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REVIEW

IMPACT OF DIETS RICH IN DAIRY FOODS ON CIRCULATING MELATONIN LEVELS AND SLEEP QUALITY

Vasile-Cosmin Andronachi[1], Mădălina Matei[1*], Răzvan-Mihail Radu-Rusu[1], Florin Gheorghe Lup[2*], Daniel Simeanu[1]

[1] "Ion Ionescu de la Brad" University of Life Sciences, 3 Mihail Sadoveanu Alley, 700489 Iasi, Romania
[2]Oradea University, Faculty of Environmental Protection, 26 General Magheru Boulevard, 410048 Oradea, Romania

* Corresponding authors: madalina.matei@iuls.ro, lup_florin@yahoo.com

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Abstract: Diet and sleep are two basic components that directly regulate each individual's overall health. Specialized studies increasingly emphasize that the contemporary human population has difficulties in maintaining optimal body health as a result of the sedentary lifestyle, specific to the 3rd millennium, which is characterized by an increasing proportion of work activity under the influence of artificial light. Scientific evidence available in the literature up to the year 2025 shows that both sleep deprivation and poor quality sleep are generally associated with the promotion of cardiovascular disease and neurodegenerative diseases. Dairy-rich diets are optimal options for improving sleep quality because they are rich in protein and especially tryptophan, an essential amino acid that is the basic precursor involved in the synthesis of melatonin, the hormone responsible for initiating, maintaining and improving sleep quality. This work is a complement to the research initiated by the authors on the development of functional dairy food products that improve quality of life by promoting good quality sleep. The paper contains concrete scientific evidence demonstrating that the type of diet and eating pattern directly influences sleep architecture and sleep quality.

Keywords: *dairy, melatonin, protein, quality sleep, tryptophan*

INTRODUCTION

The overall health of the human body is a paramount concept for 21st century society, as it is the main factor that can directly influence the quality of each individual's physical, mental and social life. In an increasingly agitated society, with a population under constant external pressures, both social and professional, health and the maintenance of balance in terms of physical and mental well-being are the main indispensable resources of the human organism that directly influence the way and direction of life.

The 21st century is characterized by a high level of evolution and a high degree of technologization. Technological progress has significantly improved the quality of human life by modernizing and automating work processes, thus reducing the amount of manual work. However, another result of technologization is the increasing demand for intellectual work, which in most cases involves spending a long time under the influence of artificial light, which can desynchronize certain physiological processes with circadian rhythms. Another situation that leads to a poor synchronization of the human body with circadian rhythms is working at night. This situation has the effect of disrupting the circadian rhythm as a result of the sleep state being achieved during the day, and the synthesis of melatonin (the hormone responsible for initiating sleep) being inhibited at night as a result of the body being exposed to artificial light for a longer period of time than normal. Melatonin is the main substance synthesized in the human body that is involved in initiating, maintaining and improving sleep quality [1].

The professional and social activities that characterize the lifestyles of the 21st century population can, in certain cases and for some individuals, be stress-generating factors. According to the definitions and explanations formulated by various authors, stress is a term used to describe a large number of conditions whose main effect on the body is the disruption of physiological and metabolic states. Mainly, stressors have been divided into three groups: psychological, physical and environmental [2].

The disruption of circadian rhythms by non-synchronization of sleep with photoperiods of natural darkness and exposure of the eyeball to high intensity light for a long period of time are factors that can cause additional stress on the body [3].

N-Acetyl-5-methoxytryptamine (melatonin), also known as the sleep hormone or dark hormone, is a product of the pineal gland [4] that occurs as a natural response of the vertebrate body to the perception of darkness [5 – 7]. Sleep is a process that occupies one-third of each individual's life [8], being defined as a complex physiological state that occurs in a cyclic manner and has major implications in animal and human organisms in the regulation of numerous physiological and metabolic functions and processes, such as immune function, homeostasis maintenance, memory formation, cognitive processes, and improved attention and endocrine system performance [8, 9].

The presence of melatonin in the animal and human body is associated by many authors with inhibiting, delaying or even halting the development of pathological conditions such as cancer, tumors and neurodegenerative diseases. Interruption of sleep, circadian rhythm alteration and temporary submission of the body to artificial light during the night are situations that lead to sleep fragmentation and the manifestation of fatigue, which can have as effects on the body, the promotion of pathological conditions associated with lack of good quality sleep [10].

MATERIAL AND METHODS

In this review article we aim to analyze the hard scientific evidence available in the literature up to the year 2025, which suggests that there is a directly proportional relationship between the quality and type of diet specific to each individual and the achievement of optimal sleep in humans.

Research hypothesis

The 21st century society is mainly characterized by a sedentary lifestyle and with work predominantly carried out under the influence of artificial light. This has undesirable effects on the overall health of the body by disrupting circadian rhythms and promoting sleep deprivation-related diseases and illnesses such as cardiovascular and neurodegenerative diseases.

The rationale for conducting the study

The association of diets rich in dairy foods, as well as following dietary patterns characterized by the promotion of high quality foods rich in protein with high biological value in relation to achieving good quality sleep has been investigated by numerous researchers whose studies have shown positive results in terms of the effects of the type of diet on improving sleep quality and the general health of the human body. This literature review article on the impact of dietary patterns on sleep architecture and sleep quality in humans aims to provide an overview of the concrete scientific evidence on how eating diets rich in dairy products or Mediterranean diets can improve overall sleep quality.

Looking ahead

On the basis of this work, we provide a real and general perspective on how good quality food can be correctly associated with improving the health of the whole body, by correctly regulating circadian patterns and sleep quality. This review is intended to be a well-documented guide that will form the basis for future practical research into the impact of balanced diets rich in high biological value protein on improving sleep quality.
This work has been carried out according to the schematic representation of the research organization shown in Figure 1.
The scientific articles and papers cited in this review, on the basis of which the work was conducted, were accessed from the digital databases Web of Sciences (WOS), Scopus, Multidisciplinary Digital Publishing Institute (MDPI) and Google Scholar, based on the keywords *melatonin*, *tryptophan*, *synthesis process*, *quality sleep*, *dairy-rich diets*, *dietary dietary patterns*.

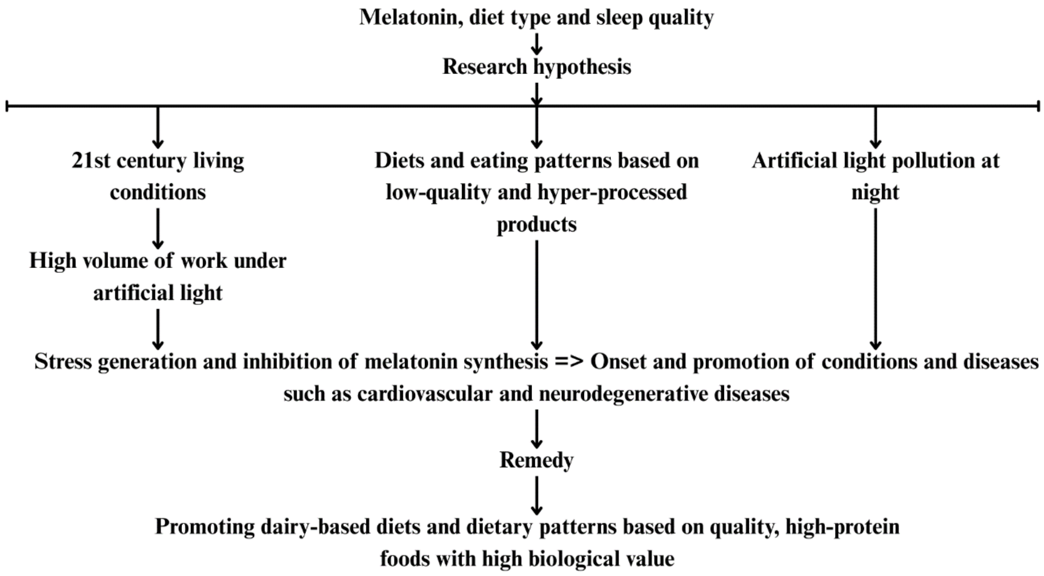

Figure 1. *Study design*

In the selection process, we have taken into account the following criteria to limit the selection:

1. In order to establish the relationship between the type of diet/type of dietary pattern and sleep quality, we selected only those studies that were conducted over a period of time over which we considered that the application of the dietary pattern could show visible effects on sleep quality, thus selecting only those studies that were conducted over a strict time period of more than 20 days;
2. We have selected only those articles in which the effects of different diets and dietary patterns on sleep quality in healthy human individuals have been studied, so as to minimize the possibility that the associations and relationships made between diet and sleep quality are influenced by different physiological or metabolic conditions.

Based on the keywords used in the documentation of this work and on the combination of the keywords in order to identify the papers that are the subject of this research, a total of 90,059 scientific papers and articles were obtained. Of these 90,059 articles, 641 were obtained based on the keyword combination *melatonin synthesis process*, 2,601 were obtained based on the keyword combination *melatonin and sleep quality*, 233 were obtained based on the keyword combination *tryptophan and sleep quality*, 85,686 were obtained based on the keyword combination *quality sleep*, 220 were obtained based on the keyword combination *milk and sleep quality*, and 678 were obtained based on the keyword combination *dietary patterns and sleep quality*.

The use of the word *melatonin* alone yielded 50,373 papers and the use of the word *tryptophan* alone yielded a total of 86,050 papers, but these were not taken into account, due to the fact that the use of these general terms yielded a very large number of papers that were not the subject of this review, and which were more focused on the effects of melatonin receptors, sources of extrapineal melatonin, the effect of tryptophan and/or melatonin on different genes, etc. Thus, from the 90,059 results identified, we selected a total of 105 articles and one textbook, eliminating those papers that presented repeated information or were not of interest for our research, as a result of the article selection limitation criteria applied in this paper (studies focused on the impact of diet on sleep quality should have been conducted over a period of at least 20 days, and the subjects analyzed should have been healthy).

MELATONIN SYNTHESIS, METABOLIZATION AND DARK DEPENDENCE

Vertebrate organisms have two sources of melatonin synthesis, namely the pineal gland (it synthesizes melatonin of pineal origin only under the influence of darkness) and other sites of synthesis represented by different organs and tissues in the body, such as the skin, kidneys, liver, brain, reproductive organs, thyroid gland and others (this type of melatonin called extrapineal melatonin does not have an affinity for darkness in the synthesis process, and can be produced at any time of the day) [10]. The bioavailability of melatonin in a wide variety of plant and animal raw materials, as well as in many finished food products, means that this vital substance for whole body health can be delivered to the body through diet and thus mitigate the effects of melatonin deficiency in the human body due to stressors and ageing. Pineal melatonin has been referred to by various authors as the hormone of darkness or sleep hormone, due to the nocturnal nature of its synthesis (the highest levels of circulating melatonin are found in vertebrates exclusively at night, and the lowest levels are found during the day). The process of melatonin synthesis involves four enzymes (tryptophan hydroxylase, 5-hydroxytryptophan decarboxylase, serotonin-*N*-acetyltransferase also called arylalkylamine *N*-acetyltransferase, and hydroxyindole-*O*-methyltransferase) that act on the amino acid tryptophan to convert it into serotonin and then, under the action of darkness, into melatonin, as schematically shown in Figure 2 [11].

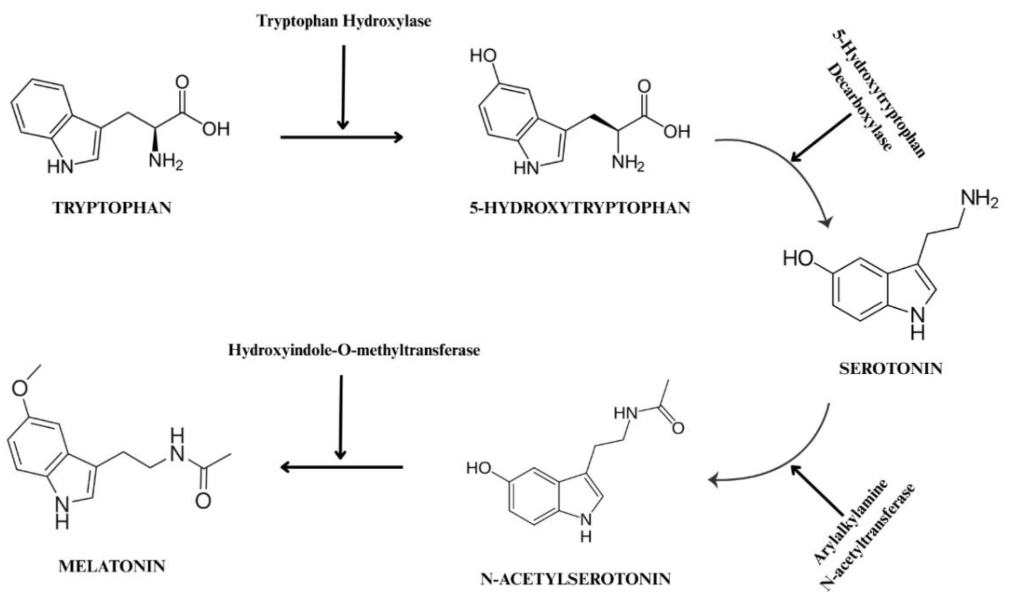

Figure 2. *Biochemical synthesis of melatonin from the essential amino acid tryptophan*

Melatonin is produced by a complex process involving the following 4 steps, which involve hydroxylation, decarboxylation, acetylation and methylation [12, 13], all of which are based on the presence of tryptophan:

1. *Stage I (onset of the process)* - the process of melatonin synthesis begins with the uptake of tryptophan from the bloodstream and the conversion of this essential amino acid into 5-hydroxytryptophan (5-HTP) as a result of the action of the enzyme tryptophan hydroxylase.
2. *Stage II (making serotonin)* - serotonin, also known as the feel-good hormone, is produced by the enzyme 5-hydroxytryptophan decarboxylase, which acts on 5-HTP, converting it to serotonin through the process of decarboxylation.
3. *Stage III (limiting action of the enzyme AANAT)* - subsequent to stage II, in the vertebrate pineal gland, serotonin is converted to *N*-acetylserotonin by the action of the enzyme arylalkylamine *N*-acetyltransferase (serotonin *N*-acetyltransferase), which limits the process of melatonin synthesis during the day as a result of the nocturnal nature of this enzyme (arylalkylamine *N*-acetyltransferase or AANAT), which is active in the presence of darkness.
4. *Stage IV (making melatonin)* - in the last stage, the enzyme, hydroxyindole-*O*-methyltransferase, acts on *N*-acetylserotonin and converts it into melatonin.

After synthesis, melatonin is released into the bloodstream, bound to albumin and transported to the liver where it is metabolized. Melatonin fulfills multiple functions and roles in the human body, being directly and indirectly involved in the process of maintaining the body's overall health, a process it accomplishes both by regulating the circadian rhythm and by its antioxidant, anti-inflammatory and anti-aging roles in various organs and tissues, such as the liver [14], brain [15], skin [16], heart [17], eyes [18], gastrointestinal tract [19, 20] and others.

The dependence of the pineal melatonin synthesis process on the intensity of light perceived from the environment by the retina, cause melatonin production to be inhibited by the body's exposure to artificial light at night [21].

The synthesis of pineal melatonin in response to environmental stimuli characteristic of the dark photoperiod (light intensity and ambient temperature) are the signals that the vertebrate body needs to initiate the physiological state of rest achieved by sleep.

Disturbance of these signals is influenced by the intensity of the light (natural or artificial) that penetrates the surface of the eyeball, is perceived by the retina as environmental information and converted into biological information, so that it can be further transmitted and understood by the hypothalamus and pineal gland.

Artificial light pollution is a phenomenon that occurs directly through the illumination of a defined area (dwellings, villages, towns), but also indirectly through the reflection of natural and/or artificial light, without there being a direct source of light propagation in that area [21, 22]. A practical example might be an agricultural field on which artificial light is reflected into a human settlement at night to illuminate the area. This phenomenon of indirect artificial light pollution at night can be diminished by the presence of fog and/or rain [23], and can be amplified by the presence of snow, which has the ability to reflect light very well [22].

Artificial light has become an indispensable facility for 21st century society, and since the advent of the first artificial light sources, people have been able to be more productive as a result of extending their work into the night. However, this aspect has unintentionally disturbed the quality of life, by deregulating and not synchronizing circadian rhythms with natural photoperiods, directly affecting both humans who are exposed to artificial light as a result of performing professional activities at night [24] and animals exposed to artificial light as a result of human settlements lighting [21]. Vertebrate organisms are naturally adapted to the environmental photoperiods characteristic of each season (cold and warm), each geographical region (northern, equatorial, southern) and different meteorological phenomena (cloudy skies, rainy conditions, snowfall), and any disturbance of these natural conditions has direct effects on the health of both animal and plant organisms [21, 24, 25]. Table 1 presents data on recorded daylight intensity values as a function of photoperiod type and climatic and atmospheric conditions, demonstrating that different meteorological phenomena directly influence daylight intensities in the external environment.

Table 1. *Natural light intensity levels in different environmental conditions*

Type of photoperiod	Environmental conditions	Light intensity	References
Day	Clear skies	~120000 lx	[21]
	Civil twilight	~3.4 lx	
	Nautical twilight	~0.008 lx	
	Rainy weather	~3000 lx	[23]
Night	Full moon	Maxim 0.3 lx	[21]
	Clear skies	~0.001 lx	

In vertebrate organisms, the melatonin content in the bloodstream varies over a wide range, depending on the action of the pineal gland, and is always dependent on the presence of the dark photoperiod. For example, during the day when the eyeball comes into direct contact with natural light from the sun, circulating melatonin levels in the human body vary in the range of 10 - 20 pg·mL^{-1} in the blood (a situation that can also occur at night when the body is under the influence of artificial light), and at night, under the influence of natural environmental conditions and characteristic of the natural dark photoperiod, due to the presence of darkness, circulating melatonin levels vary between the limits of 80 - 120 pg·mL^{-1} in the blood [26]. In the human body, melatonin can be obtained from 4 sources, as shown in Figure 3.

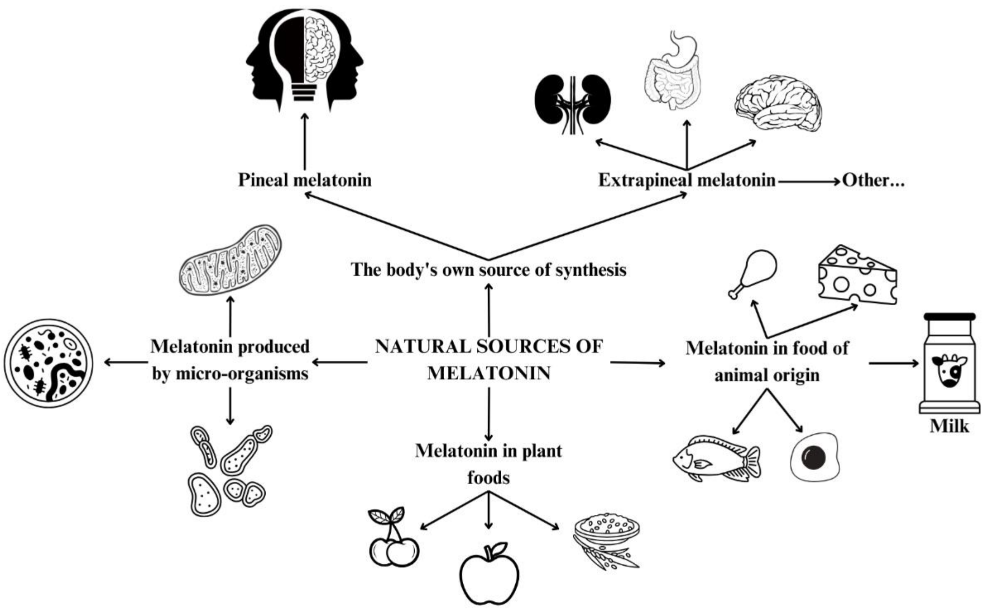

Figure 3. *Sources of melatonin in the human body*

The pineal source supplies the body with the sleep hormone or dark hormone, known under its full name of pineal melatonin, which is the main subsystem involved in regulating the circadian rhythm and improving sleep quality in vertebrate organisms, being synthesized exclusively by the pineal gland and only during periods when the body detects darkness in the environment [26].
The extrapineal source is represented by melatonin synthesized in other sites of synthesis (extrapineal organs and tissues of the vertebrate body), and is characterized by the fact that it does not enter the bloodstream, manifesting its effects only locally, in the area where it was produced and depending on the organ and tissue on which it acts [26].
The nutritional source is a component due to the presence of melatonin both in plants and in various raw materials of animal origin (meat, milk, eggs and various food products derived from these organic materials), which have made it possible for this substance to be brought into the body exogenously, through food [27].
The microbial source is the gastrointestinal tract's own microflora [28], as well as mitochondria which are rich in melatonin, so they are an additional source of *N*-acetyl-5-methoxytryptamine for the body [29].
Numerous researchers have reported in various specialized studies that the gastrointestinal tract contains about 400-500 times higher levels of extra-pineal melatonin compared to the levels of melatonin produced by the pineal gland. This estimate was made by determining the amount of melatonin present per gram of tissue harvested from the gastrointestinal tract multiplied by the total surface area of the component organs that make up this system [30, 31].
Nutritionally, melatonin levels can be increased directly or indirectly (Figure 4).

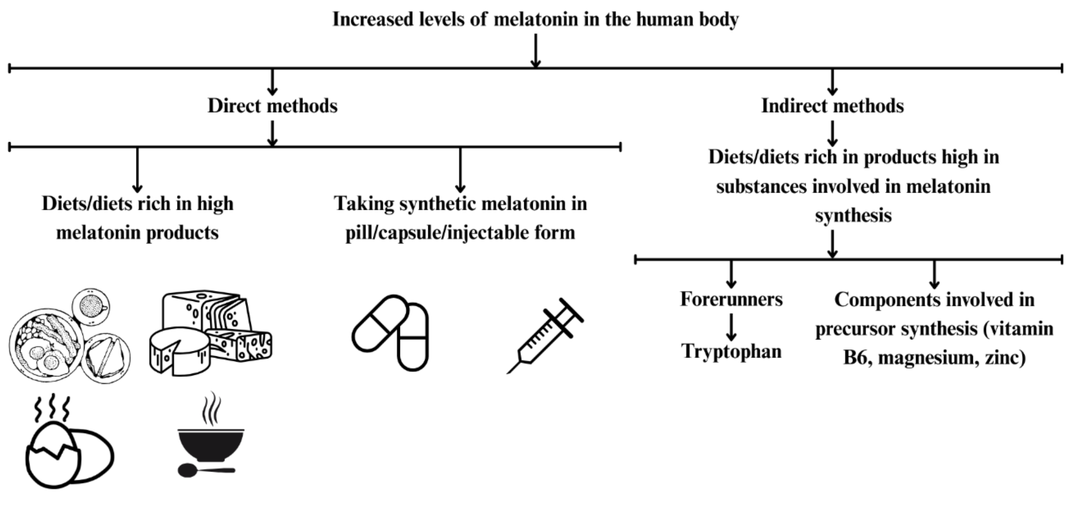

Figure 4. *Increasing melatonin levels in the human body through nutritional intake*

By the direct method, melatonin levels can be increased by eating foods high in melatonin (night milk, rice, etc.), or by taking pharmaceutical products (capsules or injectables). The indirect method aims to boost the melatonin content by eating foods that have high levels of tryptophan, vitamin B6, magnesium and zinc (substances that provide a substrate for melatonin production).
The concentrations of melatonin found in animal and human bodies can be increased directly or indirectly through nutritional intake. Increasing melatonin levels directly

through nutritional intake can be achieved by modifying rations to contain melatonin-rich (plant and/or animal) components. Through the processes of cellular digestion and absorption, melatonin can enter the bloodstream, increasing the levels of this molecule in animal and human bodies.

The circulating melatonin content can also be increased by nutritional intake and indirectly by additional intake of tryptophan or other substances that are either direct precursors involved in the melatonin synthesis process (e.g., serotonin) or are essential components in the synthesis of certain melatonin synthesis precursors (e.g., vitamin B6 which is essential in the production of serotonin from tryptophan, or magnesium and zinc which are essential macronutrients in the production of melatonin from serotonin). Thus, depending on the body's availability in melatonin, these substances (precursors or substances necessary to obtain precursors) can either come as supplements to obtain a concentration of melatonin to cover the lack of *N*-acetyl-5-methoxytryptamine (if there is a deficiency), or they can contribute to a much higher concentration of melatonin in the body, if circulating melatonin levels are normal (a higher than normal melatonin content in the body is beneficial to the health of the body and does not present toxicity or adverse health effects to the individual) [4, 32].

Night milk is a food product rich in melatonin, obtained by harvesting milk in the morning hours (04:30 - 05:00) and representing a natural functional product optimal for improving the quality of human life [32]. The level of melatonin in this product can be influenced by the correct management of technological factors (duration of photoperiod, type and intensity of light used in the animal housing) and nutritional factors (administration of rumen-protected L-tryptophan, or design of feed rations containing tryptophan and/or melatonin-rich plants). We reviewed this topic in detail in a previous paper [32].

Numerous authors have suggested the idea that higher consumption of dairy foods and dietary protein in general may improve sleep quality in humans [33, 34]. From a biological point of view, this is biologically correct, because dairy foods are rich sources of protein, and contain relatively large amounts of tryptophan. But in the case of a diet too high in protein, the possible undesirable effects of too high a protein intake also need to be taken into account, as well as balancing the levels of essential amino acids, best described by the concept of ideal protein. One principle applied in farm animal husbandry is the balancing of the essential amino acid (EAA) profile, which aims to compensate for a deficiency in one or more amino acids in the body by an additional nutritional intake that brings the levels of all amino acids in the body as close as possible to the value of the amino acid that is quantitatively the most important at a given time [35, 36]. Amino acids are basic building blocks for protein formation, and the concept of balancing the essential amino acid profile is mainly about improving nitrogen utilization efficiency, a concept that is universally valid for both farm animals and humans. For humans in particular, the protein requirement is an age-dependent nutritional parameter for each individual, so many specialized studies have had as their main research objective to determine the total protein and amino acid content of a raw material (milk, meat, eggs) and, based on the calculation of the Oser index or the essential amino acid index (EAA index), the level of protein coverage of those raw materials or finished food products for different age groups (children, adults and elderly) [37 – 41].

Tryptophan is widely used in animal and human nutrition due to its multiple benefits for the body [35]. In animal nutrition, tryptophan is administered in the form of rumen-protected L-tryptophan by supplementing feed rations [42], by intravenous administration [43] or by subcutaneous administration [44] of this amino acid. In humans, tryptophan is used as a dietary supplement or can be obtained from food sources rich in tryptophan.

Numerous studies have investigated both the effects of feed supplementation and direct administration of rumen-protected L-tryptophan intravenously or subcutaneously on stimulating increased concentrations of protein, tryptophan and melatonin in the blood and milk of animals. In general, due to the multiple roles and functions that tryptophan can fulfill in the animal organism, studies conducted up to 2025 were mainly aimed at observing and determining the manifestation of certain physiological processes in relation to increased tryptophan bioavailability.

Liu *et al.* [44] conducted a study in which they administered protected L-tryptophan in amounts of 50 and 100 g per cow per day, respectively, during the postpartum period of the animals in order to balance the energy balance of the cows. L-tryptophan was administered for a total of 42 days (21 days before parturition and 21 days after parturition) and the results showed uniformity throughout the experiment in terms of blood tryptophan content, with a slight decrease in tryptophan content after parturition. Levels of circulating melatonin were higher in the experimental groups, being about 1 $ng\cdot mL^{-1}$ in the control group, between 3 - 4 $ng\cdot mL^{-1}$ in animals supplemented with 50 g tryptophan per day per animal, and about 6 - 7 $ng\cdot mL^{-1}$ in serum samples from cows supplemented with 100 g/day/cow tryptophan, but gradually decreased in the post-calving period to values of about 0.5 - 1 $ng\cdot mL^{-1}$. Both tryptophan and melatonin present in milk showed a downward direction of quantitative evolution after parturition in all three groups studied. The tryptophan content determined in milk decreased from about 500 - 600 $ng\cdot mL^{-1}$ determined on day 1 after parturition to about 200 $ng\cdot mL^{-1}$ determined on day 21 after parturition, but in the case of melatonin in milk, the decrease was much more abrupt (from about 8-10 $ng\cdot mL^{-1}$ determined on day 1 after parturition to about 2-2.5 $ng\cdot mL^{-1}$ determined on day 4 and to about 0.5-1 $ng\cdot mL^{-1}$ determined on day 21 after parturition).

In another study, Kim *et al.* [45] reported that the administration of 20 g per cow per day of protected L-tryptophan to Holstein cows from July to September increased milk melatonin levels both in the observed comparison between the control group that did not receive protected tryptophan and the experimental group, and also in evolutionary terms during the 90-day experimental period, in the case of the group of cows that received additional administration using 20 g per cow per day of protected L-tryptophan (the results obtained by the authors of that study in terms of melatonin content found in the milk were, for the control group, 3.63 $pg\cdot mL^{-1}$ in July, 4.45 $pg\cdot mL^{-1}$ in August and 6.60 $pg\cdot mL^{-1}$ in September, and for the experimental group, melatonin levels were 6.68 $pg\cdot mL^{-1}$ in July, 5.28 $pg\cdot mL^{-1}$ in August and 13.53 $pg\cdot mL^{-1}$ in September).

SLEEP QUALITY AND ITS INFLUENCE ON THE BODY

Sleep quality is a concept described in the literature as being measurable and characterized by means of indicators that provide an overall picture, generated from the perspective of the human subject under analysis, based on the general state that the subject feels both in the first moments after waking up and during a day of activity while awake. In order to analyze the quality of sleep quality, many researchers have studied this phenomenon using questionnaires or the diary method [46]. These two techniques are useful methods for determining the level of sleep quality, but at the same time they are highly subjective, which can lead to a decrease in the accuracy of the methods and a possible depreciation of the results obtained.

The structure of sleep is looked at from a macro and micro perspective. The macrostructure of sleep is represented by a series of physiological signals, such as body posture, respiratory movement and inspiratory airflow, oxygen saturation, electrocardiogram, electroencephalogram, electrooculogram and electromyogram. These parameters, which can effectively define sleep quality, can be studied using the Full Night Polysomnography (FNP), a tool that is the most widely used standard in determining sleep quality in 2025. The microstructure of sleep is represented by the realization of transition periods between sleep stages, which are characterized by three parameters, namely: phase A, which is represented by the repetitive elements that form the activity phase, phase B, which represents a rest period manifested in order to return to the activity characteristic of sleep, and the recurrence phase, which is the sum of phase A and phase B [46].

Sleep has major implications in maintaining optimal body health, and with the exception of the occurrence and development of cardiovascular and neurodegenerative diseases, sleep deprivation and poor quality sleep is also generally associated with the promotion of type 2 diabetes mellitus as a result of insulin resistance, and with the development of obesity as a result of disordered eating patterns and impaired appetite [47 – 49].

Sleep is defined in relation to several successively occurring stages that are characterized by the intensity of brain activity, which is measured by brain waves produced by the brain. Sleep is directly involved in supporting cognitive function, regulating metabolism and maintaining optimal functioning of the immune system, and getting good quality sleep improves memory enhancement and decision-making efficiency [50].

Melatonin is the main promoter of physiological sleep for vertebrate organisms. Thus, on the basis of environmental factors (the intensity of light penetrating the surface of the eyeball and the ambient temperature, which is lower at night than during the day), the body is able to start melatonin synthesis via the pineal gland, which it then secretes into the blood and cerebrospinal fluid. Once released into the bloodstream, melatonin in the blood (also called circulating melatonin) is transported to different regions of the body, where its main role is to signal to the body's organs and tissues that sleep-rest is about to be initiated. Melatonin, secreted in the cerebrospinal fluid, is transported to the brain to inform the brain about the time of day (day/night) and to stimulate it to initiate the physiological state of sleep when it is dark outside. Basically, the presence of a higher amount of circulating melatonin than during the day is the main signal for the vertebrate organism that informs the body that the environment is dark and that the process of resting through sleep must be initiated. In relation to some specialized studies, it has been established that during the day, melatonin levels present in the blood generally do not exceed 2 - 5 $pg \cdot mL^{-1}$ blood, while during the night it can reach up to about 100 $pg \cdot mL^{-1}$ blood, so it has been proposed that melatonin acts as a messenger for the vertebrate organism, indicating to the body what time of day it is [19, 51, 52].

Achieving good quality sleep is a phenomenon that requires the presence of large amounts of pineal melatonin in the bloodstream, which implies the absence of light in the external environment [53]. In specialized studies, sleep deprivation has been shown to negatively influence plasma melatonin [54] and intestinal melatonin [55].

Sleep is defined as a natural and complex physiological state that occurs in a cyclic manner and is initiated by the presence of specific signals, such as the absence of ambient light and a drop in the body's external temperature [56]. These signals, but especially the lack of light, are the environmental information that the body perceives through the eyeball. The main molecules that regulate the body's tendency to initiate and maintain sleep are adenosine (an endogenous purine nucleoside that performs a wide variety of functions in vertebrate organisms, including sleep initiation), serotonin and melatonin [57]. According to some specialized research, it has been established that there are four major components in the human body that promote and maintain whole-body health, which are represented by each individual's diet, the quality of physical exercise, the quality of sleep and the quality of social activities [58].

SLEEP ARCHITECTURE AND FACTORS THAT CAN IMPAIR SLEEP QUALITY

In animals and humans, sleep is a resting state in which the body's response to external stimuli is reduced and body temperature is increased in response to low ambient temperature levels. Sleep occurs in two distinct states of brain activity called NREM (non-rapid eye movements) and REM (rapid eye movements) [59, 60]. The two patterns that define the architecture of sleep (NREM and REM) manifest individually and cyclically, playing major roles in replenishing the body's energy after a cycle of activity in the waking state [60].
The physiological states that characterize each stage of the sleep cycle are identified and delimited by means of electroencephalogram (EEG) signals, which are characterized by the presence of different wave types with different frequencies and whose presence is associated with different phases that define and compose sleep, as shown in Table 2.

Table 2. *Brain wave types, wave frequencies and their association with sleep architecture states*

Wave type	Symbol	Frequency [Hz]	Association with sleep onset stage	References
Delta	δ	0.5-4	Deep sleep	[59, 60]
Theta	θ	4-8	Light sleep characterized by relaxation	
Alpha	α	8-13	Relaxation sleep characterized by a state of calm with eyes closed	
Beta	β	13-30	Intense mental activity	
Gamma	γ	>30	Achieving advanced cognitive processes	

NREM sleep is the phase that begins with the onset of sleep and involves three stages (NREM1 or sleep onset, NREM2 or light sleep and NREM3 or deep sleep). The first phase of NREM sleep, referred to as NREM1, occurs immediately after the end of wakefulness, is a transitional phase between wakefulness and sleep, takes about 5 % of the total sleep duration, and is characterized by lower muscle tone than during wakefulness and slow eye movement. In the specialized literature, the concept called *complex K*, represents a natural response of the organism with an intensity of less than 1 Hz, and in correlation with the *sleep spindle*, which represents an increase in the activity of the organism during sleep, with an intensity between 10 and 15 Hz, respectively, are the main specific signals indicating that the organism is in the NREM2 stage, of the NREM sleep phase. The third stage that characterizes NREM sleep is NREM3, represents

about 25 % of the total sleep duration and is characterized by slow brain wave activity, between 0.5 and 2 Hz respectively [60].
REM sleep is also called REM sleep, and it occurs cyclically after the completion of the NREM3 phase, about every 90-120 minutes. The transition between the NREM and REM sleep phase is characterized by a decrease in body temperature, but once REM sleep is initiated, the hypothalamus maintains a constant core body temperature. Active muscle atonia and high arousal threshold are other phenomena that characterize REM sleep [60].
A circadian rhythm is defined as a periodic pattern of approximately 24 hours in duration, which is manifested by the cyclical passage of two periods, one of light and one of darkness. In general, most metabolic and physiological processes are carried out with different intensity (lower or higher), depending on the time of day determined by the circadian system that regulates the body's behavior in relation to stimuli received from the environment [61].
Poor quality sleep is defined as sleep for less than 7 hours and has negative effects on the health of the whole body, most often manifested by difficulties in staying alert/concentrated during the day, obesity and cardiovascular disease. Some authors have hypothesized that there is a direct link between lifestyle, the type of food an individual eats and sleep quality [62].
Achieving a good quality sleep is a process that involves the creation of favorable conditions that allow the achievement and efficient synchronization of quality parameters corresponding to the physiological state of sleep, which are represented by the duration of sleep (an optimal sleep duration is considered to be between 7 - 9 hours) [58], sleep efficiency (represents the duration required to initiate sleep and the quality of sleep maintenance, thus defining the notion of consolidated sleep) [58, 63], daytime ratio between alertness and sleep (a quality sleep is also determined by the level of sleepiness during the day) [58], the regularity and entrainment of the circadian rhythm (represents the daily regularity between bedtime and wake-up time) [58, 64], synchronization of sleep with the circadian rhythm (involves sleep during the night) [65], the quality of sleep perceived by each individual (satisfaction after waking) [66], the achievement of good breathing (in general, heavy breathing during sleep affects sleep quality) [62, 67], and the absence of sleep disturbances (nightmares and parasomnia, which manifest as sudden falling out of bed, can lead to sleep fragmentation) [58].
Sleep fragmentation, which may be manifested by sudden awakenings or just spontaneous movements of body parts, is a process that can lead to a deficit in staying alert, affect glucose homeostasis, impair psychomotor performance of individuals, and may also cause dysfunction in the ability to remember information [58, 63].

DAIRY CONSUMPTION AND SLEEP QUALITY

The consumption of dairy products is generally associated with better quality sleep because they are rich in tryptophan (the main precursor involved in the synthesis of serotonin and melatonin), and have certain components in their chemical structure that act as cofactors in the melatonin synthesis process [62, 68].
Dairy products are important sources of protein for human nutrition. Melatonin reaches a peak of synthesis in vertebrates at around 02:00, after which it enters the bloodstream and is transported to the mammary gland of mammalian females, where it is released into milk, resulting in melatonin-rich milk when harvested at night, in the morning hours, and

the consumption of night milk (rich in naturally obtained melatonin) has been associated with a significant improvement in sleep quality [69]. The presence of tryptophan in relatively high amounts in dairy foods, and especially in casein and serum proteins [70] is a well-documented topic, so that a high consumption of dairy products may stimulate melatonin synthesis in the human body, through a higher availability of tryptophan in the body. Dairy products are also foods rich in minerals and vitamins, and the fact that vitamin B6 (which is present in both raw milk and other dairy products) is essential for the production of serotonin from tryptophan, and magnesium and zinc are cofactors involved in the production of melatonin from serotonin, make milk and dairy-derived products a staple food in both human nutrition and in maintaining optimal sleep health in humans [68].

Tryptophan is a limiting essential aromatic amino acid [71] produced by plants [72] and various microorganisms [73], and is introduced into animal and human bodies through food. The tryptophan then enters the bloodstream and is transported to the blood-brain barrier so that it can be transferred to the brain. Thanks to this process, tryptophan also ends up in various animal products such as meat [74, 75], milk [76], eggs [41] and fish [77]. One of the most valuable foods in terms of quality protein content is milk [32, 76, 78]. During milk processing, the chemical composition of the final products obtained changes according to the type of product obtained (drinking milk, sour milk products, cheeses, etc.) and according to the technological processes to which the milk was subjected during processing (type of heat treatment applied, type of fermentation, etc.). Table 3 shows the values of fat, protein and tryptophan determined by different authors and in different dairy products.

Table 3. *Chemical composition of different dairy products in fat, protein and tryptophan*

Name of milk product	Quantity			References
	Fat [%]	Protein [%]	Tryptophan	
Cow's milk	4.17	3.57	~41*	[78]
Sheep's milk	6.82	5.15	~30*	
Goat's milk	4.61	3.35	~31*	
Buffalo milk	6.58	4.25	~38*	
Whole milk	2.96	3.41	3.39**	[76]
Standardized milk	0.72	1.87	1.83**	
Condensed milk	0.07	0.15	0.15**	
Mature cheeses	4.59	5.64	6.24**	
Cottage cheese	1.40	3.34	3.58**	
Skimmed yogurt	0.39	1.05	1.08**	
Sour milk drinks	1.12	2.60	2.61**	

* - Values expressed in $mg \cdot g^{-1}$ protein; ** - Values expressed in percent (%).

Numerous studies that have aimed to determine the influence of dairy consumption on sleep quality have mainly investigated the effects of tryptophan-enriched night milk on sleep quality compared to plain milk [79, 80].

Milk is a valuable product for human nutrition because it is the main source of food for infants, and because of its complex chemical composition, which makes it an optimal candidate for maintaining a healthy body [81 – 83].

Xu *et al*. [84] reported in a study published in 2023 that an increased intake of milk introduced in the diet of adults and elderly people has beneficial effects on improving sleep quality. That study involved finding a positive relationship between milk consumption and sleep quality. The study included a total of 768 adults aged 28 to 95 years from the Wenling region, China, who were divided into two groups (a group receiving less than 62.5 mL milk/week and a group receiving more than 62.5 mL milk/week). The authors reported that an additional nutritional intake of milk provided significant benefits in improving sleep quality in general across the entire study sample, and in particular, a more pronounced effect was observed in older people (people aged 65 years and older) and men compared to younger people and females. These observations are in correlation with other studies in which it has been reported that with advancing age, the levels of melatonin synthesized by the pineal gland in the human body decrease [85 – 87], and physiologically, the female body synthesizes more melatonin than the male body [88]. These aspects, which highlight a lack of melatonin in older people and men, explain the higher level of improvement in sleep quality in groups of individuals who need extra melatonin.

The impact of dietary patterns that include moderate or even high consumption of dairy products has been the main subject of research in other specialized studies as well. In the context of the pineal gland's reduced ability to produce melatonin with advancing age, Yamamura *et al.* [89] conducted a prospective, randomized, double-blind, placebo-controlled study with a crossover design, in which they investigated the effects of supplementing diets with a fermented milk drink containing *Lactobacillus helveticus*, consumed at a dose of 100 mL·day^{-1} for 3 weeks, in 29 subjects aged 60-81 years, which has been shown to increase melatonin levels in the blood. The fermented milk drink was prepared from skimmed milk, which was pasteurized at a temperature of approximately +80 °C for 10 minutes, and to which a *Lactobacillus helveticus* lactic acid culture was added after heat treatment. The final drink was a mix of milk fermented with *Lactobacillus helveticus*, with added aspartame, flavorings, and stabilizers. The quality of sleep was determined using actigraphy (a method for determining wakefulness rhythms during sleep), the Sleep Health Risk Index (SHRI), the SF-36 health survey, and statistical data processing. The results obtained by Yamamura *et al.* [89] suggest that fermented milk drinks have the ability to improve sleep quality and overall health in older adults, with a significant improvement in sleep observed compared to the initial period of the study, through greater sleep efficiency and a reduction in the number of awakenings during the sleep period.

Campbell and Neill [90] studied the effects of a drink made from 250 mL of water and 30 g of low-lactose skimmed milk powder, with a high level of melatonin and enriched with alpha s1 casein tripeptide hydrolysate, on reducing the level of primary insomnia in men and women aged between 27 and 73. The study included a total of 19 people, of whom 14 were women and 5 were men. The study was a crossover, randomized, double-blind, placebo-controlled trial lasting a total of 9 weeks, in which patients were asked to consume a drink prepared from 250 mL of water plus a 30 g sachet of skimmed milk powder rich in melatonin 30 minutes before bedtime. The subjects were randomly divided into one of two groups, one group that first consumed the melatonin-rich product obtained from cow's milk milked at night (the melatonin content in milk being 85.5 pg·mL^{-1}), and another group that first consumed the product with a low melatonin content obtained from cow's milk milked during the day (8.8 pg·mg^{-1}). The melatonin-rich milk powder sachets contained 2.565 ng of melatonin. The study design was structured in three stages, which involved patients consuming the first product for the first three weeks, followed by a one-week break, followed by another three weeks during which product 2 was consumed.

Campbell and Neill [90] reported that night milk consumed 30 minutes before bedtime, in the form of a fortified drink consisting of 250 mL of water and 30 g of low-lactose skimmed milk powder, with high levels of melatonin and enriched with alpha s1 casein tripeptide hydrolysate, improved the Pittsburgh Sleep Quality Index (PSQI) [91], sleep-related disorders, daytime dysfunction, and sleep onset latency, increased the percentage of sleep achieved in the NREM3 phase as determined by home polysomnography, as well as sleep efficiency monitored by actigraphy, and decreased the number of awakenings during sleep.

Other practices applied on animals (adult Wistar rats), which had positive effects on improving sleep quality, were used by Milagres *et al.* [92], and involved studying the effects of consuming melatonin-rich night milk and tryptophan-enriched night milk (consumed before bedtime) on sleep quality.

Further studies are needed to establish the exact correlation between dairy consumption and the influence of these dietary patterns on sleep architecture and quality, as there are studies in the literature that report either a weak association or a total absence of beneficial effects of dairy consumption on sleep. More detailed studies are needed to determine the impact of high consumption of dairy products on sleep architecture and quality in different consumer groups, classified according to age and eating habits. Most studies reporting effects of high dairy intake on sleep quality have short experimental durations and include observations associating higher dairy consumption with maintaining optimal/normal sleep quality and, to a lesser extent, with significant sleep improvement.

NUTRITION AND SLEEP QUALITY

Sleep quality is directly influenced by eating habits. Numerous authors have associated the quality of each individual's diet as being directly proportional to optimal sleep. Eating habits directly influence the body's health, and it has been shown in numerous specialized studies that a balanced diet, including healthy foods, has direct effects on maintaining and improving the health of the human body [93, 94].

The specialized studies carried out in the field of knowledge of the impact of diets on the achievement of good quality sleep have generally been carried out in relation to the main factors that may influence melatonin synthesis, namely the age of each individual, the dietary pattern specific to the geographical area where the study was conducted and the quality of the food products that formed the diets.

Jansen *et al*. [95] conducted a study in Mexico, in which they aimed to identify the effects of different dietary patterns on sleep quality in adolescents aged 10 to 19 years, respectively. The study involved 458 teenagers, lasted two years, looked at teenagers' bedtimes and wake-up times during the week and separately at weekends, and involved the analysis of three eating patterns (a healthy plant-based, lean protein pattern, a breakfast pattern based on milk, eggs and refined cereals, and a low-quality meat and starch pattern). Two years after the start of the study, the results showed that following a healthy eating pattern and a diet based on milk, eggs and cereals had positive effects on the overall quality of sleep achieved by adolescents following these diets. The effects of diets on sleep quality, observed by the authors of that study, were represented by an earlier than normal sleep onset and a positive correlation between bedtime, sleep duration and wake-up time, which were analyzed during the week, compared to the same parameters analyzed during the weekend. The authors of that study reported a negative correlation between poor eating pattern and sleep quality in Mexican adolescents. Thus, the results obtained by Jansen *et al*. [95] showed that an inferior meat and starch-based dietary pattern induced a social jet lag in adolescents after two years of following this type of diet, manifested by differences in sleep patterns (bedtime, sleep duration and wake-up time) during the week and weekends [95].

Some studies have aimed to identify a correlation between the characteristic patterns of a Mediterranean diet and improved sleep quality. According to Godos *et al*. [96], Mediterranean diets consist predominantly of plant foods such as fruits, vegetables, nuts and whole grains, involve a moderate consumption of milk, dairy derivatives, fish meat and other animal protein sources, and a low consumption of meat and meat-derived products. A positive correlation between Mediterranean dietary patterns and good sleep quality has been reported in several specialized studies [96 – 99].

Specialized research on the effects that diets containing good quality products can have on sleep architecture has mainly focused on the study of food models containing foods rich in melatonin, or in other mineral or bioactive components that support the melatonin synthesis process.

The use of diets rich in tryptophan-containing foods has been, and still is in 2025, a topic of interest in terms of optimal sleep quality, as these dietary patterns generate higher melatonin synthesis as a result of increased bioavailability of tryptophan. In a study published in 2013, Bravo *et al*. [100] supplemented the diets of a group of subjects aged 55 - 75 years for a period of 3 weeks using 30 g of tryptophan-enriched cereals, each containing levels of about 60 mg tryptophan. The authors of that study reported that, compared to the control group, which did not benefit from this supplementation, the experimental group showed effects in terms of increased actual sleep onset time, increased sleep efficiency and increased immobility time, as well as a decrease in sleep latency, a decrease in wakefulness and a decrease in sleep fragmentation index [100].

Depletion of tryptophan at the cellular level will lead to decreased sleep quality due to prevention of serotonin synthesis, which will subsequently limit the total amount of melatonin synthesized by the pineal gland and released into the blood [101, 102].

Unbalanced diets and consumption of ultra-processed foods, which have become staple foods for 21st century society, are also associated with the promotion of low-grade inflammation (a phenomenon that alters the body's homeostasis and favors the development of chronic diseases). The inflammatory response is the body's innate response, which naturally protects the body from external stimuli and factors that are harmful to human health (bacteria, viruses, infections, etc.) [102]. In relation to the statement made by Tristan Asensi *et al*. [103], foods can be categorized as forming an anti-inflammatory diet or food pattern (this group includes cereals, fruits, vegetables, fish meat) and pro-inflammatory (high-fat meat, fast-food, carbonated drinks and others). Some practical approaches have suggested that a diet rich in plant-derived foods would support improved sleep quality, as some plant products are rich in tryptophan [104].

The combination of plant and animal foods in the form of food supplements that meet the body's protein requirements and improve sleep quality can be achieved by using products in rations that contain good quality protein and high levels of tryptophan. Tryptophan-rich plant products include bananas (26.15 ± 0.37 $\mu g \cdot g^{-1}$), pineapple (19.83 ± 4.08 $\mu g \cdot g^{-1}$), avocado (16.27 ± 3.49 $\mu g \cdot g^{-1}$), strawberries (19.58 ± 0.22 $\mu g \cdot g^{-1}$), and the correlation of these products with different animal foods with a high tryptophan content, such as egg yolk (240 $mg \cdot kg^{-1}$), chicken (205 $mg \cdot kg^{-1}$) or mutton (198 $mg \cdot kg^{-1}$), may represent suitable dietary models to cover the protein requirements of the human body, while also providing a substrate for melatonin synthesis [105, 106]. Specialized studies have shown that foods of animal origin contain better quality protein compared to vegetable protein, which requires a balance in daily rations between vegetable and animal foods, so as to cover the daily protein requirements for each body, but also to ensure an optimal content of complex carbohydrates that promote the absorption of tryptophan in the brain [41,75 – 78, 106].

Eating habits directly influence the overall health of the human body, and in particular how well we sleep. Regular consumption of dairy products and following a Mediterranean diet can have positive effects on regulating and improving sleep. However, maintaining an optimal nutrient intake that does not lead to imbalances manifested by a deficiency or excess of proteins, lipids, carbohydrates, vitamins, minerals, and others is an aspect that must be taken into account when establishing a dietary pattern/model that improves the overall health of the human body [106].

CONCLUSIONS

In relation to the information presented in this paper, we assert that the type of diet and eating pattern applied have direct effects that may manifest themselves in the long term on sleep architecture and sleep quality. The conditions of everyday life in the 21st century, which best describe the society of the 3rd millennium, which is characterized by a hectic lifestyle, with more time than normal spent under the influence of artificial light, and an unhealthy and unbalanced diet, are putting increasing pressure on the maintenance of the general health of the human body. As a sleep promoter and a potent antioxidant, anti-inflammatory, anticarcinogenic, etc., melatonin is the ideal candidate for reducing the processes and phenomena of sleep quality impairment that can occur as a result of the stress to which the body is subjected on a daily basis.

The scientific evidence available up to 2025 demonstrates that difficulties in achieving good quality sleep, as well as complete sleep deprivation, are generally associated with a deterioration in overall health and quality of life, through the onset and promotion of various conditions such as cardiovascular or neurodegenerative diseases. Maintaining a balanced lifestyle has thus become a priority for the human population, due to the need for the body to adapt to new living conditions. According to a large body of research, nutrition is one of the main factors, along with quality of sleep, physical activity and social life, that are directly involved in shaping the overall health of the body, so the right combination and balance of these four factors can provide beneficial and long-term quality of life outcomes for each individual.

Dairy products can be successfully used in achieving a healthy and balanced diet that also improves sleep quality. Getting good quality sleep can reduce the risks associated with cardiovascular disease, and higher than normal levels of melatonin in the human body can reduce the risk of developing neurodegenerative diseases, type 2 diabetes, and obesity, and can also reduce inflammation. Diets rich in dairy foods can improve sleep quality both indirectly through tryptophan and other substances necessary for melatonin synthesis (vitamin B6, zinc, magnesium) found in the chemical structure of dairy products, which once in the body become essential substrates in the melatonin synthesis process, and directly through the additional nutritional melatonin intake, especially through night milk.

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