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SPATIAL PLANNING AND THE DEVELOPMENT OF RENEWABLE ENERGY SOURCES IN POLAND

Marta Szyba
AGH University of Science and Technology
30 Mickiewicza av., Krakow, 30-059, Poland, mszyba@zarz.agh.edu.pl
https://orcid.org/0000-0002-6340-3232

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Abstract
Due to the damage to the environment and climate caused by the generation of electricity in power plants burning fossil fuels, installations generating it from renewable energy sources are constructed. Spatial development plans for communes should consider their location. In Poland, generation of electricity in photovoltaic cells, wind farms and agricultural biogas plants has the greatest development potential. Due to the nuisance to people and the environment, wind turbines and agricultural biogas plants must be located far from residential buildings. Such conditions exist in sparsely populated rural areas. The observed development of single-family housing in rural areas is the result of the search for cheap construction sites and no local spatial development plans in most areas of rural communes. Dispersed housing construction restricts the construction of wind farms and agricultural biogas plants and thus poses a threat to renewable sources of wind and biogas energy produced in agricultural biogas plants. The situation may be changed by the requirement to include in spatial development plans the needs related to the construction of installations generating electricity from renewable energy sources and the construction of micro and small biogas plants directly at the sites where waste is generated.

Keywords
energy management, environmental protection, methane, municipal and agri-food waste, biogas

Introduction

Until the Industrial Revolution started in Britain in the 18th century, people had drawn their energy to survive and operate from sources that we now call renewable. It was their manual labor, animal labor, wind and water energy. The industrial revolution, symbolized by the steam engine, created a demand for fossil energy resources: coal and lignite, crude oil, natural gas and uranium. Currently, most of the primary energy contained in fossil energy resources is converted into electricity. The result of their combustion is an increase in the content of dust and carbon dioxide in the atmosphere, which is associated with the observed climate changes. The growing demand for energy also causes fears that these raw materials may run out, which threatens the energy security of societies. What is more, their combustion results in an increase in the content of dust and carbon dioxide in the atmosphere. It is associated with the observed climate changes. In order to counteract the threats, technologies are being developed that allow the use of renewable energy sources (RES) for the generation of electricity: wind, water, sun and biogas. The development of renewable energy depends on economic, social, environmental and legal factors [1]. One of the goals of the European Union is to increase the share of RES in gross final energy consumption. For this purpose, "National energy and climate plans for 2021-2030" must be created and their effects will be assessed by the European Commission. The Polish plan assumes that in 2030 this share will amount to at least 23% (electricity, heat and cooling) [2]. This direction will be continued after 2030, as evidenced by the resolution of the Council of Ministers on "Poland's energy policy until 2040" [3].

Generating electricity from RES requires space for the installations themselves and the associated protection zones. The need for creating protection zones results from the negative impact on people and the environment (e.g., odors from agricultural biogas plants, infrasound generated by wind turbines). It is impossible for people to live in the zones, as agricultural production and other economic activities are hindered. Reconciling the demand for space for RES installations with the needs for other user groups is the task of spatial planning at the national, regional and municipal levels. Without providing places for such installations, it will not be possible for Poland to achieve the goal of an emission-free economy adopted by the European Union.

This article will present the effects of the functioning of the existing laws: on spatial planning and spatial development and on the protection of agricultural and forest land. The current effects of implementing renewable energy programs will also be discussed and an attempt will be made to explain them using the agrarian structure of farms and demographic conditions in individual voivodships.

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The aim of this article is to indicate the factors that favor the location of wind farms and agricultural biogas plants. Recognizing them and taking them into account at the planning stage will help us avoid protests from local communities. This will enable efficient investment processes of new installations and prevent conflicts during their operation.

Methods

The following research methods were used: review and analysis of legal acts and scientific literature; analysis of data published by the Central Statistical Office, analysis of data obtained from the Energy Regulatory Office and National Support Center for Agriculture. Effects of the binding act on spatial planning and spatial development for housing investments are presented and related to the use of renewable energy. The current effects of using such sources as wind turbines and agricultural biogas plants are discussed. The current effects of implementing RES utilization programs were discussed and explained using the agrarian structure of farms and demographic conditions in individual voivodships.

Results and discussion

1. Spatial planning in Poland

Spatial development plans constitute the legal basis and an instrument of spatial policy within the territory of the country, shaping the activities of the society at various levels of integration [4]. In Poland, it is carried out based on the Act on Spatial Planning and Development of March 27, 2003 and subsequent amendments [5]. Taking sustainable development as the basis for shaping spatial order, the Act recommends that spatial planning should consider several requirements listed in Art. 1, point 2. They concern urban planning and architecture, architectural and landscape values (including monuments and cultural heritage), environmental protection (including agricultural land, forest land and water), health and safety of people and property, and the future needs related to the development of infrastructure technical and renewable energy use. Spatial planning should be open and transparent with the participation of local society and with respect for property rights.

The Act distinguishes three levels of planning: national, regional (provincial) and communal. Planning at the communal level has the greatest impact on RES-related investments due to the participation and control of the local community.

It includes the development of:

- a study of the conditions and directions of spatial development (SUiKZP),
- a local spatial development plan (MPZP) [5].

Developing UiKZP studies for communes is obligatory. They must include conditions resulting from: the current destination, land development and utilities, environment, cultural heritage, communication system, water and sewage management, energy, living conditions of residents, safety, legal status of land and facilities, mineral deposits and the implementation of supra-local public goals. In turn, the directions should define the following: changes in the spatial structure of the commune and land use, development of communication systems and technical infrastructure, planned areas for the distribution of settlement zones and large-scale commercial facilities, areas for which local development plans are to be prepared, areas of special threats, boundaries of protection zones, etc. The directions should also include provisions on the location of devices generating energy from renewable sources with a power above 100 kW and their protection zones [5]

According to the research conducted by the Institute of Geography and Spatial Organization of the Polish Academy of Sciences [6], at the end of 2017, only 5 local governments (3 rural communes and 2 urban-rural communes) had no such document, and another 4 studies were in the process of being developed. The documents can be easily changed. In 2017, 1/3 of the documents were updated nationwide, and almost a half for cities with powiat (county) status. In the studies, approximately 11% of communes' areas were allowed for development and additionally 8% for farm buildings (related to running agricultural farms). According to the authors of the report, this is too much, although less than the 14.2% allowed for this purpose in 2010.

The study of the conditions and directions of spatial development is not a legal act. The local spatial development plan (Local Development Plan) is such an act. It is binding on local government bodies that issue construction permits. The permits are issued by construction departments on behalf of the land and town starosts. The local spatial development plan is a planning study implementing the spatial policy adopted in the UiKZP study of the commune. It contains provisions on the purpose and rules for the development of specific areas of the commune [5]. The situation with local development plans is not good, it results from the previously mentioned studies. At the end of 2017, there were 51.6 thousand local plans, covering 9.6 million ha or 30.5% of the country's area. As compared to 2004, it was an increase of 13.2 percentage points and there are no indications that most of the

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country's area will be covered in the coming years. Only a few major cities and their suburban zones have local plans for more than half of their areas. The worst situation is recorded in the following voivodships: Kujawsko-Pomorskie, Podkarpackie and Lubuskie. Local plans there cover less than 10% of the area. In the local development plans, 1,188,000 ha is intended for housing and farm buildings, which constitutes 20.5% of the areas covered by them (5.9% of the country's area). According to the authors of the report, it is too much and contributes to the excessive dispersion of buildings [6].

In areas that are not covered by the Local Plan, construction permits are issued based on decisions on construction conditions and land development (WZiZT). Such decisions are issued by local government bodies (wójt, mayors, city mayors). Such a decision can be obtained with the title to the plot on which the construction is to take place. Since the study of the conditions and directions of spatial development is not a legal act, a building permit can be obtained even if the area is intended for other purposes (e.g., agricultural, public purposes, flood protection, RES energy production). Using the provisions of the Act on the Protection of Agricultural and Forest Land of February 3, 1995, it is quite easy to obtain changing the status of land from agricultural land and designate it for development [7]. A decision on WZiZT is in principle issued for an indefinite period, as it may only be repealed by the adoption of MPZP. If the plot is impaired as a result of that, the owner may apply for compensation. Low coverage of the country with local plans results in many decisions on development conditions. In the years 2003-2017, over 2 million of them were issued, including about 5% of refusals. In 2017, there were 22.7 thousand decisions to determine the location of a public purpose and 32.5 thousand zoning ones, of which 65% for individual single-family housing [6]. This results in an overflow of buildings, being the reason for high costs related to the development of infrastructure, especially the road network [8].

The data presented in [6] shows that the current planning situation is not good, due to insufficient coverage of the country's territory with local spatial development plans. It is particularly dangerous for the sustainable development of the Polish countryside defined in 2010 in the document of the Ministry of Agriculture and Rural Development [9].

2. Structure of agricultural farms

Most of the communes in Poland are rural 1,533 (62.7%) and 642 urban-rural (25.9%). According to the Statistical Yearbook of the Central Statistical Office of 2019, on December 31,2018,15,344,000 people lived in the countryside (39.95%) of Polish citizens. Most of the 1,428.8 thousand farms that conducted their activity on 14,669 thousand ha of agricultural land, which constitute 46.99% of the country's area, operated in the countryside. Utilized agricultural area (UAA) includes arable land, permanent pastures and meadows, orchards, built-up agricultural land, wooded and bushy land on agricultural area, land under breeding ponds [10]. The UAA is one of the basic parameters of an agricultural farm. The methodology of research on the typology of farms described in [11] enables studying the dynamics of changes in the agrarian structure of voivodships. Based on it, voivodships were grouped in terms of their similarity. Table 1 shows the structure of farms in individual voivodships s in 2008 and 2016. The division into groups of voivodships presented in Table 1 results from [11–13] presenting the results of research on the typology of farms in individual voivodships.

The data in Table 1 shows that in 2008-2016, the number of farms across the country decreased by 395.8 thousand (21.91%). This caused changes in the agrarian structure of individual voivodships. Group I, including three voivodships, is characterized by the most fragmented structure. There are approx. 80% farms with an area of 1-5 ha. In group II, also including three voivodships, the smallest farms constitute about half of all farms, and farms with an area of 5-10 ha are 25-30%. In this group, the percentage of the largest farms was slowly increasing. Group III includes six voivodships, where the number of the smallest farms decreased to the level below 40% and increased in the remaining ranges. In 2016, the largest farms were in the Warmińsko-Mazurskie voivodship, and 12.2% in the Zachodniopomorskie voivodship. In group IV there was over 10% reduction in farms with an area of 1-5 ha and there was over 3% increase in the largest farms. In Lubuskie voivodship they constituted 8.2%. The agrarian structure of the Świętokrzyskie Province is not included in any of the groups.

Part of the land of liquidated farms did not increase other farms, but was allocated for non-agricultural purposes, such as: communication and commercial and service infrastructure, industrial and housing construction. The knowledge of the structure of farms and the changes taking place in it is important not only for the agricultural policy but for the entire spatial planning, especially housing and the use of renewable energy sources.

Table 1. Changes in the agrarian structure of voivodships in 2008-2016. *Source: own study based on* [*11–13]*

Group	Voivodeship	Years	Number of farms in thousands	Percentage of farms with UAA in ha				
				1-5	5-10	10-20	20-50	>50
I	Małopolskie	2008	no data	84.6	12.6	2.2	0.5	0.1
		2016	139.9	82.4	13.1	3.1	1.0	0.4
	Śląskie	2008	no data	78.7	13.3	5.5	1.9	0.6
		2016	54.5	71.5	15.9	7.4	3.7	1.6
	Podkarpackie	2008	no data	82.2	14.5	2.2	0.9	0.2
		2016	13.9	82.4	12.4	3.0	1.5	0.7
II	Łódzkie	2008	no data	49.7	30.8	15.3	3.7	0.4
		2016	124.0	51.1	27.9	15.0	5.3	0.8
	Mazowieckie	2008	no data	48.3	29.4	16.6	5.1	0.5
		2016	212.9	45.6	27.9	18.0	7.2	1.3
	Lubelskie	2008	no data	56.3	27.2	12.3	3.6	0.5
		2016	180.0	55.5	25.3	12.7	5.2	1.3
III	Podlaskie	2008	no data	30.6	26.3	29.3	12.6	1.1
		2016	82.2	28.1	26.8	27.6	14.9	2.7
	Wielkopolskie	2008	no data	39.6	25.5	22.9	9.6	2.3
		2016	12.2	40.4	23.6	21.8	10.8	3.5
	Kujawsko-pomorskie	2008	no data	34.6	24.6	23.6	14.8	2.5
		2016	63.8	33.7	22.3	24.2	15.4	4.5
	Pomorskie	2008	no data	39.0	23.1	22.6	11.8	3.6
		2016	39.0	34.8	23.4	22.6	13.2	6.0
	Warmińsko-mazurskie	2008	no data	33.5	15.5	27.5	17.7	5.8
		2016	43.2	29.7	17.3	23.3	20.7	9.0
	Zachodniopomorskie	2008	no data	44.4	19.0	16.1	11.4	9.1
		2016	29.6	37.1	19.3	18.8	12.6	12.2
IV	Lubuskie	2008	no data	58.8	19.5	11.3	6.6	3.8
		2016	20.2	48.2	18.2	15.4	10.0	8.2
	Dolnośląskie	2008	no data	55.1	21.7	13.7	6.7	2.9
		2016	56.0	44.3	21.9	14.3	8.7	5.9
	Opolskie	2008	no data	57.2	18.6	12.6	8.7	2.9
		2016	26.9	45.4	18.2	17.3	12.7	6.3
	Świętokrzyskie	2008	no data	68.1	24.3	6.0	1.5	0.2
		2016	85.3	65.1	22.6	9.0	2.7	0.5
Poland		2008	1806.5	57.1	22.8	13.4	5.4	1.3
		2016	1410.7	53.8	22.0	14.5	7.2	2.5

3. Housing construction after 1990

According to the data presented in [6] too many locations related to housing construction are determined based on WZiZT. This is the result of efforts aimed at improving the housing situation of Poles, resulting from losses in both world wars and the housing policy in the planned economy system in Poland until 1990. According to the Central Statistical Office (GUS) data, in 1989 there were 10.9 million apartments with an average usable floor space of 60.5 m^2. According to the same source, in 1988 there were 10.71 million flats per 11.97 million households. The shortage was therefore about 1.25 million flats. Cities were dominated by multi-family housing; investors were mostly housing cooperatives. They constructed on land provided free of charge by the state for preferential loans. The waiting time for an apartment was exceptionally long and the size of the apartment allocated depended on the size of the family.

In the new socio-economic system, housing construction began to be financed by future users from their own resources and mortgage loans. As a result of the changes, in 2017 there were already 14.4 million apartments with an average area of 74.0 m^2, which places Poland in the sixth place from the end among 28 EU countries [14]. As the average floor space of a flat in the EU is 96.0 m^2, it should be expected that the demand for land for housing development will still be high. Developers will continue to look for such sites in rural areas. Due to the widespread automotive industry and the availability of the Internet, areas within 50 km from large cities may be attractive for single-family housing. This will result in declining urbanization rates and increasing rural population density [9]. This will have a negative impact on the possibility of using wind energy and agricultural biogas to produce electricity.

Table 2. Changes in population density and urbanization indicators in voivodships in 2009-2019.
Source: Own study based on [10]

Group	Vivodeship	Population density people / km^2		Urbanization rate %		
		Total	Rural areas	2009	2019	2019 -2009
I	Małopolskie	225*	131	49.26	48.20	-1.06
	Śląskie	366*	124	78.10	76.60	- 1.50
	Podkarpackie	119	75	41.06	41.40	0.34
II	Łódzkie	135*	54	64.16	52.37	- 11.79
	Mazowieckie	153*	58	64.62	64.46	- 0.16
	Lubelskie	84	47	46.53	46.45	- 0.08
III	Podlaskie	58	24	60.16	60.64	0.48
	Wielkopolskie	117	57	56.12	54.00	- 2.12
	Kujawsko-pomorskie	115	50	60.73	58.89	- 1.84
	Pomorskie	128*	50	66.21	63.49	- 2.72
	Warmińsko-mazurskie	59	25	59.86	59.19	- 0.67
	Zachodniopomorskie	74	25	68.66	68.43	- 0.23
IV	Lubuskie	72	27	63.61	64.90	1.29
	Dolnośląskie	145*	52	70.27	68.41	1.29
	Opolskie	104	54	52.32	53.24	0.92
	Świętokrzyskie	105	62	45.17	45.39	0.22
Poland		123	53	60.98	60.01	- 0.97

*above the average for Poland

The data in Table 2 shows that in 2009-2019, the urbanization rate in Poland decreased by 0.97%. A decrease in the urbanization rate was recorded in the following voivodships: Małopolskie, Śląskie, Łódzkie, Mazowieckie, Lubelskie, Wielkopolskie, Kujawsko-Pomorskie, Pomorskie, Warmińsko-Mazurskie, Zachodniopomorskie. The largest decreases were recorded in the following voivodeships: Łódzkie (by 11.79%), Pomorskie (by 2.72%), Kujawsko-Pomorskie (by 1.84%) and Śląskie (by 1.5%).

Migration of the urban population to rural areas already causes conflicts with farmers. They are associated with field work and animal husbandry. In order to counteract protests trying to limit agricultural activity in rural areas, there was a demand from the National Council of Agricultural Chambers that new residents, when applying for a construction permit, sign a statement that they know about the specificity of agricultural activity and the related difficulties that do not occur in cities (machinery work at night, animal sounds, smells from breeding) [15].

4. Wind farms and agro-gas plants as proposed RES systems

In Poland, it is possible to increase the generation of electricity from solar, wind and agricultural biogas [16]. Solar energy is converted into electricity by photovoltaic cells. They can be mounted on roofs of buildings of any purpose in cities and villages. Solar farms can also be established in degraded post-industrial areas and wastelands. The use of wind energy and biogas for the generation of electricity is, in principle, only possible in rural areas. They have an appropriate spatial and demographic structure enabling the construction of wind farms. In the case of agricultural biogas plants, they also have the substrates needed for methane fermentation. Currently, the largest amount of electricity from renewable energy sources in Poland is being generated by wind turbines. They are almost exclusively three-blade devices with a horizontal axis of rotation, with towers over 100

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m high and the power of generating sets over 100 kW (0.1 MW) [16]. Power plants are most often connected to the power grid in groups and treated as one installation.
According to data from the Energy Regulatory Office, on October 15, 2020, there were 1,207 wind installations in Poland with a total capacity of 5,917.243 MW (see table 3).

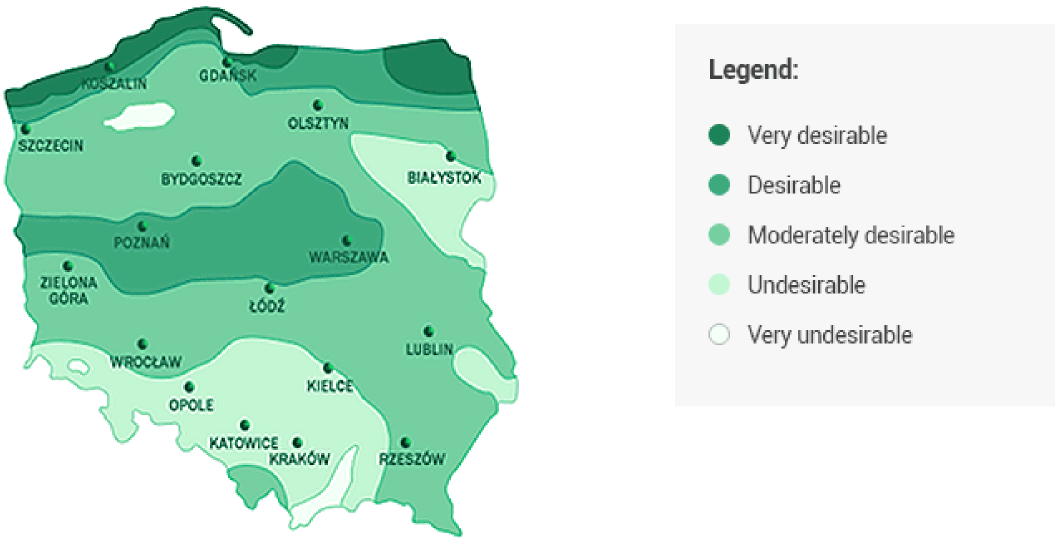

Fig. 1. Wind energy zones in Poland.
Source: [*17]*

Figure 1 shows the division of Poland into energy wind zones. The conditions of the seaside, being several kilometers long, and in the north-east of the Warmińsko-mazurskie Voivodeship are extremely favorable. They are favorable up to several dozen kilometers from the Baltic Sea and near the border with the Russian Federation and in the center of the country. This zone stretches from the western part of the Mazowieckie Voivodeship, through parts of the Kujawsko-pomorskie Voivodeship and Wielkopolskie Voivodeship, to the northern part of the Lubuskie Voivodeship. Extremely unfavorable conditions prevail in the southern part of the Dolnośląskie Voivodeship, in the following voivodships: Opolskie, Śląskie, Małopolskie, Świętokrzyskie and partly Podlaskie and Lubelskie. Appropriate wind conditions are not a sufficient condition for the location of wind installations. Appropriate distances from: buildings, protected areas, forests, lakes, etc. must also be kept. It is also important that there are MPZP adopted and approved by the commune authorities and the local community. [16].
Table 3 presents the number of installations in individual voivodships, their total capacity and the average capacity per installation. The data included therein shows that there are few installations in the 1st group of voivodships and the individual wind farms belonging to them have low capacity. It is associated with unfavorable wind conditions, but also with the high population density of rural areas and the fragmentation of agricultural farms. The influence of the recent factors may be proved by a small number of wind installations and their low capacity. In the Małopolskie Voivodeship, where there are more than 80% of the smallest farms and the population density in rural areas exceeds 76 people/km^2, there are only 11 installations with an average capacity of 0.539 MW. The largest installations are there in the 3rd group of voivodships with better wind conditions, lower population density in rural areas and a higher percentage of large agricultural farms. The best situation is in the Zachodniopomorskie Voivodeship, where there is the highest installed capacity, and the average installation capacity is 55.115 MW. In this voivodship, in 2016, one fourth of farms had more than 20 ha of UAA (including 12% over 50 ha of UAA), the population density in rural areas was below 45 people/km^2.
In Poland wind turbines have limited development opportunities due to the wind conditions and need to be constructed far away from human settlements. The act of 20 May 2016 on investments in wind farms introduced a regulation that they can be located at a distance not less than 10 times the height of the object [19]. In the case of the already existing ones, it reduces the possibility of reconstruction in order to increase their power, as this is most often associated with increasing their height. A significant increase in electricity generation from wind will be possible after the construction of planned wind farms in the offshore coastal zone.

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Table 3. Number of wind installations and their parameters in voivodships. *Source: Compilation based on [18]*

Group	Voivodeship	Number of installations	Total power in MW	Power per installation
I	Małopolskie	11	5.932	0.539
	Śląskie	29	34.195	1.266
	Podkarpackie	25	152.956	5.665
II	Łódzkie	208	580.969	21.517
	Mazowieckie	98	385.301	14.270
	Lubelskie	12	138.900	5.144
III	Podlaskie	29	197.760	7.324
	Wielkopolskie	231	726.210	26.897
	Kujawsko-pomorskie	302	606.035	22.446
	Pomorskie	61	711.615	26.356
	Warmińsko-mazurskie	44	356.985	13.222
	Zachodniopomorskie	98	1488.095	55.115
IV	Lubuskie	15	193.080	6.532
	Dolnośląskie	12	176.36	6.532
	Opolskie	12	140.900	5.219
	Świętokrzyskie	20	21.950	0.813
Poland		1207	5917.243	4.902

The second group of power plants the operation of which is related to agricultural areas are agricultural biogas plants. They use biogas for generation: animal manure, wastes from agricultural production, processing of fruit and vegetables as well as corn and grass silage. The biogas they produce contains 40-85% methane [20]. The potential of Polish agriculture and the agri-food industry allows for the production of about 5 billion m^3/ year of agricultural biogas with the parameters of high-methane natural gas [20]. The biogas produced is most often burned in cogeneration units generating electricity and heat. The former is fully transferred to the power grid. Thermal energy is partly (about 30%) used to heat the substrates in the methane fermentation process and to heat the biogas plant premises. It can also be sold to external recipients if the distance from them allows it. According to the ERO data (included in Table 4 dated October 15, 2020, there were 105 agricultural biogas plants in Poland with a total capacity of 112,158 MW [21].

The number of agricultural biogas plants running is very small in relation to the assumptions adopted in 2010 the Council of Ministers document "Trends in development of agricultural biogas plants in Poland 2010-2020" [the program]. The document states that by 2020 there will be an average of one biogas plant in each municipality. As there are 1,523 rural communes and 652 urban-rural communes in Poland, the program failed [22]. As in the case of wind farms, most agricultural biogas plants operate in voivodships belonging to group III, with the highest percentage of large agricultural farms and low population density in rural areas. In the voivodships, the average installed capacity ranges from 0.975 to 1.351 MW. The smallest (one in each) biogas plants are in the Opolskie (2.00 MW) and Świętokrzyskie (0.800 MW) voivodships. There is also a small number of biogas plants in the following voivodships: Małopolskie (2), Śląskie (2) and Podkarpackie (3), i.e., those with the most fragmented agrarian structure.

The register of biogas producers kept by KOWR shows that on June 2, 2020, on December 29, 2020, 116 cogeneration units with a total capacity of 117.804 MW were installed in Polish AgroGas plants. The most numerous group (45) were aggregates with a capacity of 0.751-1.00 MW (see Table 5.). There were 81.9% of aggregates with a capacity of more than 0.501 MW. High-power agricultural biogas plants require large acreage for the cultivation of plants suitable for biogas production (maize, grain, grass) or very large farms of cattle, pigs and poultry, which increases transport costs and causes the emission of odors that are nuisance for the inhabitants [23].

Table 4. Number of agricultural biogas plants and their parameters in voivodships. *Source: study based on [23]*

Group	Voivodeship	Number of installations	Total power in MW	Power per installation
I	Małopolskie	2	1.148	0.574
	Śląskie	2	1.596	0.798
	Podkarpackie	3	2.498	0.833
II	Łódzkie	4	5.057	1.264
	Mazowieckie	7	7.898	1.128
	Lubelskie	8	10.858	1.357
III	Podlaskie	9	7.675	0.853
	Wielkopolskie	12	12.661	1.055
	Kujawsko-pomorskie	8	10.211	1.276
	Pomorskie	9	12.159	1.351
	Warmińsko-mazurskie	12	11.705	0.975
	Zachodniopomorskie	13	12.690	0.976
IV	Lubuskie	4	2.792	0.698
	Dolnośląskie	10	10.410	1.041
	Opolskie	1	2.000	2.000
	Świętokrzyskie	1	0.800	0.800
Poland		105	112.158	1.068

Table 5. Size structure of cogeneration units. *Source: study based on [23]*

Aggregate power in MW	Number of aggregates
< 0,100	3
0.101-0.250	3
0.251-0.500	15
0.501-0.750	10
0.751-1.000	45
1.001-1.500	16
1.501-2.000	18
2.001-2.500	6
Total	116

However, the low population density is not the only factor that must be considered when choosing the location of agricultural biogas plants. A very important factor is the acceptance of the construction by the inhabitants. Its lack is due to the odors associated with such substrates as slurry and other animal excrements, which are particularly nuisance during transport from farms to biogas plants. An example of the lack of acceptance may be the commune of Tuczno, where the population density is only 20.1 people / km^2. In the village of Rzeczyca, which belongs to this commune, there is a biogas plant with a capacity of 3.985 million m^3 of biogas/year and an installed electrical capacity of 0.999 MW. The idea of building a second biogas plant in the commune led to a referendum in which the commune head was dismissed [24]. Table 5 shows that only 3 biogas plants had a power lower than 0.100 MW and 3 had a power of 0.101-0.250 MW. Meanwhile, many EU countries are building large numbers of smaller biogas plants located next to livestock farms using their own substrates. The animal excrements are directly injected from the manure tanks into the digesters. This prevents the spread of odors outside the farm. And so, in Switzerland, where the population density is over 200 people / km^2, in 2013 there were 100 biogas plants with an average capacity of 0.207 MW. In the Zurich region, the capacity of biogas plants was even lower (8 with an average capacity of 0.115 MW) [25]. On the other hand, in Austria, the average capacity of 243 biogas plants was 0.297 MW.

Impact

Achieving the goal of a climate neutral economy by 2050 is an excessively big challenge for Poland. Currently, it has 70% of energy based on hard coal and lignite. The fossil energy resources must be replaced by renewable energy sources. In Poland, photovoltaic installations, wind farms and big agricultural biogas plants will be the most important producers of clean electricity.

Due to the impact on people and the environment, wind farms and agricultural biogas plants may be in sparsely populated areas. In Poland, they are rural areas with large agricultural farms (over 50 ha of UAA). Moreover, such farms and the related agri-food industry provide the substrates needed to produce biogas. The number of such farms is growing due to the liquidation of smaller farms. At the same time, in rural areas there is an increase in single-family housing construction. It results from the housing deficit inherited from the command and distribution system, lower prices of construction sites than in cities and the no local spatial development plans for most areas of rural communes. In the absence of such, construction and land development conditions which result in dispersed residential buildings are issued. Such constructions block the possibility of locating wind farms and agricultural biogas plants. As a result, this can lead to Poland not being able to achieve the goal of an emission-free economy. Limiting the possibility of such development requires changes in the provisions on spatial planning and protection of agricultural and forest land.

Conclusions

Such renewable energy sources as wind farms and agricultural biogas plants are located in sparsely populated rural areas due to the nuisance and threats to the inhabitants. Large areas belonging to one owner also allow the construction of wind farms (wind farms) with the necessary access roads and a network of connections. There are also few residential buildings in such areas, and it is possible to keep a minimum distance from them, even with windmills over 100 meters high. Large acreages of farms foster monocultures of crops intended for fodder (e.g., maize) but also that can be used for the production of silage for biogas. On such farms, large livestock farms (poultry, cattle, pigs) are built. They breed animals that produce large amounts of waste (slurry, manure, bird droppings) that are harmful to the environment but can be used for the production of biogas. The best solution would be to introduce a requirement to locate biogas plants using manure on the area of such farms. These would be mostly micro and small biogas plants with a capacity of up to 0.1 MW, but there could be a lot of them, as there were only dairy cows herds with more than 150 heads at the end of 2018 459 [26]. The construction of such biogas plants will reduce the amount of greenhouse gas emitted, which is methane extracted from the excrements of animals stored outside.

The housing deficit and high land prices in cities, locating housing (especially single-family houses) in rural areas, may threaten plans to transition to an environmentally safe, emission-free economy. Eventually, it is necessary to accelerate the creation of local spatial development plans, especially in rural communes. When developing these plans, the needs of energy based on renewable energy sources should be considered. In addition, amendments to the Act on the Protection of Agricultural and Forest Land are needed, which now make it too easy to de-agriculture.

Conflict of interest

There are no conflicts to declare.

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METHOD FOR PRODUCING FRUIT PASTE USING INNOVATIVE EQUIPMENT

Valeriy Mykhailov
Kharkiv State University of Food Technology and Trade
Klochkivska str. 333, Kharkiv, Ukraine
https://orcid.org/0000-0003-4335-1751

Andrii Zahorulko*
Kharkiv State University of Food Technology and Trade
Klochkivska str., 333, Kharkiv, Ukraine, zagorulkoan@hduht.edu.ua
http://orcid.org/0000-0001-7768-6571

Aleksey Zagorulko
Kharkiv State University of Food Technology and Trade
Klochkivska str., 333, Kharkiv, Ukraine, zagorulko@hduht.edu.ua
http://orcid.org/0000-0003-1186-3832

Bogdan Liashenko
Kharkiv State University of Food Technology and Trade
Klochkivska str., 333, Kharkiv, Ukraine
http://orcid.org/0000-0001-7228-8814

Svetlana Dudnyk
Higher Educational Institution of Ukoopspilka "Poltava University of Economics and Trade"
Koval str., 3, Poltava, Ukraine
https://orcid.org/0000-0001-8228-7276

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Abstract
A method for the production of multicomponent fruit and vegetable paste has been developed. All components were selected considering the content of physiologically functional ingredients. The method is distinguished using the developed innovative equipment: a multifunctional apparatus for the implementation of preliminary heat treatment of raw materials; rotary film evaporator for concentrating puree. The developed devices are distinguished by increased resource efficiency due to heating with a low-temperature film electric heater with a temperature regime in the range of 45-70 °C.
The study of structural and mechanical parameters and organoleptic evaluation of the prototypes allowed to reveal the rational content of raw materials in the developed paste: apples – 30%; viburnum – 20%; black chokeberry – 20%; pumpkins – 20%, beets – 10%.

Keywords
fruit and vegetable paste, structural and mechanical characteristics, semi-finished product, concentration

Introduction
Now in the world there is a deficit in the consumption of plant raw materials, namely fruits and vegetables, in the diets of the population, since their use is usually seasonal and there is no sufficient range of products containing various plant materials. The consumption of such products prevents diseases and aging of the body, has a physiological effect, beneficially affecting one or more target functions of the body, strengthening the health of the population [1].
The solution to this problem is possible by creating food vegetable semi-finished products that combine the beneficial properties of several types of raw materials [2]. A pleasant smell and appearance, an affordable price are the main criteria both when choosing by the consumer and when manufacturing these products. This is especially true of food semi-finished products based on fruit and vegetable raw materials, requiring a gentle mode of heat treatment. The most important technological processes in the production of pastes from fruit and vegetable raw materials are heating, concentration, sterilization and cooling in the flow of a pasty product.

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Heating to a boil and concentrating puree products, in which heat is distributed mainly by thermal conduction, is a complex technical problem.

To improve the conditions for processing plant raw materials into semi-finished products of a high degree of readiness, it is necessary to carry out technical re-equipment of enterprises with effective and reliable equipment that has high productivity, stream organization of processing of raw materials, which will largely eliminate spoilage and loss of physiologically functional ingredients (PFI) due to the short duration and low-temperature conditions for their processing.

Therefore, the urgent task is to develop new methods to produce multicomponent fruit and vegetable semi-finished products of a high degree of readiness with high organoleptic characteristics, nutritional and biological value, low cost and high profitability. The most important natural resource for expanding the range of food products with high nutritional and biological value is fruit and vegetable raw materials [3], the processing of which makes it possible to obtain many different food semi-finished products and finished products.

Multicomponent fruit and vegetable semi-finished products of a pasty state make it possible to provide the population with high-quality products with a high content of biologically active substances throughout the year and create reserves. These semi-finished products, on the one hand, are a source of physiologically functional ingredients, and on the other hand, they can play the role of structure-forming agents, as well as improve the color of food products [4].

Consideration and systematization of the review of literary sources indicates that most of the produced fruit and vegetable pastes are one- or two-component [5]. These semi-finished products have a significant disadvantage, namely, a small amount and uniformity of organic acids, vitamins, and minerals. In addition, their organoleptic characteristics such as color, aroma and taste are insufficiently expressed and aesthetically pleasing. One of the ways to solve this issue is to expand the assortment of pasty semi-finished products by blending several types of plant raw materials, which will provide the product with all groups of physiologically functional ingredients with significant content to ensure their therapeutic and prophylactic properties [6].

The technology for the production of pastes has been tested in the process of concentrating plant raw materials in the form of mashed potatoes to a dry matter content of 24-45% for 80-400 minutes in evaporators [7]. It is during the concentration stage that the greatest and significant losses of useful substances of plant raw materials take place. Existing equipment is mostly characterized by high energy and metal consumption due to the use of heat carriers, pipelines and heat generating devices, which reduces their resource efficiency. Such heat supply has the difficulty of stabilizing heat flows, leading to product overheating. There are also difficulties in ensuring uniform distribution of the raw material layer over the entire surface of the device, reducing the product quality. So, now the development of new production methods with the use of efficient equipment and its implementation at food industry enterprises is relevant, will ensure the production of high-quality and enriched pasty semi-finished products through the use of gentle processing modes of raw materials [8].

In the production of fruit and vegetable pastes, it is important to take into account their structural and mechanical parameters in order to carry out calculations of technological equipment, pumps and pipelines, as well as to establish the strength of the resulting structure in multicomponent semi-finished products.

The analysis of the above materials allows to direct research towards improving the production processes of health-improving food products by reducing the concentration temperature within 45-70 °C [8], this will improve the quality indicators of the obtained semi-finished products and confectionery products based on them.

Thus, the development of new recipes for multicomponent pastes and methods of their production using innovative low-temperature equipment is promising in the creation of preventive semi-finished products and products based on them, which will provide an expansion of the existing range [9].

Methods

For research, let's use raw fruits and vegetables (Fig. 1), which grows within the Kharkiv region: apple (Antonovka variety), viburnum (Nanum variety), black chokeberry (Chornooka variety), pumpkin (Muscat Pearl variety), beets

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(Bona variety) [10]. The proposed recipe ratio of the compositions of blended fruit and vegetable pastes are given in (Table 1).
Blending of the recipe composition of fruit and vegetable paste was performed taking into account the content of biologically active substances, organoleptic properties and effect of structural and mechanical parameters of each component of raw materials on the consistency of the resulting product. Apples were used as structuring agents with high pectin content; pumpkins and beets served as dietary fiber, in addition, beet has a healing effect on the human body due to unique biochemical composition. Using non-traditional plant raw materials, in particular, guilder rose and black chokeberry, will enrich the pasty semi-finished product with biologically active substances under observing the total acidity at 3.3-3.7 pH, which will reduce the pasteurization temperature and extend the shelf life of the semi-finished product.


a b c

d e

Fig. 1. Appearance of prototypes: a – apple; b – viburnum; c – black chokeberry; d – pumpkin; e – beets

Table 1. The ratio of raw materials in blended prototypes

Raw material	Prototypes		
	1	2	3
Apple	40	30	20
Viburnum	15	20	25
Black chokeberry	15	20	25
Pumpkin	25	20	15
Beet	5	10	15

The introduction of various types of raw materials in the paste makes it possible to obtain original formulations with predictable organoleptic and structural-mechanical indicators, as well as an increased content of physiologically functional ingredients (PFI). To establish the rational content of each component of raw materials, prototypes were made with a total weight of 100 g, in three-fold repeated experiments. Changes in the structural and mechanical parameters with an increase in the shear rate in blended samples were compared with a control sample – apple cider paste. Determination of the structural and mechanical characteristics of prototypes of fruit and vegetable pastes was carried out in a rotational viscometer "Reotest-2". The blanching, boiling, blending and mixing processes were carried out in the developed model sample of a multifunctional device, and concentration in an improved rotary film device. The devices differ from analogs by reduced processing time and gentle temperature conditions with snap action control.

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Results and discussion

The study of the process of creating a recipe for a multicomponent paste using the developed method was carried out on the basis of the Research Center "New biotechnologies and equipment for the production of food products with high health properties" of the Kharkiv State University of Food Technology and Trade (Ukraine).

The composition of the recipe for the developed pasta was created from fruit and vegetable raw materials. The composition was based on apple puree (Antonovka variety), which was mixed with viburnum puree (Nanum variety), black chokeberry (Chornooka variety), pumpkin (Muscat Pearl variety), beet (Bona variety), which have a rich content of functionally physiological ingredients and have therapeutic and prophylactic properties. An apple with a high content of pectin substances, which provides interaction in a multicomponent formulation with other components.

Viburnum berries contain a huge amount of nutrients. Among them are vitamins and minerals, without which the healthy functioning of the body will be simply impossible. Its fruits contain such useful substances: tannins, organic acids, essential oils, vitamin A, ascorbic acid, vitamin P, vitamin E, potassium and magnesium. It is used for the following diseases: diabetes mellitus, cardiovascular diseases, tonsillitis, bronchial asthma, pneumonia, malfunctions of the nervous system, diseases of the digestive system, infectious diseases of the respiratory tract.

Black chokeberry is rich in vitamins C and PP, carotene, tannins and organic acids. It is often used for hypertension and prevention of atherosclerosis, cardiovascular diseases. It is known that pumpkin is a source of vitamins such as C, B_1, B_2, E, PP, carotenoids, antioxidants – powerful beta-carotene, which is converted into vitamin A in the body and reduces the risk of developing cancer, protects against asthma, supports the heart, inhibits the aging process of the whole organism. Dietary fibers of pumpkin improve the functioning of the gastrointestinal tract, promote bile secretion, and normalize water-salt metabolism.

The chemical composition of beets is represented by pectin, essential amino acids (lysine, valine, arginine, histidine, etc.), vitamins (B_1, B_2, B_5, C, B_3), carotenoids, folic acid, organic acids (oxalic, malic), mineral substances (iron, manganese, potassium, calcium, cobalt). It is known that it is beet pectin that is the best entorosorbent, which removes heavy metal salts and toxic substances from the body. The complex of B vitamins contributes to a positive effect on hematopoiesis, and also normalizes the metabolic process.

To substantiate the ratio of puree components of fruit and vegetable raw materials, experiments were carried out with their blending. The content of each individual type of raw material was carried out taking into account the PFI, organoleptic properties and structural and mechanical indicators. The use of non-traditional plant raw materials, namely viburnum and black chokeberry, allows not only to enrich PFI pastes, but also to provide total acidity at the level of 3.2-3.7 pH.

To create a pasty semi-finished product, a method for its production has been developed. The method is distinguished by the use of the developed innovative equipment: a multifunctional apparatus for the implementation of preliminary heat treatment of raw materials; rotary film evaporator for concentrating puree. The developed devices are distinguished by increased resource efficiency due to heating by a flexible film resistive electric heater of the radiant type with a temperature regime of 45-70 °C. Solutions, blanching, cooking and stirring.

In the developed method, the fruits of viburnum and black chokeberry are separately washed, inspected and blanched with water at a temperature of 90 °C for 2-3 minutes. Then the viburnum and black chokeberry are wiped. The resulting waste peel and bones with the remnants of the pulp are boiled for 5-10 minutes with a ratio of the mass of bones with pulp and peel to the mass of water 1:0.5-1:0.7. The mass thus boiled is rubbed.

For the preparation of apple, beet and pumpkin puree, the existing technology is used for the production of fruit and vegetable purees. The next step is to combine a mass of viburnum and black chokeberry puree, a mashed mass of decoction from their peel and seeds, apple, pumpkin and beet puree and mix until smooth. Blended fruit puree is heated to a temperature of 48-52 °C and sent for concentration to a rotary film evaporator. Concentration occurs at a temperature of 53-58 °C to a dry matter content of 44-45%, within 2.2-2.5 minutes. The resulting pasty semi-finished product is pasteurized and packaged at a temperature of 65-68 °C, sealed and labeled.

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To establish the mechanisms of structure formation and destruction of prototypes, the change in the structural and mechanical characteristics of puree raw materials components and the resulting pastes was investigated. Apple puree and paste were used for control.
Fig. 2 shows the shifting characteristics of the obtained samples of puree from the prescription components of raw materials: apple, viburnum, black chokeberry, pumpkin and beets (Table 1).

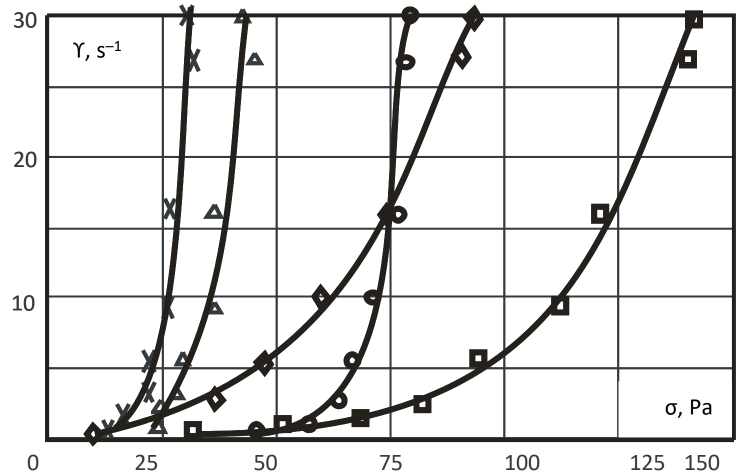

Fig. 2. Shear characteristics of raw material samples in the composition: ○ – apple; Δ – viburnum: x – black chokeberry; ✧ – pumpkin; – beets□

The curves show that the maximum shear stress for puree of all types of raw materials is greater than zero and is 45 Pa for apples, 24 Pa for viburnum, 14 Pa for black chokeberry, 12 Pa for pumpkin, and 32 Pa for beets. All components of the raw material have the ultimate shear stress and their structure is not destroyed immediately after the stress increases, that is, they are characterized as imperfectly plastic solid bodies. This behavior of the ultimate shear stress for puree from fruit and vegetable raw materials is explained by the significant content of dietary fiber. The structural and mechanical characteristics of the developed samples of multicomponent pastes are shown in Fig. 3.

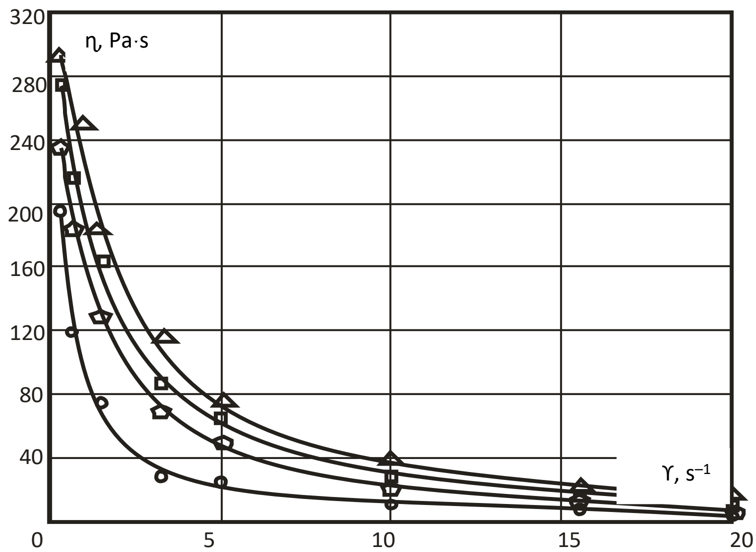

Fig. 3. Rheological curves of multicomponent fruit and vegetable pastes 45% CP: ○ – control (apple paste) Δ – sample 1; □ – sample 2; ⬠ – sample 3

The value of the effective viscosity at the moment of shear application for the prototypes is equal to η_{ef} (Pa·s): 1 – 298; 2 – 274; 3 – 237 and control – 198, respectively. Regarding the obtained indicators, it is possible to see that the introduction of other components into apple raw materials according to the recipe from 60 to 80% leads to an increase in effective viscosity by 1.2-1.5 times, which indicates the strengthening of the structure of the obtained research threads.

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To determine the quality indicators of the created pasty semi-finished products for their compliance with the established requirements, their organoleptic evaluation was carried out. The results of the organoleptic evaluation of the prototypes are shown in Table 2.

Table 2. Organoleptic evaluation of the developed fruit and vegetable pastes

Indicator	Sample characteristics		
	1	2	3
Appearance	Homogeneous wiped pasty mass		
Taste and smell	Pronounced taste and smell of apples and pumpkin, beets are almost not felt	Pleasant harmonious taste and smell of apples, viburnum and pumpkin	The smell and taste of beets are too audible; pronounced fruits of viburnum and black chokeberry
Color	reddish purple	red violet	Dark purple
Consistency	*Homogeneous pasty, formed, does not spread on a flat surface*		

As a result of the analysis of the data of the structural, mechanical and organoleptic evaluation of the prototypes, it was found that multicomponent fruit and vegetable paste with a content of 30% apples, viburnum – 20%, black chokeberry – 20%, pumpkin – 20%, beets – 10% has an advantage (sample 2). The introduction of vegetables in large quantities – provides the paste with an unpleasant specific taste and smell; in a small amount of viburnum and black chokeberry – to a decrease in the nutritional value of the semi-finished product.

Impact

The developed method of production of fruit paste with the use of innovative equipment offers the end profile consumer a multifunctional high-quality a product of organic origin with minimal loss of nutritional value. The introduction of the developed technology with the use of innovative heat and mass transfer equipment in production will help to expand the range of vegetable semi-finished products for further production on their basis of functional and health foods. The introduction of immunomodulatory products into the diet will increase resistance to infectious (including COVID-19) and chronic (cardiovascular, cancer, etc.) diseases.

The expected socio-ecological effect from the implementation of the proposed scientific and technological development will have a positive impact on the social sphere of human society and the environment. The application and use of new organic semi-finished products obtained by the developed technology with innovative equipment in general will form competitiveness and environmental impact in terms of rational processing of organic raw materials. Thus, the method of production of fruit and vegetable paste and appropriate technological equipment has been developed based on the application of innovative aspects of intensification of heat and mass transfer in the processing of fruit and vegetable raw materials on the basis of greater, compared to existing technologies, preservation of nutritional value, improving the efficiency of raw material processing while reducing material and energy costs.

The developed technology and improved equipment offer the end target consumer a multifunctional high-quality product of plant origin with minimal loss of nutritional value, as well as advanced equipment for its processing. The introduction of the developed technology and innovative equipment in the food industry will have a positive impact on the social sphere and the environment, expressed in the wide use of organic food products processed using resource-efficient technologies, which will be more competitive and environmentally friendly.

It should also be noted that the developed equipment, which will be used to carry out the main processes of processing organic fruit and vegetable raw materials, assumes the availability of appropriately qualified personnel, which will ensure the creation of new jobs, the number of which depends on the scale of implementation.

Conclusions

A method for the production of multicomponent fruit and vegetable paste has been developed. The basis for the paste recipe includes apples, viburnum, pumpkin, beets, and black chokeberry. All components were selected taking into account the content of PFIs in them and their therapeutic and prophylactic properties. The method is distinguished by the use of the developed innovative equipment: a multifunctional apparatus for the implementation of preliminary heat treatment of raw materials; rotary film evaporator for concentrating puree. The developed devices are distinguished by increased resource efficiency due to heating with a low-temperature film electric heater with a temperature regime in the range of 45-70 °C. Concentration occurs at a temperature of 53-58 °C to a dry matter content of 44-45%, for 2.2-2.5 minutes.

The structural and mechanical parameters of raw material puree samples and fruit and vegetable paste combinations have been investigated. It has been determined that the introduction of 60 to 80% of other components in apple puree according to the recipe leads to an increase in effective viscosity by 1.2-1.5 times, which indicates the strengthening of the structure of the resulting research threads. The obtained data of structural and mechanical indicators and organoleptic evaluation of pastes made it possible to recommend a rational content of raw material components: apples – 30%; viburnum – 20%; black chokeberry – 20%; pumpkins – 20%, beets – 10%.

Further research is planned to be directed to approbation of the developed semi-finished product in confectionery products in order to expand their range and increase nutritional value.

Conflict of interest
There are no conflicts to declare.

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PREPARATION OF GRAPE POMACE POWDERS AND ANALYSIS OF THEIR NUTRITIVE COMPOSITIONS

Wenjuan Lou [1,2]
[1]Department of Food Science Henan Institute of Science and Technology
Hualan St. ,453003, Xinxiang, China
[2]Department of Milk and Meat Technology Sumy National Agrarian University
Herasima Kondratieva St. 160, 40021, Sumy, Ukraine
https://orcid.org/0000-0001-8645-4641

Bo Li
Department of Food Science, Henan Institute of Science and Technology
Hualan St. ,453003, Xinxiang, China
https://orcid.org/0000-0003-4543-0090

Nataliya Grevtseva*
Department of Bakery, Confectionary, Pasta and Food Concentrates Technology
Kharkov State University of Food Technology and Trade
Klochkivska st., 333, 61051, Kharkiv, Ukraine, grevtseva66@gmail.com
https://orcid.org/0000-0001-9873-0703

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Abstract
Grape pomace (GP) is produced in large amounts worldwide, leading to waste of resources and environmental pollution. Using grapes grown in eastern China, the main nutrients and polyphenols in grape seeds (GS), skin (GSK), and GP powders were determined by conventional chemical composition analysis and HPLC-MS/MS. The antioxidative activity of a GP polyphenol extract was identified using DPPH and hydroxyl radical scavenging assays and reducing power assay. GSK and GP contained less total dietary fiber than GS. The total polyphenolic content of GS was significantly higher than that of GSK and GP. The hydrogen- and electron-donating activities of the GP polyphenol extract were superior to those of vitamin C.

Keywords
nutritional content, polyphenolic content, grape seeds, grape skin, grape pomace, antioxidative activity

Introduction

Grapes are popular cultivated fruits in the world, with approximately 80% being processed for wine production each year [1]. One byproduct of the winemaking industry is grape pomace (GP), which is made up mainly of grape skin (GSK) and grape seeds (GSs) and accounts for approximately 20%–30% of the total weight of fresh grapes [2]. In 2016, 26.7 billion liters of wine were produced worldwide, generating approximately 6.5 million to 11.5 million tons of grape residues [3]. However, only a small amount of GP is recycled as fertilizer and feed, and the rest is thrown away as garbage, causing a great waste of resources and environmental pollution [4,5]. Grape dregs are in fact rich in nutrients, such as polyphenols, tartaric acid, malic acid, proteins, vitamins, GS oil, and dietary fiber [6]. The polyphenols are the most valuable components of GP, and there has been great interest in their extraction owing to their health benefits [7]. A previous study showed that compared with butylated hydroxytoluene, a polyphenol extract had much higher antioxidative activity, with 50% inhibiting concentration (IC_{50}) values of 20.5, 52.5, 566.4, and 16.8 mg/L for the 2,2-dipheny-1-picrylhydrazyl (DPPH), superoxide anion, hydroxyl, and 2,2’-azino-*bis*(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt free radicals, respectively [8]. Wang et al. [9] evaluated the *in vitro* antitumor activity of resveratrol from GP, demonstrating its inhibitory effect against HeLa, A549, and PC-3 cells, with IC_{50} values of 128.29, 108.35, and 25.31 μmol/L, respectively. In another study, GS extracts inhibited the proliferation of MDA-MB468 human breast cancer cells by 90%–100%. In GP, polyphenols such as phenolic acids, tannins, flavones, and coumarin provide the anticancer effect and have other potential bioactivities [10,11] . Nie et al. [12] extracted polyphenols from GP and found that they had inhibitory effects on the food-borne pathogenic bacteria *Staphylococcus aureus*, *Shigella*, *Listeria monocytogenes*, *Salmonella*, and *Escherichia coli,* with the effect on *S. aureus* and *Salmonella* being the greatest.

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In recent years, consumers have been paying increasing attention to the nutritional value and health effects of foods. GP has gained interest as a raw material to produce flour products owing to its high nutrient content and bioactivities, and products produced with grape powders would have a richer nutritive value and comprehensive physiological functions. The grape variety, maturity, and growth conditions (e.g., soil, climate, rainfall, and planting techniques) are important factors affecting the composition and content of grape dregs [13]. In view of this, this study was carried out to systematically evaluate the nutritive composition of GP powders using the standard curve method and chromatography. Additionally, the antioxidative activity of a GP polyphenol extract was investigated. The results from this study should provide a reference for the further development and comprehensive utilization of GP.

Methods

Materials and chemicals

Fresh grapes (Cabernet Sauvignon, 2019 crop) were obtained from Huailai city (Hebei, China). DPPH and Folin–Denis reagent (made up of 20 g of sodium tungstate, 4 g of phosphomolybdic acid, 10 mL of phosphoric acid (all purchased from Nanjing Chemical Reagent Co., Ltd., Jiangsu, China), and 150 mL of water, condensed and refluxed for 2 h, cooled, and diluted to 200 mL), potassium ferricyanide ($K_3Fe(CN)_6$), trichloroacetic acid, ferric chloride ($FeCl_3$), hydrogen peroxide (H_2O_2), petroleum ether, acetone, aluminum nitrate, ferrous sulfate ($FeSO_4$), high-temperature-resistant alpha-amylase solution (30 U/mg), and glycosylase solution (100 U/mg) were purchased from Shanghai Ruji Bio-Technology Co., Ltd. (Shanghai, China). Alkaline protease solution (100 U/mg) was purchased from Shanghai Lanji Bio-technology Co., Ltd. (Shanghai, China). Tris-(hydroxymethyl) aminomethane (Tris), gallic acid, and rutin were purchased from Sigma-Aldrich Chemical Co. (St Louis, MO, USA). Folin–Ciocalteu (FC) phenol reagent and tannic acid were purchased from Aladdin (Shanghai, China). All other chemicals used were of analytical grade.

Preparation of the various grape powders

The Cabernet Sauvignon grapes were first fermented with 1 wt% distillery yeast at 25 °C for 7 days. Then, using a laboratory-scale extruder (Shanghai Yulushiye Instrument Co., Ltd., Shanghai, China), the GP was collected and washed four to five times with water. By contrast, the GSK and GS were gathered manually. The GP, GSK, and GS samples were then placed outdoors for dehydration to a water content of approximately 65 wt%, following which they were transferred to an air-dry oven at 50 °C for 80 h. The dried GP, GSK, and GS samples were then individually crushed using a laboratory-scale pulverizer (Shanghai Zhikai Powder Machinery Manufacturing Co., Ltd., Shanghai, China) and passed through an 80 mesh screen to gather powders with a particle diameter of >40.52 µm (Fig. 1).

Fig. 1. (a) Grape seeds powder; (b) grape skin powder; (c) grape pomace powder; (a') defatted wine grape seeds powder; (b') defatted wine grape skin powder; (c') defatted grape pomace powder. *Source: Author's.*

Chemical compositions of the various grape powders

The moisture, ash, protein, and lipid contents of the GP, GS, and GSK powders were assayed using the AACCI-approved methods 44–15, 08–01, 46–11, and 30–10, respectively [14]. The total sugar content was determined using a direct titration method [15]. The total dietary fiber (TDF), insoluble dietary fiber, and soluble dietary fiber contents were measured using the enzymatic-gravimetric method [16]. The minerals and trace elements in the powders were assayed using inductively coupled plasma atomic emission spectrometry (Optima 2100DV, PE Co., USA), with the following conditions: power, 1300 W; injection rate, 1.5 mL/min; nebulizer flow rate, 0.8 L/min; auxiliary gas flow rate, 0.2 L/min; and combustion gas flow rate, 15 L/min.

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Polyphenolic compositions of the various grape powders

The tannin content of the three groups of grape powders was determined by sodium tungstate–phosphomolybdic acid-based colorimetric analysis at a wavelength of 765 nm, whereas the total polyphenolic and proanthocyanidin contents were measured using the FC phenol reagent and molysite catalysis-based colorimetry, respectively [17,18]. The total flavonoid content was determined using the aluminum nitrate–sodium nitrite method [19]. The polyphenolic compositions of the various samples were analyzed by high-performance liquid chromatography–tandem mass spectrometry (HPLC-MS/MS) [20]. To obtain the polyphenol extracts, the GS, GSK, and GP samples were individually extracted in methanol in a 25 °C shaking water bath (SHA-C, Shanghai, China) for 24 h in a dark environment. Then, after centrifugation of the extract at 6000 rpm for 15 min, the supernatant was concentrated *in vacuo* at 30 °C and made up to 25 mL with Crypt-grade methanol. The chromatographic conditions were as follows: mobile phase A, 0.1% acetic acid in water (volume fraction); mobile phase B, acetonitrile; flow rate, 0.4 mL/min; column temperature, 30 °C; and injection volume, 5 µL. The gradient elution conditions were as follows: 0–15 min, 10% B; 15–20 min, 10%–35% B; 20–23 min, 35%–90% B; 23–24 min, 90% B; and 24–30 min, 90%–10% B. The MS conditions were as follows: electrospray ion source; ion source temperature, 325 °C; dry gas flow rate, 10 mL/min; sheath gas flow rate, 11 L/min; sheath gas temperature, 350 °C; and capillary voltage, 3000 V. The multi-reaction detection method was used.

Main mineral elements assay

Microwave digestion: Various amounts of the GSK (0.5015, 0.5019, 0.5023, 0.5029, and 0.5031 g), GS (0.5009, 0.5015, 0.5017, 0.5021, and 0.5028, g), and GP powders (0.5011, 0.5018, 0.5019, 0.5024, and 0.5029 g) were individually weighed and added to a digestion tank together with 4 mL of concentrated nitric acid. The mixtures were shaken under the following microwave digestion program: initial heating to 100 °C for 10 min, a hold for 1 min, heating to 180 °C for 8 min, and maintaining at this temperature for 25 min. After digestion, the sample solution was washed a few times with ultrapure water in a 25 mL plugged colorimetric tube and then diluted to the mark. A reagent blank was also tested.

Preparation of a polyphenol extract from grape pomace for antioxidative activity assay

To extract the polyphenols, 10 g of GP powder was first degreased with petroleum ether for 12 h. Then, the sample was mixed with 70% ethanol in a 1:5 ratio (sample:ethanol, w/v) and ultrasonic-assisted extraction was carried out six times (40 min each time) using an ultrasonic power of 250 W and extraction temperature of 30 °C. All extracts were then collected and filtered, all extracts were then collected and filtered, and an equal volume of each filtrate (50 mL) was vacuum concentrated.

DPPH radical scavenging assay

The DPPH radical scavenging activity of the GP polyphenol extract was determined using a previously published method [21]. In brief, 2 mL of different concentrations of the sample in ethanol was respectively mixed with 2 mL of 2 mmol/L DPPH in ethanol and incubated at ambient temperature for 30 min. The absorbance of the DPPH-reacted sample (A_i) was then measured at 517 nm using a UNICO spectrometer (Shanghai, China). That of the control (A_c) containing ethanol instead of the sample was also measured under the same experimental conditions. The absorbance of the original unreacted sample in ethanol was recorded as A_j. Finally, the DPPH radical scavenging activity of the sample was calculated using the following formula: DPPH radical scavenging activity (%) = $[1 – (A_i – A_j)/A_c] \times 100\%$. Vitamin C at the same concentrations as the sample was also tested for comparison of the antioxidative activities.

Hydroxyl radical scavenging assay

The hydroxyl radical scavenging activity of the GP polyphenol extract was measured using a previously reported method [22]. In brief, 2 mL of sample solutions at different concentrations was mixed with 1 mL of 9 mmol/L $FeSO_4$ and 1 mL of 9 mmol/L salicylic acid–ethanol, and the reaction was then initiated by the addition of 1 mL of 8.8 mol/L H_2O_2 solution. Following 30 min of incubation in a 37 °C water bath, the absorbance of the sample (A_x) was measured at 510 nm using the UNICO spectrometer. Controls of 2 mL of deionized water in place of the $FeSO_4$ and salicylic acid–ethanol solution (A_{x0}) and of 2 mL of deionized water in place of the sample solution (A_0) were also measured under the same experimental conditions. A system without H_2O_2 added was used as the reference solution when measuring A_0, whereas deionized water was used as the reference for determining A_x and A_{x0}. The hydroxyl radical scavenging activity of the sample was calculated as follows: hydroxyl radical scavenging activity (%) = $[A_0 – (A_X – A_{X0})/A_0] \times 100\%$. Vitamin C at the same concentrations as the sample was also tested for comparison of the antioxidative activities.

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Reducing power assay
The reducing power of the GP polyphenol extract was determined according to a previously published method [23]. In brief, 2.5 mL of samples at different concentrations was mixed with 2.5 mL of PBS (pH 6.6) and 2.5 mL of a 10 mg/mL $K_3Fe(CN)_6$ solution and the mixture was incubated for 20 min in a 50 °C water bath. Then, after the solution had cooled, 2.5 mL of 100 mg/mL trichloroacetic acid was added and the mixture was centrifuged at 3000 rpm for 10 min. Thereafter, 2.5 mL of water and 0.5 mL of 0.1% $FeCl_3$ were added to the supernatant and the absorbance at 700 nm was measured using the UNICO spectrometer. Vitamin C at the same concentrations as the sample was also tested for comparison of the antioxidative activities.

Statistical analysis
All experiments were conducted in triplicate, and the results are expressed as the mean ± standard deviation. Dunnett's T3 test was applied for multiple comparisons and differences were statistically significant at $p < 0.05$. SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical evaluations, and OriginPro 8.6.0 was used for the construction of the graphs.

Results and discussion

Chemical compositions of the various grape powders
Table 1 shows the moisture, ash, protein, and crude fat contents of the various grape powders. The main component of the three types of powder was dietary fiber, the amounts of which ranged from 59% to 68%, with GS power having a significantly richer content than GSK powder ($p < 0.01$). The main components of dietary fiber are non-starch polysaccharides and plant cell walls, which have bioactivities of maintaining normal intestinal function and lowering blood pressure. Notably, dietary fiber contains neutral polysaccharides, uronic acids, Klason lignin, and resistant proteins. Most of the TDF in GP powder was insoluble, whereas soluble dietary fiber (mainly neutral polysaccharides and uronic acids) accounted for only 13% of the TDF. Neutral polysaccharides and Klason lignin accounted for 80% of the TDF, and resistant proteins accounted for only 5.4%.

Table 1. Chemical compositions of various grape powders

Component	GS powder (% DW)	GSK powder (% DW)	GP powder (% DW)	Significance
Crude protein	8.75 ± 0.03^{C}	16.31 ± 0.02^{A}	13.62 ± 0.01^{B}	**
Crude fat	20.92 ± 0.06^{A}	10.66 ± 0.10^{C}	17.46 ± 0.04^{B}	**
Ash	2.98 ± 0.11^{C}	3.95 ± 0.05^{B}	6.02 ± 0.14^{A}	**
Moisture	3.69 ± 0.21^{C}	4.51 ± 0.18^{B}	5.86 ± 0.25^{A}	**
TDF	68.53 ± 0.29^{A}	59.38 ± 0.33^{C}	65.20 ± 0.28^{B}	**
Total carbohydrate	57.04 ± 0.48^{A}	50.25 ± 0.55^{Bc}	51.66 ± 0.71^{Bb}	*

All data are expressed as the mean ± standard deviation (n = 3). * and ** indicate significance at $p < 0.05$ and $p < 0.01$, respectively. Different Latin letters within the same column indicate significant differences among the grape powder samples (lowercase and uppercase letters represent $p < 0.05$ and $p < 0.01$, respectively). GS, grape skin; GSK, grape skin; GP, grape pomace; DW, dry weight; TDF, total dietary fiber.

The results also indicated that the dried powders still contained a certain amount of moisture. The water content has a direct relationship with the water-absorbing capacity of GP powder and wheat flour after mixing, which in turn affects the formation and stability of the gluten protein network structure in the dough. The highest ash content was GP powder, followed by GSK powder, and the lowest ash content was contained in GS powder, which is consistent with previous results [24]. Ash contains different minerals and trace elements, and as a cofactor for various enzymes, it also participates in the physiological processes that form bones, hemoglobin, and cytochromes, and maintains osmotic pressure and acid–base balance in the body. Proteins, which are major food constituents, are an essential nutrient for the human body where they have many physiological functions. The crude protein amounts in the GS, GSK, and GP powders were 8.75%, 16.31%, and 13.62%, respectively, which was also consistent with the results of previous studies [25]. In general, the crude protein content of GP, GS, and GSK was higher than that of ordinary cereal seeds (e.g., that of corn seeds powder is 8.60%). GS powder had the highest crude fat amount (20.92%). This was consistent with reports that the energy of GS is 22.64 MJ/kg because of its high fat content [26]. By contrast, GSK powder had higher protein and lower fat contents than GS powder. The amounts of the main mineral elements in the various powders are shown in Table 2. GP powder was rich in K, Na, Ca, and Mg, which are the major physiologically beneficial elements, and contained Fe, Cu, Zn, Mn, and Cr,

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which are the trace elements that are necessary for the human body. Aside from their health and nutritional value, K, Ca, Mg, Fe, and Mn play important roles in human growth and development, hematopoietic function, and immune function. The anticancer element Se was also detected in the GS powder. By contrast, the amount of harmful Pb was low in all three powders, and that of Cd was not detected at all. The Pb content in all the samples did not exceed the Chinese National standards for "Green food – dried fruits" (NY/T 1041-2010) and "Green food – temperate fruits" (NY/T 844-2010), which stipulate a Pb amount of ≤1 mg/kg and a Cd amount of ≤0.05 mg/kg.

Table 2. Amounts of minerals and trace elements in various grape powders

Elements	GS powder (mg/g)	GSK powder (mg/g)	GP powder (mg/g)	Significance
K	7.361 ± 0.21^{C}	22.746 ± 0.33^{A}	18.678 ± 0.11^{B}	**
Na	0.273 ± 0.01^{Bc}	0.364 ± 0.00^{Aa}	0.318 ± 0.02^{Bb}	*
Ca	5.575 ± 0.24^{A}	2.277 ± 0.03^{C}	3.785 ± 0.32^{B}	**
Mg	1.286 ± 0.41^{ABa}	0.778 ± 0.00^{Bb}	1.129 ± 0.02^{Aa}	
Fe	0.025 ± 0.01^{C}	0.079 ± 0.00^{A}	0.061 ± 0.00^{B}	**
Zn	n.d.	n.d.	0.001 ± 0.00	
Cu	0.019 ± 0.00^{C}	0.092 ± 0.00^{A}	0.078 ± 0.00^{B}	**
Mn	0.002 ± 0.00	n.d.	n.d.	
Cr	0.002 ± 0.00^{C}	0.004 ± 0.00^{A}	0.003 ± 0.00^{B}	
Se	0.002 ± 0.00	n.d.	n.d.	
Pb	0.001 ± 0.00	n.d.	n.d.	
Cd	n.d.	n.d.	n.d.	

All data are expressed as the mean ± standard deviation (n = 3). Significance: * and ** indicate significance at $p < 0.05$ and $p < 0.01$, respectively. Different Latin letters within the same column indicate significant differences among the powder samples (lowercase and uppercase letters represent $p < 0.05$ and $p < 0.01$, respectively). GS, grape skin; GSK, grape skin; GP, grape pomace; n.d., not detected.

The contents of minerals and trace elements were quite different among the three powder samples. The amounts of the major elements K and Na and trace elements Fe, Cu, and Cr were significantly higher in GSK powder than in GS powder ($p < 0.01$), especially K and Na, which were as high as 22.75 and 0.365 mg/g, respectively. GS powder was rich in Ca and Mg, the amounts of which (5.576 and 1.287 mg/g, respectively) were significantly higher than those of GSK powder ($p < 0.01$). Additionally, the amounts of Se, Mn, and Zn in GS powder reached 2, 2, and 1 mg/kg, respectively. These results are quite different from the Se content of grapes reported in the literature [27–29], which may be related to the grape species studied and their different origins. Depending on the contents of minerals and trace elements in GSKs and GSs, different processing methods can be considered. Because GS is rich in trace elements, such as Fe, Cu, and Cr, it can be considered to produce health-related products, but attention should be paid to whether it is contaminated.

Polyphenolic compositions of the various grape powders

The HPLC-MS/MS chromatograms of grape polyphenols in the various samples are shown in Fig. 2, and the results of the quantitative analysis are presented in Table 3. In this study, GSK powder and GS powder were selected as representatives to analyze. GSK and GS contained a large amount of polyphenols (Table 3). GSK contained the highest amounts of flavonol (quercetin, morin, myricetin, etc.) and benzoic acid polyphenols (vanillic acid, syringic acid, gallic acid, etc.), whereas it had only small amounts of flavan-3-ol (catechin, epicatechin, epicatechin gallate, epigallocatechin gallate) and cinnamic acid polyphenols (i.e., only 0.5 mg/kg coumaric acid). In the GS sample, approximately 80% of the non-anthocyanin polyphenols were flavan-3-ol polyphenols, among which those extracted by methanol reached 707.48 mg/kg and were significantly greater in amount than the benzoic acid and flavonol polyphenols. The GS powder also contained low concentrations of cinnamic acid. These data are consistent with the results of other studies [20,30,31]. It should be noted that in the GS sample, the quercetin content was much lower and the isoquercitrin amount was much higher than that presented in previous reports[20,32]. This was likely because the polyphenolic composition in GP depends on many factors, such as the grape variety, growth climate, geographic environment, fermentation time, and maturity [33,34] Among the various polyphenols in GSK, the flavonols and benzoic acids were in the highest amounts, followed by theflavan-3-ol, cinnamic acid, and stilbene compounds. By contrast, the GS sample had the highest amount of non-anthocyanin polyphenols, especially flavan-3-ol polyphenols. In the GS sample, the contents of benzoic acid and flavonol polyphenols were lower than that of flavan-3-ol polyphenols and similar to those of the GSK sample. The GS sample contained only trace amounts of cinnamic acid and stilbene polyphenols. In the GP

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sample, the flavonol with the highest content was myricetin, followed by morin, quercetin, isorhamnetin, and kaempferol, and its content of flavonols was higher than that of the GS sample. In the GSK and GS samples, catechins and epicatechins were predominant, accounting for 96%–100% of the total flavan-3-ol polyphenols. Moreover, the contents of catechins and epicatechins in the GS sample were significantly higher than those in the GSK sample ($p < 0.05$), which is consistent with other studies [20].

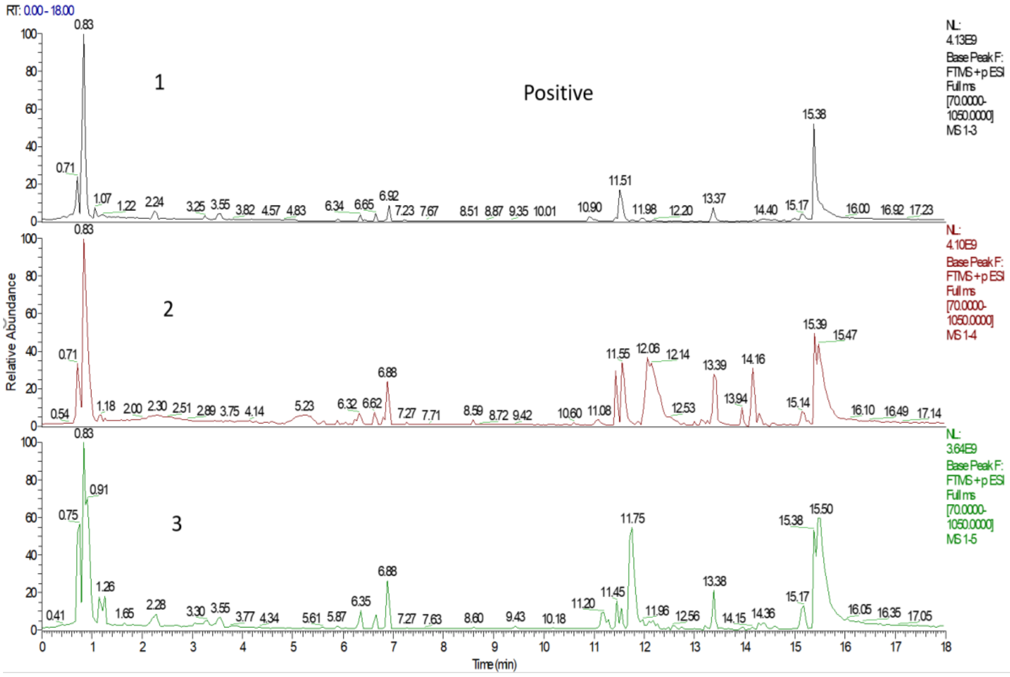


Fig. 2. HPLC-MS/MS chromatograms of polyphenols in various grape powder samples. 1: Grape seeds; 2: grape skin; 3: grape pomace. *Source: Author's*

Table 3. Polyphenolic compositions of various grape samples.

Component	GS (mg/kg)	GSK (mg/kg)	Significance
Epicatechin	405.51 ± 5.04^{A}	87.70 ± 1.12^{B}	**
Epicatechin gallate	7.85 ± 0.28^{A}	2.99 ± 0.34^{B}	**
Epigallocatechin gallate	2.00 ± 0.23^{a}	1.84 ± 0.37^{a}	
Gallic acid	152.57 ± 2.21^{A}	65.53 ± 0.78^{B}	**
Coumaric acid	1.24 ± 0.04^{A}	0.50 ± 0.04^{B}	**
Vanillic acid	93.65 ± 1.15^{B}	125.00 ± 2.21^{A}	**
Syringic acid	3.56 ± 0.23^{B}	40.89 ± 0.76^{A}	**
Catechin	316.80 ± 3.07^{A}	69.62 ± 0.45^{B}	**
Myricetin	59.98 ± 1.14^{B}	250.40 ± 2.54^{A}	**
Morin	10.92 ± 0.28^{B}	33.64 ± 1.25^{A}	**
Quercetin	1.64 ± 0.16^{B}	33.17 ± 0.89^{A}	**
Isorhamnetin	0.89 ± 0.01^{B}	11.24 ± 0.67^{A}	**
6-Gingerol	0.15 ± 0.02^{A}	0.04 ± 0.002^{B}	**
Kaempferol	1.13 ± 0.11^{B}	3.21 ± 0.13^{A}	**
Luteolin	0.28 ± 0.02^{B}	0.73 ± 0.01^{A}	**
Isoquercitrin	10.74 ± 0.30^{A}	0.02 ± 0.005^{B}	**

All data are expressed as the mean ± standard deviation (n = 3). Significance: * and ** indicate significance at $p < 0.05$ and $p < 0.01$, respectively. Different Latin letters within the same column indicate significant differences among the grape samples (lowercase and uppercase letters represent $p < 0.05$ and $p < 0.01$, respectively). GS, grape skin; GSK, grape skin.

Studies have shown that GSK and GS contain a certain amount of resveratrol, with that in red GSK being 1.11 – 12.3 mg/100 g, which was not consistent with the results of this study. This is closely related to the solvent and pretreatment method used for extracting the GP. In addition to resveratrol, GP also contains a certain amount of the stilbene compound piceid, whereas the contents of other stilbene compounds are very low [20].

These phenolic substances give wine its color and various flavor characteristics and constitute the important factors of wine quality [35,36]. The contents of total phenols, total flavonoids, tannins, and proanthocyanidins in the GS powder were higher than those in the GSK and GP powders (Table 4). The amounts of total phenols in the GS, GSK, and GP powders were the highest, at 92.68, 56.43, and 87.21 mg/g, respectively, followed by the proanthocyanidins and tannins. The proanthocyanidins give wine its bitter and astringent characteristics and are an important taste substance and key quality component in wines [37]. They can also combine with anthocyanins to form stable condensates during the wine aging process, thereby ensuring the stability of the wine color [38]. Additionally, proanthocyanidins are strong antioxidants, having the ability to absorb oxygen free radicals, and their antioxidative activity has been found to be 20 times that of vitamin C and 50 times that of vitamin E [39]. With regard to tannins, Zhang et al.[40] studied their effects on gluten protein structure, dough property, and bread quality and found that they not only could break down the disulfide bonds but also had positive effects on the dough properties and bread quality. Subsequently, those authors used this property to investigate new, safe, and efficient additives of flour [41].

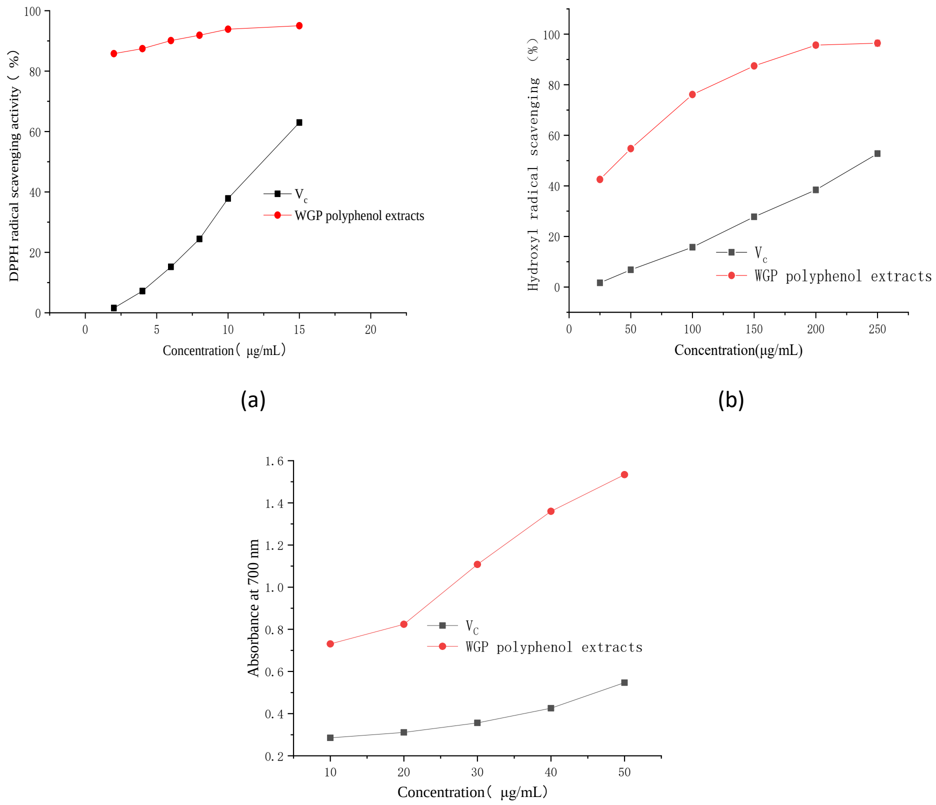
Table 4. The amounts of the main phenolics in various grape samples

Items	Standard equation	Standard plasmids	GS	GSK	GP
Total polyphenols (mg GAE/g DW)	$Y = 0.0133x – 0.0045$ $R^2 = 0.9995$	Gallic acid	92.68 ± 0.56	56.43 ± 0.35	87.21 ± 0.69
Flavonoids (mg RE/g DW)	$Y = 0.0827x + 0.0006$ $R^2 = 0.9994$	Rutin	9.86 ± 0.12	2.50 ± 0.25	7.20 ± 0.32
Tannins (mg TAE/g DW)	$Y = 0.057x + 0.0256$ $R^2 = 0.9911$	Tannic acid	19.28m ± 0.31	13.49 ± 0.55	17.91 ± 0.18
Proanthocyanidins (mg CE/g DW)	$Y = 0.0048x + 0.0226$ $R^2 = 0.9956$	Proanthocyanidin	84.50 ± 0.46	37.21 ± 0.57	71.08 ± 0.38

All data are expressed as the mean ± standard deviation (n = 3) in units of mg/g DW. DW, dry weight; GS, grape skin; GSK, grape skin; GP, grape pomace; GAE, gallic acid equivalent; RE, rutin equivalent; TAE, tannic acid equivalent; CE, cyanidin equivalent.

Antioxidative activity of the polyphenol extract from wine grape pomace

Currently, three authoritative methods are used for assaying antioxidants in herbal ingredients; namely, the DPPH and hydroxyl radical scavenging assays and the reducing power assay [42]. As shown in Fig. 3, the GP polyphenol extract had a strong capability in scavenging DPPH free radicals, exhibiting higher antioxidative activity than vitamin C, even at a low mass concentration, with the activity increasing as its mass concentration increased. At the mass concentration of 2 μg/mL, the DPPH free radical scavenging activity of the extract was 85.80%, which was 54.3 times higher than that of vitamin C (1.58%). The hydroxyl radical scavenging assay, which tests the H-donating capacity of the sample, revealed the polyphenol extract to be much more active in trapping free hydroxyl radicals than vitamin C. Additionally, according to the Fe ion-reducing power assay, the electron-donating effectiveness of the polyphenol extract was also significantly higher than that of vitamin C.



(a) (b)

(c)

Fig. 3. Antioxidative activities of a wine grape pomace (WGP) polyphenol extract and of vitamin C (V_c). (a) DPPH radical scavenging activity; (b) Hydroxyl radical scavenging activity; (c) Reducing power. *Source: Author's.*

Impact

Grape pomace is identified as a low-value by-product, and primarily used as animal feed component or feedstock for fertilizer in many small- and medium-sized enterprises, which underestimates the promising utilization value of grape pomace. Currently, grape pomace is receiving increased attention for its higher phenolic compounds content, numerous studies have supported grape phenolic compounds are associated with prevention of chronic degenerative diseases (atherosclerosis, cancer, cardiovascular disease and type 2 diabetes, among others), many researchers add grape pomace into food, the reasons of adding GPP to different food are varied, from improving the sensory qualities to increasing the nutritional value.

Grape powders have been proved to have strong antioxidant properties in this study. The polyphenols and minerals contents are rich, which can be added to flour products as nutritional enhancement agents in the food industry and can also be used as antioxidants to extend the shelf life. Therefore, the effect of grape powders on rheological properties and microstructure of wheat dough will be studied in the future, to verify whether grape powders are excellent raw material for food processing, to investigate the appropriate addition level of different food types, to make fully utilize of grape powders to process new products such as bread, biscuit and cake, etc., which can not only improve food nutritional value, but create economic benefits, as well as solve the problem of environmental and resource waste caused by improper disposal of grape residue.

Conclusions

Compared with ordinary cereal seeds and skins, GP is rich in nutrients (protein, fat, carbohydrates, etc.) and mineral and trace elements (K, Ca, etc.), and its total phenolic content is high. We have also verified that the antioxidative activity of its polyphenol extract was far superior to that of vitamin C. According to previous reports, polyphenols play a positive role in the physical and chemical properties of flour and consequently the quality of baked goods. Thus, the results of this study can be effectively applied to the development of food and health products supplemented with GP, effect of grape powders on rheological properties and microstructure of wheat dough will be studied in the future, thereby breathing new life into this wasted winery byproduct and reducing its negative impact on the environment.

Conflict of interest
There are no conflicts to declare.

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BIOFUELS – TOWARDS OBJECTIVES OF 2030 AND BEYOND

Rafał M. Łukasik
National Laboratory of Energy and Geology, Bioenergy and Biorefineries Unit
Estrada do Paço do Lumiar 22, 1649-038 Lisbon, Portugal, rafal.lukasik@lneg.pt
https://orcid.org/0000-0002-7805-5744

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Abstract
The European (and global) energy sector is in a process of profound transformation, making it essential for changes to take place that influence energy producers, operators, and regulators, as well as consumers themselves, as they are the ones who interact in the energy market. The RED II Directive changes the paradigm of the use of biomass in the heat and electricity sectors, by introducing sustainability criteria with mandatory minimum greenhouse gas (GHG) emission reductions and by establishing energy efficiency criteria. For the transport sector, the extension of the introduction of renewables to all forms of transport (aviation, maritime, rail and road short and long distance), between 2021-2030, the strengthening of energy efficiency and the strong need to reduce GHG emissions, are central to achieving the national targets for renewables in transport, representing the main structural changes in the European decarbonisation policy in that sector. It is necessary to add that biomass is potentially the only source of renewable energy that makes it possible to obtain negative GHG emission values, considering the entire life cycle including CO_2 capture and storage. Hence, this work aims to analyse the relevance of biomass for CHP and in particular, the use of biomass for biofuels that contribute to achieving carbon neutrality in 2050. The following thematic sub-areas are addressed in this work: i) the new environmental criteria for the use of biomass for electricity in the EU in light of now renewable energy directive; ii) current and emerging biofuel production technologies and their respective decarbonization potential; iii) the relevance or not of the development of new infrastructures for distribution renewable fuels, alternatives to the existing ones (biomethane, hydrogen, ethanol); iv) the identification of the necessary measures for biomass in the period 2020-2030.

Keywords
biofuel, biomass, renewable energy directive, hydrogen, ethanol

The electricity and heat sectors from biomass

During the decade 2021-2030, solid biofuels for electricity and or heat and cooling, under the terms of new renewable energy directive (RED II) [1], must also meet sustainability criteria. They must achieve minimum GHG reductions of 70% (for installations that start operating after 1st of January 2021) and 80% (for installations that start operating after 1st of January 2026). To be eligible for national targets for the introduction of renewable energies, new installations with a rated thermal power greater than 50 MW of biomass must have systems for the combined production of electricity and heat and/or cooling (cogeneration or trigeneration). Although some exceptions are foreseen in the RED II Directive such as: i) small-scale installations, i.e., dedicated installations for the production of electricity with a nominal thermal power of less than 50 MW of biomass; ii) medium-scale installations, between 50-100 MW, as long as the production takes place through the application of highly efficient cogeneration technologies, or for dedicated installations for electricity with the energy efficiency levels associated with best techniques available; iii) large-scale dedicated installations, with a rated thermal power above 100 MW of biomass, as long as high efficiency cogeneration reaching a minimum net electrical efficiency of 36% is ensured; or iv) that electricity is produced by capturing and storing CO_2 from biomass.

Considering the effect that the rules of RED II will have on the market for solid biomass for electricity and heat in the Europe, it can be concluded that biomass for the purpose of producing dedicated electricity does not make sense to be promoted, because these dedicated electricity plants will never reach the minimum GHG reduction values needed in a sector that urgently needs to be decarbonised. The alternatives to power plants dedicated to biomass could be achieved through small-scale thermal power plants (e.g., in low-density urban aggregates, but with the capacity for viable district heating solutions; with industries that consume heat), or use of biomass gasification technology for the production of biomethane, with CO_2 capture, or finally, use of pyrolysis or hydrothermal liquefaction technology for the production of bio-oils, which through deoxygenation reactions with hydrogen produced by biomass gasification or water electrolysis, will allow the production of advanced fuels with GHG emission reductions close to 100%.

More sustainable alternatives for the use of biomass for bioenergy

The potential approach for more sustainable use of biomass for bioenergy is the replacement of industrial boilers, working on natural gas or fuel oil. This means that a vast amount of fossil energy can be substituted by the renewable energy in the industry sector. In addition, the use of biomass to produce industrial steam easily reaches 90% energy efficiency and has economically affordable investments in an open market.

Another alternative for the use of biomass for bioenergy relies on the national commitments in the decarbonisation of the natural gas network. Hence, the promotion to produce biomethane, either from organic waste or from waste of lignocellulosic origin is especially relevant. However, whenever economically feasible, these systems must be coupled with CO_2 capture that will make biomethane production positive from the point of view of carbon neutrality (or even with negative CO_2 emissions). This technological solution must include the full recovery of residues from this technology, such as biochar, which can be used as a fertilizer or pH corrector for agricultural soils [2].

Other relevant aspect in the more sustainable use of biomass for bioenergy is a decarbonisation of the aviation fuel sector. It is especially relevant as the HEFA-SPK technology that converts bio-oils into aviation biofuels is currently a technology already certified by ASTM. The challenge is the sustainable production of bio-oils, hitherto only obtained unsustainably from oils of vegetable origin (soybean oil, palm oil, etc.) or in insufficient quantities from used cooking oils. Therefore, residual (renewable) biomass encompassing the following bioresources: forest, agricultural, organic, agro-industrial and algae (microalgae and macroalgae), is the best sustainable alternative to produce bio-oils for advanced biofuels.

Finally, it is important to bear in mind that the entry into the market of these new technological alternatives for the use of biomass, will imply expected increases in the price of residual biomass, but also will lead to additional gains in efficiency and productivity in the collection, logistics and supply operations of consumers and the importance of issues associated with the flow of biomass (imports/exports). This in turn will make possible to accelerate the creation of a new forest management model associated to the network of small and decentralised plants creating value locally and maintaining revenue in the region/community ensuring better penetration of the market.

The transport sector and GHG emissions

In the pre-covid era, the transport sector in the EU was responsible for almost ¼ of total greenhouse gas (GHG) emissions and still was depended on around 95% (content energy) on fossil resources [3]. Electric mobility is the European bet, however significant effects are only projected in the medium term (post-2030) in terms of expressive contribution for carbon neutrality in the transport sector. Therefore, electric mobility should be complemented with other short-medium term solutions for rapid reduction of CO_2 emissions that are currently more cost-efficient and are capable of being applied to all modes of transport (road - light and heavy; maritime - pleasure boats, medium large; rail and aviation), in the 2030 horizon. In this context, the use of advanced biofuels and other renewable fuels, are the viable and large-scale alternative until 2030. In addition to the carbon neutrality of most of these biofuels, there is an immediate improvement in national energy security and the potential for rapid replacement of current fossil fuels in the road sector, using the current fuel distribution infrastructures, accelerating the energy transition, and decarbonising this sector quicker. For this purpose, it is essential to achieve the rapid penetration of the market by different advanced technologies, of a thermochemical or biochemical nature, to ensure the production of gaseous biofuels, e.g., biomethane (synthetic natural gas, GNS), as well as for advanced liquid biofuels to replace diesel and gasoline. Another important aspect in terms of sustainable mobility are other energy vectors, such as hydrogen, produced by gasification of biomass or by electrolysis of water, however always with use of renewable energy of a variable nature.

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Role of advanced biofuels by integrating a decarbonisation policy for the transport sector

With the entry into force of the Paris Agreement on 4th November 2016 [4], the EU and the World are seeking to provide a global and effective response to the urgent need to halt the rise in global average temperature and resolve, with determination, the challenges linked to climate change. In fact, carbon neutrality (reducing GHG emissions so that the balance between emissions and removals from the atmosphere is zero) was defined as one of the priorities of the European governments, having assumed this commitment at the United Nations Conference on Climate Change in Marrakesh in 2016 [5]. To operationalise this, the Alliance for the Decarbonisation of Transport was created, whose objective is to produce a map of integrated solutions that, in the mobility sector, help achieving the goal of GHG emission reduction and stop global warming [6].

Gaseous fuels - Hydrogen, biomethane and biogas, including electrofuels

Gaseous fuels (e.g. hydrogen and biomethane) have a high potential for improving European energy security, contributing both to reduction of imports of oil, coal and natural gas and to achieve carbon neutrality, according to the national action plans towards 2030 and beyond [7]. Gaseous fuels renewable production can be carried out by different integrated technologies.

Renewable fuels of non-biological origin (RFNBO or electrofuels) - The technologies known as Power-to-Gas (PtG) and Power-to-Liquid (PtL) use water, instead of biomass, as a renewable source. The production of H_2 is carried out from the electrolysis of water, which requires high amounts of energy. Thus, the best way to achieve an adequate cost-efficiency is to use the surplus renewable energy production of a variable nature (e.g. eolic, hydro or photovoltaic) in certain periods of the day and/or night. There are three main technologies for water electrolysis: i) alkaline electrolysis; ii) electrolysis PEM (proton exchange membrane) and, iii) electrolysis of solid oxide. Alkaline electrolysis is currently the most cost-efficient technology; however, it is predictable that before 2030, PEM electrolysis can improve this cost-efficiency in PtG processes. Solid oxide electrolysis may also be an option in the future, especially if heat sources are available. The H_2 produced by electrolysis when reacting with an external carbon source (CO or CO_2) and by methanation reaction produces methane. The resulting methane, or synthetic natural gas, can be injected into the gas distribution network or stored. An alternative would be the direct injection of H_2 into the gas network. However, the amount of H_2 that can be injected into a natural gas transport network is limited by specific rules and regulations in each country. This renewable methane production process has no direct CO_2 emissions, and the use of an external carbon source contributes to the reduction of CO_2 emitted by other processes. The main disadvantages of this process are still relatively low efficiency and high costs.

These RFNBO are not eligible for double counting under RED II but are eligible for the multiplier factor of 1.2 on their energy content, if used in air and sea transport, as long as they reach a value of minimum reduction of GHG emissions of 70% for installation operation by 1st of January 2021. However, only maritime transport should benefit from this incentive from RED II mostly due to the recent restrictions on the use of fuels containing high levels of sulphur. To make it happened, it is essential to invest in port infrastructures of compressed/liquefied natural gas, as only this way PtG or PtL technologies have a margin of progression.

Biomass-to-Hydrogen - One of the promising technologies for producing renewable hydrogen, in a clean and efficient way, is through biomass gasification. However, this technology is not currently competitive for commercial hydrogen production due to the lower cost of H_2 obtained by natural gas steam reforming, a technology used to obtain more than 95% of current hydrogen. The introduction of a carbon emissions tax that penalises fossil-based processes, to the detriment of clean processes from renewable sources, will allow the diversification of technologies such as the production of hydrogen by electrolysis of water and hydrogen by gasification of biomass. The production of hydrogen by electrolysis of water has received a lot of attention from policymakers, mainly due to its role in the coupling the electricity and the gas sectors.

On the other hand, technology to produce H_2 via electrolysis is energy intensive and is only feasible using electricity from renewable sources at very low cost. The production of hydrogen by gasification of biomass is more insensitive to the price of renewable energy, mainly because water electrolysis requires demineralized water at the entrance of the electrolyser, which is a bigger obstacle to its cost-efficiency in the short term than energy cost itself. In addition, the foreseeable scarcity of water in the future suggests that in the medium-term, the production of H_2

from biomass becomes more economically and technologically effective. Although gasification, after application of commercial separation processes, allows obtaining a degree of hydrogen purity above 99.999% for its direct use in low temperature fuel cells either for stationary energy production systems or for use in electric mobility by fuel cell, in the short-term, renewable hydrogen should be seen more as an energy vector than as biofuel. In fact, its potential to contribute to the decarbonisation of the natural gas network is an alternative and helps to diversifies the end-use of hydrogen in both the industrial and residential sectors.

Biomass-to-Biomethane - The alternative to H_2 produced by biomass gasification, this technology consists of converting biomass into biomethane either by gasification or by anaerobic digestion of organic waste.

In the first case, biomass-to-gas (BtG) technology consists of biomass gasification in a gas mixture (syngas) that can be enriched in biomethane. Additionally, BtG technology can be integrated with PtG technology, which allows to overcome the problem of hydrogen storage, since with the integration of these technologies, hydrogen can be efficiently converted into biomethane (with CO_2 sequestration) and then easily stored in the natural gas network. Furthermore, the integration of the two processes can be very advantageous since the oxygen produced in electrolysis can be coupled to the gasification process, while the produced hydrogen can be used for biogas methanation or for the fuel cell. However, it is always necessary that the CO_2 contained in the syngas, has to be separated before the reaction with H_2.

In the second case, technology involving anaerobic digestion of residual biomass from agricultural and other organic matters, including municipal solid wastes, produces biogas in the well-known digesters coupled with the purification commercial systems, such as the Pressure Swing Adsorption (PSA). To avoid the release of CO_2 into the atmosphere, the last can be captured by catalytic or biological methanation. Likewise, prior to the methanation process, it is necessary to subject the biogas to commercial cleaning processes to remove H_2S. It should be noted that CO_2 capture increases the global sustainability of biomethane production technology. Another advantage of this technology is that the final CO_2 stream obtained is sufficiently concentrated to allow the use of more economically viable sequestration technologies, therefore it is more efficient than the use of CO_2 through its capture from the atmosphere. Although there are already demonstration units for these biomethane production technologies (bio-LNG or bio-GNC), their cost-efficiency has not yet reached a commercially interesting value, especially in the absence of other positive externalities, e.g., CO_2 tax emitted. In England, in Swindon, the company GoGreenGas (meanwhile acquired by Advanced Biofuels Solutions) [8] invested 30 M€ and received a European support of 13 M€ in a CDR gasification unit with a nominal conversion capacity of 1500 tonnes/year CDR in 4 MW of biomethane expected to start operating in 2020. In the Netherlands, in Alkamaar, the company AMBIGO using ECN's proprietary gasification technology, using biomass, plans to enter the market soon, producing biomethane for injection into the natural gas network [9].

On the other hand, the use of biomethane in the road or maritime sector has been continuously postponed due to a lack of legislation and incentives. Per se, biomethane may have a quota that could vary between residual or significant depending on the country's energy policy. Considering the existing infrastructure in Europe, biomethane will have more advantages in long-distance road transport. Another effective alternative is the use of liquefied biomethane as a solution for the decarbonisation of maritime transport, as long as it follows the same path as LNG, which will undoubtedly be the future of marine fuels for many years. In fact, LNG of fossil origin in the short/medium term seems to be the most suitable route in maritime transport due to the entry into force, on 1st of January 2020, of the legislation of the International Maritime Organization (IMO). This new legislation reduced the maximum sulphur content permissible in marine fuels from 3.5% to 0.5% forcing maritime transport to find an urgent alternative to Marine Fuel Oil (MFO), which has sulphur levels incompatible with the new IMO [10]. This urgent need for this new regulation was especially evident in case of last Suez crisis, which due to unprecedent blockage of the canal, the emission of sulphur pollution spiked [11]. Therefore, clearly, in the immediate future, the energy transition in maritime transport may involve mixing biofuels (without sulphur), e.g., biodiesel (up to 7%), to the MFO and in the medium-term the most realistic scenario is the adaptation of ships to the use 100% LNG, which has the advantage that it can always be progressively replaced by bio-LNG (i.e. biomethane). Both LNG and bio-LNG comply with IMO legislation specifications, regarding the sulphur content and the emission of harmful particles that are formed when the ships burn fuel. Besides those new technologies have also been announced. The major cruise lines, such as the Italian Costa Cruiser, recently launched the cruise ship Costa Smeralda, entirely powered by LNG, and intends to increase its fleet of cruise ships powered by 100% LNG [12]. Other companies such

as MSC Cruises, Aida, and the American Princess Cruises, have announced “cleaner” ship alternatives. Other companies, such as the French Pronat, announced the hybrid engine that uses diesel and LNG. Norwegian cruise company Hurtigruten has started operating two hybrid ships, powered by diesel and batteries [13].
It should also be noted that there are other variant technologies of the BtG technology, namely the biomass-to-liquid (BtL) technology (gasification followed by the Fischer-Tropsch reaction), where the final product is methanol instead of methane. In this case, only the first European commercial units in the Netherlands (Joint Venture of Air Liquide, Nouryon, Enerkem, Port of Rotterdam and Shell, location: Port of Rotterdam) [14], in Spain (Enerkem and Suez Ecoplanta Molecular Recycling Solutions; location: El Morell) [15] and Sweden (VaermlandsMetanol AB, location: Hagfors) all to produce methanol as a liquid fuel [16].

Liquid fuels

In the transport sector, biomass currently assumes a clear leadership role in renewable energies compared to existing technological solutions or those in a demonstration phase, especially in the context of the increasing production of advanced liquid biofuels, in line with the RED II [1]. The current indirect land use change (ILUC) Directive 2015/1513 [17] discouraged the use of endogenous raw materials “rich in starch” or saccharine that compete with the food market for the production of biofuels. It is done by imposing a maximum ceiling of 7% on all so-called first-generation biofuels obtained from these materials. The RED II Directive, which entered into force on 7th of January of 2021, reinforced the focus on raw materials (of lignocellulosic and non-lignocellulosic nature), residual or of low ILUC (energy crops on land of no or little agricultural aptitude) that, either by thermochemical or by biochemical conversion produces alcohols, dimethyl ether, hydrocarbons, hydrated vegetable oils (HVO), or other green biofuels as substitute for current fossil fuels.

Bioethanol (and other alcohols) - gasoline substitutes - The application of biochemical conversion technologies to lignocellulosic biomass results in the conversion of cellulose and hemicellulose into liquid biofuels (e.g., bioethanol, isobutanol, butanol). These technologies, which normally require several stages of biomass processing, through pre-treatment, enzymatic hydrolysis, and fermentation technologies, are already at pre-commercial TRL levels (TRL 7-8). Although there are still some technological barriers for their more extensive deployment. Among the most relevant are: i) energy intensity of the pre-treatment; ii) the intensification of the enzymatic process taking into account the limitations associated with the operation with high solids loads and enzyme load necessary to obtain saccharification yields above 85% that affects fermentation; iii) the final bioethanol yield necessary for economically viable processes that should reach a minimum value of 90% of the maximum theoretical yield and iv) the productivity required to make the bioconversion process economically viable that depends a lot on the type of sugars - C6 (hexoses) or C5 (pentoses) and their C5 / C6 - ratio to be used. Despite these operational difficulties, cellulosic bioethanol technology is clearly in a worldwide demonstration phase on an industrial scale and is expected to be cost-effective during this decade.
In addition to the production of ethanol as a biofuel substitute mainly for gasoline (it is also possible to completely replace diesel in road freight transport through ED95, a mixture with 95% ethanol), there are other processes for converting biomass into higher alcohols (e.g. isobutanol, n-butanol), especially that these alcohols have higher calorific contents than ethanol. All these alcohols have the great advantage of being able to use the current fossil fuel distribution infrastructures (with minimal investment costs) and without any modification to the current generation of internal combustion engines for vehicles produced after the year 2000. The main global players in the cellulosic bioethanol production technology are in Europe: Clariant, Germany; St1, Finland; Borregard, Norway; Futurol and CIMV, France; and Biochemtex/Versalis, Italy; in Brazil: Granbio, Alagoas and Raízen, São Paulo; and in India: Praj. All these industrial units, which started operating between 2012 and 2017, also carry out research and innovation actions aimed at optimising their technology, improving their performance and market position.

Biodiesel and HVO - diesel substitutes - The production of biodiesel is carried out on an industrial scale through a (trans)esterification reaction, in which the glycerides and/or free fatty acids present in each raw material are converted, in the presence of an alcohol and a catalyst, into esters. The most used commercial process to produce biodiesel, called FAME, from oil-based raw materials consists of a basic catalysis, sodium hydroxide or methylate, in the presence of methanol. In these processes, the biodiesel yield is around 85-90%. The ILUC Directive [17]

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focused on replacing edible vegetable oils with residual raw materials such as used edible oils (OAU) and animal fats. The valorisation of bio-waste through the conversion of the oils/fats contained therein by transformation into an energy product (biodiesel) will be a sustainable alternative for their reduction/elimination. However, the RED II [1] intends to limit the use of these waste materials to 1.7%, which means that there is a minimum margin of growth in the use of these waste materials. The reason behind this ceiling is the current distortion of the OAU market. For example, Portugal collects about 15000 tonnes of OAU annually from its HORECA channel but uses 190000 tonnes of OAU for biodiesel, i.e. almost 13-fold more. The difference lies in the import of OAU from 37 countries! Similar situations occur in almost all European countries.
Hydrotreated vegetable oil (HVO) is another biofuel substitute for diesel available on the market. HVO or green diesel has chemical properties identical to diesel, but it is obtained entirety from used vegetable oils or in co-processing (mixed with oil) in a refinery environment. HVO, unlike diesel, does not emit NOx. In Europe, the main production players for this type of biofuel substitute for diesel are the Finnish oil company NESTE OIL (NexBTL technology [18]), with HVO producing units, ENI in Porto Marghera, which converted its oil refinery into a biorefinery dedicated to the production of HVO from virgin vegetable oils and used cooking oils, and the Finnish UPM, in Lappeenranta, with a mega factory producing green diesel from tall oil of the pulp industry operating since 2015.

Biokerosene (aviation) - The aviation fuel sector is a good example of the fact that the energy transition is not about electric mobility, but about liquid biofuels. Aviation needs effective options for carbon neutrality in the short to medium term, and the current biofuels on the road market (ethanol and biodiesel) do not meet the technical requirements to replace the jet aviation fossil jet-A1, due to the viscosity value at low temperatures as well as other non-compliant specifications in terms of energy density. ICAO predicts that in 2050 the aviation sector will contribute 2700 M tonnes CO_2 [19]. For this reason, the search for renewable alternatives is one of the main concerns of the aviation industry.
The main issue in the development of aviation biofuels is the reduction of the level of elemental oxygen present in the biomass with the aim of increasing the H/C ratio (or the H_{eff}/C ratio) in the biofuel. This can occur using hydroprocessing technology, already known to the petrochemical industry. All types and components of biomass can be used as raw material (polysaccharides, lignin, lipids), with greater or lesser efficiency, depending on how far the H_{eff}/C ratio is from the values of interest, and this is always lower for sugars than for example, for lipids or other substrates such as bio-oils ($H_{eff}/C \sim 1.8$).

The main routes to produce aviation biofuels, already certified by ASTM, are the following:

- oleochemical processes such as the hydroprocessing of lipids (from oilseeds, algae, or animal fats), or the biomass pyrolysis to produce bio-oils and subsequent hydroprocessing and hydrocracking in biofuel aviation level. These processes are generally called HEFA technology.
- biochemical processes such as the conversion of lignocellulosic sugars to ethanol, long-chain alcohols, or hydrocarbons. These processes are generally called Alcohol to Jet (ATJ) technology.
- thermochemical/biochemical hybrid processes, e.g. biogas fermentation or aqueous phase reforming. These processes are generally called APR technology.

The transition to biofuels, in the aviation sector, should consider that three quarters of the world aviation are flights up to 1600 km, so technological alternatives should focus on this segment, in a 1st phase. Current liquid biofuels can only be mixed directly with the fossil jet-A1 up to a percentage of the order of 50%, as they do not meet all the requirements of the ASTM standards (e.g., % aromatic hydrocarbon required). New drop-in biofuels that can directly replace the fossil jet A1 are found, for the time being at the level of laboratory development, and there is no certification for them.

Recycled fossil fuels - The use of fossil-based waste, e.g. non-recyclable plastics, used tires, etc., as well as the non-biogenic CO_2 emitted by industries of fossil origin, through thermochemical, catalytic, or biological processes produces new fuels, called low carbon fuels or recycled fuels. The main difficulty in assessing the sustainability potential of these fuels lies in the absence of any methodology provided for in RED II [1] that allows quantifying, in a comparative way, the savings in GHG emissions for these fuels. However, the European Commission by means of a delegated act, will propose a uniform methodology for calculating GHG emissions for these fuels, as well as will stipulate the minimum emission savings value that these fuels must achieve to be eligible for the minimum target of 14% renewables in transport in 2030. However, the final decision of whether to include them in this transport target or not is up to each Member State. In any case, these fuels cannot be the object of incentives through double counting.

Impact

The presented consideration shows that RED II will impact the electricity and heat sector through the introduction of sustainability criteria and thus, it will change the paradigm of the use of biomass in this sector by the minimum mandatory reductions of greenhouse gas (GHG) emissions and establishment of energy efficiency criteria.

The renewable fuels of non-biological origin are not eligible for double counting under RED II but are eligible for the multiplier factor of 1.2 on their energy content, if used in air and sea transport, as long as they reach a minimum reduction of GHG emissions of 70% for plants opened before 1st of January 2021. Hence, it can be considered that only maritime transport can benefit from this incentive from RED II, largely due to the recent restrictions on the use of fuels containing high levels of sulphur. For this, it is essential to invest in port infrastructures of compressed/liquefied natural gas, as only PtG or PtL technologies to have a margin of progression.

Regarding the hydrogen production, both renewable hydrogen production technologies will have similar development in terms of cost-efficiency in the medium term (2040), although in the longer term, the production of H_2 by electrolysis may gain a decisive advantage due to three factors: reduction in the cost of electrolysers; cheaper 100% renewable electricity and possible increase in the price of natural gas. On the contrary, it can be emphasised that the growing use of water as a scarce good will only make this hydrogen production technology viable if it can be cost-efficient from non-potable water (sea, rivers, etc.).

In maritime transport, the need to liquefy gaseous biofuels (e.g. biomethane or H_2) is a heavy economic burden for the consumer in the short-term. On the other hand, knowing that the current biodiesel is perfectly suitable to be mixed with the MFO, in a scenario of energy transition in the short-medium term with no or minimum investments in fuel distribution infrastructures in sea ports, the EU Member states should consider the allocation of incentives that promote the use of liquid or gaseous biofuels in maritime transport, without privileging any particular technology, but grading the incentives according to the maximization of the reduction of GHG emissions achieved by each biofuel. With the entry into force of RED II during the period 2021-2030, the bet on both electric mobility and advanced liquid biofuels for the road sector, will reduce the biodiesel-FAME market with serious economic consequences for the current companies that produce biodiesel from vegetable oils as a by-product of its activity of producing protein for animal feed. Hence, due to the penetration of electric mobility in urban transport, the aforementioned incentives would help to direct local or national supply of biodiesel-FAME to the maritime sector. On the other hand, the specifications of Marine Distillate Fuels according to ISO 8217-2017, indicate that the maximum percentage currently recommended for the addition of Biodiesel-FAME is 7%, because the presence of biodiesel in higher quantities may increase the probability of microbial contamination, being pointed out as one of the problems of its use for maritime transport [20]. However, bet should be on port infrastructure of CNG/LNG, which can then be efficiently supplied by bio-CNG/bio-LNG (biomethane), or by PtG technologies. These technologies are considered as the only form of decarbonisation of maritime transport, as the electrification is not an alternative for this sector. However, in a market as competitive in terms of operating costs as the maritime one, the insertion of new bio-LNG/bio-GNC (biomethane) technologies or PtG technologies, seems only viable if it is a blend with the fuel currently used or blend with natural gas (e.g. diesel-natural gas hybrid ships).

The decarbonisation of long-distance road freight transport may have different scenarios according to the existing fuel distribution infrastructure or the one to be created. While in the short term, i.e. until 2030, cost-efficiency is clearly on the side of liquid biofuels, in the post-2030, both GNC (partially replaced by bio-GNC) and hydrogen (powered by electric fuel cell) seem to be the energy vectors that will emerge as the main ones as more severe emission restrictions are occurring in this transport sub-sector. However, the introduction of these new fuels (electricity, H_2) will depend on the level of investment in the creation of basic supply infrastructures. Considering the horizon until 2030, biomethane is at a higher TRL, so due to its technological maturity, it will have a more relevant role in this energy transition. In addition, biomethane will assume a major role in the transport sector and is currently

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the best way to introduce the renewable component in transport. H_2 will take over an increasing importance in the energy transition (much more than biomethane) but there are still economic challenges for its production and storage.

In short, a mix of all these energy vectors, including advanced liquid biofuels, must be invested in long-distance road freight transport, in the light of technological neutrality, so all solutions (short, medium and long term) must be considered and selected in view of their cost/benefit in reducing GHG emissions and their real contribution to achieving the goals of national and international commitments. To this end, it is essential to maximise the use of existing infrastructures, e.g. by total removal of natural gas and replacement with 100% hydrogen. This is because, in the case of mobility, the level of purity required in Fuel Cell electric vehicles prevents it from being obtained from natural gas-H_2 mixtures, always requiring a dedicated European hydrogen supply infrastructure. In the case of bio-GNC (biomethane), it can either be used locally in autonomous supply units (UAGs) or in filling stations along the European lines of the national gas transport network. The development of these alternative infrastructures should, however, evolve with the market, depending on technological progress, economic viability and consumer acceptance of the various forms of energy.

Conclusions

In conclusion, it can be stated that the evolution of electric mobility will only be effective for decarbonization when the addition of new capacity for electric energy from renewable sources and corresponding production, exceeds the increase in electricity consumption for mobility. Otherwise, this consumption will be made with electricity of fossil origin, with the corresponding associated emissions and without a positive contribution to the reduction of CO_2 emissions. Additionally, it is recognised that the investment in the creation of production, storage and supply infrastructures takes time, which makes the importance of electric mobility for the effective decarbonisation of the transport sector becoming only significant in the post-2030/2035 period. On the other hand, even in the medium to long term, it is unlikely to have great penetration in long-distance road transport, due to weight/space limitations and autonomy, as well as its contribution to the sea and air. On the contrary, it will play a crucial role in in the light passenger road sector and even in the urban distribution goods sector that its penetration is most clearly anticipated until 2030. However, it cannot neglect that extensive development of charging points for the local, urban transport system will generate pressure and the need for investment in the national electricity network. This in turn will certainly have an impact on the value of the tariffs to be borne by the consumer. To mitigate this situation, in the medium term (post-2030) fuel cells may coexist and complement the batteries in electric mobility. This hypothesis will be viable, as long as H_2 production and storage costs will be reduced. Considering that fuel cells in mobility can use both hydrogen and ethanol as a fuel source to produce electricity, the reduction of GHG emissions, environmental sustainability, social impact and the respective cost-effectiveness analysis should dictate the most appropriate solutions. With a view to using advanced biofuels in the energy transition period (2020-2050), it can be considered that it should also be a priority objective by 2030 to start a transition from the use of conventional biofuels to advanced biofuels, which allow substantial reductions in emissions of greenhouse gas and a well-to-wheel perspective allow to achieve total carbon neutrality. For that, it is necessary that there is a clear legislative framework that promotes the production of these biofuels and more importantly, that protects investors who intend to invest in biorefineries for advanced biofuels.

Finally, for these objectives to be achieved, it is necessary to adapt RED II to the national realities, so that no sector of the value chain (industry) or consumers is harmed. To this end, all stakeholders in the sector should have an essential role in the transposition of the RED II directive. The measures to promote the decarbonisation of the industry should respect the principle of technological neutrality by equally supporting all technologies and discriminating them against their contribution to the reduction of GHGs considering a complete life cycle analysis [21].

Conflict of interest

There are no conflicts to declare.

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FORMATION OF AN INTEGRATED STRUCTURAL ASSESSMENT OF THE EXPORT POTENTIAL OF THE AVIATION COMPLEX

Kateryna Andriushchenko*
Department of Economics and Entrepreneurship
Kyiv National Economic University named after Vadym Hetman
54/1 Peremogy ave., 03057 Kyiv, Ukraine
https://orcid.org/0000-0002-6274-5310

Ganna Gurina
Department of Foreign Economic Activity Management of Enterprises
National Aviation University
1 Liubomyra Huzara ave., 03058 Kyiv, Ukraine
https://orcid.org/0000-0002-1419-4956

Elvira Danilova
Department of Foreign Economic Activity Management of Enterprises
National Aviation University
1 Liubomyra Huzara ave., 03058 Kyiv, Ukraine
https://orcid.org/0000-0001-6036-7910

Viktoriia Zalizniuk
Department of World Economics
Kyiv National University of Trade and Economy
19 Kyoto str., 02156 Kyiv, Ukraine
https://orcid.org/0000-0002-7014-0207

Oleg Platonov
Department of Public Administration
Interregional Academy of Personnel Management
2 Frometovskaya str., 03039 Kyiv, Ukraine
https://orcid.org/0000-0002-3059-5389

Vitalii Tkachuk
Department of Enterprise Economics Faculty of Economics
Kamianets-Podilskyi National Ivan Ohiienko University
61 Ohiienko str., 32300 Kamianets-Podilskyi, Ukraine
https://orcid.org/0000-0002-8529-9632

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Abstract
Successful operation and development of enterprises in modern conditions involves the expansion of markets. The company's entry into international markets requires the formation of its international competitive strategy, identification of competitive advantages in the markets of selected countries, and this, in turn, implies the need for export potential of the company. In determining the export potential of the aviation complex, it is necessary to consider the specific features of enterprises in this industry, among which we can highlight the features of the products of aviation enterprises and the features of the international aviation market. To qualitatively assess the level of economic potential, we propose to use a system of classification features, developed based on the well-known Harrington scale, but slightly modified by the authors in relation to the calculated data and available statistical information. The phases of the life cycle of the economic potential of the enterprise are determined. Not only the quantitative and qualitative level of economic potential are important, but also the changes associated with the passage of time. In order to determine the importance of indicators in each group, methods of component analysis of the characteristics

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of variation series of the results of the survey of experts were used. When comparing the variation of different features in one set with different average value, we use the relative indicators of variation - coefficients of variation. The obtained result together with the results of application of the method of component analysis allows us to conclude that in the formation of the integrated indicator of the first group (K1) it is enough to consider these five indicators, and the most important of them are two: technological processes to other activities.

Keywords
aviation enterprises, integrated structural assessment, export potential, aviation complex, export-import flows, international competitive strategy, competitive advantages, risks, foreign economic relations

Introduction
The level of development of the state's economy can be characterized by the size and structure of its export-import flows. The higher the share of the country's participation in world exports of goods and services, and the structure of exports is dominated by goods of high-tech industries, the more efficient the country's economy. Successful operation and development of enterprises in modern conditions involves the expansion of markets. The company's entry into international markets requires the formation of its international competitive strategy, the identification of competitive advantages in the markets of selected countries, and this, in turn, implies the need for export potential of the company.

An important area of scientific research today is the development of the export potential of the aviation complex. Over the past 100 years, the development of the aviation complex has been characterized by rapid pace and has become an important sector of the world economy. Currently, the export potential of the aviation complex in most countries is in fierce competitive conditions, determined by trends in the world economy: global political instability, falling world oil prices, low domestic economic growth. Increasing the export potential is a necessary condition for the products of the aviation complex to enter the international market [1]. To solve this problem, it is necessary to use special tools to manage the development of the export potential of the aviation complex , contributing to the growth of competitiveness of goods in the international market. In addition, modern methods of managing the development of the export potential of the aviation complex must consider the non-tariff restrictions existing in the international aviation market and comply with the requirements and rules adopted by the WTO.

In determining the export potential of the aviation complex, it is necessary to consider the specific features of enterprises in this industry, among which we can highlight the features of the products of aviation enterprises and the features of the international aviation market. To enter the foreign market, products must strictly comply with international standards and technical regulations, as products are usually the next link in the production chain. The international aviation market is unstable: supply and demand in the market depend not only on trends in the development of the aviation complex, but also on the general level of economic and political stability of importing countries.

The analysis of the existing approaches to the definition of export potential showed that the definition of the export potential of the enterprise, corresponding to the specifics of the aviation complex , can be formulated as follows: the export potential of the aviation complex is the international market, and an opportunity of adaptation of the enterprise to continuous changes of external environment and achievement of the purposes of strategic development.

Even though there are many studies on the management of aviation complexes, there is no integrated structural assessment of the export potential of the aviation complex. In this article, we try to fill this gap, as well as shortcomings in the study of mechanisms for integrated structural assessment of the export potential of the aviation complex [2]. One of the tasks will be the development and formation of areas to ensure the company's ability to produce and supply competitive products to foreign markets, determining its entry into world markets, as well as its role in the economy determine the feasibility and objectives of the study. In the works of some authors, the export potential of the enterprise is considered as a special case of foreign economic potential. Many authors understand the export potential of the aviation complex as the level of competitiveness of its products in the foreign market. However, such an understanding does not affect the peculiarities of the organization and administration of production and foreign trade activities of the aviation complex. Considering the evolution of views on the essence of the concept of "export potential of the aviation complex", we can distinguish two areas of research of this scientific problem [3–5]. Resource direction of research of export potential: according to this concept export potential is a set of resources available to the aviation complex for production and sale of products in foreign markets, and the ability of the resources accumulated at the aviation complex to achieve the maximum possible export volume. The effective direction characterizes the considered concept from the position of result. The second approach determines the export potential of the aviation complex not only in terms of the availability of resources, achieved results or available opportunities, but also as a criterion for the competitiveness of products produced and exported. Each of these concepts has certain limitations, within which the emphasis is on the study of a particular aspect of the overall problem. Identifying the complex nature of the export potential of airlines gave grounds to prove the need to develop a methodology for export potential, which requires clarification and supplementation of their categorical and conceptual apparatus. Export potential is proposed as an organized set of internal and external economic opportunities and resources (discovered or hidden), which create conditions for development and ensure the implementation of strategic and tactical goals of the enterprise in the field of aviation, guided by adequate economic development strategy.

In our opinion, it is impossible to sufficiently agree with any of the presented approaches, as economic potential is a complex, complex education. Each approach focuses only on its individual aspects, parts. Economic potential, we believe, is a kind of tool that allows you to choose the most effective way to use the total potential of the enterprise and develop directions for its development strategy [6]. Therefore, the concept of "economic potential" should be based on the process of goal setting. The maximum possible output cannot be the goal of the company without focusing on the customer and market conditions.

Methods

In the process of implementing a synergetic approach to determine the normalized indicators, we use formulas based on deviations (xij - a) and standardized by the variational scale (x_{max} - x_{min}):

- for indicators-stimulants (the more, the better), the normalized indicator Ui is calculated as follows:

(1)
$$Y_{ij} = \frac{X_{ij} - minX_{ij}}{maxX_{ij} - minX_{ij}},$$

where Y_{ij} - is the normalized i-th indicator in the j-th population;
X_{ij} - the value of the i-th indicator in the j-th population;
$\min X_i$ - the minimum value of the i-th indicator;
$\max X_i$ - the maximum value of the i-th indicator.

That is, the larger the actual value of *X and j* within the range of their oscillations, the closer to 1 will be the value of *B and j* .

- for indicators-disincentives (the less, the better), *In ij is* calculated using the formula:

(2)
$$Y_{ij} = \frac{maxX_{ij} - X_{ij}}{maxX_{ij} - minX_{ij}}$$

The integrated indicator for each component of economic potential is defined as the average value of the selected coefficients for a certain calendar period, due to the equivalence of all indicators of each group:

(3)
$$I_j = \frac{\sum Y_{ij}}{n},$$

where Y_{ij} is the normalized *i*- th indicator in the *j* -th set;
n - is the number of indicators of a certain group.

To calculate the integrated indicator of the level of economic potential of the enterprise it is necessary to determine the weights for each component of the potential using the method of expert assessments (Table 1).

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The integrated indicator of the level of economic potential of the enterprise is calculated by the formula:

$$I = \sum_{i=1}^{n} I_j \times r_j , \quad (4)$$

where I_j - is an integral indicator of the j -th component of economic potential;
r_j - weight of the j -th group of indicators.

Table 1. Weights of components of the general economic potential of the enterprise (based on an expert method). *Source: summarized by the author for [7,8]*

Components	Score	Weights
Production and technological	22	0.22
Labor	17	0.17
Financial	21	0.21
Marketing	14	0.14
Organizational and managerial	12	0.12
Rehabilitation	8	0.08
Strategic	6	0.06
Total	100 points	1

To qualitatively assess the level of economic potential, we propose to use a system of classification features, developed based on the well-known Harrington scale, but slightly modified by the authors in relation to the calculated data and available statistical information (Table 2).

The next stage of the synergetic approach is to determine the phase of the life cycle of the economic potential of the enterprise [5,9]. Not only the quantitative and qualitative level of economic potential are important, but also the changes associated with the passage of time.

Table 2. Scale for assessing the integrated indicator of the level of economic potential of the enterprise. *Source: systematized by the author.*

The interval of the integrated indicator of the level of economic potential	The level of economic potential of the enterprise
[0; 0.2]	critical
[0.2; 0.37]	low
[0.37; 0.57]	acceptable
[0.57; 0.7]	sufficient
[0.7; 0.9]	high
[0.9; 1]	reference

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This is because the same quantitative value can correspond to different phases, because the graphical form of the life cycle involves the possibility of points with the same coordinates on the B axis (level of economic potential) at different intervals of the curve and, accordingly, at different stages of the life cycle.

Results and discussion

To determine the weight of indicators in each group, methods of component analysis of the characteristics of variation series of the results of the survey of experts were used.

When comparing the variation of different features in one set with different average value, we use the relative indicators of variation - coefficients of variation. They are calculated as the ratio of absolute variations to the arithmetic mean and expressed as a percentage [10]. The results obtained are shown in table 3 by study groups.

Table 3. Coefficients of variation of indicators X_{ij} , %. *Source: developed by the author.*

i \ *j*	1	2	3	4	5	6	7
1	25.85	14.96	13.34	15.41	30.44	-	-
2	25.60	10.30	11.77	12.51	12.51	15.55	11.76
3	24.98	13.17	13.76	12.99	13.73	21.77	-
4	16.57	15.65	14.65	13.27	12.68	11.49	15.68

X_{ij} is a relative value that characterizes the weight of each indicator in the group, it takes values from 0 to 1 (from 0 to 100%), *i* - group, *j* - indicator).

For indicators that characterize the resource potential of the enterprises of the aviation complex, the following results were obtained $X_{11} = 0.2585$, $X_{12} = 0.1496$, $X_{13} = 0.1334$, $X_{14} = 0.1541$, $X_{15} = 0.3044$

The obtained result together with the results of application of the method of component analysis allows us to conclude that when forming the integrated indicator of the first group (K_1) it is enough to take into account these five indicators, and the most important of them are two: X_{11} - capacity utilization factor and X_{14} - adaptability factor technological processes to other activities ($X_{11} + X_{14} = 25.85 + 30.44 = 56.29$).

For the second group (K_2) - important indicators are: X_{21} - management efficiency and X_{26} - the level of competence, which together amount to almost 42% of the share of the group of human resources of the aviation complex.

Significant indicators for the coefficient of the third group (K_3), which characterizes the efficiency of the aviation complex, were X_{31} - an indicator of overall profitability and X_{36} - an indicator of labor productivity. The total weight of these indicators, within the coefficient of export potential of aviation enterprises, is 47%.

Other indicators are equilibrium to determine the assessment of the efficiency of the airlines of the complex and average 13%.
When forming the generalizing coefficient of the fourth group (K_4) - assessment of the financial condition of the enterprises of the aviation complex of Ukraine, all indicators are equivalent and make on average the specific weight of the coefficient of the group about 13%. Although we should pay attention to the absolute liquidity ratio - X_{41} - which is 16% of the weight of the ratio, and the indicators $X_{42} \approx X_{47}$ and in total are about 32%.

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We evaluate the reliability of the obtained results according to Pearson's criterion x^2, which allows to determine the consistency of experts' opinions on the impact of weights on the value of the resulting indicator of the coefficient of export potential of the aviation complex of Ukraine [11]. This method is based on the calculation of the concordance coefficient:

(5)
$$W = \frac{12\sum_{i=1}^{k}\Delta_i^2}{m^2(k^3-k) - m\sum_{i=1}^{m}T_i},$$

where k - is the number of indicators;
m - number of experts;

(6)
$$T_i = \sum_{t_i}(t_i^3 - t_i),$$

where t_i - the number of identical estimates in the i -th indicator;

the sum of squares in deviations of the sum of variation coefficients of indicators of weight of each expert from the general average sum:

(7)
$$\sum_{j=1}^{k}\Delta_j^2 = \sum_{j=1}^{k}\left(\sum_{i=1}^{m}d_{ij} - \frac{\sum_{i=1}^{k}\sum_{j=1}^{m}d_{ij}}{k}\right)^2,$$

where d_{ij} - is the value of the j -th indicator according to the i- th expert.

Consistency expert evaluations assessed the criterion Pearsons χ^2 , the observed value is calculated using the formula:

(8)
$$\chi^2 = m(k-1)W,$$

critical and is determined by the data , the given significance $\alpha$and number of degrees of freedom $s = k - 1.$

Determine the consistency of the expert assessment for each group of indicators, considering the results obtained.

Then the total average amount:

$$\frac{\sum_{i=1}^{k}\sum_{j=1}^{m}d_{ij}}{k} = \frac{2695}{25} = 107.8,$$

$$\sum_{j}^{k}\Delta^2 = 92.84,$$

$$\sum_{i=1}^{m}T_i = 48$$

Observed value of the criterion: $\chi^2 = 27 \times (25-1) \times 0.098 = 63.5$

Critical value: $\chi^2(0.05;5) = 11.07$

Since the observed value is more critical , with a probability of 0.95, the obtained expert assessment can be considered consistent.

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According to the estimates conducted surveillance ratios calculated resource potential claim enterprises of aviation sector and human resources, weightings efficiency of enterprises aviation sector and financial condition [2]:

$$K_1 = \sqrt[5]{\prod_{j=1}^{5} X_{1j}} = 0.1891; \qquad K_2 = \sqrt[7]{\prod_{j=1}^{7} X_{2j}} = 0.1366;$$

$$K_3 = \sqrt[6]{\prod_{j=1}^{6} X_{3j}} = 0.1605; \qquad K_4 = \sqrt[7]{\prod_{j=1}^{7} X_{4j}} = 0.1418;$$

Based on the results of the calculations, we determine the group weighting factors according to the formula:

(9)
$$K_i = \frac{k_i}{\sum_{i=1}^{4} k_i},$$

where k_i - coefficients of variation and - that group;
K_i - weighting factor and - that group.

To calculate formulas integral factor export potential claim and reception in aviation complex weight coefficients define groups directly to experts. (Table 4).

Table 4. Weight of groups according to rating assessment. *Source: developed by the author*

Group	Expert rating,%																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	20	25	20	20	10	20	25	25	20	30	15	10	40	25	20	20	25	30	35	60	35	30	40	35	50
2	40	30	25	20	20	50	20	20	25	20	25	30	22	28	30	10	50	50	15	20	40	30	40	35	25
3	20	25	25	35	40	15	25	25	30	25	35	25	20	25	20	40	15	20	25	10	15	20	10	20	10
4	20	20	30	25	30	15	30	30	25	25	25	35	18	22	30	30	10	0	25	10	10	20	10	10	15

Applying the scheme of calculating the weight of the coefficients, we obtain $K_1 = 0.28$, $K_2 = 0.29$, $K_3 = 0.23$, $K_4 = 0.20$.

At this stage of the study, the weight of the groups and their indicators, the results are presented in (Table 5).

Note that at the first stage of the experiment to calculate the integrated coefficient of export potential of airlines used the formula of the geometric mean, i.e., the generalized indicator of export potential was calculated as the average value of the obtained coefficients (since each of the four proposed coefficients).

To obtain a more accurate formula for determining the integrated coefficient of export potential of aviation enterprises, which would consider the impact of each component on its value, we use the methods of factor analysis.

Let us determine the influence of indicators of export potential in each of the groups on the generalized coefficient of export potential of airlines [10].

Table 5. Weight of groups and their indicators. *Source: developed by (Gurina G.)*

№	Groups	Indexes	Validity
1	Resource potential	1. Capacity utilization factor	0.6
		2. Coefficient of use of fixed assets	0.63
		3. Staff utilization rate in	1
		4. Coefficient of job security	0.16
		5. Coefficient of adaptability of technological processes to other activities	0.28
2	Human resources	1. Management efficiency	0.7335
		2. The share of management staff with higher education	0.77
		3. Cost-effectiveness of the management staff	0.231
		4. Development of the management staff	0.037 the most common
		5. Educational qualification was Evan management personnel	0.67
		6. Competence of workers in	0.98
		7. Evaluation of the creative industry	0.32
3	Performance appraisal and enterprises	1. Profitability of the general (main activity)	0.11
		2. Return on fixed assets	0.023
		3. Return on investment	0.24
		4. The turnover ratio of the asset in	0.27
		5. Coefficient of suitability of fixed assets	0.14
		6. Productivity	0.938
4	Rating financial state	1. The ratio of the absolute liquidity	0.17
		2. Current ratio	0.2
		3. Financing ratio (coverage)	0.1
		4. Coefficient of autonomy	0.7
		5. Equity maneuverability ratio	0.45
		6. Investment ratio	0.202
		7. Financial ratio	0.98

Since a multiplicative model of the form f = xyzq is used for its calculation, we apply the integrated method of factor analysis, which is based on the summation of increments of a function defined as a partial derivative multiplied by the increment of the argument at infinitesimal intervals [12].

The structure of the factor system has the form:

$$\Delta f = x_1 y_1 z_1 q_1 - x_0 y_0 z_0 q_0 = A_x + A_y + A_z + A_q \quad (10)$$

We construct n -integral expressions that express the integral weights of the respective groups of indicators:

(11) $$A_x = \int_0^{\Delta x} y_x^{\prime} z_x^{\prime} q_x^{\prime} = \frac{1}{6}\Delta x\{3q_0y_0z_0 + y_1q_0(z_1+\Delta z) + q_1z_0(y_1+\Delta y) + z_1y_0(q_1+\Delta q)\} + \frac{1}{4}\Delta x\Delta y\Delta z\Delta q;$$

(12) $$A_y = \int_0^{\Delta x} x_x^{y\prime} z_x^{\prime} q_x^{\prime} = \frac{1}{6}\Delta y\{3q_0x_0z_0 + x_1q_0(z_1+\Delta z) + q_1z_0(x_1+\Delta x) + z_1x_0(q_1+\Delta q)\} + \frac{1}{4}\Delta x\Delta y\Delta z\Delta q;$$

(13) $$A_z = \int_0^{\Delta x} x_x^{z\prime} y_x^{\prime} q_x^{\prime} = \frac{1}{6}\Delta z\{3q_0x_0y_0 + q_1x_0(y_1+\Delta y) + y_1q_0(y_1+\Delta y) + x_1y_0(q_1+\Delta q)\} + \frac{1}{4}\Delta x\Delta y\Delta z\Delta q;$$

(14) $$A_q = \int_0^{\Delta x} x_x^{q\prime} z_x^{\prime} y_x^{\prime} = \frac{1}{6}\Delta q\{3y_0x_0z_0 + x_1z_0(y_1+\Delta y) + y_1z_0(x_1+\Delta x) + x_1y_0(z_1+\Delta z)\} + \frac{1}{4}\Delta x\Delta y\Delta z\Delta q;$$

where: $$x_i = \sqrt[4]{K_1^{(i)}},\ y_i = \sqrt[4]{K_2^{(i)}},\ z_i = \sqrt[4]{K_3^{(i)}},\ q_i = \sqrt[4]{K_4^{(i)}},$$

To calculate the influence of the integrated weights of the groups, the data obtained during two studies were used. The results are presented in table 6.

Table 6. The data obtained during the research.

x_1	y_1	z_1	q_1	x_0	y_0	z_0	q_0
0.82	0.94	0.91	0.96	0.79	0.87	0.93	0.92

$$\Delta f = 0.2463144 - 0.16217216 = 0.0851317;$$

$$A_x = 0.023484,\ A_x = 0.025539,\ A_x = 0.020432,\ A_x = 0.015324,$$

$$a_1 = \frac{A_x}{\Delta f} = 0.28, \quad a_2 = \frac{A_y}{\Delta f} = 0.29, \quad a_3 = \frac{A_z}{\Delta f} = 0.23, \quad a_4 = \frac{q}{\Delta f} = 0.20,$$

Consequently, the export potential integral factor and reception aviation industry of Ukraine affected by:

- resource potential ratio by 28%;
- personnel ratio by 29%;
- coefficient for assessing the efficiency of the aviation complex by 23 %;
- coefficient of assessment of financial condition by 20%.

Then, to determine the value of the integrated coefficient of the export potential of the aviation complex can be used the following formula:

(15) $$K_p = 0.28K_1 + 0.29K_2 + 0.23K_3 + 0.20K_4$$

The integrated coefficient of export potential must meet the requirements dictated by the convenience of its further use, namely [8]:

- it must be a numerical measure, which in an integrated form quite objectively expresses the level of all the most important indicators of the export potential of the enterprise;
- its value should depend on all the main characteristics that may affect the export potential, considering their significance - "weight";

- its value must have its own unit of measurement (the most natural for this type of coefficient is the measurement in shares or%);
- to compare the values of the integrated coefficient of export potential there should be a natural and convenient scale;
- since the integrated coefficient of export potential can be calculated mainly based on subjective assessments (expert assessments), the method of its determination should minimize possible bias and give a reliable result with any selected level of reliability.

According to the author, the proposed methodological approach allows to satisfy all the formulated requirements. A preliminary survey of experts made it possible to determine the full range of indicators that form the integrated coefficient of export potential of the enterprises of the aviation complex, to choose the most significant among them, to group and determine their importance [13].

The generalized coefficients for each group of indicators are calculated considering the magnitude and influence of the coefficients of the formative factors.

After calculating the coefficient of export potential, it is necessary to identify its level on a scale to assess its value.

To determine the scale of assessment of the integrated coefficient of export potential of airlines, a variance analysis of alternative and nominal characteristics was used and the standard deviation of the alternative series of distribution of integrated weights of groups was determined [1].

Quantitative variation is expressed by two nominal values: the presence of an impact on the coefficient of export potential, which is taken as 1 (q), and its absence, which is denoted as 0.

Then p is the fraction of units of integrated weights of groups, which is calculated by the formula and obtained the maximum critical value of the scale of export potential:

$$p = \sqrt[4]{a_1 \times a_2 \times a_3 \times a_4} \tag{16}$$

$a_i, i = \overline{1,4}$ - integral weights of groups

In accordance

$$q = 1 - p \tag{17}$$

Therefore, the standard deviation of the integral weights from the nominal value (σ), is calculated by the formula:

$$\sigma = \sqrt{pq} \tag{18}$$

The calculations form the result: $p = \sqrt[4]{0.28 \times 0.29 \times 0.23 \times 0.20} = 0.24$ then $q = 1 - 0.24 = 0.76$

therefore, $\sigma = \sqrt{0.24 \times 0.76} = 0.47$

The obtained result of the standard deviation of the integrated weights makes it possible to determine the length of the interval of a sufficient level of export potential of the enterprise, which is 0.47.

Using the rule, 3σ we construct a scale in units of standard deviation, setting the size of the interval $\frac{1}{2}\sigma$, and get the length of the interval of the next level (low). Then the interval of scalability of adaptability of the enterprise is defined as $2 \times \frac{1}{2}\sigma = \sigma = 0.47$, that is the difference between the upper limits of low and sufficient levels, and the difference between the lower limit of low level and the upper limit of sufficient level should be

$$3 \times \frac{1}{2}\sigma = \frac{3}{2}\sigma = 0.63.$$

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The deepening of the crisis in the socio-economic life of the country and the need to stabilize the state's economy necessitate the formation of the main directions of development of aviation enterprises [14].

Thus, based on the reliability of expert assessment and calculation of integrated weights of groups, we form a scale for estimating the value integrated coefficient of export potential of aviation enterprises (Fig. 1).

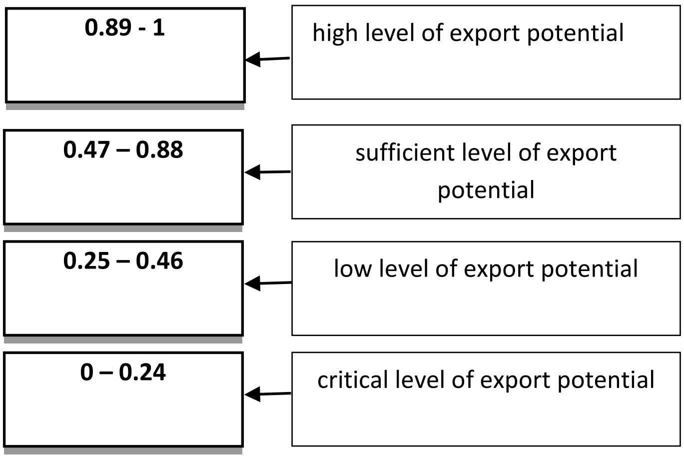

Fig. 1. Scale for determining the level of export potential of airlines.

The value of the integrated coefficient of export potential obtained with the help of the proposed formulas has the following properties: it can vary from 0 to 1 (or from 0 to 100%); as the value of each shaping factor increases, the integral coefficient of export potential increases in proportion to the significance of the group weighting factor [15].

It can be stated that the enterprises of the aviation complex have specific features inherent in the object of state regulation, the following:

- is in direct interaction with the economic, energy, environmental and social sectors, which ensures its competitiveness and efficiency;
- one of the most capital- and knowledge-intensive industries and one of the leading industries;
- provides for the predominance of the innovation component during the design and manufacture of air transport;
- its effectiveness directly depends on the availability of appropriate state regulation;
- has a direct impact on the state of national security of the state, as it is focused, inter alia, on the design and manufacture of defense products;
- focused on creating competitive products and bringing it to the world market;
- develops both at the expense of the state budget and at the expense of attraction of foreign investments and investments of the business environment (including because of participation in complex international programs with preferential terms of financing, PPP).

Impact

Considering the peculiarities of the aviation sector, the structure of interaction of enterprises of the aviation complex of Ukraine is proposed, which as a result will allow to form and implement a strategic plan of balanced development and get a synergetic effect from its implementation.

Based on certain approaches, methodological support for forecast analysis of competitiveness and export potential of airlines based on assessing the effectiveness of potential on the criteria of completeness, efficiency, degree of implementation, as well as compliance with market conditions.

The functioning of enterprises that create the basis of export potential, the structure of foreign economic relations and competitiveness of the potential of these airlines, which determine the content and relationship of purpose, object, principles and methods of capacity development to achieve certain goals; the imperfect system of state support (preferences and incentives) is analyzed; a detailed classification of aviation goods is given [1,16].

In the process of analysis, approaches to a comprehensive assessment of the export potential of aviation enterprises were established, which allowed to attract more indicators for the analysis of the competitiveness of aviation enterprises in world markets [5]. This made it possible to reorient foreign economic relations for the enterprises of the aviation complex due to the change in the vector of export orientation.

Conclusions

Strategic potential, according to author [17], "is a very broad category, which covers not only the marginal volume of production of certain products when used in the largest amount of material resources and labor". And this is the ability of the system to analyze the situation of the external environment, to assess market conditions and adapt to external conditions by constantly monitoring changes in demand for goods and services, the implementation of new ideas that can better meet such needs.

The modern enterprise of the aviation complex is a holistic, complex system operating in a dynamic mode. In this regard, it is impossible to draw a clear line between its domestic and foreign economies. Optimal intra-economic proportions create the basis for the formation of foreign economic relations, and the latter, in turn, contribute to the continuous improvement of the internal capabilities of the aviation complex. In our opinion, the existence of such a double conditionality of the external and internal economy of the enterprise allows us to conclude that the export potential should be considered in the system of economic potential of the enterprise. However, the category of economic potential is also not primary and is part of a more general concept of "aggregate potential of the enterprise", which also includes technical, social potential and intangible assets - image, brand, corporate culture, patents, inventions, etc.

Thus, the main goal in assessing the export potential of the aviation enterprise should be the process of identifying and implementing reserves to increase the efficiency and profitability of export activities of the enterprise, growth of production competitive in foreign markets with minimal production and financial resources.

Kim (2016) applied probabilistic modeling to analyze the impact of changing requirements for the aviation industry during an economic downturn [18]. Derigs and Illing (2013) presented model-based studies of the configuration and optimization of a cargo airline network [19]. Lapp and Cohn (2012) presented a new metric service availability model that measures the throughput and reliability of the planned number of flights [20]. Barnhart et al. (2012) concluded on trends and research opportunities in air travel demand and capacity management; then described a strategic approach to better managing demand and available capacity in terms of defining, allocating and using air traffic capacity [21]. Flores-Fillol (2010) proposed a congestion pricing model to justify the relationship between flight frequency and aircraft size, and carefully assessed the consequences of congestion at hubs [22]. In our opinion, the export potential is a dynamic component of the economic potential of the enterprise, which, based on available and possible resources and means and considering environmental factors, will ensure the company's ability to produce and supply competitive products to foreign markets. As for the allocation of types of export potential of the aviation complex , we propose to divide the realized and unrealized export potential (reserves). The process of identifying and implementing reserves in the formation of export potential is aimed at maintaining a balance between costs and results of the enterprise.

Conflict of interest

There are no conflicts to declare.

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METHOD OF RESEARCH FOR SOLAR COOKERS PERFORMANCE CHARACTERISTICS- ANALYSIS AND COMPARISON

Geetanjali Raghav*
University of Petroleum & Energy Studies, Dehradun, India,
email: graghav@ddn.upes.ac.in
Anjali.1109@gmail.com

Pankaj Kumar Sharma
University of Petroleum & Energy Studies, Dehradun, India

Suresh Kumar
Shri Vishwakarma skill University , India

Rajesh Maithani
University of Petroleum & Energy Studies, Dehradun, India

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Abstract
Cooking is one of the most common activity in day-to-day life of every woman. In rural areas the transportation of fuel is major problem and the increasing demand of energy for cooking applications is gaining importance and various investigations are being carried out for performance enhancement of the solar cooker. The box-type solar cooker has a complex thermal analysis due to the transient heat transfer phenomenon involved in three dimensions. A comparison of the standard correlation available are analysed for accuracy of predicted results with experimental data. The investigation involves the experimental determination of the parameters viz. wind heat transfer coefficient, side and bottom loss coefficient, inner and outer glass temperature. The extensive data is analysed with that of standard correlations and the significance of the experimental data is checked. Analysis found to have deviation of 3%-20% in experimental and correlation data, which indicates that for accuracy of performance analysis the studied parameters should be determined experimentally.

Keywords
solar cooker, cooking, plate temperature, thermal performance

Nomenclature

A	aperture area of cooker (m^2)
A_p	aperture area of absorber plate of unglazed test plate (m^2)
C_p	specific heat of unglazed test plate (J/kgK)
h_w	wind heat transfer coefficient (W/m^2K)
I	instantaneous value of solar radiation (W/m^2)
k	thermal conductivity of air (W/mK)
k_a	thermal conductivity of cement asbestos ((W/mK)
k_{gw}	thermal conductivity of glass wool (W/mK)
L	thickness of glass cover (m)
L_1	air gap spacing between absorber plate and inner glass cover (m)
L_2	air gap spacing between inner and outer glass cover (m)
a_L	thickness of asbestos sheet (m)
L_{cs}	thickness of cement slab (m)
L_{gw}	thickness of glass wool (m)
Q_a	rate of heat absorbed by test plate per unit area (W/m^2)
$Q_{b''}$	bottom heat loss flux (W/m^2)
Q_c	rate of convective heat loss per unit area of test plate (W/m^2)
Q_r	rate of radiative heat loss per unit area of test plate (W/m^2)
Q_s	Sensible heat absorbed rate to test plate temperature rise per unit area (W/m^2)
$'T_p$	thickness of test plate (m)

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T_{as} ambient temperature at stagnation (*K*)
Tp average test plate temperature (*K*)
T_{mp1} mean temperature of absorber plate and inner glass cover (*K*)
T_{m12} mean temperature of inner and outer glass cover (*K*)
U_L overall heat loss coefficient ($W/m^2\ °C$)
U_t top heat loss coefficient ($W/m^2\ °C$)
U_b bottom heat loss coefficient ($W/m^2\ °C$)
U_s side heat loss coefficient ($W/m^2\ °C$)
α_p absorptivity of the test plate
ε_p emissivity of the test plate
εg emissivity of glass
ρ mass density of test plate (kg/m^3)
σ Stefan-Boltzmann constant (W/m^2K^4)
dT difference of temperature of test plate during the time interval (*sec*)
T_{it} top insulation temperature of the test plate (*K*)
T_{ib} bottom insulation temperature of the test plate (*K*)

Introduction

The demand for cleaner and sustainable energy resources in the present scenario leads to the use of solar energy as an effective alternative to conventional fossil fuels. As the food is required on daily basis and by everyone thus if the utilization of solar cooking is taken up by a large population, then a huge amount of energy required from fossil fuel can be saved. The basic principle of solar cooking is based on the extraction of solar energy and its conversion to heat and its conduction to the cooking pot. Continuous investigations are being carried out to bring out a design of solar cooker that proves to be highly effective and with a better performance. Various geometrical and operating parameters are investigated by researchers to fulfil the aim. Thermal performance testing is one of the most prominent aspects of box-type solar cooker. A lot of research was focused on improving their efficiencies of various types of solar cookers such as concentrating type, parabolic, panel solar cookers, cookers with variation in shapes or geometry as square and rectangular and cookers with storage.

The first thermal performance analysis was led by VITA [1], Volunteers in Technical Assistance (VITA) the evaluation was on different measures, for example, cooking execution, strength, cost, weight, straightforwardness to move simplicity of activity, simplicity of assembling and versatility to local aptitudes and materials. Different techno monetary psychological factors scaled on 100 pointer scale was evaluated by an examination announced by Bowman and Blatt [2], the transient model for a single glazed box type solar cooker was proposed by Garg et al.[3] predicted the temperature profile for various elements of the cooker. That transient model included a simple steady-state model of a solar cooker neglecting heat capacity terms. The values obtained theoretically were much higher than the observed values from the experiments. Certain improvements were added by Vaishya et al. [4] in a box-type solar cooker with certain improvements in the form of the double glass cover and a plane reflector, keeping it horizontal in sunlight with reflector vertical. Data were recorded and analyzed for the highest temperature for different months at Delhi. Literature by Kandpal and Mathur [5] reported having a study on the economic feasibility of using a simple box-type solar cooker using simple engineering economics and represented it graphically using certain numerical calculations. The major contribution was reported by Mullick et al. [6]. The researchers proposed a new performance parameter named as the first and second figure of merit $F1$ and $F2$, respectively of box-type solar cookers. The methodology presented includes the no-load stagnation test and full load water boiling test to find $F1$ and $F2$ of box type solar cookers. The above method was extremely helpful and given a proper method to look at the presentation of various kinds of sun-oriented cooker. Chaaniwala and Doshi [7] developed a correlation for top heat loss coefficient based on indoor experimental data. The proposed correlation was based on the analysis that the heat loss coefficient of a solar box cooker directly varies with plate temperature and wind velocity. Jurban and Alsaad [8] were reported to develop a theoretical model for single- and double-glazed box-type solar cookers with or without reflectors. The mathematical model was created using a heat balance analysis of the various components of the cooker, the variation of various parameters such as material composition properties and the overall heat loss coefficient as a function of the absorber plate and temperature of the food item. The results of the theoretical investigation were and conform reasonably to available experimental results.

An improved strategy to evaluate the top heat loss factor of flat plate collector with single coating and twofold coating was accounted for by Mullick and Samdarshi [9]. The values of heat loss factor at the top were less than

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three percent of the values acquired by the iterative arrangement of the energy balance condition for single glazing. Thus, for authorities with twofold coating, the values of top heat loss factor were less than three percent contrasted with numerical arrangement of the warmth balance condition for twofold coating. Suharta et.al [10] devoted three years in Indonesia in promotion of solar cookers. A mathematical model speaking to the heat transfer forms required inside a box-type sunlight-based cooker, containing nourishment, was created by Pejack [11]. The outcomes announced that the nourishment temperature was influenced by scope, month, wind, mists, nourishment amount, thermal obstruction of the sides of the case and direction of the box during cooking. Mullick et al. [12] have also proposed the testing procedure for paraboloid-type solar cookers. While the impact of wind on the exhibition of paraboloid type concentrator sun powered cookers was talked about by Kumar and Kishor [13]. Das et al. [14] created thermal models for the solar box-cookers stacked with one, two, or four vessels. A thermal model was proposed by Thulsi Das et al. [15] for box type solar cooker with one to four vessel variation using heat transfer coefficient as main parameter calculated experimentally. Research also proposed that stainless steel and aluminum vessels can be used with black paint. Said and Medhat [16] recommended formulae for calculating orientation angle and tilt angle of the reflector of the sun-based cooker. El-Sebaii et al.[17] literature answered to build up a mathematical model for a box type sunlight-based cooker with external and inward reflectors. The performance of the cooker was researched utilizing a PC simulation as characteristics and specific boiling time. Sharan and Naik [18] endeavored to find the socio-psychological components determining the acknowledgment of SBCs in India. In Brunei Darussalam, a program to create, test and evaluate a sun powered cooker was done.

Various studies were carried out on the analyses of the effect of the number of pots and different load conditions. Mullick et al. [19] recommended that that the cooker must be tested with full load distributed equally in all pots based on the test results for box-type solar cooker with different loads and number of pots. The performance of the box-type solar cooker with auxiliary heating was studied and reported by Hussein [20], using heating oil to provide continuous supply during cloudy days.

Nandwani [21] reported the performance of two solar box cookers with two similar compartments and compared the behavior of a metallic slab filled with a phase change material for short term heat storage, with a conventional absorbing sheet, the use of a selective coating, as compared to a normal black painted. Amer et al. [22] experimentally evaluated four procedures to test solar cookers and analyzed the results and compared them in steady-state condition-based ASHRAE 93-86 standard. The experimental results have been compared with Saunier's method, ASHRAE standard and Exell's method.

Literature reported by Amer et. Al [23] built up a transient model with an intends to describe the dynamic conduct of flat plate sun-powered collector- based utilizing model of one node where the mean temperature is evaluated considering the heat capacity of the plate, cylinders, and the fluid, lumped together. On the other hand, Funk and Larson [24], proposed a model for estimation of the cooking intensity of a sun-based cooker dependent on sun-powered catch territory, overall heat transfer coefficient, and absorber plate thermal conductivity is known as three controlled factors and three uncontrolled factors insulation, temperature distribution and load distribution.

Gaur et al. [25] proposed a cooking vessel that gave a sunken cover. Their experimental investigation demonstrated a decrease of 10-13% in cooking time contrasted with and standard cooking vessels under similar conditions. Biermann et al. [26] conducted experiments on seven distinct types of sun-powered cookers for one year which include around 66 families in South Africa, the results revealed that the Fuel utilization estimations show overall fuel reserve funds of 38%, coming about in assessed take care of periods (through monetary fuel investment funds) from multi-month onwards, contingent upon the sort and area. Akhtar and Mullick [27] proposed correlations for the estimation of heat loss coefficients in sun-based collectors with single glazing. Semi-analytical amendment factor (f) was utilized as the proportion of internal to external heat loss coefficients as a component of collector parameters and ambient variable. They also proposed a method for precise estimation of glass cover temperatures, individual heat transfer coefficients and top heat loss factor of flat plate sun-based collectors with single and two-fold glazing without the necessity of arrangements of heat balance conditions. Funk [28] had distinguished five uncontrolled factors wind, ambient temperature, pot substance temperature, insolation and sun powered altitude-azimuth and three controlled factors loading, tracking, temperature detecting influencing cooker performance. Sharma et al. [29] developed and performed the thermal analysis an imaginative design of sun-powered cooker in which there were isolated parts for energy collection and cooking along with a capacity unit utilizing commercial evaluation erythritol as storage liquid. It was seen that early afternoon cooking has no impact on night cooking and night cooking utilizing heat storage was seen as quicker than early afternoon cooking. The cooker performance under a variety of working and climatic conditions was learned at Mie, Japan. Suharta et al. [30] compared three Indonesian solar cookers, namely the newest

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design HS 5521 with HS 7033 and HS 5521 with and without the load of heat collection rate and of cooking performance. Mullick et al. [31] analyzed the effect of some of the parameters such as optical efficiency, the latitude of location, season on the performance of box-type solar cookers. Shaw [32] compared the different Test standards for solar cookers. Right now, there are three significant testing standards for sunlight-based cookers utilized all through the world. These standards contrast generally in their degree, unpredictability, and expectations. Ekechukwu and Ugwuoke [33] had reported that the performance of the cooker with a plane reflector in place was improved tremendously as compared to that without the reflector.

Amer [34], experimentally researched the exhibition of a double exposure sun-powered cooker, which was exposed to radiation from the top and base with a set of the plane diffuse reflectors. The presentation was contrasted with the conventional sun-oriented cooker under the same environmental conditions. Results demonstrated that the absorber of the sun-oriented cooker achieved stagnation temperatures of 140 ºC and 165 ºC individually. The structure of the sunlight-based cooker was improved where the safeguard is presented to sun-powered radiation from the top and the base sides. Along with the plane diffuse reflectors with a reason to coordinate the radiation onto the base side of the safeguard plate. The exhibitions of the improved plan were contrasted and the conventional one utilizing heat balance condition. Results revealed that the safeguards of the case type cooker and the twofold presentation cooker achieved a temperature of 140°C and 165°C respectively, it was also seen that cooking time was diminished by around 30–60 min. Abdullah et al. [35] modified the designs, constructed, and tested two full tracking solar cookers, a paraboloid dish solar cooker (PDSC) and a booster mirror solar box cooker (BMSBC) to compare the performance under the same operating conditions. It was reported that the cooking rate was higher in paraboloid dish type solar cooker as compared to others, it can also cook well during intermittent conditions of sunny and cloudy days. The thermal execution also indicated a decrease of 24 to 35% in the heat loss from the recipient within the sight of the windshield. Nahar et al. [36] developed and performed the investigation on the performance of box stockpiling sun-oriented cooker with utilized engine as storage material utilizing stagnation temperature as one parameter so cooking can be performed in late night. The effectiveness of the hot box storage type sunlight-based cooker was seen as 27. Suresh et al. [37] proposed a semi-log plot method and an approximate method to find $F2$ known as second figure of merit of box-type solar cookers. Ibrahim and Medhat [16] used the standard procedure of cooking power and analyzed a box type solar cooker to adjust four cooking pots under different weather conditions prevailing at in Tatna (Egypt) during July 2002.The cooker has the ability to cook variety of food with a utilization efficiency of 26.7%. A simple test procedure for the determination of various design parameters was proposed by Kumar [38] used for the prediction of thermal performance of box-type solar cooker. Based on the experimental analysis, a correlation for the second figure of merit as a function of load was proposed. The experimental and calculated $F2$ values were found in proximity.

A cylindrical single glazed with a plane reflector box-type sun-powered cooker with one cooking pot was developed and tried by Kurt [39] under the predominant climate conditions in Karabuk, Turkey. Nandwani [40] designed and analyzed a half-breed multi-reason sunlight-based cooker, which is utilized for food making, for warming up the water to inactivate organisms and refining procedures to evacuate different minerals and items drying. Schwarzer and Vieira da Silva [41] analyzed general sorts of sun-oriented cookers, their fundamental attributes, and experimental systems to test the various kinds of sun-powered cookers, and they proposed a simplified analytical model to plan a basic cooking framework. Literature suggested by Kurt et al. [39] reported using ANN for the purpose of prediction of thermal performance parameters of the experimentally investigated box-type solar cooker.

Arezki et al. [42] proposed a modification in the shape of the cooking vessel to reduce the cooking time, which further can improve heat transfer to the food through the pot walls.

Grupp et al. [43] developed to record food temperature, atmospheric temperature, and solar radiation incident on a solar cooker and evaluated the number of the cooking cycle, cooking times and food mass. The results were compared with actual conditions for box-type and concentrating solar cookers. Performance evaluation of two different types of solar cooker viz. rectangular and square box type was conducted by Garba [44] at Usmanudanfodiyo University Energy Research Centre, observations revealed that the rectangular box type cooker performed better than the square type. Dasin et al. [45] performed an evaluation of a parabolic concentrator type solar cooker in Abubakar Tafawa Balewa University Bauchi in Nigeria, results reported that attainment of stagnation temperature was achieved on three different days during June and July, it was also observed that it took 75 mins to boil 200g of white rice. Pinar [46] analyzed and compared the performance of box- type solar cookers with and without thermal energy storage using as storage material as Bayburt stone due to its low density and notably high specific heat capacity, in prevailing climatic conditions at Bayburt, Turkey,

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results indicated a considerable improvement in the performance of solar cooker. Geddam et al. [47] worked on experimental analysis experimentally obtained $F2$ using a test procedure to determine these parameters under different load conditions of water and used the procedure to generate heating characteristic curves.
Manuel et al. [48] proposed a revision and formulated the revision in the existing standards i.e., figures of merit used for solar cooker thermal performance evaluation using easily variable and sorted instrumentation allowing these tests applicable anywhere in the World, with a minimum investment along with simple lab conditions. S. Bhavani et al. [49] worked on certain funny logic rules while analyzing the thermal performance of a box-type solar cooker with respect to the local climate prevailing at Chennai. Different tests were performed using this logic on the solar cooker. The sun-based cooker was equipped with PCM ($C_{18}H_{36}O_2$) and Nanoparticles (Al_2O_3).
Certain researchers raised the concern of fire in the buildings, and the main reason observed was cooking application [50] solar cookers are safe to operate and have negligible fire concern as they are operated in an open environment.
The literature review reveals that almost all the investigations are carried out using the standard correlation available for wind-heat transfer coefficient, side heat loss coefficient, outer glass cover temperature and inner glass cover temperature. The experimental analysis of any type of cooker should be carried out by calculating these parameters experimentally for accuracy in the results. The present investigation addresses these setbacks of correlation results and suggests experimental examination of standard data collection.
The present study involves a comparison of experimental and correlations data of selected climatic and operating variables, which affect the thermal performance parameters such as plate temperature, wind-heat transfer coefficient, side heat loss coefficient, outer glass cover temperature and inner glass cover temperature.

Methods

Description of the experimental setup

To determine the performance of the solar cooker an experimental facility has been designed and fabricated as per the BIS standard [51]. The photographic view of the experimental box-type solar cookers set up along with the test plate and its specifications are shown in Figure 1 and Table 1, respectively. The solar cooker has the dimension of (length × width × height) of 980 × 980 × 98 (mm), respectively, made of 12 mm plyboard (k=0.1154 W/mK). The absorber plate of the cooker is made up of aluminum sheet and painted with blackboard paint. The bottom and the sides of the cooker are well insulated by using glass wool (k=0.037 W/mK). The air spacing between the plate and inner glass cover is 98 mm and that between glass covers is 12 mm. Temperatures at 21 locations were measured with the help of calibrated Chromel Alumel (K-type) thermocouples to ascertain the accuracy of temperature measurement, thermocouples have been calibrated under laboratory conditions against a dry block temperature calibrated instant. (Presys Instruments T-25 N), having least count of 0.01 °C. Pre-calibrated chromel-alumel thermocouples were fixed at the center of the absorber plate, inner and outer glass surface of both glass covers, at the center of glass wool insulation layers of 25 mm each with an objective to calculate the bottom and side losses. Solar radiations were recorded by pyranometer (KIPP and ZONEN). The stagnation test experiments to determine the thermal performance of the cooker have been conducted and the environmental temperature was measured at the site of the experiments. The experimental solar cooker and the unglazed test plate were kept side by side at the same height to minimize the uncertainty due to hw.
The outdoor experiments have been conducted on the rooftop of center for alternate energy at UPES on clear sunshine days. The experiments have been performed covering a change of season in January to December excluding July and August as they are heavily rained months in the Dehradun region in India. The testing of the solar cookers has been carried out as per BIS standard [51].
To evaluate the effect of various parameters on the performance of box-type solar cooker, various parameters (Table 2) were measured and recorded in UPES data logging software customized for the setup.
The cost of fabrication of the cooker was economical and estimated to be around INR1000, which is feasible and economical for the population residing in hilly and remote locations.

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Fig.1. Experimental test setup along with plate at UPES, Dehradun

Table 1. Specifications of the test setup

Material Size Box Wooden Board	1.185×1.175×0.28 m
Tray 24 Gauge Aluminum Sheet	0.87×0.87 m
Glazing(Double) ordinary glass sheets	4 mm thick
Aperture area	0.98×0.98 m
Air gap spacing between tray and inner glass	98 mm
Air gap spacing between inner glass and outer glass	12 mm
Test plate dimensions	
Area exposed to sun (aluminum sheet)	870×870 mm
Thickness of asbestos sheet	5 mm
Thickness of insulation (3 layers)	25 mm each

Table 2. Measuring instruments.

Parameters	**Measuring equipment**
Solar insolation (I)	Pyranometer
Wind velocity(V)	Ultrasonic wind sensor
Plate temperature(T_p)	K type thermocouple
Outer glass temperature(Tg_1)	K type thermocouple
Inner glass temperature(Tg_2)	K type thermocouple

Calculation procedure

Wind-heat transfer coefficient (h_w)

Based on the above-measured parameters wind heat transfer coefficient, bottom and side heat loss coefficient were evaluated.

In the present BIS model of box-type solar cooker, the effect of wind-heat transfer coefficient (h_w) on the performance of solar cooker has not been considered. The wind heat transfer coefficient depends upon wind velocity (V). To evaluate h_w several correlations have been suggested in the literature. Most of these correlations are based on wind tunnel test whereas in actual situation (especially in outdoor conditions) the test conditions cannot always be represented by the wind tunnel conditions.

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Some of the relations available in literature are:

- Mc. Adams [52] suggested based on wind tunnel experiments

(1) $$h_w = 5.7 + 3.8\,V, \text{ for } V \leq 5m/s$$

- Mullick *et al.* [21] carried out indoor experimental study for h_w, from the outer surface of flat horizontal surface, using an industrial fan to produce forced air flow. They concluded that the values of h_w obtained by wind tunnel tests would be an underestimation and should not be employed under other conditions. They have proposed

(2) $$h_w = 10.03 + 4.68V$$

- Kumar *et al.* [19] conducted outdoor experiments on unglazed aluminum blackened plate of size 925 mm × 865 mm × 2 mm in real environment and suggested the following correlation (for wind speed recorded at an interval of 1sec and averaged over wind speed at 10 minutes interval).

(3) $$h_w = 7.15 + 3.19, \quad \text{for} \quad V \leq 1.12m/$$

The above values of the h_w were compared with the value of wind heat transfer coefficient obtained from heat balance of the box type solar cooker setup using following formula.

(4) $$h_w = \frac{[\alpha pI - Ki\frac{(Tib - Tib)}{t} - \sigma\epsilon p(T_p^4 - T_s^4) - masCpas\frac{dT_{as}}{dt} - miCi\frac{dT_{mi}}{dt} - mpCp\frac{dT_p}{dt}]}{T_p - T_a}$$

The bottom and side loss coefficient were calculated and compared with the assigned value of 0.85 W/m^2°C reported by Khan [53].

<u>Bottom and side heat loss coefficient</u>

The above assumed value of bottom and side heat loss coefficient was compared with the value obtained from heat balance of the set up using formula.

(5) $$U_{(b+s)} = (Q_b + Q_s)/(T_p - T_a)A_s$$

A comparative analysis is performed for inner and outer glass cover temperatures using experimentally, measured values and the values of glass temperature obtained from Akhtar's correlations [54].

Results and discussion

Figure 2 shows the variation of plate temperature across various months of the year at the geographic location of Dehradun. Insolation seems to have a considerable effect on plate temperature. It is obvious from the fact that a higher value of insolation will result into higher plate temperature. The value of plate was measured to be a minimum of 313 K in the month of November corresponding to the highest value of 397 K during June. The value of insolation lies between 444 W/m2 to 970 W/m2 throughout the year.

In the present work, test information of unglazed test plate during the months JAN-DEC for a long time were utilized to evaluate wind-heat move coefficient. Wind speed was recorded at the site of investigations with a testing time of 1 second. Estimated wind speed was arrived at the midpoint of over a time of 10 minutes to give a delegate estimation of wind speed for that period. The heat transfer coefficient for the wind was assessed from equation (4) on various exploratory runs when conditions were near steady state. Tests were performed on an unglazed test plate of about 0.9 m square in size.

Moreover, there is a considerable difference in the values of wind-heat transfer coefficient (*hw)* obtained from different correlations at the same wind velocity. The comparative study of the above correlations is shown in Figure.3. At certain wind velocities, Harples and Charlesworth [55] correlation gives the minimum value whereas the maximum value is obtained from the correlation proposed by the experimental data analysis using equation (4). The percentage difference is considerably higher at lower wind velocities, and it decreases with increasing velocities.

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Figure 3 shows the comparison between the average values of wind-heat transfer coefficient obtained during experimentation throughout the year in respect to the values of wind heat transfer coefficient calculated using different correlation suggested by Kumar et al. [19], Mc Adams [52], Harples and Charlesworth [55] and Sparro et al. [56], using the respective values of measure wind velocity. The average value of insolation and plate temperature for a particular month is calculated for comparison. It is observed from the figure that the values of h_w increase from January to June and then decreases during experimentation and theoretical investigation. Experimental values were observed to be higher than the theoretical values resulted from various correlations. It shows that wind velocity has a considerable effect on the wind heat transfer coefficient. For correlation, the results of various investigations were normalized for a plate length of 0.9 m.

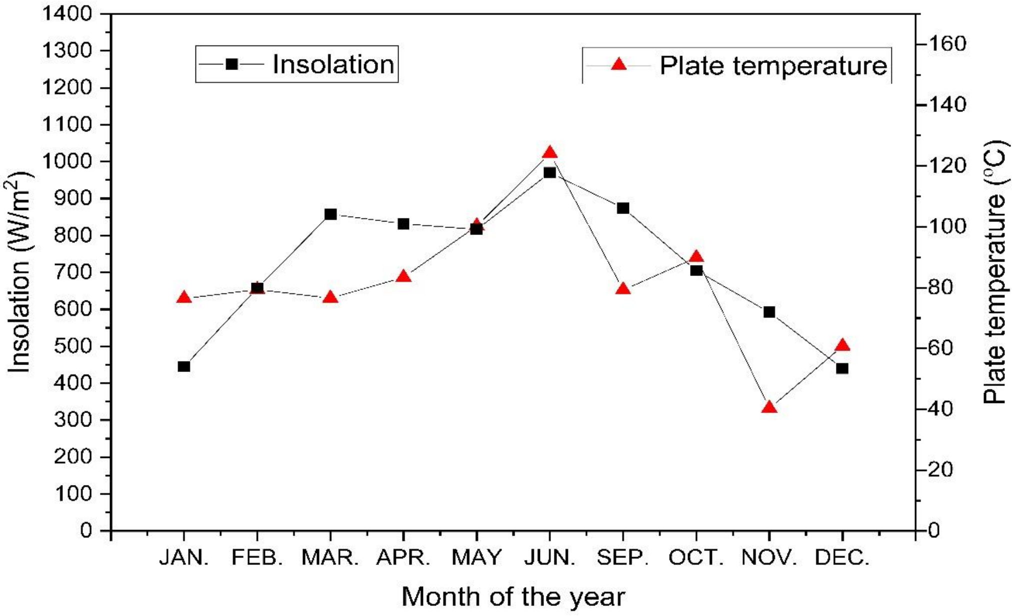

Fig.2. Variation of plate temperature with insolation during different months of year

Figure 4 depicts the variation of the summation of bottom and side heat loss coefficient (U_{b+s}) across various months of the year and compared with assumed values [53], the value of loss coefficient varies between 0.4 to 0.5 throughout the year. It is observed that an average variation of 20% is observed between the calculated and assumed values throughout the year. There is an increase seen in the bottom and side heat loss coefficient from April to June because of the wind velocity factor. As seen in Figure 3 the wind heat transfer coefficient is higher in these months, thus the losses will be enhanced. The quantum of change is not seen to substantially influence during experimentation.

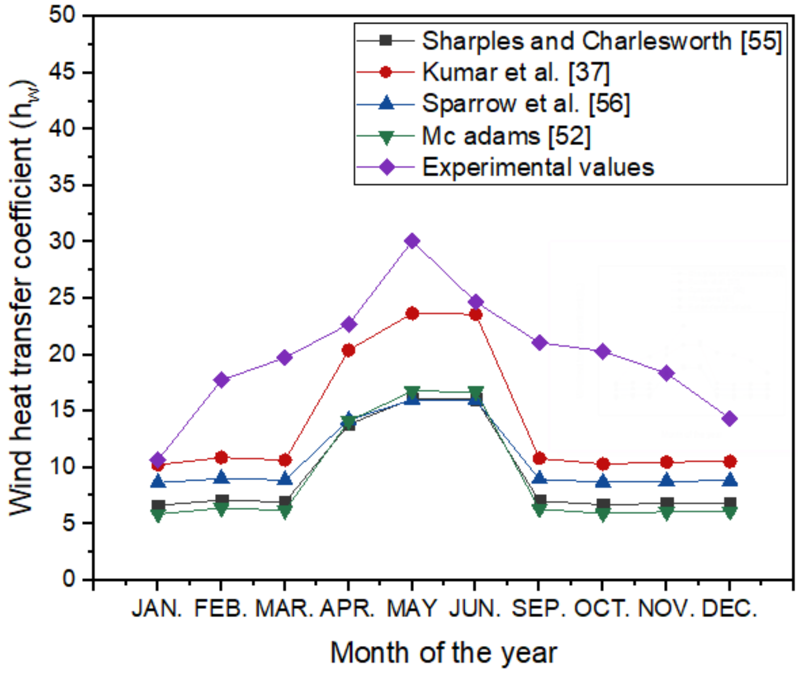

Fig. 3. Variation of wind heat transfer coefficient using different correlations

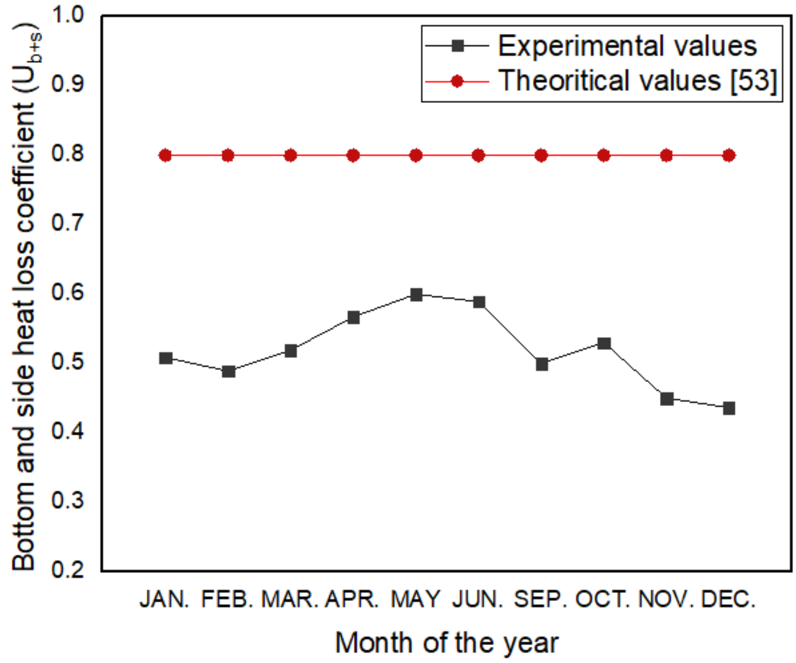

Fig. 4. Variation of wind heat transfer coefficient using different correlations

Figure 5 shows the variation of outer glass cover temperature measured during different months of the year and compared with the values obtained using Akhtar [54] correlation. The outer glass cover temperature is highest in September and lowest in November. The variation between the experimentally measured values and calculated values lies between 4% to 20%. The variation of inner glass cover temperature measured during different months of the year and compared with the values obtained using Akhtar [54] correlation is depicted in figure 6. The inner glass cover temperature is highest in the month of September and lowest in the month of November. The variation between the experimentally measured values and calculated values lies between 3% to 20%.

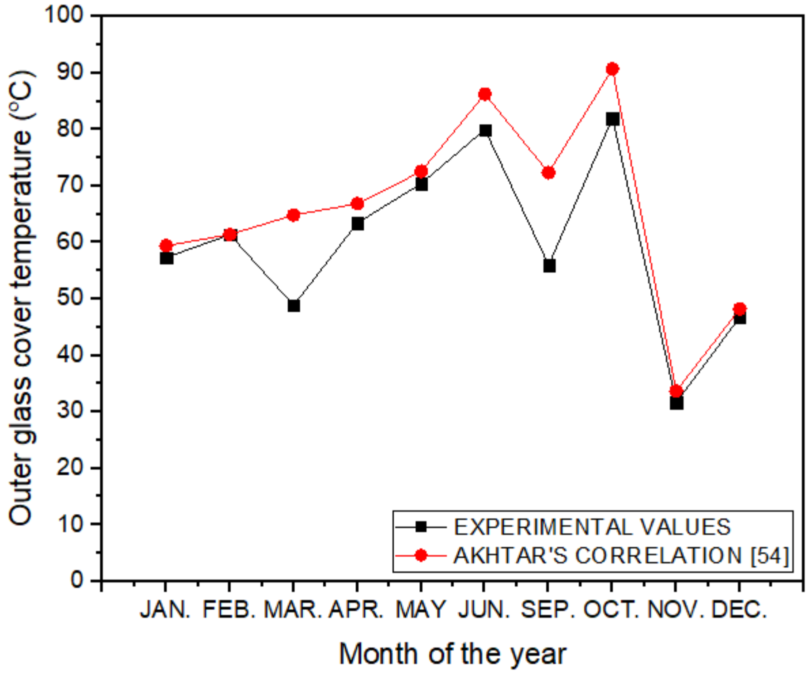

Fig. 5. Variation of experimental and predicted outer glass cover temperature

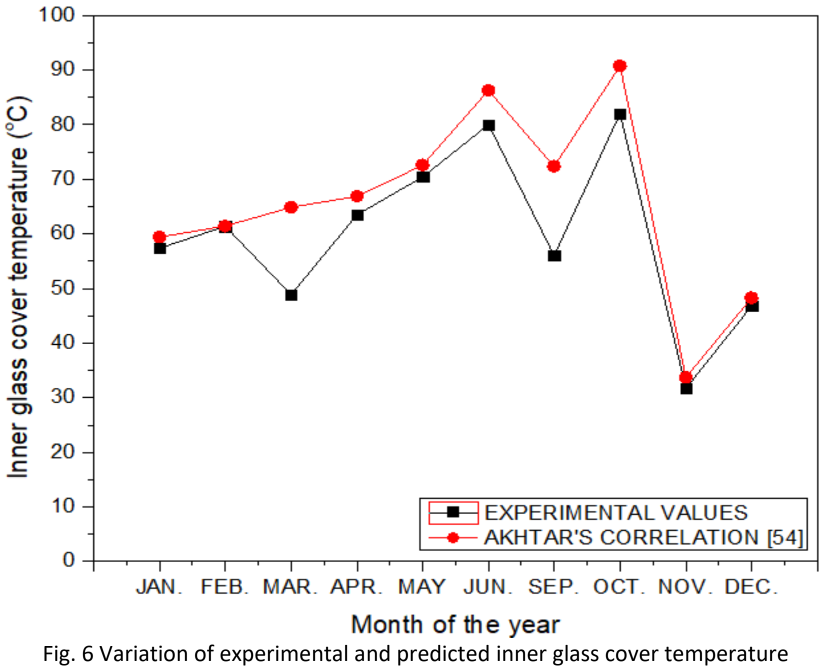

Fig. 6 Variation of experimental and predicted inner glass cover temperature

Conclusion

An extensive review was carried out to determine the testing standards for the solar cooker as well as the parameters that determine the performance of the cooker. Finally, comparison of experimental data with that of correlations data of selected climatic and operating variables was carried out. The wind heat transfer coefficient, side and bottom heat loss coefficient, outer glass cover temperature and inner glass cover temperature data was compared with that of the standard correlations. It was revealed that there was a deviation of a maximum 20% for all the selected parameters, which can be in the acceptable range but leads to an increase the inaccuracy of the results. Therefore, it is suggested that all these parameters should be calculated based on the geometry of the cooker and the geographical location of the experimentation to get accurate results. It is concluded that the geographical location plays a dominating role in the performance of the cooker and the operating parameters should be calculated rather than placing correlation values.

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Conflict of interest
There are no conflicts to declare.

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