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ASSESSMENT OF DAIRY PRODUCTION DEVELOPMENT ON THE EXAMPLE OF POLISH CONDITIONS AND COMPARISONS WITH CERTAIN EUROPEAN COUNTRIES

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ABSTRACT. Changes observed in the European dairy sector in the last decades constitute an important example of transformation processes taking place in the global food economy. The aim of the study was to present an analytical approach to assessment of advance concerning certain technical and biological resources in the farm dairy production system. Data from the Polish dairy production system were used to show and assess some of the trends regarding the dairy system development, including some comparisons with other EU countries. As a result of undertaken studies, there are scientific premises to identify technical and biological solutions for optimizing the farm dairy production system, allowing sustainable improvement. Further effective transformation of the Polish dairy sector requires overcoming certain barriers hindering development of the sector, connected first of all with high dispersion in raw milk production and its low technology level, high dispersion of dairy processing, and others. Implementation of modern technical equipment for milking at dairy farms needs simultaneous improvement of dairy cow herds and other factors, e.g. economic profitability.

Introduction

Not only are milk and dairy products a vital source of nutrition for people, but they also present livelihood opportunities for farmers, processors, shopkeepers and other stakeholders in the dairy value chain (Muehlhoff *et al*., 2013). As a result, dairy production ranks among the most important agricultural activities in many countries of the world, including developing as well as developed countries.

Significance of dairy production translates into dynamic improvement of all elements which create the dairy production system, *i.e*. set of objects and relationships between the objects, according to the system definition (Pabis, 1985). Improvement is expressed by achievement of advance in many areas of the dairy production system. Technical advance is represented by more and more sophisticated milking systems, ranging from bucket milking systems to AMS (automatic milking system) and AMR (automatic milking rotary). The milking systems improvement is assessed in the context of efficiency aspects (Castro *et al*., 2012; Steeneveld *et al*., 2012), farmer satisfaction (Wagner *et al*., 2001), economic aspects (Rotz *et al*., 2003), energy consumption (Calcante *et al*., 2016), animal welfare (Jacobs, Siegford, 2012) and others. The general public seems to be increasingly interested in the welfare of farm animals and this apprehension, along with uncertainty about food safety, may necessitate increased emphasis on functional traits to maintain or improve the consumption of milk and dairy products (Boettcher, 2001).

The assessment of dairy production also concerns the use and adoption of precision dairy farming technology by producers (Borchers, Bewley, 2015). Gathered information concerning parameters is limited to precision technologies used in or around dairy parlours (Jago *et al*., 2013).

Many examples of dairy production development generate the research problem concerning the approach to assessing and comparing different kinds of improvement in the field of the dairy production system. One of the results of various kinds of improvements implemented can be sustainable development of dairy production as one of the most important trends in the dairy industry (von Keyserlingk *et al*., 2013). Many farms have a common goal of becoming more sustainable.

According to the US legal definition (US Code Title 7, Section 3103), sustainability includes "an integrated system of plant and animal production practices having a site-specific application that will over the long-term: … make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls, sustain the economic viability of farm operations, and enhance the quality of life for farmers and society as a whole".

Once the definition of sustainability is considered, it is possible to ask about the most efficient use of non-renewable resources and on-farm resources within the farm dairy production.

The aim of the study was to present an analytical approach to assessment of advance concerning certain technical and biological resources in the farm dairy production system. The dairy production system comprises different kinds of biological and technical objects as well as technological solutions, so it is the area allowing identification of some aspects of dairy production development and advance. Advance in dairy production may be analyzed in the regional and national scale. The national scale was included as the scope of analysis. Poland is one of the countries where dairy production plays an important role in the agri-food market and economy (Agriculture and Rural Economy in Poland, 2014). Especially since EU accession, Polish dairy production has experienced dynamic changes in all spheres of its performance (Malak-Rawlikowska, Żekało, 2014). Therefore, data from the Polish dairy production system were used to show and assess some of the trends regarding the dairy system development, including some comparisons with other EU countries.

The analyzed dairy production system in fact includes a wide range of material and non-material elements and their mutual relationships. For the sake of the undertaken analysis, the scope of the dairy production system was limited to some technical equipment used on dairy farms, cows, their production indices and relationships connecting elements of the dairy production system.

Materials and methods

The transformation process in the field of dairy production is characterized by many specific features and determined by initial conditions, assumed change objectives and other factors. Each material object in the dairy production system represents some kind of potential (Gaworski, Leola, 2014), so it is possible to distinguish biological and technical potential. Moreover, human potential complements the dairy production system, that including the role of human capital as management staff.

Taking into account farm dairy production as an example, biological potential expresses data describing dairy cows, *i.e.* annual milk yield per cow. Basing on the mentioned biological potential and cow herd size, it is possible to find the amount of produced milk. Technical potential in the field of dairy production is a set of more or less sophisticated technical equipment needed to operate the cow herd and the milk stream at the farm.

Moreover, economic potential may be considered in the dairy production system. Economic potential is a set of data, which decide about economic effectiveness of farm dairy production, *e.g.* ex-farm milk price, dairy production costs.

Changes within each kind of potential can be identified by adequate progress, *i.e.* biological, technical and economic progress.

Because changes within the considered system (*e.g.* dairy system) include moreover different kinds of potential, there exist premises to compare them in order to assess the effectiveness of progress implementation. When different kinds of progress are achieved at the same time, it is possible to investigate the effects of simultaneity (Gaworski, 2005) translating into certain analytical indices. One of such indices is the coefficient of AMS (automatic milking system) potential use (Gaworski, 2006), which involves a comparison of the biological potential of dairy production, *i.e.* annual milk yield per cow and technical potential expressed by necessary capacity of the automatic milking system (AMS) installed at the dairy farm. Data concerning the current annual milk yield per cow in the national scale (27 EU countries) and data concerning the minimum annual milk yield per cow operated by AMS were taken in order to calculate the coefficient of AMS potential use (c_{pu}) according to the following formula:

$$c_{pu} = \frac{A_{myc}}{A_{AMS\,\min}} \text{ [-]} \qquad [1]$$

where

A_{myc} – current annual milk yield per cow [kg·cow^{-1}·year^{-1}];

A_{AMSmin} – minimum annual milk yield per cow operated by AMS [kg·cow^{-1}·year^{-1}].

The minimum annual milk yield per cow operated by AMS is the yield, which – for the operated cow herd size – allows obtaining such an amount of milk per year as to ensure the minimum efficiency of AMS use. The minimum efficiency of AMS use is expressed by the minimum amount of milk milked by AMS per year, which determines the performance balance of AMS use. Data concerning the minimum amount of milk milked by AMS per year are presented in the specialist literature on dairy production.

The second stage of analysis on progress at dairy farms involved a comparison of specialist technical equipment. Detailed data concerning two groups of technical equipment used at dairy farms, *i.e.* milking machines and milk coolers were taken into account.

Within the group of milking machines, some changes concerning the number of bucket milking installations and pipeline milking installations at Polish dairy farms were analyzed. Within the group of milk coolers, some changes in the number of coolers of milk in buckets and tank milk coolers were calculated. The changes were considered for an 8-year period.

To analyze changes in the technical potential for milking and milk cooling at dairy farms, an index of equipment modernity (i_{em}) (Gaworski, Priekulis, 2014) can be proposed. The general method to calculate the i_{em} index requires, first, identification of the generations of technical equipment used in the area of activity under analysis. When the area of activity in farm dairy production is milking, it is possible to identify the following generations (G) of technical equipment:

- bucket milking machines (GI_m),
- pipeline milking machines (GII_m),
- milking parlors ($GIII_m$),
- automatic milking system – AMS (GIV_m).

Next, in the field of milk cooling at dairy farms, the following generations of technical equipment can be taken into account:

- coolers of milk in buckets (GI_c),
- tank milk coolers (GII_c)

The proposed index of equipment modernity (i_{em}) can be calculated basing on the following formula:

$$i_{em} = \frac{N_{Gh} \cdot 100}{N_{Gn}} \% \qquad [2]$$

where

N_{Gh} – number of technical objects representing highest generation of modernity [-];

N_{Gn} – total number of technical objects used for the considered activity, representing all generations of technical equipment [-].

The proposed approach, expressed by equation (2), allows to compare modernity of technical equipment and changes in modernity between some dairy farms, dairy regions and countries. There can be some problems to find the value of equipment modernity (i_{em}) index for preceding periods, when the current state of the art solutions were unknown. So, for the undertaken analysis, the index of equipment modernity was calculated for two generations of milking technical equipment (GI_m and GII_m) as well as two generations of cooling equipment (GI_c and GII_c).

Results

The set of data concerning cattle production and other group of animals producing milk in Poland is available in Table 1. Taking into account such criteria as year and group of animals, it is possible to compare changes in the number of animal population directly before Poland's EU accession as well as 10 years later. Poland, like 9 more European countries, joined the EU on May 1, 2004.

The data in Table 1 show certain trends concerning the number of heads in particular groups of animals. Comparing the periods before (2003) and after (2013) EU accession, there is a decrease in the number of cows, sheep and goats kept at Polish farms. Only the total number of cattle shows an increasing trend in the considered period. Positive changes in cattle population result from the dynamic increase in the number of beef cattle, as opposed to the number of cows which showing a falling trend.

Table 1. Data concerning cattle production and other group of animals producing milk in Poland in 2003 and 2013

Group of animals, heads	Year		Change, %
	2003	2013	
Cattle	5,488,943	5,859,541	+6.75
incl. cows	2,816,000	2,530,500	–10.14
Sheep	337,792	249,481	–26.14
Goats	192,470	81,727	–57.54

Source: faostat.fao.org; stat.gov.pl, own calculations

Elaborating on the problem of cow population changes, it is possible to state that the decrease in the total cow herd size in the 2003–2013 period was accompanied by an increase in annual milk yield per cow, translating into balance of milk production in the national scale. The difference in annual milk yield per cow at Polish dairy farms within the period of 2003–2013 was shown in Table 2 together with data from other EU countries for comparison purposes.

Table 2. Changes in annual milk yield per cow during the period of 2003–2013, in $kg \cdot cow^{-1} \cdot year^{-1}$

EU country	Year		Change, %
	2003	2013	
Austria	5,483.9	6,459.8	+17.8
Belgium	6,077.7	7,547.1	+24.2
Bulgaria	3,653.3	3,977.6	+8.9
Cyprus	5,621.3	6,395.1	+13.8
Czech Republic	5,701.9	7,644.4	+34.1
Denmark	7,626.4	8,765.9	+14.9
Estonia	5,285.3	7,898.0	+49.4
Finland	7,205.0	8,222.1	+14.1
France	5,954.1	6,414.1	+7.7
Germany	6,536.8	7,292.6	+11.6
Greece	5,248.7	3,800.8	-27.6
Hungary	5,626.0	6,869.0	+22.1
Ireland	4,585.5	4,800.3	+4.7
Italy	5,916.8	5,175.4	-12.5
Latvia	3,827.7	5,527.2	+44.4
Lithuania	4,035.0	5,446.7	+35.0
Luxembourg	6,579.3	6,984.1	+6.2
Malta	5,142.0	6,374.2	+24.0
Netherlands	7,138.7	7,643.9	+7.1
Poland	4,135.1	5,387.8	+30.3
Portugal	5,763.3	7,508.1	+30.3
Romania	2,863.3	3,771.0	+31.7
Slovakia	4,962.6	6,405.1	+29.1
Slovenia	4,731,4	5,391,6	+14.0
Spain	5,764.9	7,655.4	+32.8
Sweden	8,081.6	8,458.8	+4.7
United Kingdom	6,846.7	7,757.9	+13.3

Source: faostat.fao.org, own calculations

Positive changes in annual milk yield per cow put Poland in the group of 8 countries with the highest (above 30%) increase in the amount of milk produced by one cow during the 2003–2013 period. On the other hand, it is difficult to draw explicit conclusions from a comparison of data and result of the calculations because of different initial (2003) annual milk yield per cow and some limitations of maximum milk production by cows.

The annual milk yield per cow expresses the current state of biological potential in dairy production, while changes of annual milk yield per cow represent biological progress in dairy production. In order to discuss the significance of biological progress, one should compare this one with specific needs resulting from another, *i.e.* technical progress implemented at dairy farms. One of the most important examples of technical progress in dairy farms is the use of automatic milking systems (AMS) as an alternative solution to other milking installations (Kiiman *et al.*, 2013).

Effective use of one-stall milking robot, according to data given in some reports (Meskens *et al.*, 2001) is achieved at the level of 500,000 litres (*i.e.* 515,000 kg) of milk per year. Considering the herd size of 69 cows (60 milking cows + 15% dry off cows) operated at a dairy farm equipped with a one-stall milking robot, it is possible to calculate that one cow in the barn with an automatic milking system should produce about 7,465 kg of milk per year.

The above minimum annual milk yield per cow constitutes information about expected production potential of cows at farms equipped with the automatic milking system (AMS). On the other hand, it is possible to quote data concerning current annual milk yield per cow. Basing on such parameters, the coefficient of AMS potential use was calculated. The coefficient was calculated as a relationship between the current milk yield per cow and the above mentioned capacity of 7465 kg of milk per year.

The coefficient of AMS potential use was calculated for 2003 and 2013 taking into account the data (annual milk yield per cow) from 27 EU countries (Table 2). Differentiation of the calculated coefficient for 27 EU countries was presented in Figure 1 for 2003 and 2013.

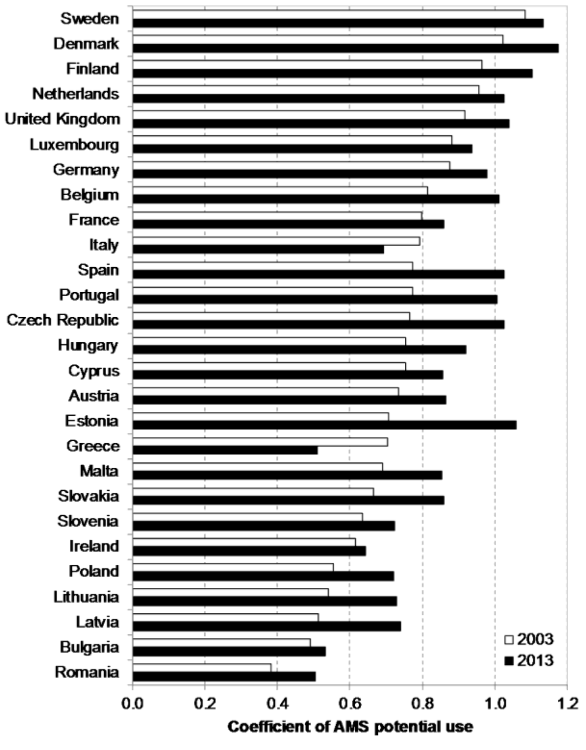

Figure 1. Coefficient of AMS potential use for 27 EU countries in 2003 and 2013
Source: author calculations on the basis of faostat.fao.org

Comparison of the coefficient values shows considerable polarization in some regional conditions connected with implementation of technical progress at dairy farms. The highest values of the coefficient can be found in north-western European countries. This means that this group of countries achieved the highest level of biological progress, as one of significant circumstances allowing effective implementation of technical progress at dairy farms.

The distribution of data presented in Figure 1 suggests the possibility to analyse changes in the coefficient values and, indirectly, increase in the biological potential of dairy production, *i.e.* annual milk yield per cow within the group of countries. For a deeper analysis, one could propose the following classification ranges for the coefficient: 0.00–0.40, 0.41–0.60, 0.61–0.80, 0.81–1.00 and 1.01–1.20. Some details concerning the number of countries in each range and mean value of the coefficient for particular ranges and compared years (2003 and 2013) were given in Table 3.

Table 3. Distribution of the coefficient of AMS potential use (c_{pu}) including ranges of values and analysed years (2003 and 2013)

Range of the c_{pu}	Number of countries in the range for the year		c_{pu} mean ± SD for the range and year	
	2003	2013	2003	2013
0.00–0.40	1	0	0.38	0.00
0.41–0.60	4	3	0.52 ± 0.03	0.52 ± 0.01
0.61–0.80	14	6	0.73 ± 0.06	0.71 ± 0.04
0.81–1.00	6	8	0.90 ± 0.06	0.89 ± 0.05
1.01–1.20	2	10	1.05 ± 0.04	1.06 ± 0.06

Source: author calculations

Comparing the results of calculations given in Table 3, it is possible to refer to an increase in the number of countries within the highest ranges of the c_{pu} (coefficient of AMS potential use) values for the considered period, *i.e.* 2003–2013. The results show that 37% of EU countries were characterized by biological potential of cow herds which met the requirements on annual milk yield of cows operated by the automatic milking system (AMS) in 2013.

Within the second stage of analysis, the indices of equipment modernity for milking systems and milk cooling systems at Polish dairy system were calculated for two selected years (2002 and 2010), *i.e.* before and after EU accession (Figure 2).

Analysing values of the equipment modernity index within the considered period, one can indicate an increasing trend within the changes. The index of equipment modernity for milking systems (i_{emm}) increased from 3.9% to 13.8% during the 2002–2010 period. The same trend is noticeable in the case of equipment modernity index for milk cooling systems (i_{emc}). Yet, the level of changes is completely different. The value of i_{emc} index increased from 31.8% to 76.4%.

Considering the changes in the equipment modernity index, it is possible to conclude that modernity of Polish farms in respect of milk cooling equipment is higher than in the area of milking equipment. It seems important that equipping dairy farms with milking systems generates considerably higher costs than equipping them with milk cooling techniques.

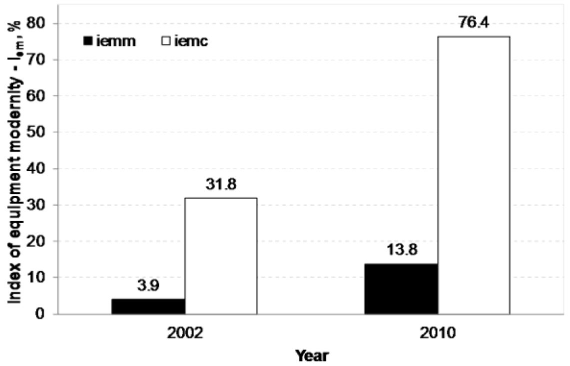

Figure 2. Index of equipment modernity: i_{emc} – index for milk cooling systems, i_{emm} – index for milking systems
Source: own calculations on the basis of data from the Polish Statistical Office

Discussion

Discussion of the proper approach to some aspects concerning the annual milk yield per cow seems important. The said yield, according to the data used for analysis, can be presented based on the overall (national) population of dairy cows as well as a group of cows under the system of dairy recording. The dairy recording system is developed in many countries, including Poland. Each year, more and more Polish farms are included in the dairy recording system managed by the Polish Federation of Cattle Breeders and Dairy Farmers. In 2014, the percentage (in relation to the total population) of cows under the dairy recording system was 32.9% and it had increased by 2.4% in comparison with 2013. Taking into account dairy farms with cow herds under the dairy recording system alone, this constituted an 8% increase in the number of recorded cows between 2013 and 2014. According to the data edited by the Federation's statistical office, the annual milk yield per cow under the recording system in Poland amounted to 7,441 kg·year^{-1} in 2013. This is about 38% more than the average annual milk yield per cow (5,388 kg·year^{-1}) presented in Table 2. In 2014, the annual milk yield per cow under the recording system in Poland amounted to 7,582 kg·year^{-1}. Including such data in the calculation of some indices, e.g. coefficient of AMS potential use, it is possible to show that differences between some countries in the field of biological potential of dairy production are lower, so, for some farms, it is justified to equip them effectively with a modern milking technique such as the automatic milking system (AMS).

Including data from the dairy recording system managed by the Polish Federation of Cattle Breeders and Dairy Farmers, one can analyse an additional aspect important for assessment of dairy production and its effectiveness. Figure 3 presents the relationship between annual milk yield per cow and dairy cow herd size for Polish dairy farms under the recording system, including data for 16 regions (voivodeships) in 2014.

One can state (Figure 3) that the annual milk yield per cow increases with a higher size of dairy cow herd. The relationship can be depicted by a curve with the coefficient of determination (R^2) of over 0.8. For bigger cow herd sizes (more than 40 cows per herd), the increasing trend bases on the points (data) not highly dispersed around the curve.

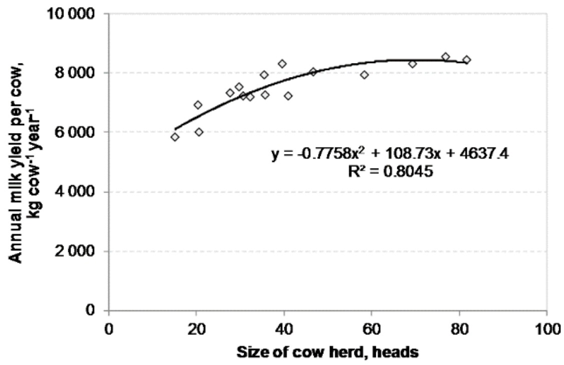

Figure 3. Relationship between the annual milk yield per cow and the dairy cow herd size for Polish dairy farms under the recording system in 2014
Source: author calculations on the basis of data from the Polish Federation of Cattle Breeders and Dairy Farmers

The growing size of dairy cow herds is accompanied by a higher annual milk yield per cow and, at the same time, needs to use higher capacity milking systems. Higher capacity milking systems are operated on cows with a higher annual milk yield, *i.e.* higher biological potential. Thus, it is possible to confirm significance of simultaneous implementation of different kinds of progress in agriculture and agricultural activities (Gaworski, 2006).

In the last 50 years, the dairy sector in most developed countries has shifted towards larger herds and greater annual milk production per cow. The driving force in this development has been the need to adopt technologies that require large capital investments and, hence, depend on larger herds to be profitable. On the other hand, most milk in developing countries is still produced in traditional small-scale systems with little or no mechanization or technological innovations (Gerosa, Skoet, 2013). In developing countries, it is evolving in response to rapidly increasing demand for livestock products. However, in developed countries, demand for livestock products is stagnating, while many production systems are increasing their efficiency and environmental sustainability (Thornton, 2010).

Equipping of dairy farms with more and more modern equipment for milking is first of all undertaken to save labour input and increase the milking capacity, especially at farms with a higher number of cows. However, implementation of more and more modern equipment for milk cooling at farms results from the need to save energy and fulfil the standards concerning milk quality, including the TBC (total bacteria count). Nowadays, in Poland, like in most European countries, there is only one obligatory class of milk quality, *i.e*. extra class. There are no other classes, so high efficiency of milk cooling and, as a result, highly effective milk coolers constitute the most important condition to purchase milk from a farm to a dairy plant. More effective cooling is achievable by means of modern technical equipment, *i.e*. tank milk coolers, so fast increase in the number of such coolers as compared with bucket milk coolers can determine high values of the equipment modernity index for milk cooling systems.

Carried out investigations emphasize the role of annual milk yield per cow and its improvement in the context of increase of farm dairy production effectiveness. Annual milk production per cow constitutes the outcome of many factors. Advances in genetics, nutrition, and herd management have resulted in a 4-fold increase in milk yield between 1944 and 2007 (Capper *et al*., 2009). When the problem of milk production per cow as well as farm scale is analysed, consideration of the effectiveness of dairy production against the background of sustainability seems essential. Sustainability is more than economic profitability; it also relates to environmental and societal concerns, including the quality of life of workers and the animals in dairy farms (von Keyserlingk *et al*., 2013) and imagining the ideal dairy farm (Cardoso *et al*., 2016). Such quality of life of animals at dairy farms can be identified by the keeping system and other facilities determining animal welfare. In 2010, a considerable share (61%) of cattle at Polish dairy farms was kept in barns with the tiestall system, while only 15.3% of cattle were kept with the use of the free-stall system. Generally, an increase in cow herd size is accompanied by preference for barns with the free-stall system. The increase in dairy production scale is the key determinant of Polish dairy farm development (Ziętara, 2012).

Conclusions

Results of carried out analyses show that many possible comparisons of dairy potential can be made in the European dairy production sector to outline differences between countries and their dairy production.

Further effective transformation of the Polish dairy sector requires overcoming certain barriers hindering development of the sector, connected first of all with high dispersion in raw milk production and its low technology level, high dispersion of dairy processing, and others.

As a result of undertaken studies, there are scientific premises to identify technical and biological solutions for optimizing the farm dairy production system, allowing sustainable improvement.

Implementation of modern technical equipment for milking at dairy farms needs simultaneous improvement of dairy cow herds and other factors, *e.g*. economic profitability.

Conflict of interests
The author declares that there is no conflict of interest regarding the publication of this paper.

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