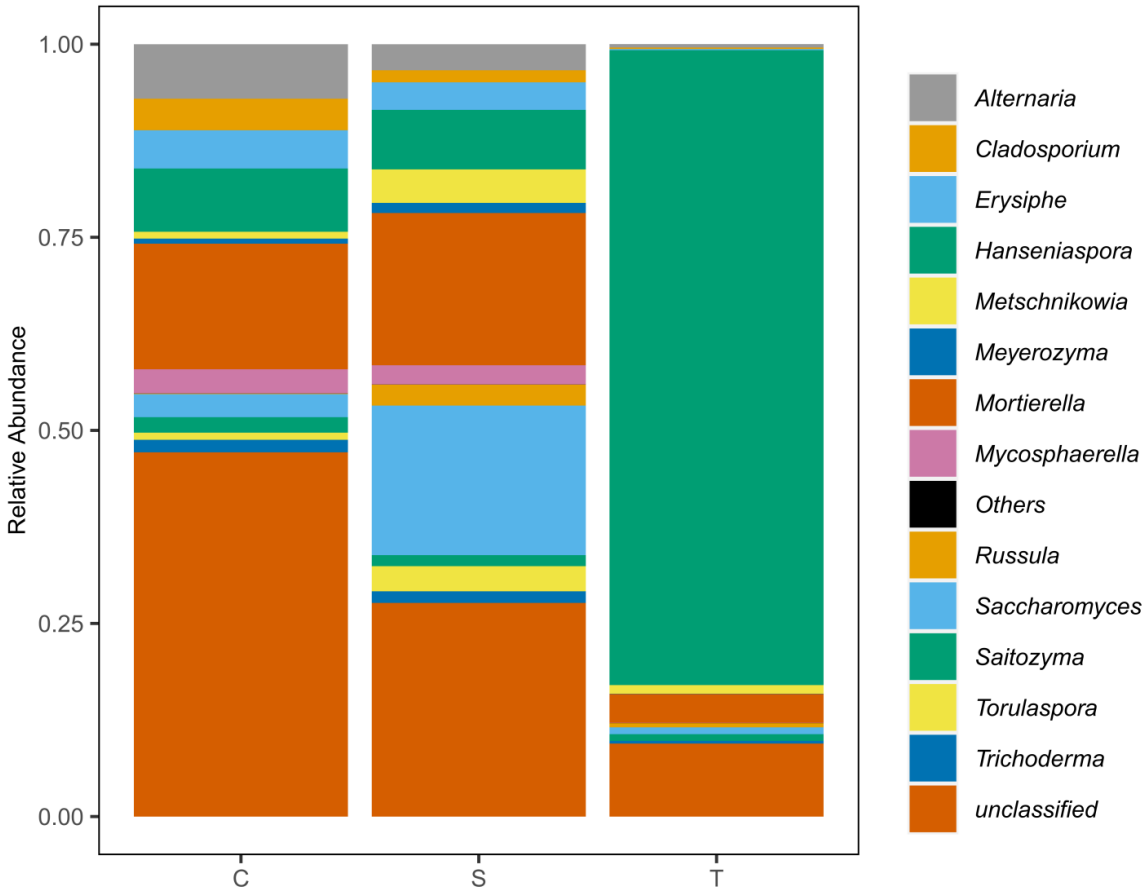

Figure 2. The fungi diversity of 3 PGI regions: C-Codru, S-Stefan Voda, T-Vadul lui Traian.

This resilience positions *Saccharomyces cerevisiae* as an indispensable component in the production of high-quality wines. Additionally, there is a growing exploration of the active involvement of these non-*Saccharomyces* yeasts in mixed starter cultures, aimed at enhancing the complexity of wine aromas. *Metschnikowia spp*. is a kind of non-*Saccharomyces* yeast conducting the fermentation before the alcoholic fermentation takes place, it is recognized for a weaker alcohol-producing ability than *Saccharomyces*. *cerevisiae* which can vary between 20%-30%. The advantage of this is that the varietal aroma is not masked by the high alcohol concentration [21]. *Saitozyma podzolica* is an oleaginous yeast that was found in the sample from Codru and Stefan Voda. This yeast isolate produces large amounts of single-cell oil (SCO) and gluconic acid (GA), although so far there is no report on the effect of *Saitozyma podzolica* on the wine taste, it has the potential to enhance the "fatty" taste of the wine [22]. This recognition of the diverse contributions of different yeast species underscores the evolving understanding of microbial dynamics in winemaking and the potential for optimizing wine quality through strategic yeast management [23]. The origin of grape berry-associated microbes is so far not fully understood [24]. The microbial community present on the surface of the fruit is believed to derive from the surrounding vineyard environment. Each locality, marked by its unique geographical and environmental conditions, contributes to the establishment of a distinct microbial signature. This microbial signature is fundamental in shaping the regional characteristics of wines produced in that specific area. The intricate interplay between the local environment, including soil, air, and vegetation, gives rise to a unique microbial ecosystem on the fruit surface. Understanding and appreciating this microbial diversity not only enhances our comprehension of the intricate ecology of vineyards but also underscores its profound impact on the distinctive qualities and flavors encapsulated in wines from different regions [25].

3.3 The results of physical-chemical and organoleptic analysis of the 3 wines

Caroline Knoll et.al studied the influences of pH and ethanol esters and acids that are important for the sensory profile and quality of wine [26]. Figure 3. shows, that the alcohol content across the three stations varies between 12.8% and 14.0%, with wine Stefan Voda displaying the highest alcohol content.

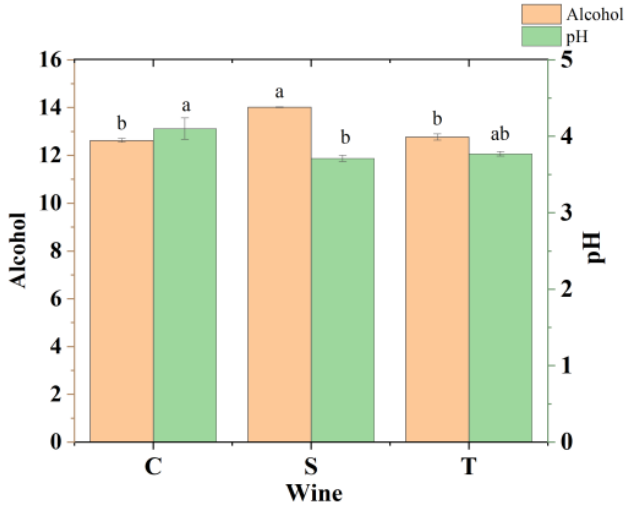

Figure 3. The result of alcohol and pH of 3 wines: C-Codru,S-Stefan Voda, T-Vadul lui Traian.

Average value with standard deviation represented by error bar (n=2). Different letters are significantly different for P ⩽ 0.05 between PGI regions. The difference between any two values, followed by at least one common letter, is insignificant.

The pH levels range from 3 to 4, and notably, the wine Stefan Voda has the lowest pH. These differing alcohol content and pH values can exert subtle effects on the sensory characteristics of the wines, an aspect that is reflected in the sensory evaluation of the three wines.

Organic acids, constituting one of the foundational components of wines, play a crucial role in influencing the sensory quality. Key organic acids include tartaric acid, malic acid, citric acid, and lactic acid. Among these, tartaric acid is distinctive for its rougher and more robust flavor compared to other acids. It is typically derived from grapes, occurring naturally in the fruit. The variations in organic acids, along with alcohol content and pH levels, contribute to the nuanced sensory profile of each wine, making them unique and reflective of the specific viticultural and winemaking conditions at each station. Malic acid is one of the more prevalent organic acids in plants, mostly in the form of L-malic acid, which tastes tart, slightly tangy, slightly bitter, astringent, and long presentation [27].

Table 5

The result Organic acids of 3 wines in vintage 2022

	Total Acidity (g/L)	Volatile Acidity (g/L)	Lactic Acid (g/L)	Tartaric Acid (g/L)
C	6.03±0.04 ^{b}	0.54±0.02 ^{b}	1.75±0.01 ^{a}	3.36±0.01 ^{b}
S	6.46±0.01 ^{a}	0.51±0.01 ^{b}	1.43±0.01 ^{b}	5.01±0.01 ^{a}
T	6.45±0.06 ^{a}	0.65±0.04 ^{a}	1.19±0.01 ^{c}	5.07±0.05 ^{a}

Note: C-Codru,S-Stefan Voda,T-Vadul lui Traian. Average value ± standard deviation (n=2). Different letters are significantly different for P ⩽ 0.05 between PGI regions. The difference between any two values, followed by at least one common letter, is insignificant.

In terms of total acidity Table 5 shows, that Codru exhibits the minimum at 6.03 g/L. There is not a substantial difference between Stefan Voda and Vadul lui Traian, but both are higher than Codru.

Figure 4. The result of sensory analysis of 3 wines:
C-Codru, S-Stefan Voda, T-Vadul lui Traian.

The highest volatile acid content is found in Vadul lui Traian at 0.65 g/L, while the lowest is in Stefan Voda at 0.51 g/L. Codru has the highest lactic acid content at 1.75 g/L, whereas Vadul lui Traian has the lowest at 1.19 g/L. Tartaric acid content is also highest in Vadul Lui Traian at 5.07 g/L, with a slight difference of 5.01 g/L compared to Stefan Voda. The lowest content is in Codru at 3.36 g/L.

Regarding sensory evaluation indicators, the radar chart (Figure 4) reveals that the three samples have the closest scores in plums. However, there are notable differences in the scores for cherries, violets, and black pepper. Stefan Voda wine exhibits more creaminess, while Codru has more pronounced herbal characteristics. Vadul lui Traian's scores in the four indicators of berries, cherry, violet, and black pepper are higher compared to the other two wines.

Table 6

The organoleptic analysis results of 3 wines from the 2022 vintage

		Bugeac	Purcari	Mircesti
Olfactory	**Forest fruit**	3.33±0.47 ^{a}	3.00±0.0 ^{a}	3.33±0.0 ^{a}
	Cherry	3.33±0.00 ^{a}	2.67±0.0 ^{c}	3.00±0.0 ^{b}
	Plums	2.83±0.24 ^{a}	2.83±0.24 ^{a}	3.00±0.0 ^{a}
	Violet	2.33±0.00 ^{a}	1.33±0.0 ^{c}	2.00±0.0 ^{b}
	Sweet spice	2.67±0.00 ^{a}	2.17±0.24 ^{a}	2.67±0.47 ^{a}
	Black pepper	2.17±0.24 ^{a}	1.33±0.47 ^{a}	1.67±0.47 ^{a}
	Plant	1.17±0.24 ^{a}	1.33±0.00 ^{a}	1.83±0.24 ^{a}
	Dairy	1.83±0.24 ^{a}	2.50±0.71 ^{a}	2.00±0.94 ^{a}
	Smoke	0.67±0.47 ^{a}	1.00±0.0 ^{a}	0.83±0.24 ^{a}
	Oak	0.83±0.24 ^{a}	0.67±0.0 ^{a}	0.67±0.0 ^{a}
Gustatory	**Structure**	3.17±0.24 ^{ab}	3.33±0.0 ^{a}	2.50±0.24 ^{b}
	Body	2.83±0.24 ^{a}	3.33±0.0 ^{a}	2.83±0.24 ^{a}
	Tannin	3.33±0.0 ^{a}	4.00±0.47 ^{a}	4.67±0.47 ^{a}
	Bitter	1.33±0.0 ^{a}	1.33±0.0 ^{a}	1.67±0.47 ^{a}
	Alcohol	2.83±0.24 ^{a}	2.83±0.24 ^{a}	2.67±0.0 ^{a}
	Oak	1.50±0.24 ^{a}	1.00±0.0 ^{a}	1.17±0.24 ^{a}
	Persistence Gustatory	3.33±0.47 ^{a}	3.00±0.0 ^{a}	3.17±0.24 ^{a}
	Persistence Aromatic	3.50±0.24 ^{a}	3.00±0.0 ^{a}	3.17±0.24 ^{a}

Note: C-Codru, S-Stefan Voda, T-Vadul lui Traian. Average value ± standard deviation (n=2). Different letters are significantly different for $P \leqslant 0.05$ between PGI regions. The difference between any two values, followed by at least one common letter, is insignificant.

This nuanced analysis provides a comprehensive understanding of the compositional and sensory distinctions among the three wines, contributing to a detailed appreciation of their unique qualities, Table 6.

4. Conclusions

The climatological investigation conducted for Moldovan PGI regions in 2022 reveals nuanced insights into the regional climatic dynamics. Notably, the Codru region is characterized by favorable heliothermal conditions, as evidenced by a Heliothermal Index (HI) of 2017, indicative of a temperate warm climate. Conversely, the Stefan-Voda and Vadul lui Traian regions exhibit warmer climatic profiles, with HI values of 2408 and 2433,

respectively. Nevertheless, all regions benefit from nocturnal cooling, a phenomenon conducive to the synthesis of secondary metabolites pivotal for wine quality enhancement. Disparities in the Dryness Index (DI) across regions are also evident, with Stefan-Voda predominantly classified as sub-humid, while Vadul lui Traian experiences notably arid conditions. These indices, corroborated by antecedent research findings, underscore the oenological potential inherent in Moldova's viticultural locales.

Furthermore, the scrutiny of fungal diversity elucidates the intricate nexus between environmental parameters and microbial ecology within grapevine ecosystems. Variables such as temperature, UV radiation exposure, and precipitation exert substantial influence on the abundance and diversity of microflora. Employing high-throughput sequencing methodologies augments our understanding of grapevine microbiota dynamics, wherein Saccharomyces cerevisiae assumes a central role in fermentation processes, while non-Saccharomyces yeast strains contribute to olfactory and gustatory nuances. Each viticultural enclave imparts a discernible microbial imprint, thus endowing regional wines with distinctive organoleptic profiles.

The comprehensive physico-chemical and sensory appraisal of wines from the 2022 vintage reveals discernible differentials in compositional attributes and sensory characteristics. Parameters such as ethanol content, pH levels, and organic acid composition exert a pronounced influence on the sensory perception of wines. Notably, Stefan Voda manifests the highest ethanol content among the regions, ranging from 12.8% to 14.0%, alongside the lowest pH level. Sensory evaluations further delineate the unique olfactory and gustatory profiles exhibited by wines from each viticultural zone, with Stefan Voda evincing heightened creaminess, Codru showcasing prominent herbal nuances, and Vadul lui Traian displaying elevated scores in berry, cherry, violet, and black pepper descriptors.

In essence, this exhaustive inquiry endeavors to delineate the terroir specificity inherent in each viticultural precinct in Moldova, thereby enriching our comprehension of the singular attributes encapsulated in Moldovan Fetească Neagră wines. By amalgamating macroclimatic scrutiny, microbial examination, and sensory assessments, this study seeks to elucidate the multifarious factors underpinning the distinctive oenological character of Moldovan wines.

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HARNESSING GRAPE POMACE: NUTRITIONAL ASPECTS, RECOVERY AND EXTRACTION TECHNIQUES FOR HEALTH BENEFITS

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Abstract. Nowadays, grapes represent the third most widely cultivated horticulture crop in the world. For the Republic of Moldova, grapes have been recognized as the most culturally important crop. About 70% of the total production of Moldovan grapes is processed in the wine industry, 30 % of which are by-products that tend to be not fully exploited, being frequently burned or landfilled. Due to its chemical composition, grape pomace is one type of agricultural waste that can be used to achieve sustainability in the food business by converting waste into useful resources. In this sense, the pomace chemical composition, with demonstrated antioxidant potential, is a viable source of biologically active compounds, as a cheap agricultural waste product, for the development of functional products. This paper is an overview of the characteristics and potential uses of wine industry waste, namely grape pomace and explores the implementation of eco-friendly technologies that have the potential to convert this perishable material into a unique ingredient, unveiling fresh opportunities for the grape pomace's utilization and consumption.

Keywords: *extraction, grapes, polyphenols, pomace, sustainability.*

Rezumat. În zilele noastre, strugurii reprezintă a treia cea mai cultivată cultură horticolă din lume. Pentru Republica Moldova, strugurii au fost recunoscuți ca fiind cea mai importantă cultură culturală. Aproximativ 70% din producția totală de struguri moldovenești este procesată în industria vinicolă, dintre care 30% sunt produse secundare care tind să nu fie exploatate pe deplin, fiind frecvent arse sau depozitate. Datorită compoziției sale chimice, tescovina de struguri este un tip de deșeu agricol care poate fi folosit pentru a atinge durabilitatea în industria alimentară prin transformarea deșeurilor în resurse utile. În acest sens, compoziția chimică a tescovinei, cu potențial antioxidant demonstrat, este o sursă viabilă de compuși biologic activi, ca deșeu agricol ieftin, pentru dezvoltarea produselor funcționale. Această lucrare este o prezentare generală a caracteristicilor și potențialelor utilizări ale deșeurilor din industria vinicolă, și anume tescovina de struguri și examinează implementarea tehnologiilor ecologice care au potențialul de a transforma acest material perisabil într-un ingredient unic, dezvăluind oportunități noi pentru utilizarea și consumul tescovinei de struguri.

Cuvinte cheie: *extracție, struguri, fenoli, tescovină, durabilitate.*

1. Introduction

In accordance with the Sustainable Development Goals (SDGs) outlined in the United Nations' 2030 Agenda, which the Republic of Moldova seeks to align with through the discussion of the Environmental Strategy project for the years 2023-2030 [1], one of the major objectives is related to the management of sustainable resources and the reduction of environmental impact. This involves a significant decrease in waste production through prevention, reduction, recycling, and reutilization. In other words, it entails promoting recycling practices of materials such as packaging, agricultural by-products, and other waste generated in agro-industrial processes [2].

At the same time, the European Commission has adopted the sustainability agenda under the framework of the European Green Deal, and the Republic of Moldova, as a country aspiring to integrate into the European Union, has adopted and implemented a series of measures and policies in the field of environmental protection that reflect the principles and objectives of the European Green Deal. As a result, aspects such as Sustainable Agriculture and Circular Economy are incorporated into the legislation of the Republic of Moldova, encouraging sustainability in the agricultural sector and promoting waste reduction and material recycling [3-5].

According to several authors and statistics, around one third of the global food production generated by agri-food sector is lost or wasted during processes as handling, processing, transport and final consumption [6,7]. The significant impact of this waste on climate and environment change has been proven by many studies [8,9]. Taking all this into consideration, currently many researches are oriented towards the valorization and reuse of food waste in order to protect the environment and natural resources [10-12].

The Republic of Moldova has a long tradition in wine production, with roots stretching back hundreds of years. The wine sector has always been one of the main pillars of the Moldovan economy[13]. The favorable climatic conditions for the cultivation of vines make the vineyard area cover a significant part of the country's territory[14]. The Republic of Moldova is known for a multitude of native varieties of grapes, which are adapted to the climatic conditions specific to the region. Some of these varieties include: Rara Neagră, Feteasca Neagră, Feteasca Regală, Feteasca Albă, etc. Acording to Bondarciuc et al. (2018), there are 140,000 hectares of grapevine plantings in the Republic of Moldova [15]. It is estimated that about 70% of the grape production in the Republic of Moldova is used in winemaking, thus generating about 30% of their wine waste (20% pomace, up to 7% stalks and 5% wine lees). However, these particular waste parts can serve as the initial raw material for the ingredient production with a high concentration of biologically active compounds [16]. The development of biologically valuable foods and beverages based on secondary grape raw materials containing mineral substances, organic acids, polyunsaturated fatty acids, vitamins, amino acids, pectin substances, etc. is relevant within the context of the modern theory of positive nutrition [17]. The aim of this study is to characterise grape by-product and assess existing sustainable methods for its utilization. This iconic fruit, valued since ancient eras, can be consumed fresh or processed, yet its by-product could be harnessed as a unique food ingredient with untapped potential. The core concept is to make the most of this valuable source of bioactive compounds whenever possible.

2. Grape By-product

Grape by-product could be defined as the solid residue left over after processing grapes to make wine or juices, among other items. It mainly consists of grape skin, seeds, stems, and wine lees. Concerning the proximate composition of grape pomace (Table 1), the

main constituents are dietary fibre (grape skin and stems), lipids (seeds), polyphenols and minerals (Figure 1).

Many researches have proven that grape pomace has health-promoting properties (Table 2) being classified as source of biologically active compounds [18-20]. The majority of compounds that exhibit antiradical activity are polyphenols, which are mainly located in skin, stems and seeds, thus most polyphenols are wasted after wine production, according to Moro et al. (2021) this waste can reach up to 70% from the total phenolic content [21]. Phenolic compounds found in grape pomace include phenolic acids, flavonoids, and proanthocyanidins [22]. These compounds exhibit antioxidant, antibacterial and cardioprotective activity [23,24]. Lachman et al. (2015) revealed that linoleic acid was most abundant in grape seed oil, its content ranging between 68.10 and 78.18 g/100 g oil, while the content of linolenic acid was insignificant (0.29 - 0.77 g/100 g oil) [25]. In the same regard, Martin et al. (2020) stated that the share of unsaturated fatty acids from grape seed oil is roughly 90% of the total fatty acid content [26].

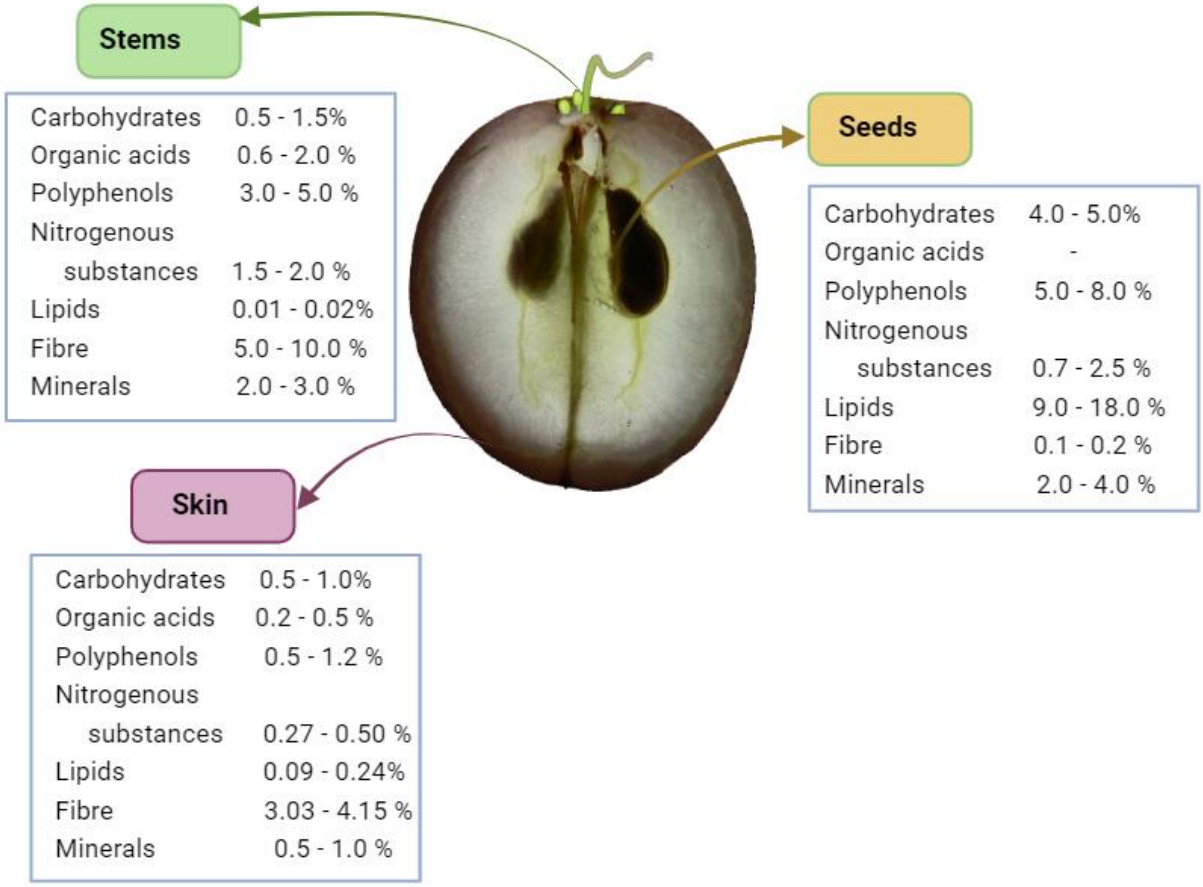

Figure 1. Grape by-product as a source of biologically active compounds [27].
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Regarding fibre, many authors state that fibre have the highest share in the proximate composition grape pomace (60 - 90% of dry matter), the wide range in fibre content being due to variety, soil and clime condition [28–30]. According to Kunzek et al. (2002), there is an ideal fiber ratio, concerning soluble and insoluble fractions (1:3) [31]. In this sense, several studies showed that grape pomace is low in soluble fibre (around 15 % of total fibre amount) [29,32]. However, the higher insolubility of grape pomace fibre opens wide directions in developing functional food products.

Table 1

Proximate composition of grape pomace, % dry matter (DM)

Carbohydrates	Protein	Lipids	Fibre	Mineral	Polyphenols	Reference
29.20±0.02	8.49±0.02	8.16±0.01	46.17±0.80	4.65±0.05	131±0.4 mg/100 g	[33]
1.34 – 55.77	5.4 – 12.3	1.1 – 4.7	17.3 - 53.2	3.3 – 7.6	15.8 – 26.7 mg/g	[29]
19.68	13.8	4.21	51.38	5.55	21.6 – 42.4 mg/g	[34]
2.11 – 50.8	5.3 – 14.0	4.8 – 9.5	26.4 – 59.0	2.9 – 6.3	41.2 ± 1.1 mg/g	[35]

González-Centeno and collaborators [28] determined the configuration of the total dietary fibre of grape pomace indicating pectic substances (40 - 54 % of total dietary fiber) and Klason lignin (20 - 25 %) as principal components. In addition, the study of Deng et al. (2011) demonstrated that white grape pomace was significantly lower in dietary fibre (17.3 - 28.0% DM) than red grape pomace (51.1 - 56.3%) [29].

Although preclinical research on the impact of grape pomace consumption on lipid metabolism, body weight, gastrointestinal health, glucose management and antioxidant activity has found positive effects (Table 2), it has mostly been conducted in animals (mice, rabbits or chickens) [36-40], while few human studies have explored the health benefits of consuming grape pomace.

Table 2

Review of the researches on the grape pomace effect on health

Research characteristics	Results	Reference
Male rats were fed with food comprising 15% grape pomace instead of starchy component.	The presence of grape pomace (15%) in cholesterol diet (0.3%) produced a significant reduction in cholesterol and triacylglycerols in the rat liver and serum.	[41]
The antioxidant activity of pure phenolic compounds from wines and grapes was assessed, through the capacity of inhibition of in vitro oxidation of LDL particles.	Wine and grape phenolic compounds inhibited the oxidation of LDL particles	[40]
Proanthocyanidin from of grape seeds, was tested for its anti-thrombotic effect using *in vitro* and *in vivo* induced thrombosis tests in the mouse carotid artery.	It was shown that grape seed procyanidins, when administered intravenously (20 mg/kg body weight) or orally (2×200 mg/kg body weight), greatly inhibited the formation of laser-induced thrombus in the carotid artery of mice.	[37]
Researchers looked into how grape pomace and seed polyphenol extracts affected the gut microbiota's ability to recover in mice given a high-fat diet following treatment with an antibiotic cocktail.	Compared to the spontaneous recovery group, grape pomace and seed extract improved the relative abundance of gut microbiota. The diversity of the gut microbiota was also significantly changed by grape pomace and seed extract. According to these results, grape polyphenol extracts play a significant role in the gut microbiota's ability to recover following treatment with antibiotics and high-fat diets.	[42]

Continuation Table 2

Mice were given a combination of the usual diet and a mix of grape skin and seeds powder, 14 days prior to the inoculation of Ehrlich ascites carcinoma cells.	The growth of the tumor was tracked, and the effects of extracts from grape skin and seeds on apoptosis and the advancement of the cell cycle were assessed. The results showed that the diet supplementation with mixed seed and skin powders prevented tumor development in the case of 47% of mice inoculated with Ehrlich ascites carcinoma, in the same time a decrease in the tumor volume and weight by 93.9% and 86.3%, respectively was observed.	[38]

Based on the positive properties of grape pomace on human health, industry and scientists have formulated common objectives regarding the creation of new products fortified with grape skin or grape seeds powder in order to increase the biological value of food, Figure 2.

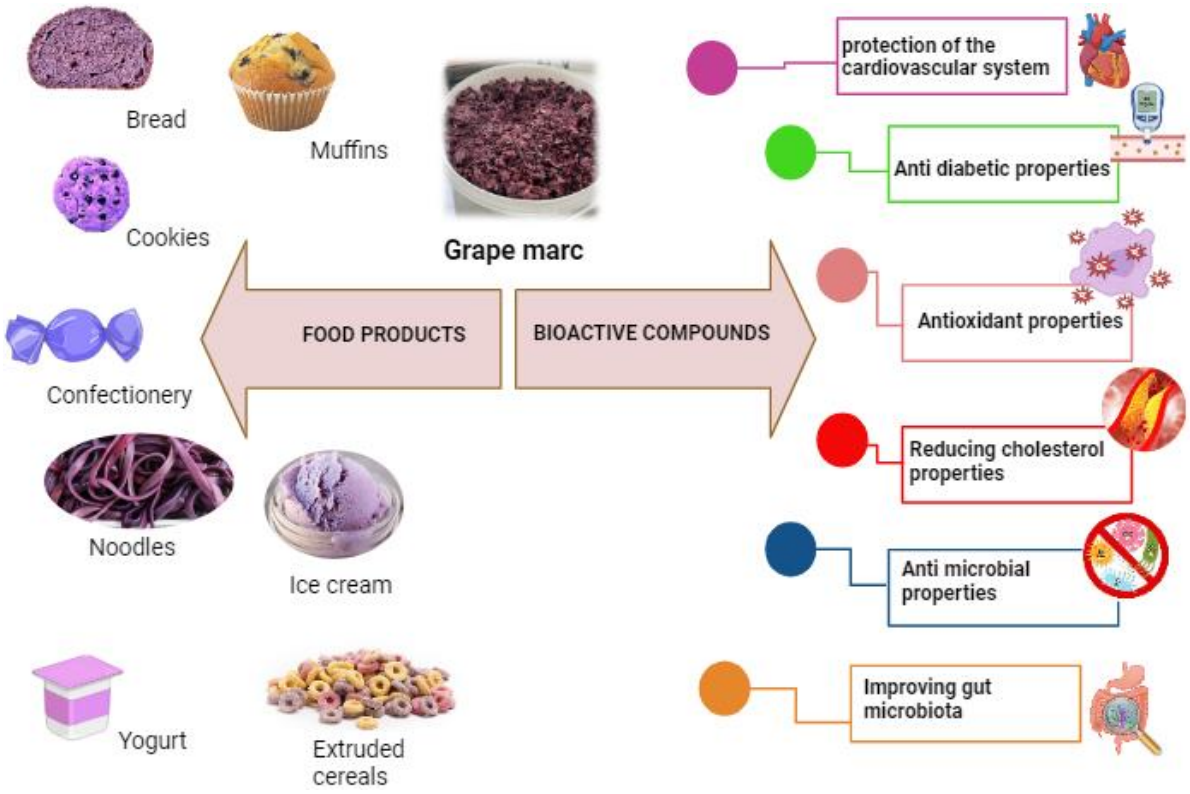

Figure 2. Food products infused with grape skin components and their influence on human health, modified after [43].

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In the food industry, grape pomace and its constituents have traditionally been utilized in powdered form as a nutritional supplement in various foods due to their abundance in phenols, dietary fiber, and anthocyanins [44]. Through a comprehensive review of existing literature, grape pomace and its constituents have been extensively studied for their potential incorporation into a variety of foods including bread [45-48], confectionery [49-51], cookies [52-54], yogurt [55-57], ice cream [58-60], pasta [61-63], noodles [64], fruit candies [65-67], beverages [68-70] and more. Consequently, incorporating grape pomace into foods presents a two-sided outcome, yielding both advantageous and disadvantageous effects on the final products.

2. Innovation for grape pomace recovery and extraction

According to sustainable chemistry, food byproducts are a great source of bioactive substances [71]. The ease of enhancing the functionality of this raw material - that is, making the components that promote health more accessible - suggests that many transformation strategies might be applied.

The nutritional and biological enhancement of food products from the use of by-products is of great relevance due to the benefits of the compounds of these by-products for human health, the economy and the environment [72]. The primary goal of by-product recovery processes is to create new, valuable goods from natural resources while cutting down on waste production and adhering to Green Europe guidelines. Over the past 50 years, new technologies have been created, including pulsed electric fields, enzyme digestion, and ultrasound [39,73,74].

Da Rocha and collaborators [75] demonstrated that utilizing microwave-assisted extraction, employing citric acid solution as solvent system, proved to be a successful method for extracting bioactive compounds from grape pomace. Nevertheless, the levels of phenolic compounds and antioxidant activity were less than those achieved with comprehensive extraction employing methanol solution acidified with acid.

Table 3

Analytical extraction methods of grape pomace compounds

Extraction Methodology	Application	Condition tested	References
Microwave	EXTRACTION OF BIOACTIVE COMPOUNDS EXTRACTION OF PHENOLICS COMPOUNDS	Solvent: 2 % citric acid solution. Microwave power: 600, 800 and 1,000 W. Extraction time: 5, 7 and 10 min. Liquid/solid ratio: 50/1 mL/g. Solvent types: water or water:ethanol (1:1) solutions. Extraction temperature: 50 ºC. Microwave power: 200 W. Extraction time: 60 min.	[75] [76]
	PECTIN EXTRACTION	Solvent: ultrapure (Milli-Q) water. pH: 1, 2 and 3. Solid–liquid ratio of 1:10 g/mL. Microwave power: 280, 420 and 560 W. Extraction time: 60, 90 and 120 s.	[77]
Ultrasound-assisted extraction (UAE)	Extraction of phenolic compounds	Drying temperatures of 60, 65, 70, 75, 80, and 85 ºC, air velocity of 1.2 m/s. Solvent types - EtOH:H_2O ratios: 50:50, 70:30, MeOH:H_2O ratio: 70:30. Liquid/solid ratio: 8/1 - 24/1 mL/g. Extraction temperature: 20 - 40 ºC. Sonication power: 130W Pulse duration: 5/15 - 2/1.	[73]
	Extraction of pectin	Liquid/solid ratio: 10/1. Extraction temperature: 35, 55, 75 ºC. Extraction time: 20, 40, 60 min. pH of the citric acid solution: 1, 1.5, 2. Sonication power: 140W.	[78]

Continuation Table 3

	Extraction of anthocyanins	Solvent type: 50 % vol. ethanol–water mixture. Liquid/solid ratio: 40:1. Extraction temperature: 20, 45, 65 ºC. Extraction time: (5, 10, 15, 20, 25 and 30 min. Sonication power: 160W. Sonication time: 30 min.	[79]
	Extraction of hemicelluloses	Solvent type: 2M and 4 M KOH solution. Solid:liquid ratio: 1:50 g/mL. Extraction temperature: 20 ºC. Extraction time: 1, 2, 3, 4 and 5 h. Sonication power: 140 W.	[80]
Enzymatic	Extraction of phenolics compounds	Solvent: phosphate buffer saline, pH 7.3. Solid:liquid ratio: 1:9 g/mL. Enzymes: Cellulase and gluco-amylase. Temperature: 55 °C. Time: 24 h.	[81]
	Extraction of phenolics compounds	Enzyme: Pectinex 3XL, Pectinex Ultra SPL, Termamyl, Fungamyl, Pentopan 500BG	[82]
High hydrostatic pressure and enzymatic	Extraction of phenolics compounds	Pressure: 50, 100 and 200 MPa. Extraction time: 0, 5, 10, 15 and 30 min. Enzyme: Carboxymethylcellulase, β-glucosidase, Polygalacturonase. Orbital agitation: 150 rpm. Incubation time: 2, 6, 24 h. Temperature: 24, 30 or 37 °C (depending on the used enzyme).	[83]
Supercritical CO_2	Extraction of anthocyanins	Pressure: 100 bar. Extraction temperature: 95 °C. Extraction time: 30, 60, 90, 120, 150 and 180 min.	[84]
	Extraction of resveratrol	Pressure: 100, 400 bar. Extraction temperature: 35, 55 ºC. Co-solvent: ethanol (5%).	[85]
	EXTRACTION OF OLEANOLIC ACID	Pressure: 25 - 35 MPa. Extraction temperature: 40 - 50 ºC. Co-solvent: ethanol (5%).	[86]

Drosou and collaborators [76] compared the effect of polyphenol extraction methods (using Soxhlet, microwave assisted and ultrasound assisted extraction). The water:ethanol extracts obtained through ultrasound extraction were found to be richest in phenolic compounds (up to 438984 ppm GAE in dry extract) with high Antioxidant activity. Furthermore, Spinei and Oroian [77] applied microwave extraction for pectin recovery from grape pomace and concluded that the ideal parameters for the extraction procedure involved a microwave power of 560 W, a pH level of 1.8, and a duration of 120 minutes. The obtained results suggest that grape pomace holds significant promise as a valuable pectin source, extractable through straightforward and rapid methods, while ensuring comparable quality to traditional pectin sources. Goula, Thymiatis and Kaderides [73] evaluated drying behavior

and ultrasound extraction of phenolic compounds from grape pomace and and expressed the combined effect of moisture content and temperature on effective diffusivity by an empirical model. The authors concluded that that employing ultrasound to extract phenolics yielded a maximum of 9.57 mg GAE/g of dry pomace within a 10-minute extraction period. In addition, Minjares-Fuentes and collaborators [78] reported the optimal studied conditions for ultrasound extraction of pectin. Therefore, parameters were established at a temperature of 75 °C for 60 minutes employing a citric acid solution with a pH of 2.0, along with sonication power of 140 W. Specifically, pectic polysaccharides were primarily comprised of galacturonic acid units, accounting for less than 97% of the total sugars.

Bonfigli and colleagues [79] conducted a study on anthocyanin extraction using both conventional and ultrasound-assisted techniques at temperatures of 25, 45, and 65 °C. The results indicated a higher efficiency of ultrasound-assisted extraction, with the maximum concentration of anthocyanins obtained through conventional extraction being 0.475 mg/mL (at 65 °C), while ultrasound-assisted extraction yielded a concentration of 0.479 mg/mL at the same temperatures. Additionally, approximately 80% of anthocyanins were extracted within the first 600 seconds using conventional methods, whereas ultrasound-assisted extraction recovered 90% of anthocyanins within the same timeframe. Another study of Minjares-Fuentes and collaborators [80] imply that ultrasound-assisted extraction may present a viable choice for extracting hemicellulosic polysaccharides from grape pomace on an industrial scale. The optimal conditions for maximizing the extraction yield of hemicelluloses and the levels of xyloglucans, mannans, and xylans were as follows: an extraction time of 2.6 hours, a solid-to-liquid ratio of 1:48 (w/v), and a KOH concentration of 0.4M. These conditions resulted in a maximum extraction yield of approximately 7.9% for hemicelluloses, around 3.6% for xyloglucans, approximately 1.1% for mannans, and roughly 1.2% for xylans.

Enzymatic extraction has been utilised also for phenolic compounds extraction from grape pomace. Kabir et al. [81] found that enzymatic breakdowns, employing cellulase and gluco-amylase, were effective in extracting polyphenols from grape pomace. In addition, the cellulase treatment exhibited notably elevated levels of polyphenolic compounds in the Folin-Ciocalteu's assay, as well as markedly enhanced reductive activities in DPPH radicals, in comparison to the gluco-amylase treated pomace. Ferri et al. [82] conducted a study with the aim of optimizing a two-stage enzymatic and solvent-based process to extract bioactive compounds from white grape pomace. In their research, they utilized six commercial enzymes (Pectinex 3XL, Pectinex Ultra SPL, Termamyl, Fungamyl, Pentopan, Celluclast) for the extraction of both wet and dry pomace, followed by ethanol extraction. The findings indicated that ethanol-based extraction of wet and dry pomace yielded higher amounts of phenols compared to water extraction, with observed variations in their compositions and bioactivities.

Cascaes Teles et al. [83] conducted a study to evaluate the impact of enzyme-assisted extraction and high hydrostatic pressure on the retrieval of phenolic compounds from grape pomace. They applied these methods individually as well as in combination to the pomace. The results revealed that high hydrostatic pressure significantly enhanced the effectiveness of the enzymes used in extraction, increasing their activity by up to 16 times. Techniques incorporating high hydrostatic pressure were found to be more efficient compared to relying solely on enzyme-assisted extraction. Consequently, the findings suggest that employing high hydrostatic pressure could offer an efficient and cost-effective means of recovering

phenolic compounds from grape pomace, particularly when compared to more complex and prolonged processes.

Pazir et al. [84] investigated the use of supercritical carbon dioxide extraction for the retrieval of anthocyanins from grape pomace. Conditions were settled at 95 ◦C, whereas pressure was established at 100 bar. The evaluation of the total monomeric anthocyanin content and total antioxidant capacity was performed at the 30th, 60th, 90th, 120th, 150th, and 180th min. Since around 63% of the monomeric anthocyanin content in the red grape pomace samples was extracted by the end of the extraction process (180 min), while 47% was achieved within the initial 30 minutes, the authors conclude, that there is no need to continue the extraction beyond 90 minutes.

Casas and collaborators [85] proposed supercritical carbon dioxide as a method for the extraction of resveratrol from grape components. The impact of varying pressure (100, 400 bar), temperature (35, 55 °C), and the inclusion of a modifier (5% *v/v* ethanol) was assessed to determine the most effective method for extracting resveratrol. The most favorable outcomes, in mg resveratrol/g extractor, (5.97 in grape seeds, 1.12 in stems, 21.35 in grape skin, 10.73 in pomace) were observed when operating at high pressure (400 bar), low temperature (35 °C), and incorporating 5% *v/v* ethanol as a co-solvent. Chronopoulou and collaborators [86] investigated the application of supercritical CO_2 extractions to obtain oleanolic acid from grape pomace and that this method effectively retrieved oleanolic acid from grape pomace samples, with an extraction yield comparable to established extraction techniques like Solid Liquid extraction, which can sometimes have drawbacks.

3. Conclusions

The grape stands as one of the primary crops on a global scale. Annually, the wine industry produces hundreds of tons of grape pomace, typically disposed of as waste. However, this by-product is recognized as a natural reservoir of bioactive compounds with significant potential health benefits. Employing eco-friendly technologies on grape by-products offers a fresh perspective for maximizing the value of grape pomace to preserve and enhance its functionality and nutritional properties. Various methodologies are explored to compare conditions and identify the primary target bioactive compounds. Following processes like enzyme-assisted extraction, supercritical fluids, microwaves, or ultrasound treatments, there appears to be a viable opportunity to convert this perishable material into a valuable source of health-enhancing compounds such as phenols, anthocyanins, and pectins. Consequently, the grape, with its historical significance, can be fully utilized, extending its potential to the often-overlooked grape by-product, thus transforming it into a newly recognized value-added product.

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