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A response of dairy animals to heat stress and mitigation strategies: A literature review

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Abstract
The climate is changing and temperature is increasing day by day due to global warming. Dairy animals are homeothermic in nature so they maintain their body temperature when temperature exceeds. Within thermo-neutral zone there is no need to regulate the body temperature by physiological and behavioural changes by animals but if environmental parameters (temperature and humidity) exceed certain point then dairy animals cannot maintain their welfare in normal conditions, also there is imbalance between metabolic heat production and heat dissipation to the surrounding results in heat stress. Heat exchange between animal's body and surrounding is carried out in sensible and evaporative way and the sensible heat loss via conduction, convection, radiation and evaporative heat loss through respiration and sweating loss. Heat stress has various negative impacts on dairy animals like feed intake, production and reproduction. There is various heat stress indices used to measure the effect of heat stress on animals. Each index has potential to measure the heat stress according to climatic conditions. The different kinds of heat stress reducing techniques are in practice which is used according to climates and structural design of dairy barn.

Keywords: Climate change, heat stress, thermo-neutral zone, conduction, convection, radiation, THI, CCI, evaporative cooling system

Introduction
Climate change, especially global warming has direct and indirect effects on the health and welfare of dairy animals [22, 46]. The average global temperature has increased by 0.8°C over the past 100 years and is projected to increase by 1.5-4.8 °C by the end of this century due to global climate change [1]. Cows and buffaloes are major contributors for milk production. The global milk production is approximately 906 million tonnes in 2020 that increases 2.0% year-on-year [2]. India's milk production in 2020-2021 is 209.96 million, accounting for 23% of the world's milk production [2]. India is projected to produce 266.5 million tonnes of milk by 2030 [3]. This goal could be achieved when the balance between productivity of milk and fertility of dairy animals is optimized [4]. Crossbreeds, high-dairy cows are more susceptible to physical stress when exposed to hot weather compared to other livestock and regional breeds [5]. As compared to other domestic ruminants, buffaloes are less heat-tolerant, have poorly distributed sweat glands, have a dark body colour, and have sparse body surface hair, making them susceptible to heat stress (HS) [24]. Long-term exposure of animals to ambient temperatures below or above the thermo neutral range can alter the physiological functions of animals; accordingly animals can be characterized as cold-stressed or heat-stressed. Stress is the body's response to stimuli that disrupt homeostasis, often with adverse effects [6].
Heat stress is caused by a combination of various environmental factors [45, 47] and has both direct and indirect negative effects on animal production. Animal health and productivity are closely related to the environment in which they operate [7]. There are numerous indicators that combine various environmental elements to gauge the severity of heat stress. Most research on livestock heat stress has concentrated primarily on temperature and relative humidity [26, 33]. Heat stress is chronic in nature, there is frequently little relief from the heat during the evening hours, and intense bursts of combined heat and humidity further impairs performance [23]. The high yielding cow has greater metabolic activity and produces more body heat than those with lower yields; thus, greater milk yield may increase heat stress [13]. The majority of India experiences climatic conditions that make the warm (or hot) season relatively protracted, intense radiant energy is present for an extended period of time, and high

relative humidity is typically present [23].

In India, the summer temperature goes beyond 45°C which is 18°C above the upper critical temperature of dairy cattle. Even in moderate humidity, temperatures above 27°C are too hot for dairy cows to tolerate. Heat exhaustion is significantly influenced by humidity [9]. High ambient temperatures in tropical and subtropical areas are the principal factor limiting animal productivity, and the effects of heat stress are amplified by high humidity levels [10]. Heat stress is defined as any combination of environmental elements resulting in conditions that are higher above the temperature range of the animal's the rmoneutral zone. Various methods are employed to ease the effects of heat stress and provide comfort for animals.

Heat Stress

The term "Heat Stress" (HS) refers to the combination of outside factors that affect an animal and raise its body temperature as well as trigger physiological reactions [11]. Combining the influences of dry bulb temperature (T_{db}), relative humidity (RH), solar radiation (SR), and wind speed (WS) results in the magnitude of HS [11, 23]. Additionally, HS develops in dairy cows when they exposed to hot or excessively hot and humid climatic circumstances [13]. Animals experience heat stress when there is an imbalance between the amount of heat produced by their bodies and how quickly it is expelled, leading to a higher core body temperature and maybe less comfortable animals [20]. Heat stress shift body temperature from the resting state and reduces feed intake, milk yield, growth rate [14] also drastically affects the productive and reproductive performance of animals in addition to causing welfare issues [12]. Humidity was the limiting factor of heat stress in humid climates, whereas dry bulb temperature was the limiting factor of heat stress in dry climates [15]. Farmers and livestock producers in tropical nations are very concerned about HS since it results in significant economic loss [14]. Growing cattle have significant levels of heat load, with solar radiation having only a modest impact. This is due to their high energy intake, which is necessary for high levels of output [19].

Thermo-neutral zone (TNZ) and animal comfort

The thermo-neutral zone is defined as the range of ambient temperature where thermoregulation is only accomplished by controlling sensible heat loss, i.e. without regulatory changes in metabolic heat production or evaporative heat loss, or in which there are no discernible fluctuations in the physiological processes of the cow [42]. Animals constantly receive and lose heat from their surroundings; therefore they don't need to change their behaviour or physiology to keep their internal body temperature stable during the thermo neutral zone [42]. The ambient temperature below, which the rate of heat production of a resting homeotherms increase to maintain thermal balance is the lower critical temperature (LCT) and the upper critical temperature (UCT) is the ambient temperature when the metabolic rate increases, evaporative heat loss increases, tissue thermal insulation is minimal [42, 66]. The thermo-neutral zone typically ranges from lower critical temperature to upper critical temperature shown in Fig. 1 [67, 70, 71, 66] and is influenced by factors like an animal's age, species, breed, feed intake, diet composition, prior state of temperature acclimation or acclimatisation, production, particular housing and pen conditions, tissue insulation (fat, skin), external insulation (coat), and behaviour [20, 68]. The thermo-neutral zone describes the inter-relationship between the animal and the environment and within thermo-neutral zone metabolic rate is modest, and a healthy animal may physically adapt to maintain the usual body temperature with little change in metabolic activity. The highest critical temperature i.e. (UCT) for dairy cows is 25-26°C [38].

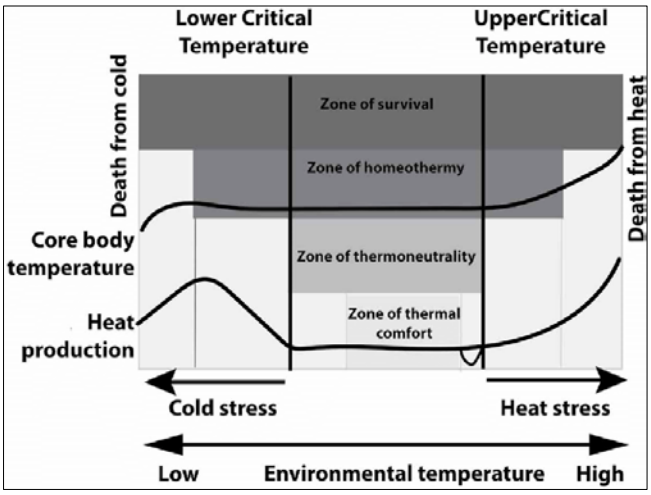

Fig 1: Thermo neutral zone showing UCT and LCT

The predicted temperature range for the most effective energy usage, with the exception of neonatal calves, is around 13 °C - 18 °C; in spite of that, major changes in feed intake or in a number of physiological processes will not occur within the range of 5 -25 °C [48, 70]. Whether it's over 25 °C or below 5 °C, The environment will affect the appetite of cow when the temperature is above 25 °C or below 5 °C [69]. The cow is most comfortable and maintains a normal body temperature in thermo-neutral zone, which maximises milk output [14, 42]. Cattle experiences HS above this zone and feels uncomfortable because she needs to increase her metabolic rate to divide her metabolic energy into heat-dissipating actions including increased breathing (panting), sweating, and increased blood flow to her body's periphery [14]. The term "cow comfort" merely refers to the surrounding climate or "comfort zone." The biological efficiency of the energy input to output in thermo-neutral zone is good, and all physiological processes are operating within the normal ranges [43]. A comfortable cow is one that is at peace with her environment [43].

Table 1: Approximate daily time budget for a typical milking cow

Sr. No.	Daily activities	Spend time
1	Eating	5.5 h/day with 9 to 14 meals/day
2	Resting	12 to 14 h/day, including 6 h rumination
3	Standing or walking in alleys	2 to 3 h/day, which includes grooming, rumination, socialising and other activities
4	Drinking	0.5 h/day
5	Total time needed	21 to 22 h/day

The table 1 revealed the approximate daily time routine for a typical milking cow in shed in US, a fairly good time budget of the comfortable cow shows that a comfortable cow spent more time in resting [43].

Heat Exchange

The heat exchange in body of dairy animals comprises of three modes heat production, non-evaporative heat loss, and evaporative heat loss showed in Fig. 2 [73, 35]. Heat exchange by conduction, convection, or radiation is the subset of sensible heat loss i.e. non-evaporative heat loss. During peak summer temperature sensible heat can be gained through environment when ambient conditions exceed the threshold limits [73, 35 47]. Evaporative heat loss occurs unidirectionaly i. e. away from body [47]. The net exchange of heat produced or obtained from the environment must match the net heat loss to the environment for the animal to maintain thermal equilibrium according to following Equation:

$$M = \pm K \pm C \pm R + E$$

Where, M is the amount of heat produced by metabolism,
K is the heat transferred by conduction,
C is the heat exchanged by convection,
R is the heat exchanged by radiation,
E is the heat exchanged by evaporation [72].

The metabolic heat is gained from maintenance, development, lactation, gestation, and feeding. In addition to the heat produced by metabolism, the environment also produces heat. Heat loss is caused by elimination of metabolic waste products (such as faeces, urine, and milk) as well as environmental variables. Both during and after feeding, heat generation rises [16, 44]. The feeding during the cooler periods of the day, non-evaporative heat loss from the body to the environment is made easy due to temperature difference. Reducing feed quality and/or giving animals feed in the late afternoon would be helpful to animals in reducing their heat loads in the event of an impending high heat load condition [19]. Dairy cows give off heat to the environment in a number of ways, including conduction, convection, radiation and evaporation as shown in Fig. 2 Conductive, convective, and radiant heat transfer are forms of sensible heat transfer because there must be a temperature difference between the cow and the environment for these three modes of heat transfer to occur [42, 70, 71]. The surface area per unit body weight determines the amount of sensible heat loss through conduction and convection [73]. Evaporative heat loss involves the latent heat of vaporisation; it is also known as insensible heat exchange. Beneficial latent heat transfer (evaporation) occurs when liquid water undergoes a phase change vapour. Vapour pressure differences between cows are required for latent heat transfer to occur Skin/airway and ambient air [16].

Conduction

Conduction has two main roles. It contributes to both the flow of heat from the periphery to nearby objects which are in touch with the skin surface and the transfer of heat from the core of body to the skin surface [44, 45, 73]. Therefore, through ground contact most of the conductive heat flow occurs in cattle. When an animal is standing, heat transfer with the ground must happen through its feet, which make up only 2%age of its body surface area [44]. Conductive heat transfer will be substantially stronger if an animal is lying on a chilly or wet surface with as much as 20-30 percentage of the body surface in touch with the ground. This will depend on a number of factors, including thermal conductance, temperature gradient, and area of contact [44]. If the air temperature is higher than skin temperature or if the animal is resting against a surface hotter than its skin then heat is transfer to skin from surrounding [16].

Convection

The total heat transfer in a moving gas or fluid (i.e., by convection) between different parts of an organism, or between an organism and its external environment; it may develop and be amplified by temperature difference (natural convection) and by forces such as wind, fans, pumps or body movement (forced convection) usually expressed in terms of unit area of the total body surface [42]. A medium like increased air flow is used for convective heat exchange to accomplish through peripheral vasodilation, which raises the temperature gradient and encourages more heat loss to the environment [38, 42, 45, 47]. At cooler air temperatures, convective and conductive heat losses are larger and have minimal effect in hot conditions [16].

Radiation

Radiation heat transfer involves the emission of electromagnetic waves, which, depending on the surface-temperature difference, transport energy away from the emitting object [42]. Furthermore, the visible spectrum is used to gain heat, while thermal radiation is used to lose it [45]. Nearly all of the heat that the environment produces during the daytime is caused directly or indirectly by solar radiation. In situations where all or some of the environment is colder than the animal's surface, radiation is a significant means of heat loss. At night, when the animal radiates toward the cooler sky, it is extremely significant. High humidity and clouds prevent radiative cooling [16]. With the animal radiating to the colder sky, there is often a net heat gain from radiation during the day and a net heat loss from radiation at night during the summer.

Evaporation

Evaporation is a sturdy way of dissipating body heat using vapour pressure gradients independent of temperature and can effectively reduce the temperature gradient and increase heat dissipation even as ambient temperature approaches or exceeds core body temperature [49]. This is a useful means of heat loss when temperature gradients become too narrow for radiative, conductive or convective heat loss [47]. Evaporative heat loss through sweating can be a successful way of heat loss in livestock including cattle, horses, sheep, and goats, but species like pigs and poultry lack functional sweat glands [75] [50] and thus can only effectively utilize evaporation through behavioural thermoregulation (i.e., wetting of the skin) or by increasing respiration rate [50]. When the dew point temperature of the air surrounding the animal is lower than the temperature of the animal's evaporative surfaces, evaporative heat loss occurs (skin and respiratory passages). Evaporative heat losses are made easier when there is low humidity and increased air velocity around the animal. Evaporative heat loss replaces conduction and convection as the primary means of heat loss as the ambient temperature rises because it is not reliant on the thermal gradient [16].

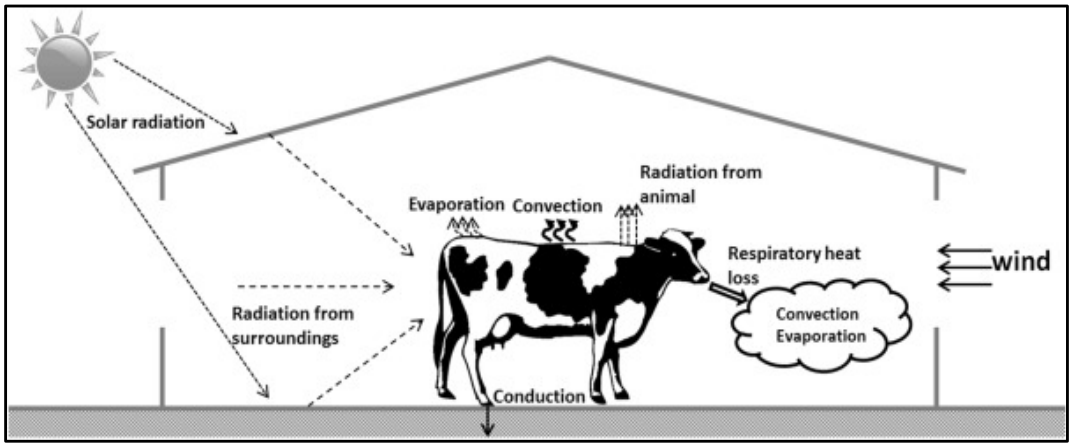

Fig 2: Heat exchange between animal and surrounding [51]

Heat stress indices

Various indices have been used to assess the degree of HS affecting cattle and other animals. The most popular of these is the Temperature Humidity Index (THI) by scentist E. C. Thom in 1959. The Temperature humidity index was originally called the Discomfort Index [39, 75]. Several thermal humidity indices were used to estimate the level of heat stress experienced by dairy cows and it composed of temperature and relative humidity [11]. Different temperature humidity indices have differed potential in measuring the HS in animals at different climatic conditions [15, 11]. The high humidity weighted index act as a best temperature humidity index in humid climate, while index with bearing higher weights on temperature serves as the best indicator of heat stress in the arid and semi-arid climates [15]. Nevertheless, the original THI and some of its variations are widely used to estimate heat stress levels in dairy and beef cattle [15, 41]; although not being formulated from cattle data, THI is associated with body temperature in heat stress-exposed cattle [76, 40]. THI is a sensitive index of HS and is more affected by ambient temperature than relative humidity. Higher THI significantly increases respiration rate (RR) [36]. In recent decades, most efforts to develop new thermal indices have been directed in two directions: modified THI and apparent ambient temperature. The modified THI is achieved by adding new climatic factors into the THI models by substituting old parameters, and the typical thermal indices that are often used as the adjusted THI (THI_{adj}) and the black globe humidity index (BGHI) [76, 77]. The second is apparent ambient temperature are achieved by converting the thermal effects of other environmental parameters into the equivalent thermal effect of air temperature, and the typical examples include the equivalent temperature index (ETI), the comprehensive climate index (CCI), and A predictive model of the equivalent temperature index for dairy cattle (ETIC) [79]. The comprehensive climate index (CCI) that has provision for an adjustment to ambient temperature (Ta) for relative humidity (RH), wind speed (WS), and radiation (RAD) [80]. A new HLI (heat load index) was developed [78]. The THI model [THI = (0.55 × Tdb + 0.2 × Tdp) × 1.8 + 32 + 17.5], developed by National Research Council (1971) is best for subtropical climatic conditions India for estimating effect of heat stress on monthly test day% and yield of fat and SNF of Murrah buffaloes under subtropical climatic conditions in India [81]. The theoretical and actual performance evaluation of the thermal indices (TIs) in a temperate climate in china and the actual relationships

Between the TIs and the animal-based indicators of heat stress CCI could be the most ideal thermal index to assess heat stress for housed dairy cows as well as semi-confined housing systems [82]. The predictive performance of the four indices (CCI, HLI, and BGHI) was correlated well with the six physiological characteristics exhibited by Holstein cattle (i.e. rectal temperature, respiratory rate, convective heat loss, skin surface evaporation, respiratory evaporation, radiative heat) in a tropical environment. Analysis showed that CCI correlated most closely with actual rectal temperature, respiratory rate, and respiratory evaporation [82, 83].

Physiological Responses to Heat Stress

Cattle react to heat stress with physiological changes and behavioural responses [74] are the primary coping means to unsuitable environment these responses can change from normal to impaired levels corresponding to both the level and duration of adverse thermal conditions [84]. The table 2 reveals the changes in animal physiology due to heat stress in nutshell [17].

Table 2: Changes in animal physiology and other parameters due to HS

Decreases in	Increases in
Dry matter intake	Weight loss
Rate of feed passage	Somatic cell counts
Blood flow to organs	Clinical mastitis
Rumen buffering capacity	Respiration rates
Milk yield and quality	Rectal temperature
Reproductive efficiency	Reproductive efficiency
Body condition score	Sweating
Heifer growth	Salivation
Immune function	Health care costs

Rectal temperature, skin temperature, respiration rate, and udder skin temperature are physiological variables that respond immediately to environmental stress and, as a result, the degree of discomfort experienced by the animals [20]. Compared to different breeds of cattle, buffaloes are less physiologically adapted to extremes of heat and cold. Compared to cattle, a buffalo's body temperature, pulse rate, respiration rate, and overall discomfort rise more quickly [93] [25]. Vapour pressure was more closely correlated to physiological responses than was air temperature [52].

Rectal temperature

The bodily cavity is directly measured for rectal temperature, which is normally a little warmer than skin temperature.

Change in rectal temperature has been regarded as a crucial sign of physiological condition and as the best way to evaluate animal stress [32]. Dairy cattle's body temperatures demonstrate their extreme sensitivity to heat [93]. Most dairy animal's performance was reduced by even a rise in rectal temperature of less than 1℃. Changes in RT predict changes of a similar magnitude in deep body temperature. Even though there is a significant difference in the body's core temperature in different sections of the body at different times of the day, RT is still regarded as a reliable indicator of body temperature [34].

Respiration rate

Respiration rate is an indicator of heat stress in the hot environment and gave significant correlations with circulating corticoids concentration [85]. Respiration rate and rectal temperature appeared to be more sensitive indicator of heat stress than pulse rate [86]. An evaporative heat loss from the respiratory tract is regarded as one of the primary mechanisms for maintenance of heat balance [91]. Normal respiration rate is approximately 10-30 breaths/minute [87] and the respiration rate increased when environmental temperature increased [88] [89, 90]. The skin and respiratory tract of cattle have great capacity to dissipate heat by evaporation, through sweating and panting, respectively [93]. The increase in the rate of respiration in response to heating depends on peripheral stimulation and is of major importance when the mean temperature of the body is within the normal range [90].

Heat stress mitigation practices

Basically there are three fundamental management practices that can be carried out to reduce heat stress: 1) Physical modification of the environment, such as reducing incoming radiation via shade, thus reducing the heat load of the animal 2) Genetic development of less heat-sensitive breeds and 3) Improved nutritional management schemes [21] but physical modification of the environment is the primary means. The common techniques can be classified into two categories: either those who alter the environment to lessen or minimise the amount of HS that animal experience, or those who improve heat exchange between animal and their surroundings [54, 55].

Shade

The main method of protecting against sun radiation is shade [59, 53]. Performance can be improved and the impacts of sun radiation can be immediately mitigated by shade [61, 62, 63, 64]. To reduce direct solar radiation, shade can be either natural (from trees) or artificial. Trees offer good shade, but typically die from cows nearby rubbing against them and disturbing the soil [60]. Depending on whether the application is in a dry or wet climate, different shade orientations are required, and the position and amount of the shade are critical [58]. When compared to control cows, the shade treatment reduced respiration rate by 30% and body temperature by 0.3 °Cover the 90-min treatment period [65].

Ventilation

Air ventilation is an important aspect for the relief of heat stress, as it affects both convective and evaporative heat losses. Additional circulation fans can be installed in the barns if airflow provided by natural or mechanical ventilation is not sufficient. Good ventilation air exchange is important to bring in drier air and avoid excessive relative humidity levels [55] [60]. Currently, cooling heat-stressed animals is one of the most commonly applied approaches [32]. Cooling ponds should not be too far from the milking parlour as long walks in the sun increase HS [56].

Cooling with water

Evaporative cooling of the air may be required when the ambient temperature is higher than the cow's body temperature. Evaporative cooling pads, high-pressure misting systems, and low-pressure sprinkler systems used to cool the air by evaporating water. Liquid water evaporates to become water vapour. It requires energy to evaporate water and as water evaporates the energy source is cooled. The low-pressure sprinkler system gets the energy from a cow's skin [57]. And air provides the energy to the high-pressure misting system and evaporative cooling pads. All of these evaporative cooling techniques increase the relative humidity of the air by moistening it. High-pressure systems operate at water pressures equal or greater than 200 psi as higher water pressures can produce smaller droplets. In low water pressures system, size of droplets increase so that they do not evaporate before reaching the ground where they wet floor and feed. High-pressure system nozzles can be placed above head locks, on the intake side of a cross-ventilated barn, or coupled to fans that direct the mist. To prevent nozzle blockage in high-pressure systems, pure water and in-line filters are necessary. Low-pressure systems use nozzles with flow rates close to 0.5 gallons per minute and operate at water pressures between 20 and 40 pounds per square inch (psi) [23] [57]. Recently, it has become industry standard practise to combine mechanical ventilation with another form of cooling, including evaporative coolers (indirect cooling) or sprinkler systems, especially for large-scale operations (direct cooling). The effects of putting sprinklers, misters, or evaporative coolers in large-scale mechanically ventilated dairies have been the subject of numerous researches. A device that moistens the animals and then allows the water to evaporate directly off their skin is more effective, according to one study, than one that just lowers the dry-bulb temperature of the air [37].

Conclusions

Heat stress comprises mainly of temperature and relative humidity. It negatively affects the efficiency of animal production, productivity and health during all lifecycle stages. When dairy animals are not in the range of thermo-neutral zone they are in discomfort and within the range of thermo neutral zone there is no need to physically adapt the changes in environment. Animals can continuously gain or loss heat from and to the environment through various heat exchange mechanisms. The temperature difference is the most important factor for sensible heat transfer and for evaporative heat transfer vapour pressure difference is important factor. There are various heat stress indices for evaluating the heat stress on livestock was developed. The comprehensive climate index (CCI) and adjusted temperature humidity index (THI_{adj}) are some of the precise temperature humidity indices used by the researchers. Physiological parameters mainly rectal temperature and respiration rate are the primary indicators to evaluate the heat stress on animals. The environmental conditions are exceeding some limits for longer exposure then the heat stress mitigation practices are used by dairy owners for heat stress reduction, so different cooling techniques such as shade system, air ventilation and

evaporative cooling system carried out. Different cooling techniques have different potential to reduce heat stress on the basis of climate.

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