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Effects of dietary supplementation with yeast chromium or dihydropyridine on milk composition and serum biochemical indices of periparturient dairy cows under heat stress

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Abstract

The objective of the current study was to evaluate the effects of dietary supplementation with chromium yeast (Cr-yeast) and dihydropyridine (DHP) on nutrient utilization, milk composition, and antioxidative status of prepartum dairy cows under heat stress. Twenty-four perinatal dairy cows (600 ± 14 kg; parity 2–3) were divided into three groups and fed the same basal diet with no supplement (control group), 8 g of Cr-yeast (Cr-yeast group), or 3 g of DHP (DHP group) per day. The experimental period consisted of a 7-d adaptation period and a 30-d data collection period from day 27 prepartum to day 3 postpartum. The temperature humidity index (THI) observed at daytime during the trial period exceeded 72, and the mean daily THI was 79.43. Norepinephrine in the Cr-yeast group decreased in prepartum cows. Serum cortisol in Cr-yeast or DHP group cows was lower in the postpartum period than in the control; however, serum cortisol levels decreased in the DHP group in the prepartum period. Dietary supplementation with Cr-yeast increased the digestibility of ether extract and the concentration of milk fat, while the solid non-fat (SNF) level was reduced. In the DHP group, the lactoprotein content was higher than the control. Total antioxidant capacity (T-AOC) was higher and the malondialdehyde (MDA) content tended to increase before calving in the Cr-yeast and DHP groups. Dietary supplementation with Cr-yeast or DHP can relieve the adverse impact caused by heat stress in prepartum dairy cows.

Keywords: nutritional supplement, periparturient cows, heat stress, nutrient utilization, milk composition

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Introduction

Stress is the physical response of animals to external and internal stimuli. Changes in the environment induce a stress response in animals. Mild stress helps organisms adapt to environmental changes. However, there is a threshold of stress tolerance that, when exceeded, leads to irreversible

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injury, inflammatory responses, and even death. It is well known that high-producing dairy cows are very sensitive to temperature changes (Bernabucci *et al*., 2014). Previous studies have reported that dairy cows produce heat stress in high temperature and humidity environments (Gao *et al*., 2017; Zachut *et al*., 2017). There is an increased likelihood that dairy cows will experience heat stress with increasing temperatures due to global warming (Fournel *et al*., 2017). The reason dairy cows experience heat stress is that the balance between heat production and heat dissipation is disrupted (Bellagi *et al*., 2017). Heat stress can cause not only an inflammatory response but also oxidative stress (Li *et al*., 2021). Additionally, heat stress can negatively impact the productive performance of dairy cows, for example, reducing milk yields and quality (Kino *et al*., 2019). Recent studies have shown that milk production losses are expected to accelerate across the United States alone at a mean rate of 174 ± 7 kg/cow/decade (Gernand *et al*., 2019). Heat stress causes economic losses to the dairy industry and thus has gradually become the focus of related research.

For dairy cows, the periparturient period is generally considered to be the period from three weeks before to three weeks after parturition. High-yielding cows are particularly vulnerable to heat stress during the periparturient period, which affects metabolism, immunity, health, fertility, milk production, and hormonal changes. The peripartum period is critical for dairy cows. If peripartum cows experience heat stress, calves born to heat-stressed dams show impaired immune function and therefore higher susceptibility to disease (Ouellet *et al*., 2020). Some studies have shown that feed additives can alleviate the damage caused by heat stress.

Chromium (Cr) is an essential micronutrient for ruminants and can be considered a metabolic modifier. In mammals, Cr has been shown to be involved in carbohydrate, lipid, and protein metabolism (Vincent, 2004). Several studies have demonstrated that Cr plays a role in biotic stress responses in pigs (Li *et al*., 2013) and chickens (White and Vincent, 2019). A previous study showed that chromium picolinate may play an anti-heat-stress role in lactating cows by promoting antioxidant capacity (Zhang *et al*., 2014). Although there are studies on the use of chromium yeast in beef cattle (Van Bibber-Krueger *et al*., 2016), few have specifically investigated the productive performance of dairy cows under heat stress. Dihydropyridine (DHP), a new, multifunctional antioxidant that can be supplemented in food, has been shown to protect oil, vitamin A, and beta-carotene from oxidation (Vijesh *et al*., 2011). DHP had no toxicity and facilitates chicken growth (Niu *et al*., 2010). Additionally, studies have revealed that DHP can enhance the antioxidant capacities of lactating dairy cows under heat stress conditions (Yu *et al*., 2020). This evidence indicates that Cr and DHP are good feed additive candidates for alleviating the harmful responses induced by heat stress.

Given the potential effects of Cr and DHP supplementation on heat stress, we hypothesized that supplementation with Cr-yeast or DHP could improve the productive performance and antioxidative status of heat-stressed prepartum cows. To improve cow health and performance under heat stress, the effects of Cr-yeast or DHP on dairy cows must be elucidated.

Materials and Methods

Cr-yeast with a chromium content of 1‰ was obtained from Senyo (Zhejiang, China), and DHP （$C_{13}H_{19}NO_4$, purity > 99%） was purchased from Hengshui He Chuan Bio-Technology Co., Ltd (Hebei, China). The protocol for the experiments was approved by the Institutional Animal Care and Use Committee at Huazhong Agriculture University (Wuhan, China), and the animal trial was conducted in accordance with the National Institute of Health Guidelines for the Care and Use of Experimental Animals (Beijing, China). The official approval number for the trial protocol is HZAUCA-2013-001.The experiments were conducted at the Yangzijiang dairy farm (Huangpi, Hubei Province, China) from August 16, 2013, to September 16, 2013.

A total of 24 prepartum dairy cows with body weights of 600 ± 14 kg and a parity of 2–3 were randomly divided into three groups (n = 8): the control group (basal diet), Cr-yeast group (dietary supplementation with 8 g of Cr-yeast per day), and DHP group (dietary supplementation with 3 g of DHP per day). All cows were housed in a semi-open barn with ventilation fans and sprinkler facilities. When the temperature of the barn reached 28°C or above, the ventilation fans and sprinkler facilities were turned on. The sprinkler facilities worked for two minutes every half hour and the ventilation fans were always on. All cows had free access to feed and drinking water throughout the experimental period. From day 27 prepartum to day 3 postpartum, the Cr-yeast group and DHP group were administered a blend consisting of 8 g of chromium yeast or 3 g of dihydropyridine, respectively, in conjunction with 100 g of total mixed ration (TMR) via self-locking headgates before each milking session of the day. Each control group cow concurrently received 100g TMR through self-locking headgates. The cows were fed the remaining TMR during morning feeding. The experimental period consisted of a 7-d adaptation period and a 30-d data collection period from day 27 prepartum to day 3 postpartum. The ingredient and nutrient details of the basal diet are presented in Table 1. The basal diet was formulated following the Feeding Standard of China Holsteins (NY/T 34-2004).

The temperature–humidity index (THI) was employed as an index to evaluate the degree of heat stress in dairy cows. Air temperature and humidity were measured using a dry and wet thermometer (HTC-1, Xin Yuan Xiang Bio-Technology Co, Ltd, Shenzhen, China). The dry bulb temperature (Td) and wet bulb temperature (Tw) were recorded at seven time points of 07:00, 09:00, 11:00, 13:00, 15:00, 17:00, and 19:00 every day. The THI was calculated using the equation of McDowell *et al*. (1976):

$$THI = 0.72 \times (T_d + T_w) + 40.6 \quad (1)$$

On the 20th day of the experiment (a sunny day before periparturient cows calving), the rectal temperature of each animal in each group was measured at 2-h intervals from 06:00 until 18:00. Measurements of rectal temperature were conducted with a veterinary thermometer; the probe was inserted into the rectum to a depth of 12 cm. The rectal temperature was recorded when the reading stabilized. After each test, the veterinary thermometer was cleaned with water.

Representative samples of 500 g were collected at morning feeding every Monday and stored at -20 °C. Feed samples were collected for the determination of the chemical compositions. Analyses of crude protein (CP), ether extract (EE), neutral detergent fibre (NDF), acid detergent fibre (ADF), calcium (Ca), and total phosphorus (P) were carried out according to the procedures of the Association of Official Analytical Chemists (AOAC, 2000).

A digestibility test lasting 5 d was carried out from day 12 prepartum. Four cows were used to test the feed intake and nutrient digestibility in each group, and acid-insoluble ash was used as an endogenous indicator (Block *et al*., 1981). During the trial period, the dairy cows were fed as described in the production study and were provided with adequate feed three times per day. The feed was weighed before feeding, and the remaining feed was weighed again at 07:00 the next following day. According to the results, the daily feed intake and average daily dry matter intake (DMI) of each group were calculated. Approximately 150 g of the feed samples was collected each time before feeding and was marked and sealed in a refrigerator at -20 °C. Approximately one third of the total fresh faecal samples were collected in the morning, noon, and evening for five consecutive days. Then, 10% sulfuric acid was added to these samples at a proportion of 2% of the total faecal weight. Subsequently, all faecal samples were sealed and stored in a refrigerator at -20 °C. After the experiment, all the collected feed samples were mixed and then sampled from the mixed feed samples. The samples obtained again were dried and stored until further analysis. These samples were analysed for the contents of acid-insoluble ash, dry matter (DM), ADF, CP, EE, crude ash, NDF, Ca, and P according to Feed Analysis and Detection Technology. Determination of acid insoluble ash followed the protocol of GB/T23742-2009. The nutrient digestibility was calculated as follows with acid-insoluble ash as an endogenous indicator:

$$\text{nutrient feed intake} = \text{DMI} \times \text{feed nutrient content} \quad (2)$$

$$\text{total faeces} = \text{DMI} \times \text{acid-insoluble ash in feed/acid-insoluble ash in faeces} \quad (3)$$

$$\text{nutrient excretion} = \text{total faeces} \times \text{nutrient content in faeces} \quad (4)$$

$$\text{nutrient digestibility} = [(\text{nutrient intake} - \text{nutrient excretion})/\text{nutrient intake}] \times 100\% \quad (5)$$

Fresh milk samples were collected with sterile centrifuge tubes from three consecutive milkings and pooled according to a 4:3:3 volume ratio (08:00/15:00/22:00 milking) on the third day after delivery. Moreover, 0.05 g of potassium dichromate powder was added to each milk sample. Then, the samples were stored at 4 °C until analysis. The milk samples were analysed for the contents of butterfat, milk protein, lactose, solid non-fat (SNF), total solids (TS), and urea nitrogen by an automated colorimetric assay (Lactoscan LWA, Chengdu Dongli Hengda Technology Co. Ltd, Sichuan).

Blood samples (5 mL) were collected from the caudal vein into clot activator tubes (Ping'an Medical Technology Co. Ltd, Hunan) on day 7 before the expected calving and on day 3 after calving at 07:00. Serum for analysis of the biochemical parameters was obtained by centrifugation of whole blood at 3000 rpm (600 × *g*) for 10 min in a laboratory centrifuge at 4 °C (HC-2518R, USTC Zonkia Scientific Instruments Co. Ltd, Anhui) and subsequently transferred into microcentrifuge tubes (2 mL). The sera were stored at -20 °C until assayed.

The activities of glutathione peroxidase (GSH-Px), and superoxide dismutase (SOD); total antioxidant capacity (T-AOC); and malondialdehyde (MDA), cortisol, norepinephrine (NE), and serum total calcium levels in serum were determined using commercial kits (Jiancheng Biochemical Reagent Company, Nanjing, China) according to the manufacturer’s instructions. The serum concentration of SOD was measured using the hydroxylamine method, and the concentrations of T-AOC and GSH-Px were determined using colorimetric methods. The thiobarbituric acid method was used to determine the serum MDA concentration.

To evaluate the effect of Cr-yeast and DHP supplementation, data were analysed using SPSS 21.0 (SPSS, Chicago, IL). Duncan’s multiple range tests were used to test the differences among treatments. The experimental results are presented as the mean ± standard deviation. Significance was declared at $P < 0.05$.

Table 1 Ingredient composition and nutrient content of the experimental diet of prepartum dairy cows under heat stress

Item	Content
Ingredient composition（%）	
Oat grass	10.61
Chinese wild rye	5.33
Maize silage	53.03
Beet pulp	1.33
Distillers dried grains with solubles	1.33
Cottonseed	1.33
Concentrate supplement	26.48
Calcium hydrogen phosphate	0.30
Calcium carbonate	0.26
Nutrient levels [analysed value]（%）	
Crude protein	15.68 ± 1.74
Ether extra	5.25 ± 0.37
Crude ash	9.66 ± 0.74
Neutral detergent fibre	34.56 ± 3.04
Acid detergent fibre	16.31 ± 1.45
Calcium	1.66 ± 0.15
Total phosphorus	0.27 ± 0.04

Results and Discussion

The THI on the dairy farm was recorded. During the experimental period, the THI observed during the day in the trial period exceeded 72, and the mean daily THI was 79.43 (Figure 1). According to the thresholds described by Armstrong (1994), a THI value greater than 72 is considered to indicate heat stress, including mild heat stress (average THI: 72–78), moderate heat stress (average THI: 79–88), and severe heat stress (average THI > 89), and a value lower than 72 indicated no heat stress. All the THI values were above the heat stress threshold of 72 indicating that the cows were in a heat-stressed state. There was no difference in rectal temperature observed between groups, and the rectal temperature ranged from 38.6 °C to 40.9 °C (Table 2). The rectal temperature and THI value can be used as direct indicators of heat stress in dairy cows (Dikmen and Hansen, 2009). In the present study, the THI observed during the day in the trial period exceeded 72 (Figure 1). We measured the rectal temperature during the daytime, and the lowest rectal temperature was 38.7 °C. The rectal temperature was determined to be 38.6 °C when heat stress was triggered (Li *et al*., 2020). Some researchers have reported that cows experience heat stress between THI values of 67 and 76 (Ekine-Dzivenu *et al*., 2020). Therefore, our data indicate that the cows were in a state of heat stress.

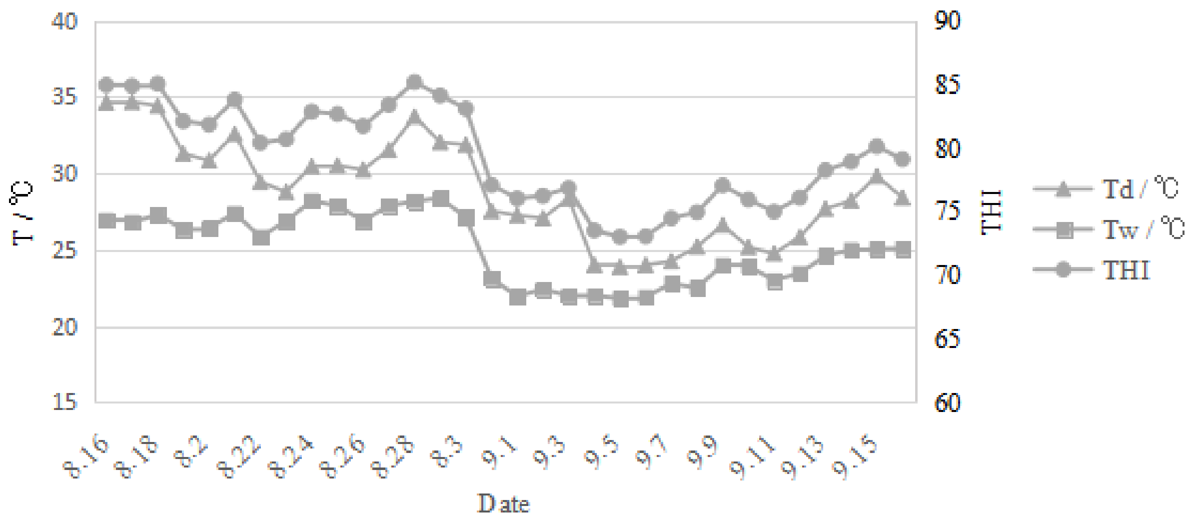

Figure 1 Temporal temperature–humidity index (THI) pattern, dry bulb temperature (Td), and wet bulb temperature (Tw) at daily average during the experimental period

Table 2 Effects of Cr-yeast and dihydropyridine (DHP) on rectal temperature of prepartum dairy cows under heat stress conditions

Item		**Treatment**			***P* valve**
		Control	Cr-yeast	DHP	
Rectal temperature (°C)	06:00	39.17 ± 0.42	39.33 ± 0.15	39.23 ± 0.21	0.777
	08:00	38.83 ± 0.32	39.37 ± 0.25	38.93 ± 0.31	0.140
	10:00	39.43 ± 0.32	39.47 ± 0.15	39.20 ± 0.40	0.460
	12:00	39.53 ± 0.32	39.70 ± 0.17	39.47 ± 0.68	0.085
	14:00	40.03 ± 0.12	40.10 ± 0.36	39.60 ± 0.70	0.051
	16:00	39.73 ± 0.31	39.83 ± 0.50	39.83 ± 0.83	0.228
	18:00	40.20 ± 0.30	40.53 ± 0.32	40.13 ± 0.74	0.144

Control: cows were fed a basal diet without supplementation; Cr-yeast: cows were fed a basal diet supplemented with 8 g/d chromium yeast; DHP: cows were fed a basal diet supplemented with 3 g/d dihydropyridine

Supplementation with Cr-yeast increased EE digestibility compared with the control group and DHP group (P <0.05, Table 3). Other parameters were not different among the three groups (P >0.05). In this experiment, there was no difference in DMI between the controls and treatments. Similarly, some studies report no effect of Cr supplementation on prepartum DMI levels (Sadri *et al.*, 2009; Yasui *et al.*, 2014; Wu *et al.*, 2021). However, dry matter intake was increased to varying degrees when Hayirli *et al.* (2001) supplemented periparturient dairy cows with three different doses of chromium.

The effect of Cr-yeast or DHP on DMI in the current study was modest. Furthermore, these results suggest that dietary Cr-yeast or DHP supplementation has no effect on digestibility of protein and fibre. Supplementation with Cr-yeast improved the digestibility of EE in prepartum dairy cows, which has not been reported before. The mechanism of influence of Cr-yeast on fat digestibility remains to be studied.

Table 3 Effects of Cr-yeast and dihydropyridine (DHP) on DMI (kg/d) and nutrient digestibility (%) of prepartum dairy cows under heat stress conditions

Item	Treatment			*P* value
	Control	Cr-yeast	DHP	
Dry mater intake, kg/d	11.00 ± 0.07	11.02 ± 0.52	10.81 ± 0.39	0.693
Dry matter, %	73.11 ± 1.79	74.32 ± 0.97	72.24 ± 2.70	0.360
Crude protein, %	70.68 ± 2.05	73.64 ± 1.12	71.23 ± 3.59	0.253
Ether extract, %	85.78^b ± 0.97	88.38^a ± 1.30	80.89^b ± 5.74	0.037
Neutral detergent fibre, %	63.37 ± 2.72	62.48 ± 4.70	60.47 ± 4.76	0.618
Acid detergent fibre, %	55.45 ± 2.86	54.29 ± 5.75	49.35 ± 5.29	0.217

Control: cows were fed a basal diet without supplementation; Cr-yeast: cows were fed a basal diet supplemented with 8 g/d chromium yeast; DHP: cows were fed a basal diet supplemented with 3g/d dihydropyridine

$^{a, b}$Within a row, different superscripts indicate a significant difference (*P* <0.05)

The content of butterfat was increased in the Cr-yeast group compared with the control group (*P* <0.05), and that of lactoprotein was lower in the DHP group compared with the other groups (*P* <0.05, Table 4). The lactose content in DHP group was substantially higher than that in the control and Cr-yeast groups. Additionally, the content of SNF in the Cr-yeast group was reduced compared to the control group (*P* <0.05). Many studies have shown the effect of dietary Cr on milk composition in dairy cows. Hayirli *et al*. (2001) found that dietary Cr supplementation during the perinatal period and early lactation resulted in a secondary increase in postpartum milk fat content with the increase in chromium dose, and the non-fat solid content of milk in the experimental group was lower than that of the control.

Chromium supplementation to Holstein cows during late gestation and early lactation had no marked effect on milk protein composition in postpartum milk (Kafilzadeh *et al*., 2012). Additionally, milk samples collected and analysed during the first and fourth weeks after chromium additives were fed to cows in late pregnancy produced no marked differences in lactose content between groups (Pantelic *et al*., 2018). Our research is consistent with the results from the literature.

Collectively, the literature suggests that the effects of Cr supplementation on milk composition are negligible (Smith *et al*., 2005; Soltan, 2010). It has even been suggested in the literature that Cr supplementation can lead to reduced milk quality; for example, Cr supplementation decreased milk protein content (Sadri *et al*., 2009) and milk fat (McNamara & Valdez, 2005). In the current study, lactoprotein and lactose were not affected in the Cr-yeast group compared with the control group, which is in agreement with previous reports. In the present study, Cr-yeast supplementation increased milk fat (*P* <0.05). Cr-yeast supplementation may be able to regulate lipid metabolism through the insulin pathway and thereby affect milk fat.

At present, there are few studies on DHP application in cows. Our results suggest that DHP supplementation has a substantial impact on improving the level of lactose and decreasing lactoprotein levels. Dihydropyridine can alter the levels of hormones in the serum, which may cause changes in milk protein and lactose levels.

Table 4 Effects of Cr-yeast and dihydropyridine (DHP) on milk composition of prepartum dairy cows under heat stress conditions

Item	Treatment			*P* value
	Control	Cr-yeast	DHP	
Butterfat, %	$2.49^{b} \pm 0.65$	$4.03^{a} \pm 0.75$	$3.10^{ab} \pm 0.68$	0.035
Lactoprotein, %	$4.11^{a} \pm 0.37$	$3.58^{ab} \pm 0.57$	$3.09^{b} \pm 0.30$	0.026
Lactose, %	$4.13^{b} \pm 0.29$	$4.09^{b} \pm 0.46$	$4.96^{a} \pm 0.54$	0.036
Solid non-fat, %	$9.27^{a} \pm 0.51$	$8.48^{b} \pm 0.29$	$9.08^{a} \pm 0.32$	0.044
Total solids, %	13.17 ± 3.22	13.08 ± 1.31	13.50 ± 1.96	0.964

Control: cows were fed a basal diet without supplementation; Cr-yeast: cows were fed a basal diet supplemented with 8 g/d chromium yeast; DHP: cows were fed a basal diet supplemented with 3 g/d dihydropyridine
$^{a,\,b}$Within a row, different superscripts indicate a significant difference ($P < 0.05$)

The effects of Cr-yeast and DHP on serum NE and cortisol are shown in Table 5. The serum cortisol of the cows was decreased in the DHP group at 07:00 in the prepartum cows ($P < 0.05$). However, serum cortisol of the cows in the Cr-yeast and DHP groups both decreased at 07:00 in postpartum cows ($P < 0.05$). Supplementation with Cr-yeast or DHP had no effect on NE at 07:00 in prepartum cows ($P > 0.05$). However, NE content in the Cr-yeast group was decreased at 07:00 in postpartum cows ($P < 0.05$). The hypothalamic–pituitary–adrenal (HPA) axis is known to be the primary neuroendocrine system involved in the heat stress response and secretes cortisol and NE (Collier & Gebremedhin, 2015). The change in cortisol and NE adapts to the adverse environment, which is the evaluated index for the degree of stress and plays an extremely important role in the body (Shi *et al*., 2021). According to the results, DHP-supplemented diets decreased the serum concentration of cortisol both pre- and post-parturition. Cr-yeast supplemented diets decreased serum cortisol concentration after delivery, and also decreased the serum norepinephrine concentration after parturition. High cortisol and NE levels are indicators of stress (Li *et al*., 2021), and these results suggest that adding chromium yeast or dihydropyridine to feed can alleviate the heat stress of dairy cows during the perinatal period.

Table 5 Effects of Cr-yeast and dihydropyridine (DHP) on cortisol and norepinephrine of prepartum dairy cows under heat stress conditions

Item		Treatment			*P* valve
		Control	Cr-yeast	DHP	
Cortisol, (ng/mL)	07:00 prepartum	$5.73^{a} \pm 0.16$	$5.30^{ab} \pm 0.55$	$4.94^{b} \pm 0.34$	0.050
	07:00 postpartum	$6.27^{a} \pm 0.60$	$5.36^{b} \pm 0.36$	$5.51^{b} \pm 0.07$	0.025
Norepinephrine, (ng/L)	07:00 prepartum	368.80 ± 40.63	334.13 ± 25.21	372.58 ± 43.69	0.434
	07:00 postpartum	$378.13^{a} \pm 13.45$	$314.58^{b} \pm 31.89$	$362.47^{ab} \pm 24.33$	0.044

Control: cows were fed a basal diet without supplementation; Cr-yeast: cows were fed a basal diet supplemented with 8 g/d chromium yeast; DHP: cows were fed a basal diet supplemented with 3 g/d dihydropyridine
07:00 prepartum: 07:00 before calving; 07:00 postpartum: 07:00 am after calving
$^{a,\,b}$Within a row, different superscripts indicate a significant difference ($P < 0.05$)

T-AOC activity in prenatal cows in the Cr-yeast and DHP groups was higher than in prenatal cows in the control group (*P* <0.05, Table 6). The MDA content in the Cr-yeast and DHP groups tended to increase at 07:00 in prepartum cows compared with those in prepartum cows in the control group (*P* = 0.086). In the postpartum period, the GSH-Px activity in the Cr-yeast group was increased compared to that in the control group (*P* <0.05). Recent studies suggest that heat stress participates in the induction of tissue oxidative stress, as elevated levels of reactive oxygen species are observed in dairy cows exposed to hot conditions (Guo *et al*., 2021). Heat stress disturbs the redox status, resulting in the generation of a large quantity of ROS (Amaral *et al*., 2021), which will induce oxidative stress. Excess ROS disturb the oxidant/antioxidant balance and damage DNA, protein, and lipids within cells (Wang *et al*., 2019). Zeng *et al*. (2022) suggested that improving antioxidative capability could effectively eliminate ROS and protect cells from heat stress. In the current study, Cr-yeast or DHP supplementation increased the serum level of T-AOC before parturition (*P* <0.05). Additionally, Cr-yeast supplementation increased the serum level of GSH-Px during the postnatal period (*P* <0.05). These results indicate that Cr-yeast or DHP supplementation can enhance the antioxidant capacity of animals by increasing the concentrations and activities of antioxidant enzymes.

Table 6 Effects of Cr-yeast and dihydropyridine (DHP) on serum antioxidative parameters of prepartum dairy cows under heat stress conditions

Item		Treatment			*P* value
		Control	Cr-yeast	DHP	
T-AOC, (U/mL)	07:00 prepartum	5.89^{b} ± 0.76	8.51^{a} ± 1.31	8.26^{a} ± 1.46	0.025
	07:00 postpartum	4.96 ± 0.66	5.58 ± 0.68	6.04 ± 1.16	0.261
SOD, (U/mL)	07:00 prepartum	9.81 ± 1.85	10.68 ± 1.12	11.45 ± 1.49	0.867
	07:00 postpartum	18.92 ± 1.22	17.47 ± 2.36	17.82 ± 2.16	0.985
MDA, (nmol/ml)	07:00 prepartum	3.97 ± 0.21	5.32 ± 1.27	4.35 ± 0.34	0.086
	07:00 postpartum	5.10 ± 0.89	6.11 ± 1.34	5.17 ± 0.67	0.332
GSH-Px, (U/0.1ml)	07:00 prepartum	128.12 ± 13.18	138.05 ± 13.58	158.80 ± 26.14	0.112
	07:00 postpartum	134.27^{b} ± 58.39	225.73^{a} ± 14.30	153.30^{b} ± 52.23	0.046

T-AOC: total antioxidant capacity; SOD: superoxide dismutase; MDA: malondialdehyde; GSH-Px: glutathione peroxidase

Control: cows were fed a basal diet without supplementation; Cr-yeast: cows were fed a basal diet supplemented with 8 g/d chromium yeast; DHP: cows were fed a basal diet supplemented with 3 g/d dihydropyridine

07:00 prepartum: 07:00 before calving; 07:00 postpartum: 07:00 am after calving

$^{a, b}$Within a row, different superscripts indicate a significant difference (*P* <0.05)

Conclusion

The comprehensive evaluation of the impact of Cr-yeast or DHP in diets for prepartum and postpartum dairy cows in this study indicated that dietary supplementation with Cr-yeast or DHP could improve the nutrient digestibility, milk quality, and antioxidative status of dairy cows. Hence, under the specific conditions of the current study, dietary supplementation with Cr-yeast (8 g/d) or DHP (3 g/d) in prepartum dairy cows could relieve the harm caused by heat stress.

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Authors' contributions

L.W. Zhang (ORCID 0000-0002-3791-7432) designed the experiments, collected and analysed the data, and prepared the manuscript; Y.F. Zhang (ORCID 0000-0001-9807-9383) designed the experiments and supervised the progress of the studies; C. Wang (ORCID 0000-0002-4762-3884) collected and analysed the data; S.Q. Wang (ORCID 0000-0003-4027-3284) collected and analysed the data; S.B. Zhang (ORCID 0000-0001-5291-2229) collected and analysed the data; J.D. Li (ORCID 0000-0003-4839-3547) collected and analysed the data; S. Gao (ORCID 0000-0002-7974-4605) collected and analysed the data; Z.L. Qi (ORCID 0000-0003-0112-0162) prepared the manuscript; H.J. Chen (ORCID 0000-0001-9299-9015) participated in data analysis and manuscript preparation.

Conflict of interest declaration

There were no conflicts of interest regarding this work.

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