# Effect of spray drying temperature on physical properties and quality characteristics of dry mare's and sheep's milk

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**Keywords:**

Milk
Sheep
Mare
Spray drying
Infant formula

**Article history:**

Received 01.07.2024
Received in revised form 23.08.2024
Accepted 31.12.2024

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**DOI:** 10.24263/2310-1008-2024-12-2-5

## Abstract

**Introduction.** The aim of the research was to determine the influence of spray drying temperature of sheep and mare's milk, intended for use in the technology of products for infants, on its physical properties and quality indicators.

**Materials and methods.** Native cow, mare and sheep milk were used for the research. Milk was dried using a Niro-Atomiser spray dryer at a temperature range of 130–190 °C. The peroxide value, particle size, insolubility index, and wettability were studied. The relative dissolution rate, viscosity, insolubility index and moisture content were determined in the prepared infant formulas.

**Results and discussion.** In mare's milk, the peroxide index increased by 12% with increasing temperature from 140 to 150 °C. At lower drying temperatures (130–140 °C), the peroxide index also increased. Slow migration of fat in the particles during spray drying due to differences in density, non-polar nature and particle size resulted in excess fat on the surface of the powders. In sheep's milk, the peroxide index increased by 12% when dried in the temperature range from 160 to 170 °C and by 36% in the temperature range from 170 to 180 °C. The particle size of the dry milk depended on the chemical composition of the milk and the drying temperature. With an increase in the spray drying temperature in the range of 130–190 °C, the particle size of mare's milk decreased by 67%, and that of cow's milk by 29%. For sheep's milk, the particle size decreased by 21% with an increase in temperature to 180 °C, and a further increase in temperature contributed to the solidification of the dry milk particle and a partial increase in size. Mare's milk dried at low temperatures (130 °C) had a high insolubility index (0.4 $cm^3$), which was unacceptable for infant formulas. When it was dried at a temperature of 140 °C, the insolubility index decreased 4 times, and at a temperature of 150 °C – the insolubility index was 2 times higher compared to the drying temperature of 140 °C. The increasing of the insolubility index was related to the increase in the amount of denatured whey protein during drying at high temperatures. Sheep milk dried at high temperature 180 °C was characterised by a high insolubility index of 0.4 $cm^3$. At a drying temperature of 170 °C, the insolubility index was the lowest 0.1 $cm^3$. A wettability time shorter than 1 minute was achieved when mare's milk was dried at a temperature of 130–160 °C and sheep's milk at 170–180 °C. The rational temperature of the drying agent for spray drying of milk for the purpose of using in the infant formula technology was 140 °C for mare's milk, and 170 °C for sheep and cow's milk.

**Conclusions.** Infant formulas based on mare's and sheep's milk produced at rational drying temperatures had similar viscosity curves to the control, and were characterised by high quality indicators and relative dissolution rate.

## Introduction

A large number of infants in the world are bottle-fed. Despite the fact that human breast milk is considered the best product for supporting the growth and development of infants in early childhood, only 38% of infants are exclusively breastfed during the first 6 months of life (Kondrashina et al., 2024). Dry milk mixtures for infants are mainly produced on the basis of cow's milk (Martin et al., 2016). There are also mixtures based on goat's milk (Hageman et al., 2019; Nayik et al., 2022). Meanwhile, it is known that cow's milk proteins can cause food allergy (Paschke and Besler, 2002; Wal, 2002). Therefore, it is necessary to expand the range of raw materials for infant food mixtures and to research other types of milk, such as mare's and sheep's, for their use in the technology of these products.

Dry milk is the main component in mixtures for artificial feeding of infants, so its quality will significantly affect the quality of the product. Studies of the chemical composition and nutritional value of vegetable and mare milk have been the focus of many recent studies (Blanco-Doval et al., 2024; Li et al., 2022), but the drying technology of mare and sheep milk and its effect on the physical properties of milk wasn't investigated enough. The quality of dry milk is determined by its physical properties (Dec et al., 2023), which are extremely important for infant formula (Masum et al., 2019). Usually, the physical properties of dry milk are determined by its composition and surface properties of powder particles, which change during technological processes (Sharma et al., 2012). The factors that are most important in the spray drying process are the inlet temperature between 120-180 ºC, the inlet air flow and the feed flow rate, these variables affect the physical properties of the powders, such as: yield, moisture, hygroscopicity, water activity, solubility and bulk mass (Samsu et al., 2020).

There are data on the spray drying of sheep's milk at a temperature of 160 °C with the addition of 2% soy lecithin. The product was evaluated according to the content of moisture, fat, protein, pH, water solubility, microbiological and sensory indicators (Endres et al., 2024). The results obtained during drying at this temperature did not fully justified the feasibility of the selected temperature regime for drying sheep's milk.

High-quality dry mare's milk was obtained by spray drying at an inlet air temperature of 273-280 °C after concentration of mare's milk by vacuum evaporation. Physical characteristics of dry milk were: solubility index >99.5%; dispersion index >97.0%; wettability index < 5 s (Schuck et al., 1995). Such a high drying temperature negatively affected the preservation of the nutritional value of milk, which was a significant disadvantage, considering its potential use for infant food products.

The process of freeze-drying had a positive effect on the indicators of preservation of components of mare's milk, which practically did not change in terms of dry matter (Cais-Sokolińska et al., 2023). But it was also necessary to take into account the economic component of the methods of drying mare's milk, since freeze-drying was eight times more expensive than spray drying of milk, and vacuum drying was four times more expensive than spray drying (Lee et al., 2018).

Therefore, the aim of the work was to investigate the influence of the spray drying temperature of sheep and mare milk on its physical properties and quality indicators for use in the technology of products for infants based on dry milk.

## Materials and methods

### Materials

Native cow's milk, mare's milk and sheep's milk were used for the study. Milk was collected on farms in eastern, central and southwestern Ukraine.

### Methods

**Milk drying** was carried out on a semi-industrial spray dryer "Nyro-Atomizer" with a working volume of the chamber of 0.9 $m^3$ and productivity in terms of evaporated moisture up to 5.0 kg/h. The dryer made it possible to ensure the temperature of the drying agent in the range of 120 – 250 °C at the entrance to the dryer and 60 – 100 °C at the exit from it.

Drying took place according to the following parameters: the speed of movement of the drying agent was 0.5 m/s, the relative humidity of the drying agent was 25%, the size of the droplets of the sprayed product was 40-50 µm, the mass fraction of dry substances in the product was 40 – 43%.

Milk powder was tested 2 hours after drying.

#### Determination of the peroxide value

Milk powder sample (5.0 g) was mixed with chloroform-glacial acetic acid solution (40:60, v/v, 5 ml), and saturated potassium iodide solution (1 ml) was added. The mixture was reacted in the dark for 3 min. Then, it was diluted with distilled water (50 ml) and added to starch solution (1%, w/v, 1 ml). The clear liquor was separated by filtration, and the POV was determined at 585 nm (Wang et al., 2020).

#### Size of milk powder particles

Particle size distribution of the milk powder samples was measured by a mechanical tapping sieve shaker. 100 g sample was weighed using the weighing balance and poured into the top sieve. After being vibrated with the same strength and time, a different aggregate of particle sizes was collected on each sieve and weighed. The particle size distribution was measured twice for each trial to increase accuracy. Particle size distributions were calculated based on results from sieve analysis (Zhang et al., 2023).

#### Insolubility index

Studies on the determination of the insolubility index were carried out according to ISO 8156:2005 (Majadi et al., 2024; Pugliese et al., 2017). Dry milk was dissolved in water at a temperature of 25 °C and centrifuged. The supernatant was removed and replaced with water, centrifuged again and the volume of insoluble sediment was measured. The insolubility index indicated the amount of substances that did not dissolve in the reducing agent (water), but precipitate.

#### Wettability of dry milk

The wettability of dry milk was determined by the GEA NIRO method (Koca et al., 2015; Salunke et al., 2023). 13 g of dry whole milk was poured into a special funnel made of antistatic plastic (funnel height 100 mm, diameter 40 mm), and the bottom of the funnel was covered with a 130 mm long glass pestle. 100 $cm^3$ of distilled water with a temperature of 40±2 °C was poured into a chemical beaker with a volume of 400 $cm^3$, a diameter of 70 mm and a height of 135 mm. A glass of water was placed under the watering can, the pestle was raised and the stopwatch was turned on at the same time. The stopwatch was turned off when all the powder was wet. Wettability was estimated by the time required for complete wetting of the powder.

**Speed of dissolution**

The speed of dissolution was determined by the modified method described in (King, 1966). 5 g of dry milk was placed in a mixing glass, 35.2 $cm^3$ of water was poured through the inclined channel in the eccentric of the stirrer along the wall of the glass. The water temperature was 20±2 °C. The electric drive was turned on and stirred for 5 seconds, then the resulting mixture was filtered under vacuum through a Schott glass filter No. 1. The content of dry substances was determined in the resulting filtrate using a refractometer. The amount of dry substances of the product that went into solution, related to the weight of the product, represent the speed of dissolution, which was expressed as a percentage.

**Moisture content**

Moisture content was determined by oven drying method (GEA, 2024).

**Rheological indicators**

The rheological parameters of the mixtures were studied on a rotary viscometer "Rheotest-2" with a system of coaxial cylinders S/S1 in the strain rate range 3 – 1312 $c^{-1}$ (Kambulova et al., 2020).

**Statistical analysis**

The statistical processing of the results was performed by sequential regression analysis using the Microsoft Excel XP and Origin Pro8 software calculating correlation coefficients (Hinkle et al., 2003).

## Results and discussion

The chemical composition of milk is important for the formation of the nutritional value of products based on it. The chemical composition of mare's and sheep's milk is significantly different from cow's milk (Table 1).

**Table 1**

**Chemical composition of native milk**

| Type of milk | Content, % on dry matter | | |
|---|---|---|---|
| | Protein | Fat | Lactose |
| Cow | 24.2±0.3 | 27.3±0.2 | 41.0±0.4 |
| Mare | 16.7±0.1 | 12.4±0.3 | 69.1±0.2 |
| Sheep | 26.6±0.2 | 33.6±0.2 | 22.4±0.4 |

* Results given as: M±SD (mean±standard deviation) of triplicate trials.

Mare's milk contains less protein by 31% and fat by 54.5% than cow's milk, but more amount of lactose. Sheep's milk is high in protein, but fatter than cow's milk.

Different fat content, namely the amount of free fat on the surface of milk particles, the amount of hydrolyzed triglycerides affected the change in the peroxide value during milk drying. The surface free fat content of spray-dried powders depends on many factors, including total fat content, fat type, product composition and drying conditions (Pisecky, 2012). The peroxide value was determined 2 hours after drying.

The peroxide index was differrent in all types of milk (Table 2). In sheep's milk, it was 2.1-2.4 times higher than in mare's milk, and 1.3-1.5 times higher than in cow's milk. This difference is explained by the fact that milk contains a different mass fraction of fat (Pietrzak-Fiećko and Kamelska-Sadowska, 2020), and therefore a different amount of free fat, which is primarily oxidized.

**Table 2**

**Peroxide index of fat in dry milk at different drying temperatures**

| Temperature, °C | Peroxide index of fat, mmol/kg | | |
|---|---|---|---|
| | Cow milk | Mare milk | Sheep milk |
| 130 | 1.38±0.01 | 0.88±0.03 | 1.89±0.02 |
| 140 | 1.41±0.02 | 0.95±0.02 | 1.92±0.03 |
| 150 | 1.55±0.02 | 1.06±0.01 | 2.05±0.02 |
| 160 | 1.76±0.02 | 1.09±0.01 | 2.20±0.02 |
| 170 | 2.30±0.01 | 1.23±0.02 | 2.46±0.03 |
| 180 | 2.33±0.01 | 1.32±0.01 | 3.35±0.01 |
| 190 | 2.33±0.01 | 1.38±0.02 | 3.37±0.01 |

* Results given as: M±SD (mean±standard deviation) of triplicate trials.

When the air temperature increased, there was a rapid increase in the peroxide index of milk. In mare's milk, with an increase in temperature from 140 °C to 150 °C, the peroxide value increased by 12%. However, even at lower drying temperatures (130 – 140 °C), the peroxide value also increased. This is explained by the fact that during spray drying, water molecules diffused from the inside to the surface of the droplets and evaporated. Components such as fat, protein, lactose, and minerals counter-diffused or migrated into the middle of the drop. The slow migration of fat due to differences in density, nonpolar nature, and particle size led to an excessive amount of fat on the surface of powders (Kim et al., 2003). According to the data (Deshwal et al., 2020; Foerster et al., 2016), the coating of the surface of the powder with fat for dry whole and skim milk, dried by the spray method, was 90% and 18%, respectively. Higher surface fat content is known to increase susceptibility to lipid oxidation (Hardas et al., 2000).

In cow's milk, when the temperature changed from 140 °C to 150 °C, the peroxide value increased by 10%, and when the temperature changed from 160 °C to 170 °C, the peroxide value increased by 31%. In sheep's milk, the peroxide number increased by 12% in the temperature range of 160-170 °C and by 36% in the temperature range of 170-180 °C. The total increase in peroxide value when the drying temperature changed from 130°C to 190°C in cow's milk was 69%, mare's milk – 57%, sheep's milk – 78%.

Cow's milk accumulated 4-5% more peroxides than mare's milk and 15-16% less than sheep's milk. This difference is explained by the fact that triglycerides of milk fat during thickening and drying were partially hydrolyzed with a decrease in their composition of unsaturated fatty acids. However, the amount of free fat increased during drying with increasing temperature, and since sheep's milk contained the most amount of fat (Li et al., 2022), and a larger amount of free fat was formed in it during the drying process. Cow's milk contained less fat than sheep's milk, but the amount of unsaturated fatty acids in it was more than in sheep's milk. Mare's milk was the least capable of oxidation, since the mass fraction of fat in it was the smallest.

Thus, it was found that with an increase in the drying temperature, the amount of peroxide compounds in milk increased, which negatively affected its storage. It was found that the intensity of the accumulation of peroxides in milk, in addition to the drying temperature, was influenced by the mass fraction of fat. Therefore, it must be taken into account when choosing rational parameters for drying milk.

When setting the rational temperature of the drying agent during spray drying of milk, the size of the formed particles was of great importance (Panthi et al., 2021). The size of the particles of dry milk made it possible to predict the quality of the recovery of the product. The smaller the milk powder particles, the greater the specific surface area for the reducing agent, and the faster the reduction process wase. Drying milk at different temperature ranges allowed obtaining particles of different sizes (Figures 1–3).

When drying milk with an increase in temperature, a decrease in dry milk particles was observed. When the drying temperature increased from 150 to 160 °C and from 160 to 170 °C, the size of cow's milk powder particles decreased by 9% and 5%, respectively. With the next increase in temperature by 10 °C, the size of the particles decreased by another 10%. The decrease in the size of the powder particles with increasing temperature was caused by more intense evaporation of moisture from the inner layers. Also, when the air temperature increased, the fat balls were crushed. And since fat molecules had a significant influence on the formation of particle size, as the diameter of fat globules decreased, the size of the particles on which it was located decreased.

When drying mare's milk at low temperatures of 130 °C, larger particles were obtained than at higher drying temperatures. This is explained by the incomplete removal of free moisture, which kept proteins in a colloidal state. With an increase in temperature to 140 °C, due to greater removal of moisture from a drop of the sprayed product, the size of the particles decreased by 40%. The subsequent increase in temperature contributed to the further reduction of the particle size.

When drying sheep's milk in three temperature ranges, a decrease in the size of the particles was observed, and at a temperature of 190 °C, the size of the particles increased. The smallest particle size of sheep's milk were found at a temperature regime of 180 °C. When the temperature droped to 160 °C, the particle size already increased by 28%. It was obvious that the reason for this phenomenon was a decrease in the diffusion rate. The temperature of the drying agent 190 °C caused obtaining powder with large particles. Their size was increased by 14% compared to the particles obtained at a temperature of 180 °C. The explanation for this was the instant hardening of the surface of a particle of dry milk. In spray-dried milk samples, the presence of vacuoles on the particle surface was observed, which were caused by the removal of water (López Fialho et al., 2019; Nuzzo et al., 2017). Drying milk at elevated temperatures removed surface water from particles and increased surface viscosity, resulting in a dry, hard surface (Kim et al., 2009; Westergaard, 2004). This solid barrier prevented the diffusion of water vapor and air, which, in turn, led to an increase in particle size. In the process of storage, such a powder loosened.

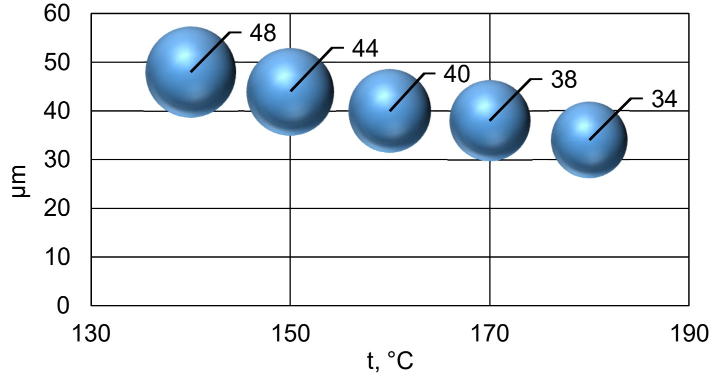


**Figure 1. Particle size of cow milk powder depending on the drying temperature**

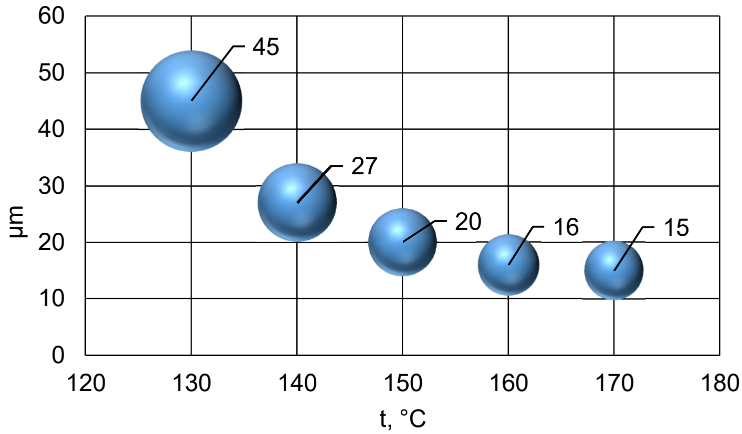


**Figure 2. Particle size of mare milk powder depending on the drying temperature**

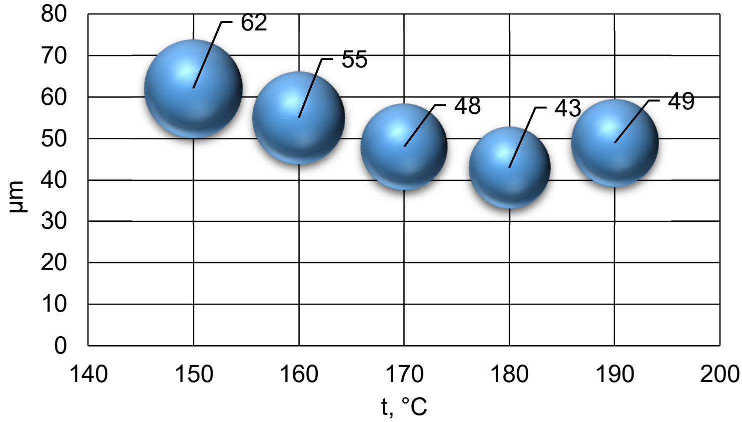


**Figure 3. Particle size of sheep milk powder depending on the drying temperature**

There were also significant differences between the particle sizes of different types of milk. It was likely that such a difference was due to the chemical composition of milk, namely the size of casein micelles. Because both whey proteins and casein proteins had larger molecules, they almost always turned into amorphous powders during spray drying. The slower migration of protein due to the large size and surface-active nature of the droplets, compared to lactose and minerals, led to an overrepresentation of protein on the surface of the powders (Kim et al., 2003; Masum et al., 2019). Therefore, the size of the particles of milk powder depended on the chemical composition of whole milk and the drying temperature. With an increase in the temperature of spray drying in the range of 130 – 190 °C, the particle size of mare's milk decreased by 67%, cow's milk – by 29%. For sheep's milk, the particle size decreased up to a temperature of 180 °C (by 21%), a further increase in temperature contributed to solidification of the dry milk particles and a partial increase in size.

When recovering dry milk, one of the main indicators of its quality was the insolubility index. The insolubility index indicates the amount of substances that do not dissolve in the reducing agent (water), but precipitate. The rate of dissolution was also important (Sharma et al., 2012). Since milk powder was being studied for use in instant infant products, its dissolution in water should also be quick. The solubility of milk powder was mainly influenced by the amount of insoluble denatured protein and the amount of free fat in the milk powder (Deshwal et al., 2020), as well as the particle diameter and temperature of the drying agent (Straatsma et al., 1999). The insolubility index of dry milk was determined 2 hours after drying milk.

Mare's milk, dried at a low temperature of 130 °C, had a high insolubility index (0.4 $cm^3$), which was unacceptable for infant food products (Figure 4). This temperature of the drying agent did not ensure complete removal of free moisture. As a result, lactose crystallized, thereby causing fat destabilization. The poor solubility of dry milk can be caused by the high moisture of the product.

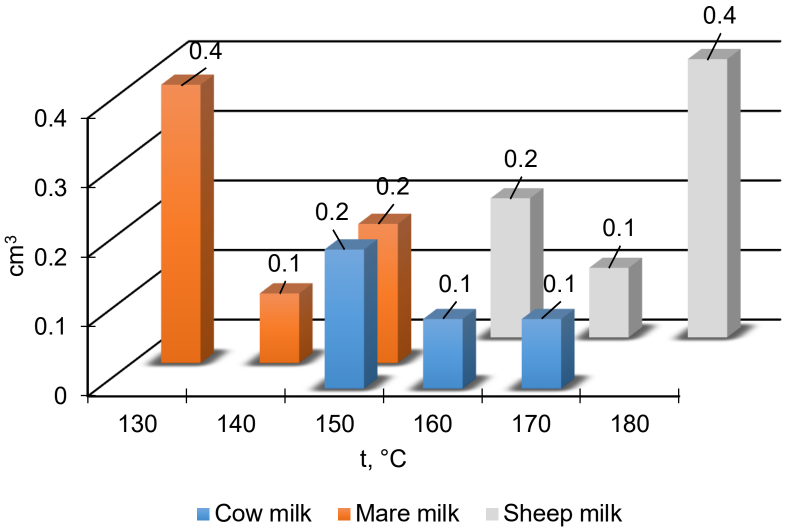


**Figure 4. Insolubility index of milk powder**

Drying mare's milk at a temperature of 140 °C allowed to reduce the insolubility index 4 times. When the temperature increased to 150 °C, the insolubility index of dry mare's milk was 2 times higher compared to the drying temperature of 140 °C. During spray drying, the main factor controlling the insolubility index was the temperature of the particles when their moisture content was between 10 and 30%. The insolubility of milk powder was explained by the unfolding of β-lactoglobulin and its aggregation with casein (Thomas et al., 2004). Mare's milk contained a significant part of whey proteins, which are heat-labile proteins. The zone in which casein proteins were most sensitive to heat was in the moisture range that occurred during spray drying (Baldwin, 2010).

Therefore, increasing the drying temperature led to an increase in the amount of denatured whey protein, which in turn reduced the solubility of dry milk. Sheep's milk dried at high temperature (180 °C) had a high insolubility index, which was unacceptable for infant food products. A loose product with a large number of cracks was formed. This created favorable conditions for the concentration of free fat on the surface of a particle of dry milk. As a result, the wetting of particles and, as a result, the solubility of dry milk deteriorated. The high temperature of the drying agent led to intensive denaturation of proteins, increasing the amount of insoluble sediment during recovery of dry milk.

At a drying temperature of 170 °C, the insolubility index was characterized by the best indicators. When drying cow's milk in the temperature range of 160 – 170 °C, a product with a low solubility index was formed, which also met the requirements for fast-dissolving products. When the drying temperature was reduced to 150 °C, the insolubility index was 2 times higher. The reason for this can also be the lower dispersion of fat, which reduced the specific surface for the action of water.

The main physicochemical indicator of the quality of dry dairy products, on which their speed of recovery depended, was wettability. The different wettability of dry products obtained with different drying modes was explained primarily by the unequal intensity of thermal effects on milk proteins and salts, as well as the difference in the shape and size of their particles (Pugliese et al., 2017; Schuck, 2011).

Quick-dissolving dry products for infant food were characterized by a short duration of wettability, so this indicator should be taken into account when choosing rational parameters for drying milk powder.

For this purpose, the influence of the drying temperature on the wettability of dry milk was analyzed (Figure 5).

In samples of mare and cow milk powder, with an increase in the drying temperature, a decrease in the duration of wetting was observed. This phenomenon was probably related to the size of the milk powder particles. It is known that the smaller the particle size, the greater the surface area for contact with water. As previous studies showed, with an increase in the drying temperature, the size of the particles of milk powder decreased. This explains why the wettability of milk dried at higher temperatures was better than that of milk dried at lower temperatures.

In sheep's milk, as the drying temperature increased, the duration of wetting decreased, but at a drying temperature of 180 °C longer wetting was observed than at lower temperatures. This was probably also due to the size of the particles and the large amount of free fat on their surface. Because when drying sheep's milk at a temperature of 180 °C, large particles were formed, which was established by previous studies. It is known that with an increase in the content of surface fat, the wettability of powders decreases (Fäldt and Bergenståhl, 1996).

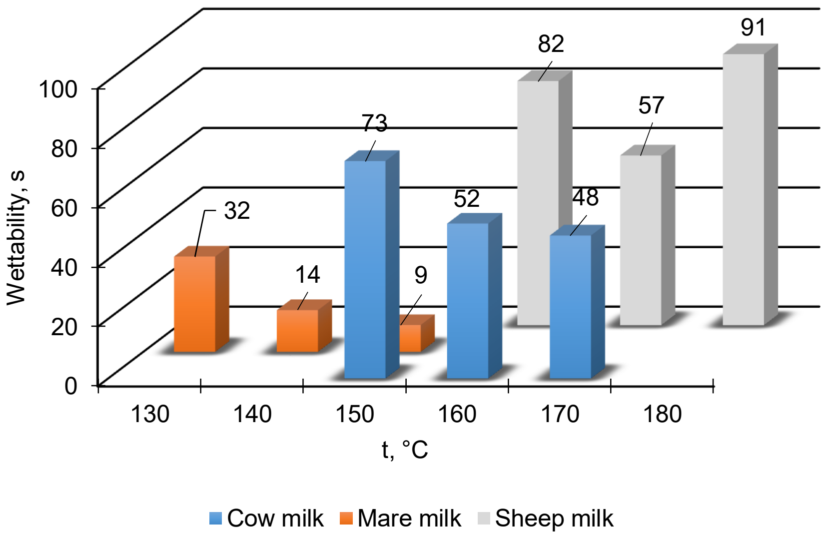


**Figure 5. Wettability of milk powder**

Dry mare's milk wetted the fastest among all samples. The explanation for this phenomenon can be the low fat content, the smallest particle size, a large amount of lactose, which did not prevent the penetration of water into the pores of the product, while in other types of milk, the mass fraction of fat was larger and the particle sizes were larger, compared to mare's milk.

The shortest duration of wettability, which was desirable for fast-dissolving products, was achieved when drying cow's milk at a temperature of 170 °C, mare's milk – 130 – 150 °C, sheep's milk – 170 °C.

The lowest value of the insolubility index, which allowed obtaining high-quality fast-dissolving products and powdered milk for infant food, was achieved at the drying temperature of cow's milk 160–170 °C, mare's milk – 140 °C and sheep's milk – 170 °C.

Based on the results of the research, rational temperatures for drying milk were found, which are presented in Table 3.

**Table 3**

**Characteristics of milk drying**

| Indicator | Cow's milk | Mare's milk | Sheep's milk |
|---|---|---|---|
| Temperature of the drying agent at the entrance, °C | 170±2 | 140±2 | 170±2 |
| Dry milk amount, % | 11.9±3 | 9.8±2 | 15.5±2 |
| Moisture, % | 2.9±0.2 | 2.3±0.1 | 2.6±0.1 |

* Results given as: M±SD (mean±standard deviation) of triplicate trials.

Indicators of ready-made mixtures for infant food mainly depend on the quality of dried milk. Dry milk mixture «Malyutka hypoallergenic» (Khorolsky milk-canned plant for children's products, Ukraine) was chosen as a control.

Formulations of dry milk infant formulas based on sheep's and mare's milk were developed (Table 4).

**Table 4**

**Formulations of sheep and mare milk based infant formulas**

| Components | Content in the mixture, % | |
|---|---|---|
| | Ligans (with dry mare's milk) | Agnus (with dry sheep's milk) |
| Dry sheep's milk | – | 56.00 |
| Dry mare's milk | 84.65 | – |
| Soybean oil | – | 4.00 |
| Sunflower oil | 7.00 | 2.00 |
| Olive oil | 8.00 | – |
| Lactose | – | 36.30 |
| Lactulose | – | 1.00 |
| Fat-soluble vitamins | 0.0003110 | 0.0002800 |
| Water-soluble vitamins | 0.0022854 | 0.0031056 |
| Mineral substances | 0.207 | 0.556 |
| Taurine | 0.03 | 0.03 |
| Inositol | 0.11 | 0.11 |

Physico-chemical characteristics of mixtures are given in Table 5.

**Table 5**

**Physico-chemical characteristics of infant formulas**

| Mixture | Moisture, % | Insolubility index, $cm^3$ |
|---|---|---|
| Control | 4.0±0.1 | 0.2±0.02 |
| With dry sheep's milk | 3.0±0.1 | 0.1±0.01 |
| With dry mare's milk | 3.0±0.1 | 0.1±0.02 |

* Results given as: M±SD (mean±standard deviation) of triplicate trials.

The moisture in the developed mixtures was 1% lower than in the control. This difference was due to the different moisture content in the raw materials from which the mixture was prepared. In the mixtures with sheep's and mare's milk the insolubility index was 2 times lower than in the control. The explanation for this can be the different composition of the mixtures, the quality of the raw materials, and the difference in the main nutrients in the raw materials – proteins, fats, carbohydrates.

Dry infant formulas are quick-cooking products. The use of milk powder as an ingredient in formulations or as a finished product consumed by consumers may be limited by the poor rehydration characteristics of the powder when reconstituted in a liquid medium (Xu et al., 2024). When in contact with water, they must quickly restore the structure and ensure the transition of dry substances into the solution. Therefore, studies were conducted to determine the relative rate of dissolution of mixtures. Water for infant food, heated to a temperature of 37–40 °C, was used to restore the mixtures.

The results of the study (Figure 6) indicated that in one minute of preparation of the mixture, there was almost a complete transition of dry substances into the solution. However, in the mixture with dry mare's milk, dissolution occurred more intensively than in other mixtures. The rate of dissolution of the product depends on the size of the particles and on the depth of protein denaturation (Singh and Creamer, 1991). This is the explanation of the different rate of dissolution of mixtures. Thus, the composition of the mixture with dry sheep's milk, which, according to previous studies, had the largest particle size. Therefore, the intensity of dissolution of the mixture with dry sheep's milk was the lowest.

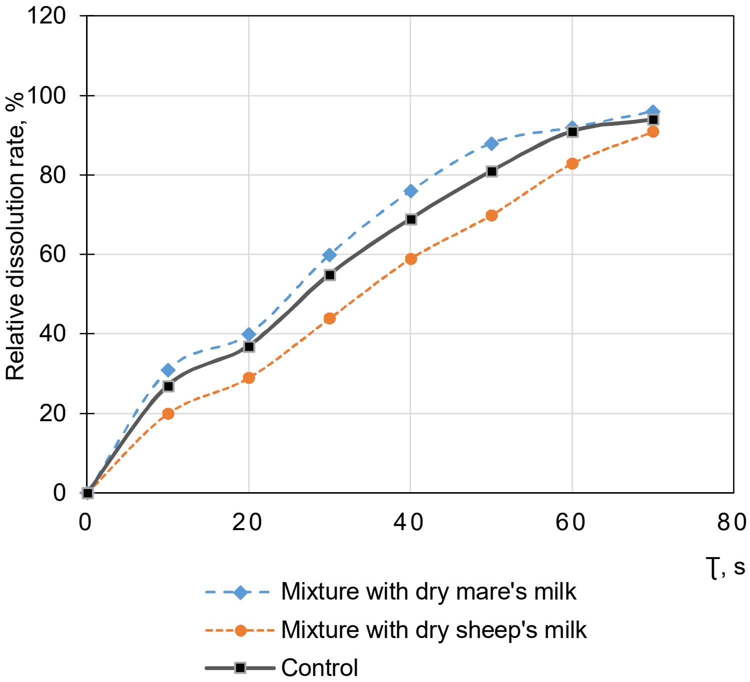


**Figure 6. Relative dissolution rate of infant formulas**

Despite the differences in the intensity of dissolution of the mixtures, in a minute of cooking, all the mixtures almost completely restored their structure, which was evidenced by the amount of substances that transferred into the solution: for the mixture with dry mare's milk – 97.5%, for the mixture with dry sheep's milk – 96.0 %, for the control – 97.0%.

The results of the change in the viscosity of the samples are shown in Figure 7.

Analyzing the nature of the obtained dependencies, the viscosity of the samples decreased as the shear stress increased. Probably, as a result of the destruction of the structure of these systems, their macromolecules were more oriented in the direction of the flow, which contributed to a decrease in viscosity (Kambulova et al., 2020).

At a shear stress (300–360 $s^{-1}$) intensive destruction of the structure occurred in the experimental and control samples. With a further increase in shear stress, the viscosity acquired a stable minimum value, characteristic of an almost completely destroyed structure.

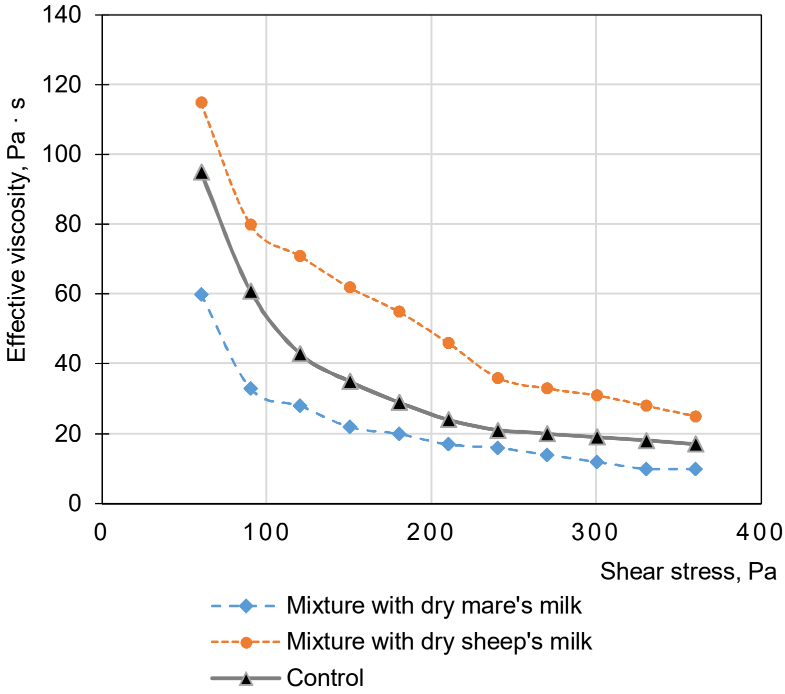


**Figure 7. Dependence of viscosity of the reconstituted solutions of infant formulas on shear stress**

A similar character of the viscosity curves was observed for all samples. The value of the effective viscosity of the experimental systems differred little from the viscosity of the control sample, that is, they had a similar structure, which confirmed the introduction of a rational amount of reducing agent into the dry mixtures. The viscosity values for the mixture with dry sheep's milk and the mixture with dry mare's milk were respectively 116.2 and 58.1 Pa·s., for control – 96.8 Pa·s. It was found that with an increase in voltage shear viscosity of systems decreased.

## Conclusions

Studies of mare's, sheep's and cow's milk powder showed that with an increase in the temperature of the drying agent in the range of 130 – 190 °C, there was a rapid increase in the peroxide value (up to 78% depending on the type of milk), a decrease in the particle size (up to 67% depending on type of milk), the insolubility index (2-4 times depending on the type of milk) and for most samples the duration of wetting was reduced.

Based on a complex of studies, it was found that the rational temperature of the drying agent for spray drying of milk for the purpose of its use in the technology of mixtures for infant food was: 140°C for mare milk and 170°C for sheep and cow milk. The study of the developed dry mixtures for infant food showed that the relative rate of dissolution of these products was similar to the value of the same indicator in the control, which indicated the high quality of the product. In 1 minute of cooking, all mixtures almost completely restored their structure, as evidenced by the amount of dissolved substances: mixture with dry mare's milk – 97.5%, mixture with dry sheep's milk – 96.0%, control – 97.0%.

The values of the effective viscosity of the reconstituted mixtures of mixture with dry sheep's milk and the mixture with dry mare's milk were 116.2 and 58.1 Pa·s, respectively. Viscosity curves had a similar character to the control sample. It was found that the selected rational temperatures for spray drying mare's milk (140 °C) and sheep's milk (170 °C) provided quality indicators of the finished mixtures that corresponded to the control samples.

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**Cite:**

UFJ Style

Falendysh N., Bobel I., Belinska K., Kovbasa V. (2024), Effect of spray drying temperature on physical properties and quality characteristics of dry mare's and sheep's milk, *Ukrainian Journal of Food Science*, 12(2), pp. 131–147, https://doi.org/10.24263/2310-1008-2024-12-2-5

APA Style

Falendysh, N., Bobel, I., Belinska, K., & Kovbasa, V. (2024). Effect of spray drying temperature on physical properties and quality characteristics of dry mare's and sheep's milk. *Ukrainian Journal of Food Science*, *12*(2), 131–147. https://doi.org/10.24263/2310-1008-2024-12-2-5