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Effect of yeast culture (*Saccharomyces cerevisiae*) supplementation on growth performance, blood metabolites, carcass traits, quality, and sensorial traits of meat from pigs under heat stress

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ABSTRACT

The objective of this study was to evaluate the effects of dietary supplementation of yeast culture (YC) in pigs under heat stress conditions on growth performance, blood metabolites, carcass traits, quality, and sensorial values of the meat. Thirty pigs (29.487 ± 1.46 kg) were stratified by body weight (BW) and randomly assigned to the following treatments: 1) Control group animals received only the basal diet; 2) 0.2 % YC group animals received the basal diet with the addition of 0.2 % YC; 3) 0.3 % YC group animals received the basic diet supplemented with 0.3 % YC. The study was conducted in three phases based on BW: phase I (30–65 kg), phase II (65–95 kg), and phase III (95–128 kg). In phase I, the supplementation with YC at 0.2 % and 0.3 % produced average daily gain (ADG) values that were higher by 25.52 % and 23.701 %, respectively ($P < 0.05$), average daily feed intake (ADFI) values that were higher by 13.42 % and 11.85 %, respectively ($P < 0.05$), and a higher final weight (by 8.09 % and 7.26 %; $P < 0.05$), compared with the control diet. In phase II, the final weight was 7.35 % higher with the addition of 0.3 % YC ($P < 0.05$) compared with the control. In phase III, the final weight was higher by 4.16 % and 4.67 % with the addition of YC at 0.2 % and 0.3 % ($P < 0.05$), respectively, compared with the control. During the whole period (29.487–128.701 kg), improvements in ADG were observed with both levels of YC supplementation (0.2 % and 0.3 % YC) by 5.38 % and 6.09 % ($P < 0.05$) compared with the control. In terms of blood metabolites, supplementation with 0.3 % YC increased platelet numbers compared with the addition of 0.2 % YC ($P < 0.05$). For carcass traits, a higher carcass weight was recorded with the YC treatments at 0.3 % and 0.2 % (by 4.63 % and 5.27 %, respectively: $P < 0.05$) compared with the control. In terms of meat quality, the use of 0.2 % YC caused a decrease in redness (a*) by 10.03 %, ($P < 0.05$) and in yellowness (b*) by 15.52 % in contrast with the control ($P < 0.05$). A trained panel detected minimal changes in the sensorial values of the meat with YC supplementation ($P > 0.05$). In conclusion, YC improved

Abbreviations: ADFI, average of daily feed intake; ADG, average of daily gain; AED, amplitude of erythrocyte distribution; BW, body weight; CK, creatine kinase; F:G, feed conversion ratio; HCW, hot carcass weight; Hue, hue angle; LM, longissimus muscle; LT, *longissimus thoracis*; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; MCV, mean corpuscular volume; WBSF, Warner–Bratzler shear force; WHC, water-holding capacity; YC, yeast culture

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both growth and carcass weight without markedly changing blood metabolites, carcass traits, quality, and sensorial values of the meat from pigs under heat stress conditions.

1. Introduction

The state of Sonora is located in the northwest of México, is currently the second largest producer of pigs in the country. In summer, the main problem encountered by pig farmers in the area is high temperatures, which can range between 26 °C and 50 °C and are accompanied by an average relative humidity of 47.5 %. Studies have determined that the thermoneutral zone for growing to finishing pigs is between 18 °C and 25 °C (De Oliveira et al., 2019). Additionally, the production of any domestic animal (including pigs) is affected when the animals are exposed to heat stress (Cerisuelo et al., 2012). Therefore, it is important to identify improvement strategies to increase the production of these animals in adverse climates.

Diet supplementation with yeast can improve the productive performance of pigs during different growth phases (Liu et al., 2017; Galaz-Galaz et al., 2018; Lee et al., 2018) as well as improve their immune system and intestinal health (Vieira et al., 2013; Hancox et al., 2015; Palma et al., 2015). Li and Kim (2014) demonstrated that the use of yeast in pigs improves the digestibility of food. In a study of a different species (feedlot heifers), it was reported that the addition of yeast can mitigate the effects of heat stress and improve productive performance (Broadway et al., 2016).

On the other side, some blood components are modified when the animals are under any type of stress (Dantzer and Mormède, 1979; Morales et al., 2016), which could influence animal performance.

Currently, information is scarce regarding the use of yeast culture (YC) and the associated effects on blood components, meat quality, and sensorial traits of the meat produced by pigs fattened in adverse climates of heat stress, such as those in the region of Hermosillo in Sonora, Mexico. This study hypothesized that supplementing with YC improves growth performance, blood components, carcass traits, meat quality, and sensorial traits. Hence, the objective was to assess the effect of adding YC to the pigs' feed during the growing–finishing phases under heat stress.

2. Materials and methods

All procedures involving animal handling were conducted in accordance with the approved official Mexican guidelines for domestic animal care (NOM-033-ZOO-1995; NOM-051-ZOO-1995) and were in compliance with the National Institutes of Health guide

Table 1
Composition of the experimental diets of growing–finishing pigs.

	Treatments								
	Phase I			Phase II			Phase III		
Ingredients (kg)	Control[1]	0.2 % YC[2]	0.3 % YC[3]	Control[1]	0.2 % YC[2]	0.3 % YC[3]	Control[1]	0.2 % YC[2]	0.3 % YC[3]
Corn grain	68.85	68.70	68.64	76.10	75.94	75.86	77.00	76.86	76.76
Soybean meal	26.40	26.35	26.32	19.30	19.26	19.24	18.40	18.34	18.34
Fat	1.75	1.75	1.74	1.60	1.60	1.60	1.60	1.60	1.60
Yeast	0.00	0.20	0.30	0.00	0.20	0.30	0.00	0.20	0.30
Premix Initiation[4]	3.00	3.00	3.00	–	–	–	–	–	–
Premix Growth[4]	–	–	–	3.00	3.00	3.00	–	–	–
Premix Finishing[4]	–	–	–	–	–	–	3.00	3.00	3.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition, as fed basis									
ME, Mcal kg^{-1}	3,360	3,360	3,361	3,360	3,360	3,361	3,361	3,361	3,362
Total lysine %	1.18	1.18	1.18	0.98	0.98	0.98	1.01	1.02	1.02
Dig. lysine %	1.05	1.05	1.05	0.87	0.87	0.87	0.90	0.91	0.91
DM %	88.98	88.97	88.98	88.76	88.74	88.77	88.72	88.74	88.71
CP %	18.27	18.33	18.36	15.48	15.54	15.57	15.13	15.19	15.22
Ca %	0.65	0.65	0.65	0.66	0.66	0.66	0.67	0.66	0.66
Available P %	0.31	0.31	0.31	0.28	0.28	0.28	0.26	0.26	0.26

[1] Control = control animals receiving only the basal diet without yeast supplementation.
[2] 0.2 % YC = animals receiving basal diet supplemented with 0.20 % yeast culture.
[3] 0.3 % YC = animals receiving basal diet supplemented with 0.30 % yeast culture.
[4] Premix provided the following per kg of complete diet for phases I, II, and III was the same in vitamins and microminerals: 8000 IU vitamin A, 800 IU vitamin D3, 40 IU vitamin E, 3.5 mg K, 7 mg riboflavin, 20 mg pantothenic acid, 30 mg niacin, 30 µg vitamin B12, 550 mg choline, 64 mg Zn, 64 mg Fe, 4 mg Cu, 4 mg Mn, 0.4 mg Y, and 13 mg Se. Macrominerals, amino acids, and ractopamine were: phase I (initiation) 5.3 g Ca, 0.6 g P, 2.2 g lysine, 0.6 g methionine, and 0.6 g threonine; phase II (growth) 5.2 g Ca, 0.6 g P, 2.2 g lysine, 0.5 g methionine, and 0.5 g threonine; and phase III (finishing) 5.4 g Ca, 0.4 g P, 2.8 g lysine, 0.6 g methionine, 0.3 g threonine, and 10 mg of ractopamine hydrochloride.

for the care and use of laboratory animals (NIH Publications No. 8023, revised 1978).

2.1. Animals, housing, and treatments

The experiment was conducted during the summer season at the pigs' experimental unit of the Departamento de Agricultura y Ganadería of the Universidad de Sonora in Hermosillo, Sonora, Mexico. A total of 30 9-week-old [(Landrace × Yorkshire) × Duroc] pigs (15 gilts and 15 barrows) with an initial body weight (BW) of 29.487 ± 1.46 kg were used. Pigs were individually housed in pens (0.6 × 2.0 m) equipped with shade, feed troughs, and automatic sprues. The animals were selected at the start of the growth phase with uniform weights and ages to create 10 replicates per treatment (5 gilts and 5 barrows). The supplementation with YC (*Saccharomyces cerevisiae* N. Strain 7907, Ganadero plus®, Grupo Biotecap, S. A, de C. V., Tepatitlán, Jalisco, México) was performed over a period of 96 days to include the growth, development, and finishing phases. The dietary treatments were as follows: 1) Control: the animals received only the basal diet without YC supplementation, 2) 0.2 % YC: the animals received the basal diet with YC supplementation at 0.2 %, and 3) 0.3 % YC: the animals received the basal diet with YC supplementation at 0.3 %. The basal diet was formulated to satisfy the nutritional requirements of the pigs' typical summer diet (NRC, 2012). Table 1 shows the ingredients and the chemical composition of the experimental diets.

2.2. Growth performance

The duration of the study period was 96 days, during which the experimental diets were offered in the morning (7:00 am). The amount of feed offered and rejected was weighed and recorded daily to determine the feed intake. From the collected data, the average daily gain (ADG), total BW gain, average daily feed intake (ADFI), and the feed conversion ratio (F:G) were calculated according to the phase. All feedlot performance variables were evaluated during the growth (phase I: 30–65 kg), development (phase II: 65–95 kg), and finishing (phase III: 95–128 kg) phases. The ADG was estimated using the difference between the initial and final weights of each period divided between the days of supplementation in each phase. The F:G was based on average feed consumption and ADG.

2.3. Blood metabolites

At the end of the finishing phase, blood samples were taken from the 10 pigs in each treatment (approximately 14 ml of blood was collected via jugular venipuncture) using two Vacutainer tubes (Becton, Dickinson and Company, Franklin Lakes, NJ). One tube contained ethylenediaminetetraacetic acid (EDTA), and the other contained no additive. Blood containing EDTA was used for the hemogram blood test, and the tubes containing no additive were centrifuged at 10,000 rpm for 10 min. The serum was separated and stored at −20 °C until it was assayed for blood parameters [cortisol, glucose, total protein, albumin, and creatine kinase (CK)].

The hemogram included the determination of leukocytes, lymphocytes, monocytes, red blood cells, hemoglobin, hematocrit, mean corpuscular volume, mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), amplitude of erythrocyte distribution (AED), platelets and mean volume of platelets. This was performed using an automated Coulter Electronics × 10 system. Cortisol was determined using ELISA methodology (SIGMA-ALDRICH®). Glucose, total protein, albumin, and CK were determined using the appropriate laboratory kits (Manual RANDOX®).

2.4. Slaughter and carcass traits

All pigs were slaughtered in the slaughterhouse of the Departamento de Agricultura y Ganadería, UNISON, in compliance with current regulations (NOM-033-Z00-1995). The carcasses were individually weighed to record the hot carcass weight; they were then chilled for 24 h at 4 °C to obtain the carcass lengths, cooling loss, dressing, pH, fat thickness, the longissimus muscle (LM) area, and marbling 24 h postmortem. The pH of the *longissimus thoracis* (LT) muscle was measured 24 h postmortem using a portable pH meter (model HI 99163; Hanna Instruments, Wilmington, MA, USA) with a puncture electrode. Fat thickness and the LM area (cm^2) were measured at the 10th and 12th ribs. Marbling was also evaluated according to the guidelines of the United States Department of Agriculture. Finally, cooling loss and dressing values were calculated.

2.5. LT muscle dissection

Twenty-four hours postmortem, the LT muscle was removed from the carcass between the 4th and 12th intercostal spaces. It was vacuum-packed and transported under refrigeration for further analysis of its qualities and sensorial traits in the Laboratory of Science and Technology of Meat at the CIAD, in Hermosillo, Sonora, México.

2.6. Sample sectioning

After arrival at the laboratory, the samples were kept frozen at −18 °C. Before analyses, samples were thawed for 24 h at 4 °C and then sectioned to carry out chemical, physicochemical, and sensorial determination. Sectioning of the samples was consistently performed following the same protocol and in the same order from the distal end (the 12th-rib interface) to the cranial part of the LT muscle. The first cut (2.0 cm) was used to determine the contents of moisture, protein, and intramuscular fat. Four pairs of samples

(2.54 cm each) were used for the Warner–Bratzler shear force (WBSF) test, cooking loss determination, and sensorial analysis. A 2.5 cm slice was used to analyze color, pH, and water-holding capacity (WHC). All measurements were recorded immediately after the samples were sectioned.

2.7. Proximate analysis

The samples of meat were evaluated in triplicate for moisture, protein, and intramuscular fat content following the AOAC official methods (AOAC, 1990). The moisture content was measured by oven drying the samples at 100 °C for 16 h and calculated as the proportion of weight loss after oven drying (method 950.46). The protein content (expressed as a percentage) was measured using the Kjeldahl method (method 955.04). The intramuscular fat content was extracted from the dry muscle sample using the Goldfish method (method 920.39). The results are expressed as a percentage of fresh weight.

2.8. pH and meat color

The determination of pH was performed at 4 °C using a portable digital pH meter (model HI 99163; Hanna Instruments, Wilmington, MA, USA). The color measurements were obtained using a Minolta CR-400 colorimeter (Konica Minolta Sensing, Inc., Japan) with D65 illuminant with a 10° and 8 mm aperture in the observer. The color parameters evaluated were L* (lightness), a* (redness), and b* (yellowness) (Cassens et al., 1995). The hue angle (Hue) was calculated using the formula $\text{Hue} = \tan^{-1}(b^*/a^*)$, and chroma was calculated using the formula $\text{chroma} = (a^* + b^*)^{½}$. Color determinations were made at five different surface locations (perpendicular to the fibers) of the cold samples (4 °C).

2.9. WHC

An analysis of WHC was conducted following the procedure described by Sutton et al. (1997). This process is based on the ability of meat samples to hold water after centrifugation (3600 rpm × 5 min). The WHC percentage was calculated based on the difference in weight of the sample before and after centrifugation.

2.10. WBSF

WBSF was measured using a texture analyzer texturometer T.A.X.T Plus (Texture Technologies Corp., Scarsdale, NY, USA). For texture measurement, the cuts were cooked in an electric skillet (Cook Master Oster, model 3222-3, Mississauga, Ontario, Canada) until they reached an internal temperature of 71 °C. The cooked samples were cooled to between 20 °C and 25 °C, and chilled at 4 °C for 24 h. Subsequently, the meat was cut into pieces (diameter: 1.50 cm) in a longitudinal direction to the muscle fibers, and the WBSF was determined using a Warner–Bratzler attachment cutter on 10 specimens per sample. The WBSF value is expressed in kilograms.

2.11. Cooking loss

To evaluate cooking loss, the cuts were cooked in an electric skillet under the same cooking conditions used for WBSF analysis. The samples were weighed in their raw state and then immediately after they had reached their final cooking temperature (71 °C).

2.12. Sensorial analysis

The meat's sensorial traits were evaluated by a trained 10-member panel (ISO 8586-1 1993), and the samples were prepared according to AMSA guidelines (AMSA, 1995). The steaks were cooked following the same procedure previously described for WBSF determination. Each cooked steak was cut into a sample measuring 1.50 × 1.50 cm. The line scale was anchored on the left (0 cm) with a descriptive term representing the lowest degree of odor intensity, flavor intensity, fat mouthfeeling, tenderness, juiciness, and amount of connective tissue. At the right end (10.0 cm) of the scale was a descriptive term representing the highest sensorial degree for each sensorial trait. The sensory panel evaluated the cooked samples under a soft red light using the descriptive terms above on an unstructured 10.0 cm line scale. The two visual traits of overall color and overall appearance were evaluated on raw samples under white light using the same type of scale.

2.13. Statistical analysis

Animals were assigned to each treatment by gender, BW, and age using a randomized complete block design (Steel and Torrie, 1980). The data for growth performance, blood metabolites, carcass traits, and meat quality were analyzed using a one-way analysis of variance. One pig was the experimental unit. For the sensorial data, the model also included the random effect of the panelists. Tukey's multiple-range test was applied for a comparison of means, and significances were estimated at a probability level of 0.05 in error type I. All data were processed using the NCSS statistical software.

3. Results

3.1. Climatic conditions

The temperature and relative humidity within the installation that housed the metabolic cages were recorded daily throughout the experimental period (Fig. 1). The average temperature was 32.35 °C (25.8 °C–38.9 °C), and the relative humidity was 44.14 % (19.26 %–80.47 %).

3.2. Growth performance

Table 2 shows the growth performance results during phase I. The addition of 0.2 % and 0.3 % YC induced higher ADG (by 25.52 % and 23.70 %, respectively, $P < 0.05$), ADFI (by 13.42 % and 11.85 %, respectively, $P < 0.05$), and the final weight (by 8.09 % and 7.26 %, respectively, $P < 0.05$) without an observable impact on F:G ($P > 0.05$) compared with the control diet. In phase II, the addition of 0.3 % YC induced higher numerical values in both ADG and ADFI compared with those recorded for the 0.2 % YC and the control diet ($P > 0.05$). There were no differences in F:G, but the final weight was higher with the supplementation with 0.3 % YC compared with the control diet (by 7.35 %, $P < 0.05$). During the last phase (III), there were no differences in ADG and ADFI, but F:G exhibited an improvement ($P < 0.10$) with the addition of 0.2 % YC compared with both the control (by 8.44 %) and with 0.3 % YC (by 9.75 %). The final weight was higher with the addition of the YC at 0.2 % and 0.3 % compared with the control diet (by 4.16 % and 4.67 %, respectively, $P < 0.05$). Evaluating the entire trial period (29.487–128.701 kg of live weight), an improvement was observed in ADG with both levels of YC supplementation (0.2 % and 0.3 %) compared with the control diet (by 5.38 % and 6.09 %, respectively, $P < 0.05$). There were no differences in ADFI and F:G ($P > 0.05$).

3.3. Blood metabolites

The results of the blood metabolite analysis are shown in Table 3. Cortisol levels were numerically lower in the diets supplemented with 0.2 % and 0.3 % YC compared with the control diet (by 26.40 % and 34.86 %, respectively, $P > 0.05$). Levels of glucose, total proteins, and CK were numerically higher in the diets supplemented with 0.2 % and 0.3 % YC compared with the control diet ($P > 0.05$). Levels of leucocytes, lymphocytes, monocytes, erythrocytes, hemoglobin, hematocrit, mean corpuscular volume, MCHC, and AED did not exhibit any changes due to YC supplementation ($P > 0.05$), and platelet numbers were increased with the addition of 0.3 % YC compared to those for the supplementation with 0.2 % YC ($P < 0.05$).

3.4. Carcass traits

In terms of carcass traits (Table 4), the carcass weight was greater in the 0.3 % and 0.2 % YC treatments compared with the control (by 4.63 % and 5.27 %, respectively, $P < 0.05$). The 0.2 % YC and the control diet induced a higher lean index compared with the 0.3 % YC treatment (by 1.50 % and 1.08 %, respectively, $P < 0.05$). With the addition of the YC at 0.2 %, the fat thickness measured at the 12th rib was lower compared with the control diet (by 21.74 %, $P < 0.05$). In the 24 h postmortem pH test, a difference between treatments ($P < 0.10$) was observed.

3.5. Chemical and physicochemical parameters of meat quality

Table 5 shows the chemical composition of the meat from the pigs supplemented with YC. The addition of 0.2 % YC increased the moisture content compared with the meat from the animals that received no supplementation (by 1.38 %, $P < 0.05$) and compared with the addition of 0.3 % YC (by 1.18 %, $P < 0.05$). There were no changes in the percentage of intramuscular fat with the supplementation of YC ($P > 0.05$). In terms of protein content, no changes were evident with the addition of YC ($P > 0.05$).

Table 5 shows the physicochemical parameters of the meat of pigs supplemented with YC. The supplementation with 0.2 % YC induced some changes in the assessed color parameters. In this respect, parameter L*, a variable that measures the lightness of the meat, diminished with the 0.2 % YC supplementation compared with the meat from the non-supplemented animals (by 6.41 %, $P < 0.05$). In terms of parameter a* (red hue of meat), supplementation with 0.2 % YC decreased this parameter compared to that in

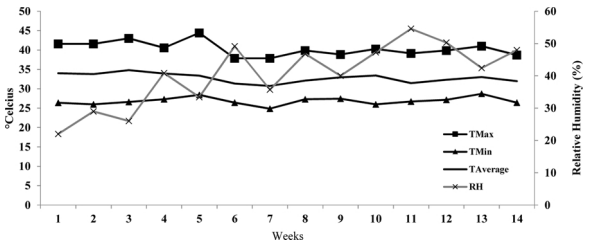

Fig. 1. Maximum temperature (TMax), minimum temperature (TMin), average temperature (TAverage) and relative humidity (RH, %).

Table 2
Growth performance of growing–finishing pigs supplemented with yeast.

	Treatments				
Variable	Control[1]	0.2 % YC[2]	0.3 % YC[3]	SEM[4]	P-Value[5]
Repetitions (n)	10	10	10		
Phase I (30–65 kg of live weight)					
Initial BW kg	29.500	29.460	29.500	0.069	0.989
ADG kg/d	0.709[b]	0.890[a]	0.877[a]	0.009	0.011
ADFI kg/d	1.840[b]	2.087[a]	2.058[a]	0.017	0.007
F:G kg/kg	2.407	2.359	2.354	0.025	0.871
Final BW kg	61.840[b]	66.840[a]	66.330[a]	0.352	0.009
Phase II (65–95 kg of live weight)					
ADG kg/d	1.073	1.046	1.154	0.012	0.127
ADFI kg/d	2.711	2.847	3.002	0.028	0.101
F:G kg/kg	2.529	2.726	2.603	0.022	0.146
Final BW kg	89.740[b]	94.040[ab]	96.340[a]	0.501	0.027
Phase III (95–128 kg of live weight)					
ADG kg/d	1.216	1.240	1.191	0.012	0.645
ADFI kg/d	3.758	3.515	3.722	0.034	0.252
F:G kg/kg	3.094	2.833	3.139	0.029	0.063
Final BW kg	125.020[b]	130.222[a]	130.860[a]	0.411	0.010
Growing–finishing period (30–128 kg of live weight)					
ADG kg/d	0.985[b]	1.038[a]	1.045[a]	0.004	0.008
ADFI kg/d	2.612	2.690	2.779	0.018	0.144
F:G kg/kg	2.645	2.592	2.657	0.016	0.640

[1] Control = control animals receiving only the basal diet without yeast supplementation.
[2] 0.2 % YC = animals receiving basal diet supplemented with 0.20 % yeast culture.
[3] 0.3 % YC = animals receiving basal diet supplemented with 0.30 % yeast culture.
[4] SEM = standard error of mean.
[5] Probability values associated with yeast supplementation.

the non-supplemented animals (by 10.03 %, $P < 0.05$); this represents a decrease in contrast with the animals supplemented with 0.3 % YC (by 10.43 %, $P < 0.05$). The meat's red color was not modified by supplementation with 0.3 % YC and represented similar values to those of the control animals. Regarding parameter b* and chroma, the YC supplementation of 0.2 % also generated a reduction compared with the values presented by the control (by 15.52 %, $P < 0.05$) and the 0.3 % YC-treated animals (by 17.74 %, $P < 0.05$). Hue values did not change with YC supplementation ($P > 0.05$), and the pH values and water-retention capacities were not modified by supplementation with YC ($P > 0.05$). Texture values, a parameter assessed based on cutting effort, were higher in the meat from the animals supplemented with 0.2 % YC compared to those in the meat from pigs supplemented with 0.3 % YC (by 16.03 %, $P < 0.05$). The loss due to cooking did not differ among treatments ($P > 0.05$).

3.6. Sensorial quality of the meat

Table 6 shows the sensorial quality parameters of the meat from the control diet and the YC-supplemented animals. The trained panelists observed a slight reduction in the visual color of the meat from 0.3 % in the YC-supplemented pigs in contrast with that from the non-supplemented animals ($P < 0.05$). In general, the color, appearance, flavor, odor, tenderness, juiciness, feeling fat, and connective tissue sensations were not modified with either the 0.2 % or the 0.3 % supplementation with YC compared with the meat from the animals on the control diet ($P > 0.05$).

4. Discussion

4.1. Climatic conditions

In general, animals grow optimally within a temperature range often referred to as the thermoneutral zone. The thermoneutral zone is defined as the range of effective ambient temperature within which the heat from the normal maintenance and productive functions of an animal in non-stressful situations offsets the heat lost to the environment without requiring an increase in the rate of metabolic heat production (NRC, 1981). For growing pigs, the thermoneutral zone ranges between 18 °C and 21 °C (Holmes and Close, 1977), whereas for pigs in the growing to finishing phases, the range is between 20 °C and 23 °C (NRC, 1998). De Oliveira et al. (2019) reported that the thermoneutral conditions for the same stages (for growing to finishing pigs) are between 18 °C–25 °C; it is well-known that temperatures above the thermoneutral zone induce heat stress (Nyachoti et al., 2004). In this study, the average temperature was 32.35 °C (25.8 °C–38.9 °C), which was always higher than the optimum temperature for growing to finishing pigs.

Table 3
Blood metabolites of growing–finishing pigs supplemented with yeast culture.

Item	Treatments			SEM[4]	P-Value[5]
	Control[1]	0.2 % YC[2]	0.3 % YC[3]		
Repetitions (n)	10	10	10		
Cortisol µg/dL	6.97	5.13	4.54	0.348	0.194
Glucose mg/dL	85.50	89.30	89.20	1.048	0.659
Total proteins g/dL	6.24	6.26	6.45	0.022	0.101
Creatinine Kinase (CK) µ/L	2021.00	3423.20	2265.90	176.252	0.193
Albumin g/dL	4.16	4.13	4.28	0.019	0.213
Leukocytes 1 × 10^3 µL	17.33	16.95	17.60	0.300	0.890
Lymphocytes %	68.63	69.98	68.01	0.663	0.797
Monocytes %	6.84	5.89	5.52	0.170	0.228
Red blood cells %	24.53	23.51	26.47	0.662	0.605
Lymphocytes 1 × 10^3 µL	11.86	12.07	11.92	0.185	0.967
Monocytes 1 × 10^3 µL	1.17	1.21	0.97	0.044	0.457
Red blood cells 1 × 10^3 µL	4.29	4.08	4.69	0.161	0.696
Erythrocytes 1 × 10^6 µL	7.29	7.36	7.33	0.057	0.957
Hemoglobin g/dL	11.56	12.07	11.96	0.083	0.373
Hematocrit %	39.83	41.54	39.99	0.297	0.382
Average corpuscular volume fL	54.56	55.37	54.50	0.287	0.755
MCH[6] PG	17.46	18.23	17.63	0.450	0.923
MCHC[7] g/dL	31.66	32.94	32.25	0.776	0.934
AED[8] %	22.08	20.53	21.55	0.193	0.216
Platelets 1 × 10^3 µL	335.70^{ab}	293.93^{b}	413.20^{a}	7.794	0.010
Average platelet volume fL	11.99	10.11	10.06	0.212	0.095

[1] Control = control animals receiving only the basal diet without yeast supplementation.
[2] 0.2 % YC = animals receiving basal diet supplemented with 0.20 % yeast culture.
[3] 0.3 % YC = animals receiving basal diet supplemented with 0.30 % yeast culture.
[4] SEM = standard error of mean.
[5] Probability values associated with yeast supplementation.
[6] MCH = mean corpuscular hemoglobin.
[7] MCHC = mean corpuscular hemoglobin concentration.
[8] AED = amplitude of erythrocyte distribution.

Table 4
Traits of the carcass of growing–finishing pigs supplemented with yeast.

Item	Treatments			SEM[4]	P-Value[5]
	Control[1]	0.2 % YC[2]	0.3 % YC[3]		
Repetitions (n)	10	10	10		
HCW kg	103.79^{b}	108.60^{a}	109.26^{a}	0.384	0.010
Dressing %	82.97	83.01	83.36	0.088	0.562
Lean %	53.27^{a}	53.49^{a}	52.70^{b}	0.033	< 0.001
Fat thickness cm 10th	1.87^{ab}	1.41^{b}	2.08^{a}	0.053	0.032
Fat thickness cm 12th	1.15^{a}	0.90^{b}	1.25^{a}	0.015	< 0.001
LM area cm 10th	60.77	63.60	70.84	1.235	0.199
LM area cm^2 12th	118.60	119.55	122.40	1.449	0.832
LM depth cm 10th	7.68	7.50	8.16	0.127	0.495
LM depth cm 12th	8.02	7.98	8.10	0.074	0.936
Carcass length cm	106.20	109.05	108.30	0.443	0.350
Marbling	1.60	1.55	1.75	0.046	0.606
pH postmortem 24 h	5.44	5.45	5.54	0.031	0.052

[1] Control = control animals receiving only the basal diet without yeast supplementation.
[2] 0.2 % YC = animals receiving basal diet supplemented with 0.20 % yeast culture.
[3] 0.3 % YC = animals receiving basal diet supplemented with 0.30 % yeast culture.
[4] SEM = standard error of mean.
[5] Probability values associated with yeast supplementation.

This indicates that the pigs were under heat stress.

4.2. Growth performance

The addition of YC induced an improvement in both the final weight and the ADG. This corresponds with the work of many authors who have reported an improvement in ADG when yeast was added to the food of weanling pigs (Veum et al., 1988; Collier

Table 5
Chemical and physicochemical parameters of the meat quality of growing–finishing pigs supplemented with yeast.

Variable	Treatments				
	Control [1]	0.2 % YC[2]	0.3 % YC[3]	SEM[4]	P-Value[5]
Repetitions (n)					
Moisture	71.25[a]	72.23[b]	71.39[a]	0.273	0.036
Protein	22.67	21.46	21.46	0.493	0.155
Intramuscular fat	2.49	1.77	2.23	0.260	0.149
Lightness (L*)	58.31[a]	54.57[b]	56.19[ab]	0.662	0.001
Redness (a*)	6.68[a]	6.01[b]	6.71[a]	0.216	0.047
Yellowness (b*)	7.41[a]	6.26[b]	7.61[a]	0.220	0.002
HUE angle[6]	48.08	46.01	46.42	0.719	0.110
Chroma[7]	10.01[a]	8.70[b]	9.77[a]	0.285	0.004
pH	5.44	5.45	5.54	0.031	0.052
WHC[8]	79.23	77.69	78.84	0.731	0.333
Cooking loss %	24.48	25.49	27.11	0.647	0.530
WBSF[9] kg	6.90[ab]	7.31[a]	6.30[b]	0.262	0.020

[1] Control = control animals receiving only the basal diet without yeast supplementation.
[2] 0.2 % YC = animals receiving basal diet supplemented with 0.20 % yeast culture.
[3] 0.3 % YC = animals receiving basal diet supplemented with 0.30 % yeast culture.
[4] SEM = standard error of mean.
[5] Probability values associated with yeast supplementation.
[6] Hue = tan−1 (b*/a*) × 57.29.
[7] Chroma = (a* + b*) ½.
[8] WHC = water-holding capacity.
[9] WBSF = Warner–Bratzler shear force.

Table 6
Sensory quality of meat of growing–finishing pigs supplemented with yeast.

Variable	Treatments				
	Control[1]	0.2 % YC[2]	0.3 % YC[3]	SEM[4]	P-Value[5]
Repetitions (n)	10	10	10		
Visual color[6]	1.94[a]	1.72[ab]	1.55[b]	0.360	0.034
Overall color	6.41	6.43	6.42	0.286	0.998
Appearance	6.45	6.06	6.12	0.333	0.667
Odor	6.46	7.09	7.01	0.223	0.731
Flavor	5.16	5.82	5.85	0.357	0.316
Feeling fat	1.17	1.26	1.34	0.271	0.898
Tenderness	5.41	5.54	5.28	0.407	0.906
Juiciness	4.39	4.83	4.14	0.478	0.585
Connective tissue	1.59	1.57	1.53	0.358	0.993

An unstructured 10.0 cm line scale is used. The line scale is anchored on the left (0 cm) with a descriptive term representing the lowest degree of odor intensity, flavor intensity, fat mouthfeeling, tenderness, juiciness, and amount of connective tissue. At the right end (10.0 cm) of the scale is a descriptive term representing the highest sensorial degree for each sensory trait.
[1] Control = control animals receiving only the basal diet without yeast supplementation.
[2] 0.2 % YC = animals receiving basal diet supplemented with 0.20 % yeast culture.
[3] 0.3 % YC = animals receiving basal diet supplemented with 0.30 % yeast culture.
[4] SEM = standard error of mean.
[5] Probability values associated with yeast supplementation.
[6] Visual color: 1 = pale-pink red, 2 = pale pink, 3 = pale-pinkish gray.

et al., 2011). During the growth–finishing phases in pigs, as in this study, improvements in ADG have also been observed (Lu et al., 2017; Galaz-Galaz et al., 2018). In the current study, no differences in F:G were found; this corresponds with Martínez et al. (2000) but disagrees with Lu et al. (2017) who did observe improvements not only in ADG but also in F:G. These improvements in productive behavior have also been documented in other species (Keyser et al., 2007; Vieira et al., 2013; Plaza-Diaz et al., 2014; Salinas-Chavira et al., 2018). However, Bowman and Veum (1973) and Reynoso-González et al. (2010) did not identify any effects of yeast supplementation on the productive behavior of growing pigs. In addition to the mentioned, there are numerous studies that demonstrated that yeast and its derivatives may have beneficial effects on growth performance and health, especially when animals are reared in suboptimal sanitary conditions or are experiencing a disease challenge (Shurson, 2018). The differences between studies can possibly be attributed to the conditions in which the studies were conducted, such as the environment or varying sanitary conditions.

4.3. Blood metabolites

Some blood components are increased when animals are under stress, e.g., cortisol, glucose, and leukocytes (Dantzer and Mormède, 1979; Fraser and Broom, 1990). Additionally, CK activity is generally considered to be an index of skeletal and cardiac muscle damage and a possible indicator of damage in the gastrointestinal tract (Payne and Payne, 1987). Conversely, a reduction in cortisol indicates stress relief (Liu et al., 2016). According to Etim et al. (2014), hematological blood parameters are good indicators of an animal's physiological and health status.

When the treatments were compared, no differences were found in most of the blood parameters, except in the level of platelets. With the addition of 0.3 % YC, platelet levels were higher than those found with 0.2 % YC, and there was a tendency for platelet volumes to be lower in the YC-supplemented diets than in the control. However, there were no differences in platelets when we compared the YC-supplemented diets with the control diet; the level of platelets and platelet volume could be an indicator of changes in health (Carrillo-Esper et al., 2013). In a study involving weanling pigs, the addition of yeast had no effect on most parameters of blood components, but there was an effect on the number of platelets (Van der Peet-Schwering et al., 2007).

It is accepted that cortisol levels are one of the main indicators of stress, and it has been found that the addition of yeast diminishes its levels (Ma et al., 2017). Fagundes et al. (2008) observed differences between cortisol levels in animals housed conventionally with temperatures close to the comfort (17.6 °C–26.6 °C) and animals housed in a climatic chamber under conditions of heat stress (22.32 °C–32.8 °C); in this study revealed average cortisol levels of 4.82 and 7.06 μg/dL, respectively. The cortisol values for the control were similar to those of the animals that were housed in the high-temperature climatic chamber; the values obtained after supplementation with YC were close to the average values of those animals housed at a comfortable temperature. However, in the current study, there was no effect when any of the treatments was used, although the level of cortisol was numerically lower.

In general, all these parameters provide evidence that the addition of yeast does not have any negative effect on blood components; furthermore, it is important to note that the expected change in stress variables with increasing weight was not observed.

4.4. Carcass traits

A higher carcass weight was obtained with the addition of YC. The animals fed on both the 0.2 % YC diet and the control diet demonstrated a higher lean-mass index than the pigs that received the 0.3 % YC diet. The rest of the variables showed no differences under any of the treatments. Some studies found no effects on carcass traits (Bowman and Veum, 1973; Mir and Mir, 1994; Galaz-Galaz et al., 2018); these studies may have involved animals with other weights or ages at the time of slaughter.

4.5. Chemical and physicochemical parameters of meat quality

Milewski and Zaleska (2011) found higher moisture and intramuscular fat contents when supplementing lambs' diets with yeast. However, this finding does not agree with the present study, in which only differences in the moisture content were found when the 0.2 % YC-supplemented diet was compared with the control diet; furthermore, no differences in intramuscular fat were observed. Conversely, an improvement in meat color was observed when yeast components were used (a* increased, and b* decreased, Ma et al., 2017). Cho et al. (2013) identified a positive effect on the meat quality of broiler chicks with the addition of yeast components. In the present study, a decrease in the a* and b* values was found with the addition of 0.2 % YC compared with the control, but when compared with the 0.3 % YC diet, no differences were observed. Hue values were not modified by the use of yeast. Despite finding statistical changes in the color parameters after supplementation with YC, these changes were detected with specialized measuring instruments and are probably not perceivable by consumers.

Lui et al. (2013) revealed an improvement in the loss from dripping and cooking with the use of probiotics. Furthermore, a decrease in fat thickness occurs when one uses a yeast polysaccharide and an improvement in meat color was observed (Ma et al., 2017). In terms of shear force, some authors have found a reduction when adding yeast cell components and extracts to broiler chicks (Zhang et al., 2005b); a similar finding was observed when comparing the control diet with the 0.3 % YC-supplemented diet. However, the texture values of the meat from the non-supplemented and 0.2 % YC-supplemented animals were similar, indicating that no drastic textural changes occurred. In terms of meat quality, it is evident that the addition of yeast had no major effects on the pigs in the growing–finishing phases under heat stress.

4.6. Sensory quality of meat

The addition of *S. cerevisiae* has been confirmed to increase both tenderness (Bonomi et al., 1978; Zhang et al., 2005a) and the water-retention capacities in broiler chicks (Lee et al., 2002).

Most sensorial qualities (color, appearance, odor, flavor, tenderness, juiciness, and connective tissue) were not affected by the addition of the two YC concentrations, except in terms of visual color, where the panelists observed a higher intensity in the control compared with the 0.3 % YC-supplemented diet. The observed sensorial traits correspond with the results of the performed chemical and physicochemical analyses. The results obtained in the sensory quality from the current study agree with those found in lambs and broiler chicks supplemented with yeast (Milewski and Zaleska, 2011; Pelicano et al., 2003).

5. Conclusions

The addition of YC to the feed of pigs during the growth–finishing phases can improve growth and carcass weight without markedly changing blood metabolites, carcass traits, quality, and the sensorial values of meat from pigs under conditions of heat stress.

Author agreement/declaration

All authors have seen and approved the final version of the manuscript being submitted.

Ethical approval

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed all procedures, involving animal handling were conducted, following the approved Mexican official guidelines for animal care (NOM-051-ZOO-1995: Humanitarian care of animals during mobilization; NOM-033-ZOO-1995: Slaughter of domestic and wild animals).

Declaration of Competing Interest

The authors declare no conflicts of interest

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Appendix A. Supplementary data

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